AN IMPROVED POWERTRAIN ATTRIBUTES DEVELOPMENT PROCESS WITH THE USE OF DESIGN STRUCTURE MATRIX

by

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Submitted to the System Design and Management Program
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Engineering and Management
at the
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ABSTRACT

Automobiles are becoming increasingly complicated and are creating more of a challenge for the engineering teams working on them. This thesis focuses on improving the methods of managing powertrain attributes and the interactions between them. We are concentrating on the particular attributes of Shift Quality, Performance Feel, Driveability, and Trailer Towing. Engineering work to achieve specific attributes is currently handled attribute by attribute and the system is brought together later. This lack of a more holistic view results in a large amount of engineering rework as attributes are balanced. Reducing or eliminating this rework is the goal.

A Design Structure Matrix (DSM) was used to document interactions between the powertrain attributes, sub-attributes and design parameters. Research on various reporting formats was done to determine the best method to communicate the interactions. DSM experts were interviewed about the benefits and pitfalls of using a DSM for reference. Several surveys were done to determine engineering's familiarity with various methods of displaying system interactions and their preferences for reporting the interactions. We also compared the interactions to existing CAE capability to determine the current state of attributes management.

The DSM showed numerous interactions between powertrain attributes, other vehicle attributes and design parameters. The analysis of existing CAE tools showed a significant percentage of interactions are not currently being modeled. The responses to survey questions on output methods indicated that a DSM, while being an excellent tool for capturing the interactions, might not be the best tool for displaying the interactions to engineers. The surveys revealed that engineers are looking for more information than a DSM or any systems interactions model contain, such as probability that an interaction exists, expected direction and levels of the interaction, and quick and simple methods for better understanding of these potential interactions. This desired level of detail highlights the need to share Lessons Learned, develop a corporate knowledge base and develop best practices. A review of the organizational structure and engineering focus indicated that increased focus is needed on powertrain attributes to better match customer expectations. Additionally, organizational structure changes are recommended to increase visibility of powertrain attributes.

Thesis Supervisor: Daniel E. Whitney
Title: Senior Research Scientist

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Author Biographies

Daniel J. Rinkevich

Mr. Rinkevich is a Powertrain Project Management Supervisor on Sport Utility Vehicles at Ford Motor Company, where he is responsible for organizing the engineering efforts on numerous high-value cost reductions known as Mega projects. Before this he was the project manager on the 2005 Expedition powertrain. Prior to his involvement with Sport Utility Vehicles he was the Attribute PAT leader for Emissions and Driveability on the Mondeo. This led to a Foreign Service assignment as the powertrain Project Management and Launch supervisor on the for the 2001 Mondeo.

Mr. Rinkevich started the SDM program in January 2001. He currently serves on the SDM Leadership Committee and the SDM International Business Trip Committee. He has a Bachelor of Science degree from Oakland University (1982) in Mechanical Engineering. His academic interests are Business, and Applied Statistics.

He lives in Commerce, Michigan. He has a wife Jill and 2 children Joel and Kate. His outside interests include spending time with his family, motor boating, sailing, and woodworking.

Frederick P. Samson

Mr. Samson is part of North America Vehicle Engineering as a Vehicle Integration and Powertrain Brand Attributes DNA Supervisor at Ford Motor Company responsible for developing Powertrain Attributes DNA. Mr. Samson recently completed metric and targets development for Ford Outfitters (all Sport Utility Vehicles) and is now in the process of completing targets for Trucks to be used for all future model programs. Prior to this position, he was the 2003 Expedition and Navigator platform Performance Feel/Shift Quality attributes and Accelerator Controls Design and Release Supervisor. Mr. Samson has also held positions in Core and Advance Powertrain as a Technical Specialist in Vehicle Performance Feel, several engineering positions in design, development and vehicle integration within North American Product Development, positions as a Powertrain Project Management analyst and Ford Division marketing analyst, and last but not least, a Powertrain Launch Leader for the launch of the 1999 Expedition and Navigator at the Michigan Truck Plant. Mr. Samson has received a patent from one of his Transmission Shift Cable designs, and has designed and developed software for accelerator controls design.

Mr. Samson has a Bachelor's and Master's of Science in Mechanical Engineering from the University of Michigan, Dearborn. He received his undergraduate degree with honors (Cum Laude), graduating with distinction.

Mr. Samson lives in Novi, Michigan with his wife Deanna, and three children Alicia, Freddie and Jimmy. His outside interests are spending time with his family, traveling, hockey, music, playing guitar and mountain biking.

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We would like to thank our thesis advisor Dan Whitney for his guidance and encouragement throughout the thesis process. We would also like to thank all the people at Ford and MIT that assisted us with material for our thesis. We extend our appreciation to the MIT SDM program faculty and other students that helped create an incredible educational experience. Their insights and knowledge made this thesis possible. We would like to thank our management at Ford Motor Company for sponsoring us in this program, despite the difficult economic conditions. In addition, we would like to extend our warmest thanks to our family, friends and co-workers for their unending support, patience and understanding throughout the two-year program.

Dan Rinkevich and Fred Samson

I am extremely grateful for the incredible support and infinite patience of the most important people in my life: my lovely wife Jill, and two fantastic children Joel and Kate. Without their love, encouragement and help, this educational experience would not have been possible. While I cannot fully describe my deep and profound appreciation to them, I can simply offer this: It is now my turn to devote time to each one of you, to deepen our relationships, and to enjoy the family times to come. Finally, I have a special thanks to Fred for working with me on this thesis. I admire his dedication, hard work, and drive for excellence.

Dan Rinkevich

I would like to dedicate this thesis to my parents Felino and Nelia Samson. My dad who passed away close to the beginning of the SDM program is very much missed by his family. Dad we love and miss you very much.

I am especially thankful for the tremendous support, understanding, and great patience provided by my wonderful family: first and foremost my beautiful wife Deanna, my lovely daughter Alicia and two incredible boys Freddie and Jimmy. They are my life. Without their love and support, my MIT experience wouldn't have been possible. I would also like to thank my wonderful mother, Nelia Samson and my sister-in-law Marcia Laybourn for helping Deanna when she needed help. I would also like to give a special thanks to my brother Felino Samson who lives in Boston. Having him there always made it seem like I was home. Lastly, I would like to thank Dan for working with me on this thesis. His creativity, perseverance, sense of humor and dedication to his family are virtues I truly appreciate and admire.

Fred Samson

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Chapter 1 - Introduction and Problem Statement

There are many things that people take into consideration when buying an automobile. In this thesis we will be dealing with improving the perception of the vehicle to the customer. We will do this by focusing on the handling of powertrain attributes of a vehicle.

Automobiles are very complicated pieces of equipment, which makes designing them a challenge. As automobiles become more complicated, it is increasingly difficult for the engineers to understand all aspects of the vehicle. Consequently there are specialists for each area of the vehicle. Vehicles have many interactions between these different areas. Keeping track of all the interactions within systems and between systems has become a very difficult task.

Meanwhile research on the man-machine interactions has taken place. So today we know far more about the characteristics that make an automobile pleasing. Tools have been developed to allow these unique features to be understood, quantified and engineered. While we are better able to tune specific aspects of an automobile, tuning all the components together to create an overall pleasing vehicle remains difficult.

We are also interested in improving the organization that develops the attributes that endear customers to a vehicle. The organization is vital to ensuring that future products give customers everything they expect and provide a value to the customer.

As we look at the organization and how it develops the vehicle we will be looking at it from a perspective of the way it is organized, the tools available and also how it rewards people. Figure 1 shows this framework.

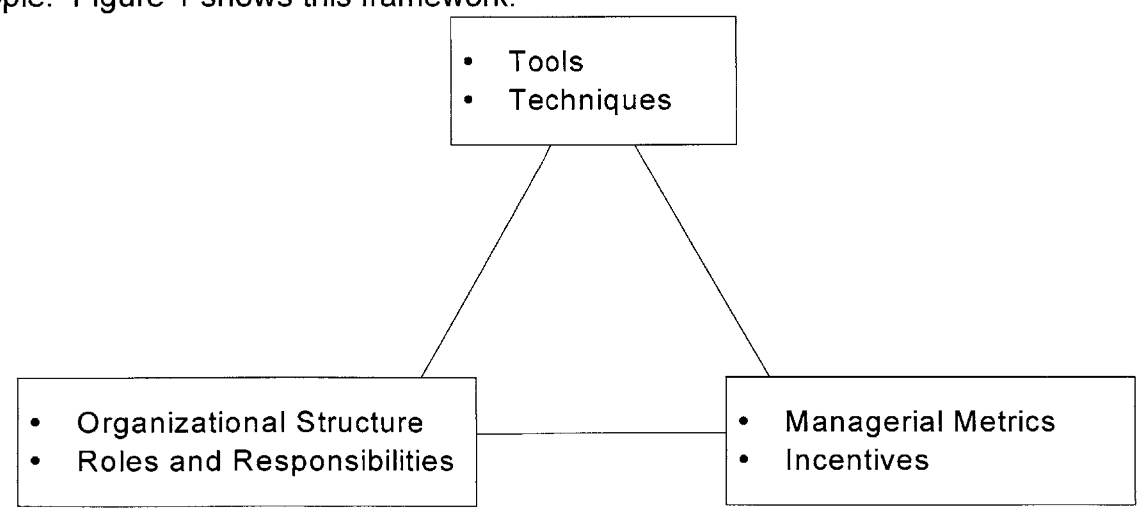

Figure 1 - Organizational Perspectives

We are particularly interested in two of the three areas shown in Figure 1. We are interested in tools and techniques used to help people understand and produce high quality attributes, which are characteristics by which we judge a vehicle. And we will look at the organizational structure and its affects on attributes and attribute interactions.

In this first chapter we will look at the issues we will be dealing with in this thesis, and how we have gotten to this point. We will introduce our hypotheses, objectives and the methodologies we have employed to prove them. We will also cover the limits of what we have done and talk about how the thesis is outlined in general.

Issues

We are focusing on how to better handle powertrain attributes. The powertrain is a vital part of an automobile and is very important to the customer. The powertrain itself is a very complicated system typically controlled by one or two computers to ensure that all the competing requirements are managed despite ever changing driver inputs.

Ford has a very low level of experience in many areas. Ford has a long history of rotating engineers around from job to job. It is part of Ford's culture for people to change positions every 1 to 3 years. It is thought that this is a requirement for promotion. When people are promoted, they are typically moved to a position not directly related to the area they were working in. And this continues as the individual rotates to new positions every couple of years at a higher level. This leads to management that is often less qualified than the people working for them, who may not be highly experienced.

Historical data

Numerous changes have driven the automobile industry to its current state. Originally, vehicles were very crude and numerous improvements were made to obtain an acceptable level of operation of the basic features. Increasing feature content drove more changes and complexity. Durability and dependability have increased dramatically as the average number of miles traveled has increased. Increasing safety requirements are also driving changes.

Lower emissions and reduced fuel consumption requirements are driving even more change and complication into automobiles. Items needed for meeting these requirements are adding more items that need to be tuned and balanced. For example throttle opening, previously controlled by a cable on a pulley is now electronically controlled, providing additional controllability and the capability to tune for different throttle responses for different conditions.

Meanwhile competition between automakers has increased. Today's automakers sell globally, not just nationally. This has led to many more offerings in each market. Consequently, consumer acceptance of less than ideal characteristics has diminished. All this leads to an automobile needing to be near perfect in all attributes to have a chance of selling.

Hypothesis

This thesis is an attempt to answer 2 hypotheses:

1. A complete understanding of all powertrain attribute interactions is needed to prevent needless rework during product development.
2. The DSM format, while being particularly good at capturing all these interactions is an imposing document to look at and may not be the ideal method of displaying these attributes for engineers needing to understand them.

Objective

Our object is to aid engineers and engineering management by developing a tool to use in assessing whether an action taken has consequences on other attributes and hardware. This tool needs to be fast and easy to use, as engineering help is not inexpensive. Additionally, the development and maintenance of this tool must be equally quick and easy, because any time used in tool construction/maintenance is time that could be spent developing a vehicle.

Our goal is to improve the development and management of Powertrain Attributes at Ford Motor Company. We intend to improve team efficiency through improved understanding of the attributes and better understanding of the interactions between them. Additionally, we will work on developing a framework for attribute leaders to better manage their duties. This will focus on determining who should talk to who and when, and determining component/subsystem interactions to better understand powertrain attributes and its potential effects on other non-powertrain related attributes.

Methodology

We created an attribute based DSM. We consulted with numerous DSM experts to discuss the unique nature of our DSM. Based on their input we formulated the basic DSM layout and sorting methodology. In the creation of the DSM we used input from attribute experts to determine and understand the interactions. This involved interviewing numerous experts to solicit their input over an eight-week period. The DSM was then separated into attributes and design parameters to develop a format for Program Activity Team (PAT) and Program Module Team (PMT) leaders.

In addition to the parameter DSM, we also developed a process DSM using the same interactions to analyze our current powertrain attributes development process and to determine how the product development process can be improved. Using the DSM as a baseline, we analyzed the current process for inadequacies and recommended resolutions.

Since we are interested in providing a tool to use, we did research in this area as well. We did literature searches on the usability of DSMs as documentation. We also consulted DSM experts about the usability of DSMs. We found very little relevant information. We compared the benefits of various systems engineering formats for presentation of interactions. We did a number of surveys of potential users of the documentation to determine their needs and also acceptance of a DSM as a documentation tool.

Project Scope/Boundaries

We needed to make some decisions about what we would solve and what we would not. In the undertaking of any project one discovers many issues that need to be resolved. Since it is impossible to solve too many things and do a quality job of it, we decided to do the following.

We created a powertrain systems parameter DSM (Attribute DSM) bringing together the numerous interactions seen in Shift Quality, Performance Feel, Driveability, and Trailer Tow. We have also included Fuel Economy in a limited sense, only as it applies to these other attributes. The DSM would cover all levels from the highest-level attribute down to each relevant sub-attribute and onto the relevant design parameters. This means that we would not cover component-to-component interactions that do not involve the powertrain attributes directly.

We researched different methods of displaying the interactions that we found. This research was vital to ensure that we were giving the proper tool. We want to ensure that engineers use the tool and find benefit in using it.

Thesis Structure

The thesis is laid out as follows:

Chapter 1. Introduces the issues involved in attribute management, why it's an issue of particular importance today, the two hypotheses that we are attempting to prove, our goals in this work, methodology, scope, and boundaries.

Chapter 2. Provides a general background needed to understand the problem of attribute management including; Ford's history, definitions a powertrain, attributes in general, and the particular attributes we are interested in. We discuss the particular importance of powertrain attributes, and how the current organizational structures handle those attributes. We will also look at the current CAE tools and their capabilities as well as the methods of documenting attribute interactions.

Chapter 3. Examines the current challenges in handling of attribute interactions and the importance of powertrain attributes to the customer versus what the current emphasis at Ford is.

Chapter 4. Analyzes current product development processes and the shortfalls that they have. We show how a Design Structure Matrix can help to document numerous powertrain attribute interactions and plan for potential rework.

Chapter 5. Presents the Powertrain Attributes DSM, findings and recommendations to address the interactions above the diagonal (feedback loops).

Chapter 6. Covers the results of surveys from the engineering community taken to determine the importance of attribute interactions and to gage the level of help desired to deal with them.

Chapter 7. This is a summary of the Finding and Recommendations for immediate action as well as recommendations for future work.

Summary

In this first chapter we looked at the issues we will be dealing with in this thesis, and the history behind them. We introduced our two hypotheses that we will attempt to prove, our overall goals in this project, and the methods we will employ. We covered the limits of our efforts and outlined what is covered in the various chapters of this thesis. So let us begin.

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Chapter 2 - Corporate Background and General Information

Introduction

In this chapter we provide a general background needed to understand the problem of attribute management including; Ford's history, definitions of a powertrain, attributes in general, and the particular attributes we are interested in. We discuss the particular importance of powertrain attributes, and the current organizational structures that handle those attributes. We will also look at the current CAE tools and their capabilities as well as the methods of documenting attribute interactions.

Corporate History

Henry Ford became an engineer in 1891 with the Edison Illuminating Company in Detroit. In 1896, Henry Ford completed the "Quadracycle", his first vehicle. Ford Motor Company incorporated on June 16, 1903, when Henry Ford and eleven business associates signed the company's articles of incorporation with $28,000 in cash. The first vehicle was delivered to a Detroit physician approximately one month later.

Ford Motor Company introduced the moving assembly line to automotive manufacturing at the Highland Park plant (in Michigan, US) in 1913. The new technique allowed individual lower-skilled workers to stay in one place and perform the same task repeatedly on multiple vehicles that passed by them. The line was very efficient and helped Ford to increase production levels far above their competitors. This also helped make the vehicles more affordable.

Ford focused on the production of affordable cars for a mass market. The company began using letters of the alphabet to name new cars in 1903. In 1908, the Model T was introduced. Model T production lasted 19 years and 15 million units. Ford acquired the Lincoln Motor Company in 1925, thus branching out into luxury cars, and created the Mercury division the in the 1930's, to establish a division centered on mid-priced cars. The company went public on Feb. 24, 1956, and had about 350,000 new stockholders. [1]

Current Statistics

Ford Motor Company is a global company with two core businesses: automotive and financial services:

Automotive – The Ford Motor Company designs, developments, manufactures, sells and services:

- Cars
- Trucks
- Related parts and accessories

Financial Services - Ford Financial Services primarily includes two segments: Ford Motor Credit Company, a wholly owned subsidiary of Ford, and The Hertz Corporation, an indirect, wholly owned subsidiary of Ford:

- **Ford Credit** - Provides vehicle-related financing, leasing and insurance

[1] http://www.ford.com/en/heritage/history/default.htm

- **Hertz** - Rents cars, light trucks and industrial and construction equipment

Family of Brands

Today, Ford Motor Company sells millions of vehicles annually under a variety of brand names through thousands of independent dealers. Figure 2 shows these details.

- **Automotive:** (No. Dealers)
  - Ford (>13,000)
  - Mazda (5,294)
  - Mercury (2,229)
  - Lincoln (1,610)
  - Volvo (2,500)
  - Jaguar (694)
  - Land Rover (2,300)
  - Aston Martin (81)
- **Other:**
  - Ford Credit (12,500)
  - Hertz

Sales: Over 7 million vehicles sold worldwide

Revenue: $163.4 Billion

Figure 2 - Ford Automotive Brands, No. Dealers, Sales & Revenues

Competition

Ford is the world's 2nd largest automaker, but struggled in 2002 to transfer sales to profits. The 2002 financial results of 5 largest makers are shown in Figure 3. Although revenues are 2nd highest, net profit is lowest of the companies. This low profit number is reflected in Ford having the lowest market capitalization of the five automakers.

2002 Year Results	General Motors Corp	Ford Motor Company	Daimler Chrysler AG	Toyota Motor Corp	Nissan Motor
Market Cap	$23.9B	$23.8B	$38.3B	$104.0B	$49.3B
Employees	365,000	350,300	365,570	246,900	127,625
Rev. Growth (5 yr. Avg.)	7.5%	-6.5%	3.5%	4.5%	-11.0%
Revenue	$186.8B	$163.4B	$156.8B	$129.0B	$56.9B
Operating Margin	18.4%	17.3%	6.8%	13.8%	16.2%
Net Profit	$1.7B	$0.3B	$5.1B	$6.2B	$4.1B
Net Profit Margin	0.9%	0.2%	3.3%	4.8%	7.3%

Figure 3 - Financial Details of 5 Largest Automakers[2]

Powertrain

Since we will be dealing with powertrain attributes, let us first define what we mean by a powertrain. The vehicle's powertrain consists of engine, transmission and supporting hardware needed to transmit power to the wheels. About 25%-30% of a vehicle's content by cost and part count is included in the powertrain. The picture below in Figure 4 shows a detailed view of the powertrain components, which consist of:

[2] Anthony P. Pandolfi, December 5, 2003, Value Line Publishing

- Engine
- Transmission
- Powertrain Control Module (PCM)
- Radiator, Fan, coolant container and other cooling components
- Exhaust System including Catalytic converters
- Air Intake System (AIS)
- Fuel and Vapor Management Systems
- Axles and half shafts
- Driveshafts
- Engine Mounts
- Accelerator Controls and Speed Control
- Transmission Shifter and Cables

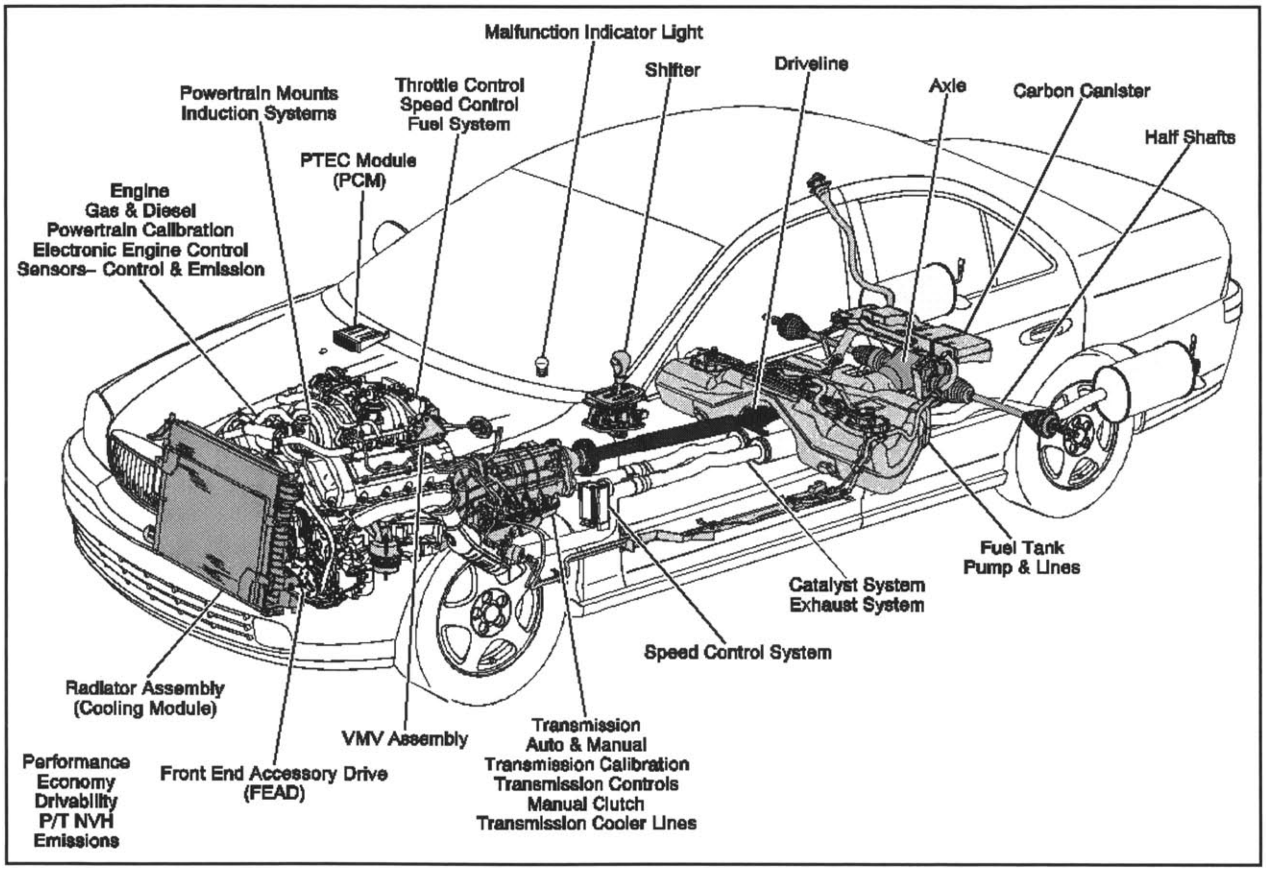

Figure 4 - Powertrain Systems

Attribute Descriptions

This thesis concentrates on the powertrain attributes of Shift Quality, Performance Feel, Trailer Tow, Driveability and a limited portion of Fuel Economy. By attribute we mean, "Those characteristics by which we judge a vehicle."

Shift Quality

Shift Quality is a very complex attribute comprising of a few critical sub-attributes, shift sound and feel, shift duration (length of shift), shift delay (time lag before shift command and actual shift), and shift scheduling (positioning of shifts as a function of vehicle speed and engine RPM (revolutions per minute)affecting performance and fuel).

Performance Feel

The customer's perception of vehicle performance that includes the effects of vehicle acceleration, shift character, shift scheduling, sound loudness, sound quality and accelerator control characteristics. Performance Feel is significantly more complicated than just vehicle performance.

- Accelerator Controls affects performance feel with pedal force magnitude, force linearity, pedal travel, and force hysteresis (the lighter the pedal force gives the perception of better performance feel). Since customers typically do not depress the throttle completely in normal driving the perception of additional power being available is often more important than the actual availability of additional power. There is a point in which the efforts become too low and it starts to adversely affect launch controllability, which is a driveability sub-attribute.
- Transmission character affecting performance feel is shift feel (acceleration disturbance), shift scheduling (placement of shifts), shift delays (time lag before a downshift event), and shift duration (timeliness of shifts), which affects sound of transmission shift. Balancing these character-defining sub-attributes is a challenge as they affect powertrain NVH (Noise, Vibration, Harshness), Fuel Economy and Performance Feel. Typically upshifting early is beneficial for fuel economy and NVH, but may cause a sag in acceleration feel. Not all shift quality sub-attributes affect performance feel.

Driveability

Driveability is the ability to achieve a smooth and controlled vehicle response to driver input, such as throttle and gear change. It relates to the fore/aft acceleration of the vehicle. Most of Driveability may be contained within engine calibration, some influencing factors are driveline lash and powertrain natural frequencies.

Trailer Tow

Trailer Towing is mainly a form of customer usage for pick up trucks and SUV (or body on frame vehicles), although some car owners also tow small trailers. The trailer tow attribute is significantly impacted by the trailer weight or the vehicle's maximum load carrying capacity. Payload and maximum capability is an important advertisable feature of the vehicle; Ford trucks and SUV's are almost always the Best in Class. Sub-attributes of Trailer Towing include Gradeability (vehicle's ability to climb grades) and Automatic Transmission Shift Busyness (shift cycling).

Fuel Economy

Refers to mileage per gallon of gasoline (metro-highway duty cycle) as is measured on the emissions drive cycle. This is the sticker fuel economy on a new vehicle. Fuel Economy is also a real world concern for customers who need to pay for fuel as it impacts vehicle cost of ownership.

Rational for Choosing These Powertrain Attributes

The area we have decided to address is that of Powertrain attributes, because they are known to be high leverage for customer satisfaction. By improving our attributes management process, we significantly increase our chance that we achieve our design targets, thus achieving our customer satisfaction targets. By improving our Powertrain attributes management process, the outcome can lead to improved customer satisfaction and loyalty, and improved sales.

High Customer Leverage

Powertrain attributes are a large determinant in a customer's long-term impression of a vehicle. Powertrain attributes also dominate customer satisfaction surveys, quality reports, and also are an important first impression on a test drive. Since the overall impression of a vehicle is greatly dependant on the powertrain, getting the attributes correct is vitally important.

JD Power Regression

J. D. Power regression data shows that powertrain satisfaction dominates the overall consumer satisfaction of a vehicle. This supports the need to concentrate on powertrain attributes.

The JD Powers APEAL (Automotive Performance Execution and Layout) Model, is a linear regression model of the importance of nine key "Attribute Groups" in determining the "Overall Satisfaction" of a given vehicle. This information was regressed independently for each of the eight different "model segments".

Figure 5 displays the relative importance of each "attribute group" within each vehicle segment. The larger the percentage, the more important the variable is in terms of predicting "Overall Satisfaction". Note that the attribute group of Engine and Transmission Performance dominates the customer's perception of the vehicle, and is the highest attribute category in every model segment.

	Vehicle Segment							
	Compact Car	Midsize Car	Full-size Car	Luxury Car	Sporty Car	Pickup	SUV	Van
Engine and Transmission Performance	22%	18%	26%	22%	26%	28%	21%	19%
Vehicle Styling/Exterior	19%	16%	19%	15%	20%	18%	18%	15%
Ride, Handling and Braking	10%	17%	10%	15%	12%	13%	15%	11%
Cockpit and Instrument Panel	12%	13%	12%	14%	13%	8%	11%	9%
Seats	9%	10%	6%	10%	11%	7%	10%	16%
Comfort and Convenience	10%	8%	10%	9%	5%	9%	10%	15%
Sound System	8%	9%	10%	8%	7%	9%	8%	7%
Heating, Ventilation and Cooling (HVAC)	9%	9%	8%	7%	7%	7%	8%	9%

Figure 5 - Top Level Importance Weighs in Terms of Predicting Overall Satisfaction

We took the average of the 8 vehicle segments and graphed them in Figure 6 to show visually how important Engine and Transmission Performance is compared to the other attribute groupings. We will also compare the engineering community's impression on how Ford ranks these attributes internally, based on our survey data.

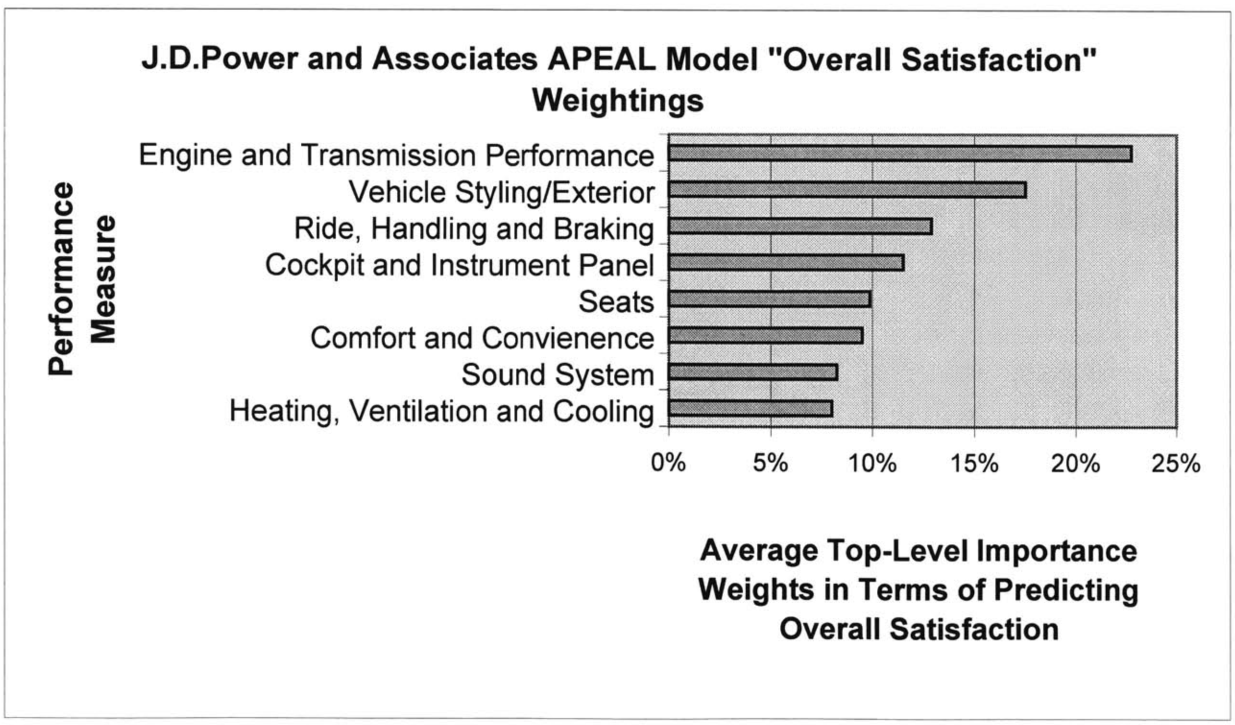

Figure 6 - APEAL Model Average "Overall Satisfaction" Weightings

Brand DNA Attributes

Brand DNA attributes are the vehicle attributes, which are character defining. Getting DNA attributes right is key to supporting the brand/nameplate image and vision. Powertrain, Driving Dynamics and Package are the 3 high level attributes that are focused on to achieve the envisioned driving experience. Supporting the Powertrain attribute are sub-attributes of Performance Feel, Driveability and Smoothness and Trailer Tow, which are balanced to achieve the desired brand image through attaining DNA objective target ranges. Figure 7 shows how the powertrain attributes are critical to achieving Ford's, D^{2}ADE (Dependable, Desirable, Affordable Driving Enjoyment) product strategy.

The sub-attribute of Powertrain NVH (Noise, Vibration, Harshness) supports three higher-level attributes; Trailer Tow, Performance Feel and Vehicle NVH. This gives an understanding of the importance of the powertrain; despite being out of sight, it is very important to the customer.

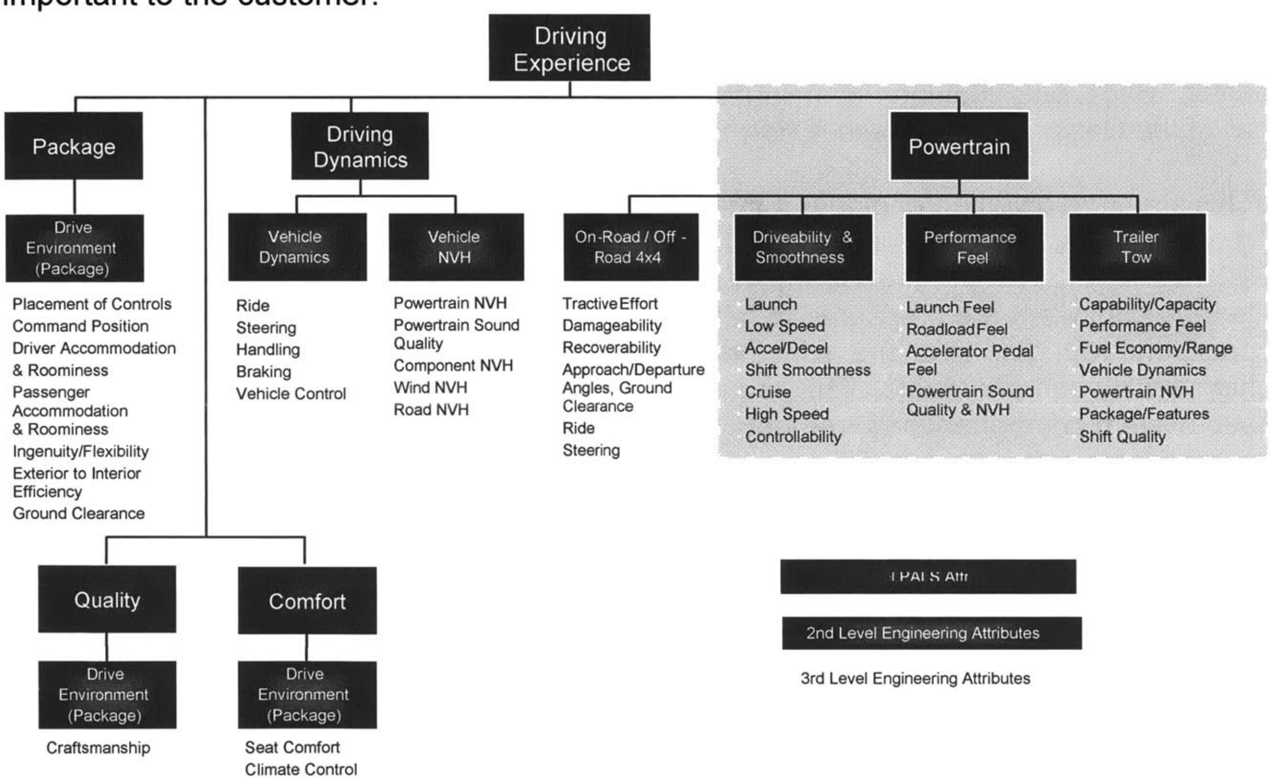

Figure 7 - D^{2}ADE DNA Driving Experience Cascade

Organizational Structure

It is critical to get the organizational structure correct to ensure that the desired attributes are achieved. Here is a brief description of Ford's engineering organization, which delivers Powertrain attributes.

Ford Motor Company's North American Product Development (NAPD) divides its business units chiefly by family and sport cars, personal use and commercial pickup trucks and Sport Utility Vehicles. Within NAPD, the majority of Ford Motor Company's products are of the Ford (Blue Oval) brand, but engineering of the Lincoln and Mercury brands, derivatives of the Ford brand is also included. Most of these have common parts; however, a majority of the brand differentiation is addressed with Brand DNA metrics and predetermined sub-system tunables.

Ford has strong program leaders for each vehicle program to ensure focus on the vehicles. The engineering program manager has many business, management, functional, and manufacturing requirements to fulfill. Most of the engineering staff that supports a program comes from backbone engineering. The engineering backbone is intended to drive stability in engineering staff and retain knowledge despite constant changes to program staffing. The intent of organizing this way is to ensure that a given engineer will get rotated to another assignment within their current area of expertise on their next rotation.

Figure 8 shows the inter-relationships between vehicle program managers and the engineering backbone. Program managers are shown down the left hand side of the chart. Backbone engineering includes most all of the engineers on a program including all of the Design and Release (D&R) Engineers PMT leaders and PAT leaders.

This structure gives an engineer a functional reporting path as well as a program-reporting path. This dual reporting structure is important to ensure vehicle quality and affordability. Since program teams are under considerable pressure to meet cost targets engineers are pressured to take risks to achieve these targets. The strong backbone reporting structure is intended to ensure that their section of the vehicle is of high quality and affordable. This requires the functional management to ensure that all sub-system component requirements are met, and allows the use of common components between vehicles to achieve economies of scale. This prevents the design and release engineers from being pushed by the generalists on vehicle team to make less than optimal choices for the company as a whole.

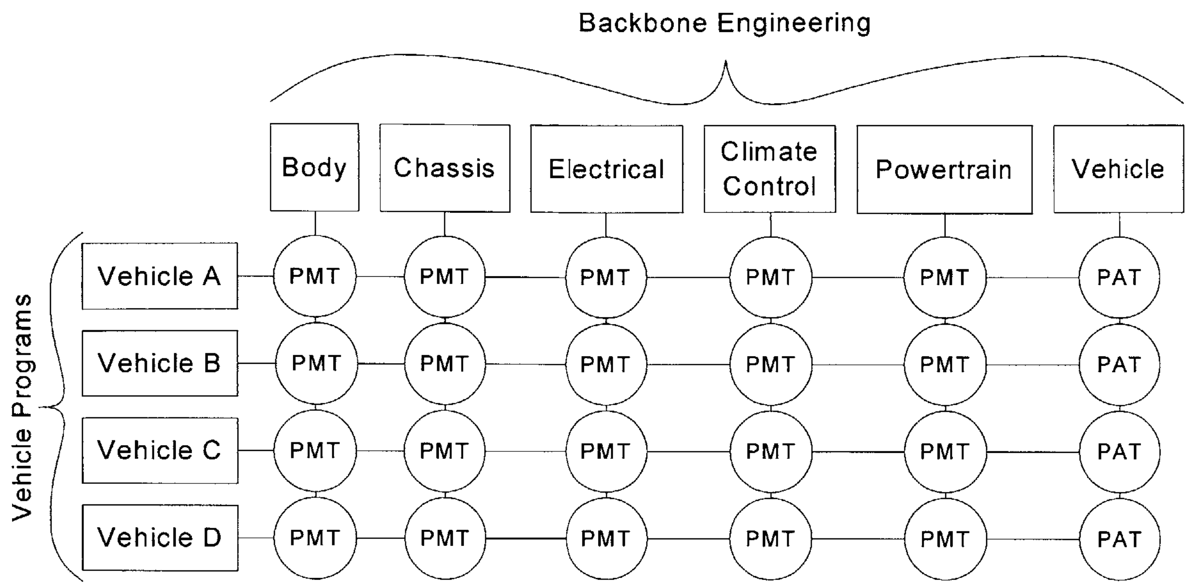

Figure 8 - Relationship of Engineering Resources to the Programs

For each vehicle program a PMT (Program Module Team) is assigned to the vehicle team to provide direction from the Program Team to the assigned backbone engineers. These PMTs are represented as circles in Figure 8. For vehicle engineering, a Vehicle Engineering Manager is assigned to work with the program chief engineer as part of the vehicle team. The Vehicle Engineering Manager is responsible for developing the vehicle build, test and sign-off plan, which keeps them very busy. They are also responsible for handling all vehicle attribute PATs as well as interfacing with the various PMTs. The PMTs typically handle the business end of engineering like cost, weight, and manufacturability, while the PATs cover the cross-functional needs of a particular attribute. The reporting structure for PMTs and PATs within a vehicle team hierarchically (dotted line reporting) looks like Figure 9.

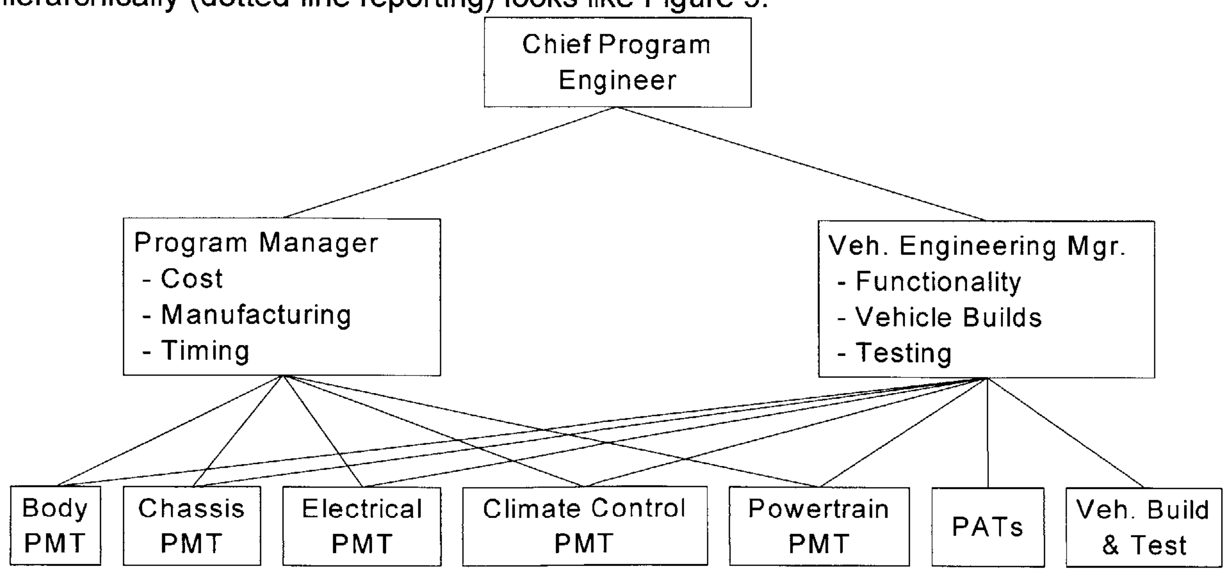

Figure 9 - Vehicle Reporting Structure of PMTs and PATs

Vehicle Program Management

The vehicle program management team uses customer data when determining vehicle program direction. A Program Direction Letter (PDL) is issued by project management to communicate product and engineering direction to the program. A PDL also provides the financial authority to execute that direction. The primary interfaces between project management and design & release (D&R) engineering are the Program Steering Team (PST) at the manager level, Program Module Teams (PMT) at supervisor and working level, and Program Activity Teams (PAT) at supervisor and working level. See Figure 10 below.

Program Steering Team (PST)

Each vehicle program has a Program Steering Team (PST). The Program Steering Team is a cross-functional group that serves as the primary forum for planning, directing, and coordinating the key events essential to the product development process. This team generally consists of Chief Program Engineer and his/her managers responsible for various systems or functions.

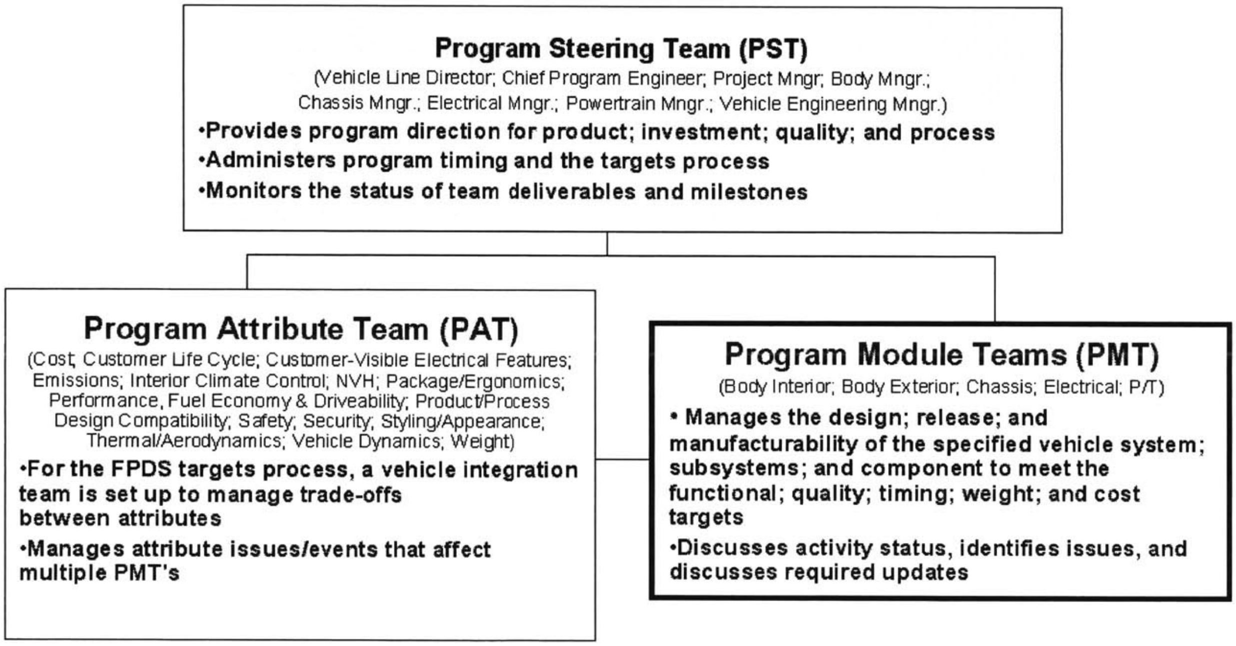

Figure 10 - PST, PMT and PAT Hierarchy and Responsibilities

Program Module Team (PMT)

Program Module Teams are cross-functional groups who manage the development of a set of related parts or modules, according to specific quality, function, cost, weight, and timing targets. The vehicle is broken down into 5 major modules: Body, Chassis, Powertrain, Electrical and Climate Control. The PMT helps pull together the overall vehicle business case for the different design variations that a Design and Release Engineer may be considering. The PMTs generally consist of engineers and program planners. Each PMT is further broken down to CPMTs (Chunk Program Module Teams), which handle sub-systems. Figure 11 on the following page shows how a vehicle is subdivided into PMTs and CPMTs. A CPMT may be the D&R engineer or in the case of the engine and transmission in particular is another group leader pulling together many sub-systems each with one or more D&R engineers for the components involved.

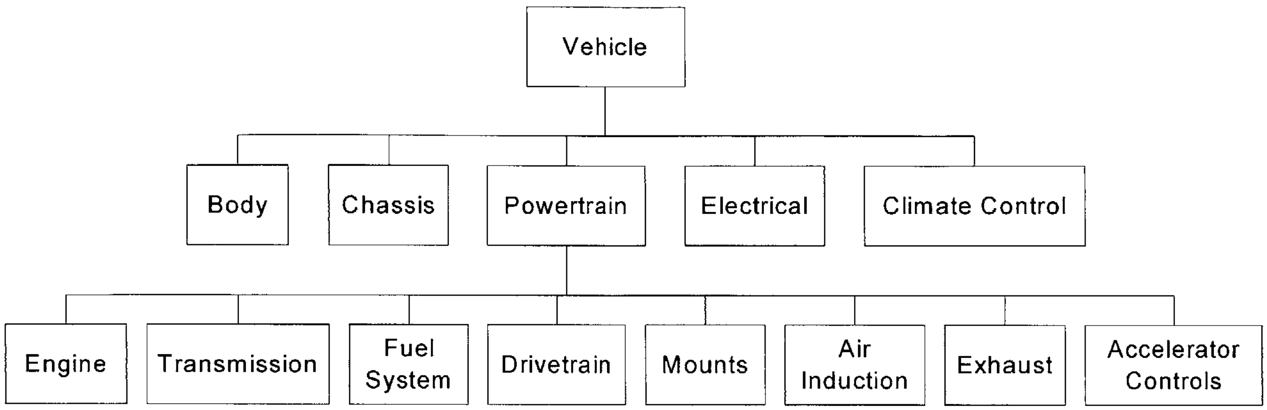

Figure 11 - Decomposition of Vehicle Systems down to CPMT Level for Powertrain

Program Activity Teams (PATs)

Program Activity Teams are cross-module or component teams working toward a specific function such as Noise, Vibration, and Harshness (NVH), Vehicle Dynamics, or Performance Feel. They are typically responsible for delivering vehicle-level attributes across a family of vehicles over multiple model years. PATs all are contained within vehicle engineering and support each vehicle team through the vehicle integration manager. Some PATs are developed on an as-needed basis and may be active for only certain phases of the design process, while others continue through the entire vehicle development process.

The powertrain attribute PATs run through the life of the program. They have core members and additional members depending on the time frame and issues involved. Figures 12 and 13 show the memberships on these two teams.

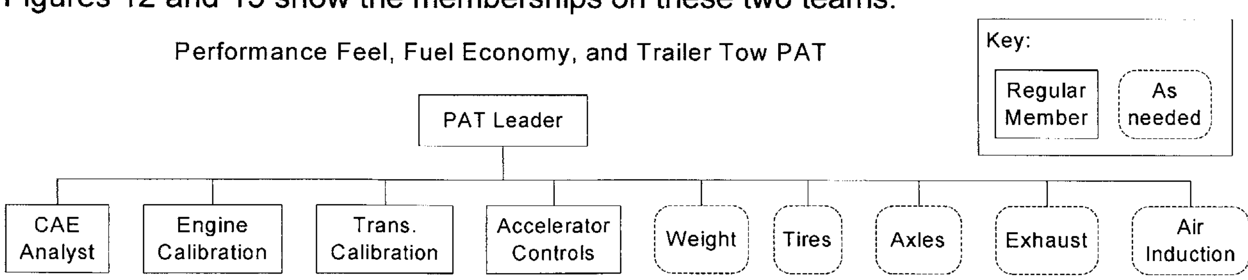

Figure 12 - Performance Feel, Fuel Economy, and Trailer Tow PAT Memberships

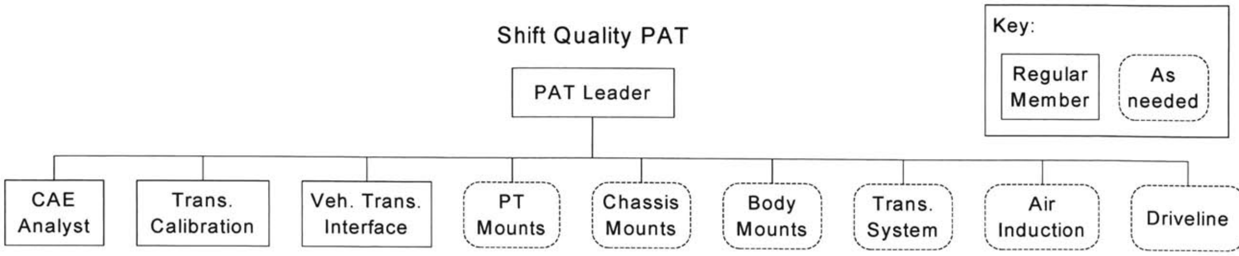

Figure 13 - Shift Quality PAT Membership

To achieve overall system functional targets, D&R Engineers must design their subsystems, while taking into consideration the other subsystems involved as well as the overall function of the system as a whole. Thus, participation by CPMT leaders / D&R engineers in the PMTs and PATs is vital.

Ford Product Development System (FPDS)

Ford Product Development System is a staged-gate product development process. The stock timing is shown in Figure 14. This timing may be significantly shortened depending on the level of change to the vehicle and powertrain. The product direction letter (PDL) will be started at KO and updated at each phase of the program.

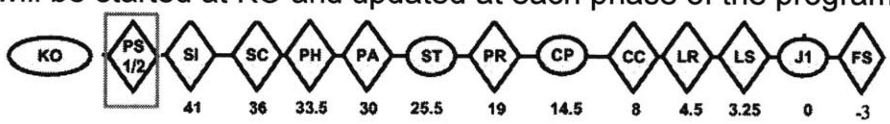

Figure 14 - Standard Timing in Months

The acronyms in Figure 14 are as follows:

- KO – Kick-off - Beginning of program specific work including initial PDL
- SI – Strategic Intent – Strategy for Product, market, supply chain
- SC – Strategic Confirmation – Vehicle & System level targets committed
- PH – Proportions Hardpoints – Selective Hardpoints Frozen
- PA – Program Approval – All targets become program objectives in PDL
- ST – Surface Transfer – All hardpoints frozen
- PR – Product Readiness – Full vehicle analysis complete
- CP – Confirmation Prototype – Prototype vehicles built
- CC – Change Cut-off – Preliminary Engineering sign-off
- LR – Launch Readiness – Final Engineering Sign-off
- LS – Launch Sign-off – Production Tools Trial complete
- J1 – First vehicles built

FPDS Target Setting Process

The FPDS target setting process is intended to be a consistent structured process for program teams to follow when setting targets. The first step is converting the program vision, competitive information, setting future customer targets, etc. into initial product attribute targets. See Figure 15 in following page.

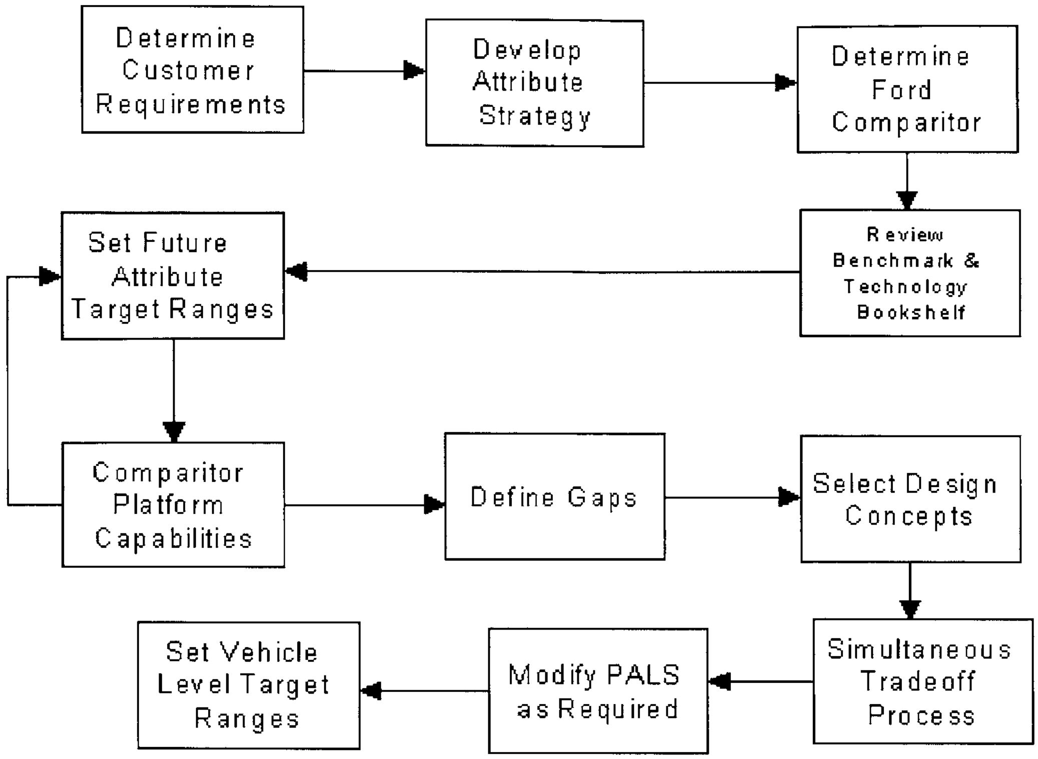

Figure 15 - Setting Vehicle Level Target Ranges – Pre<SI>

The Product Attribute Leadership Strategy (PALS) defines the desired level of competence for each attribute compared to key competitors:

- Market Leader – Noticeably better than the best competitors in a given attribute
- Among the Leaders – Equal to the best competitors in this characteristic
- Competitive – Goal is to be about average in this regard.
- Uncompetitive – Used on qualities of a given vehicle that customers value less, so engineering effort can be spent on more important attributes.

This strategy is planned out for each of the 15 key attributes:

1. Safety
2. Security
3. Package/Ergonomics
4. Thermal/Aerodynamics
5. Vehicle Dynamics
6. Emissions
7. Performance, Fuel Economy & Driveability
8. NVH
9. Electrical/Electronic
10. Interior Climate Comfort Environment
11. Weight
12. Product/Process Design Compatibility
13. Customer Life Cycle

14. Styling/Appearance
15. Cost

Once these vehicle targets are confirmed compatible with assumptions, Target cascading begins. The process of breaking down high-level functionality down to low-level functionality involves the iterative process of choosing the correct form, or hardware, which we will discuss in Chapter 4. Recognizing these iterations, targets are cascaded down from the Vehicle Level to the Component Level over time, following these 3 principles:

1. Cascade targets one level at a time
2. Compare targets to hardware. Modify the assumptions if necessary
3. Verify assumptions and targets are compatible before proceeding to next level

We will see from the actual DSM of powertrain attributes in Chapter 5 that there are many more interactions than can be considered one level at a time. For example a component level assumption may require changing sub-system, system and vehicle level targets, which is not included in the one step at a time approach. This changing of multiple levels at once is not budgeted in the program timing and may result in program delays. Recognizing this, let's look at the planned process.

Targets Cascade Timeline

Target cascading occurs along the following timeline within FPDS. Targets cascade begins before <SI> (Strategic Intent) and finishes at <PA> (Program Approval). At Program Approval all end item targets are frozen and become objectives. See Figure 16 depicting this on the following page.

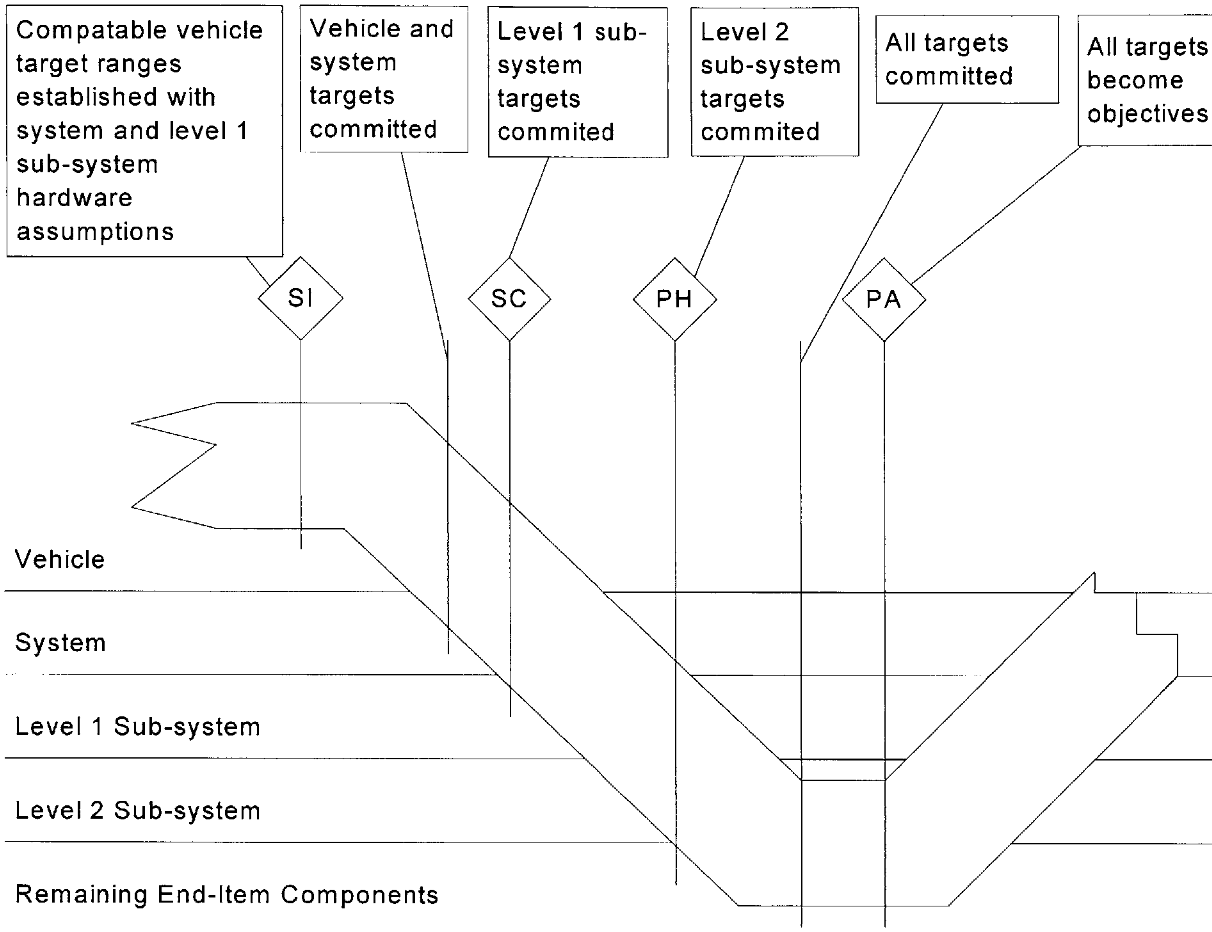

Figure 16 - Cascade and Balance Targets Timeline

Committed targets are those cascaded targets the team feels they must meet in order to achieve the program's vision for the vehicle. These targets are flexible at the time they are set, because the team has yet to conduct all the required analysis at each level to determine if the program can attain the total vehicle targets. After further analysis, if a target is deemed unattainable, the Program Team attempts to rebalance the unachievable targets within the system or PMT, thus maintaining the overall vehicle target. By one month prior to <PA> all the required analysis is completed in order to ensure attainment of a particular target. All targets become objectives at <PA>. After a target becomes an objective it cannot be re-opened for negotiation except by the Vehicle Engineering Manager or Chief Program Engineer.

Existing CAE Tools and Capabilities

Computer aided engineering tools are very important in helping set targets for attributes and also to help determine if the hardware chosen is capable of meeting the desired attributes prior to vehicle builds.

A number of Computer Aided Engineering (CAE) modeling tools are used to help ensure the powertrain meets all the attributes, these include (Details in Figure 17):

- CVSP (Corporate Vehicle Simulation Program)
- VDM_Generate (Vehicle Driveability Model) used to assess transmission and driveline effects on Driveability
- StratSim to analyze Shift Strategy
- HCS_Generate (Hydraulic Control System) used to analyze transmission hydraulics
- VSIGN – Used for NVH analysis of linear systems
- ADAMS – General purpose code used for Vehicle Handling Simulation
- MatLab and Xmath – General purpose and control
- Excel – Driver Demand Table construction

Model	Use	User	Comments
CVSP	Corporate Vehicle Simulation Program - Performance, - Fuel Economy, - Limited Driveability - Trailer Tow	P&E and FE Analysts	Models of most vehicles Excellent support group 50+ stock reports Lacks "Feel' & "Sound" needed for Shift Quality Lacks many driveability sub-attributes
VDM	Vehicle Driveability Model assesses transmission and driveline effects on Driveability - Tip-In - Tip-Out - Gear Shifts - Torque Converter Damper Tuning - Trans Component Dynamic - Torques	Calibration	50+ models including: vehicle, engine, clutches, shafts, planetary gear sets, differential, tire compliance, tire slip, torque converter, backlash, and damper.
StratSim	Shift Strategy Simulation	Transmission Calibration	Mimics PCM scheduling, accepts inputs from the Driver and VDM, and outputs control signals to HCS
HCS	Transmission Hydraulic Control System	Transmission Systems	- Models of most Ford Trans. - 100+ comp. models including; valves, lines, ball checks, orifices, solenoids, pump flow, accumulators, and clutches.
VSIGN	NVH analysis of linear systems	NVH	- Body & Frame can be modeled as rigid or flexible - Acoustic cavity modes like "boom" - No feedback coupling between Vehicle response and trans. Dynamics
ADAMS	Shift Feel & Vehicle Dynamics	Vehicle Transmission Interface CAE Analyst	- Many models exist for vehicle dynamics - Expensive & complicated software/hdwr req'd. - Load cases must be determined in VDM. - Numerical stability problems - Limited user base. - No feedback coupling between vehicle response and trans. dynamics
MatLab & Xmath	General Purpose & Control System modeling	Various	
Excel	Driver Demand Calculation	P&E Analysts & Calibration	

Figure 17 - Computer Aided Engineering Tools used in Powertrain Attribute Management

These tools however do not provide a holistic view of the all the sub-attributes for a given vehicle characteristic. The tools used for each attribute are listed in Figure 18. For some attributes it takes a number of tools to fully understand the qualities being tuned.

Attribute	Tools Used							
	CVSP	VDM	StratSim	HCS	VSIGN	ADAMS	MatLab & Xmath	Excel
Perfomance Feel	X							X
Shift Quality			X	X	x	X		
Driveability	x	X						
Trailer Tow	X							
Fuel Economy	X							

Key:

X	Tool provided significant benefit
x	Tool provides only marginal benefit

Figure 18 - Tools Used for Each Attribute

A holistic model of the powertrain and its effect on vehicle attributes is a significant challenge at Ford Motor Company. For example, an integrated Shift Quality package is still not available, nor will it be in the immediate future. Given that, a complete model for all powertrain attributes is even further into the future.

Since the reality is that an integrated powertrain attributes model will not be available in the foreseeable future, other process enabling methods must be utilized to better manage the attributes development and balancing process. This is explored in the next section.

Available Powertrain Attributes Knowledge and Formats Utilized

This section addresses the current knowledge and process tools for communicating the interactions between the attributes and their design parameters. Unfortunately, Ford uses many processes and there isn't a single "deemed" best practice. There is a lack of consistency among not only powertrain attributes, but attributes in general. For example the format used for Vehicle Dynamics work (Figures 25 and 26) is different than all those used for powertrain attribute work (Figures 19 - 24).

Quality Function Deployment (QFD) developed by Professors Mizunno at the Tokyo Institute of Technology and Yoji Akao of the Asahi University in the 1960's and 1970's is useful for converting customer desires into engineering metrics. The following page (Figure 19) has a QFD Ford did on Performance Feel.[3] QFD has limitations, most importantly that it typically handles only one system at a time and that attribute

[3] Akao,Yoji, QFD: Past, Present, and Future, 1997, International Symposium on QFD '97 – Linköping

interactions are not easily communicated. Additionally, it cannot be "re-arranged" as a partitioned DSM displaying potential iterations and when they will most likely occur. In other words, its not really a systems management tool like DSM.

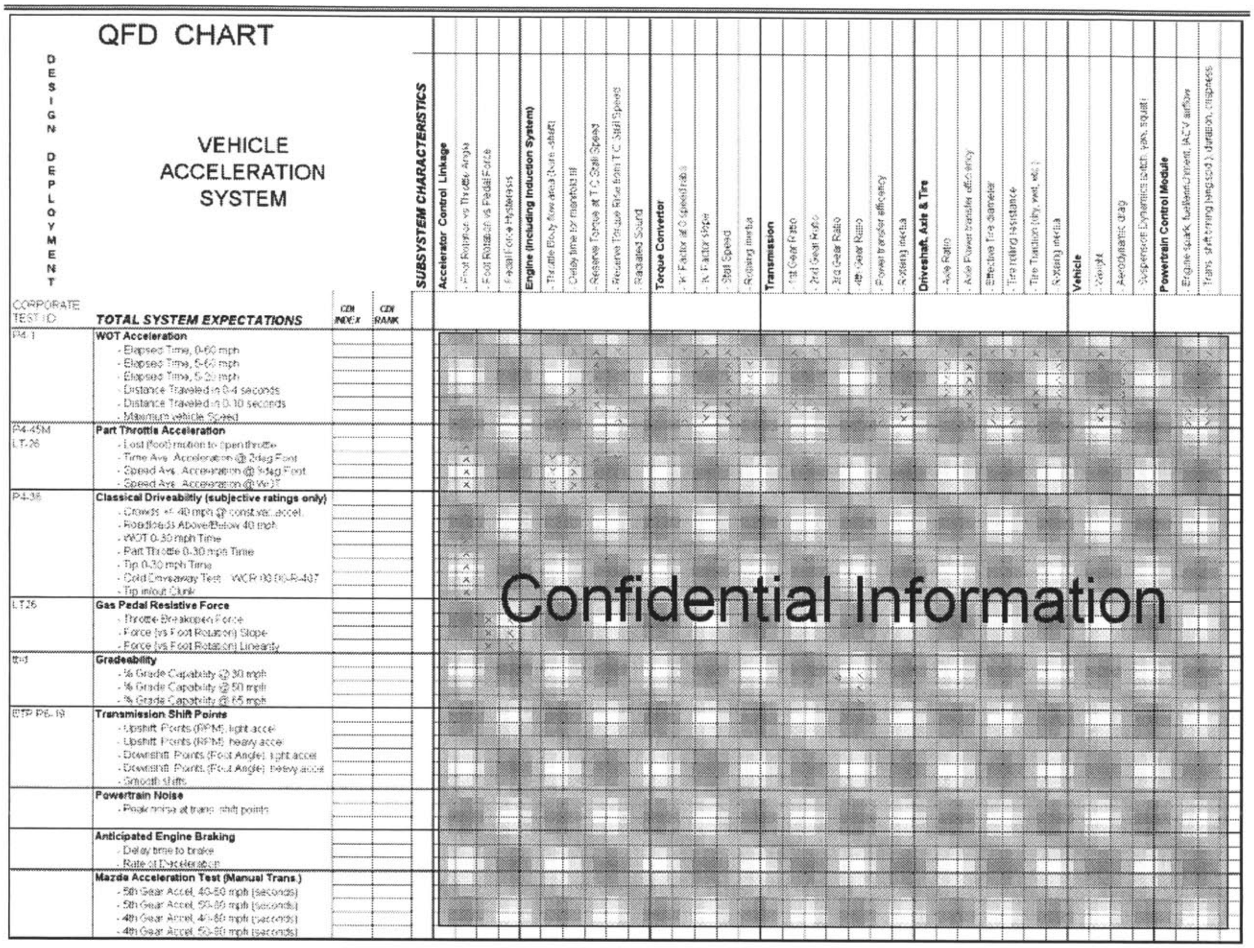

Figure 19 - Performance Feel QFD

The figure in the following page (Figure 20) is our Performance Feel cascade diagram. The intent of this diagram is to begin from the system level attribute, in this case Performance Feel and is used as a visual of its contributing factors (sub-attributes) and the systems/sub-systems that you would cascade targets to from a systems V perspective. This also mixes form and function as in our DSM, but the information provided is extremely limited. For instance, the interactions are not provided, just the contributors to the sub-attributes and the vehicle-level attribute. A couple of examples of missed interactions are, gearing affecting sound level and sound level affecting all sub-attributes of shift quality.

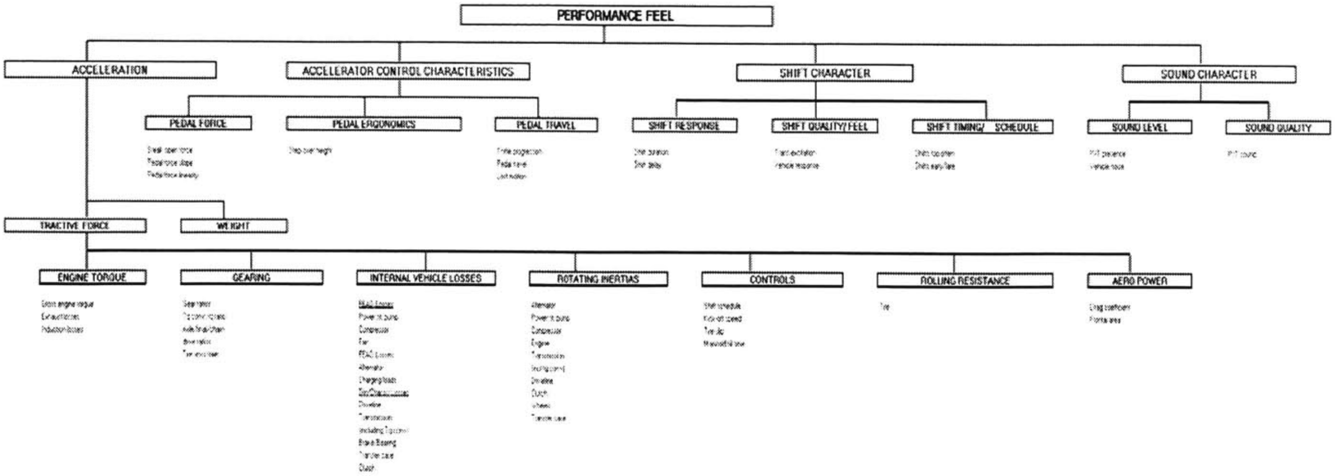

Figure 20 - Performance Feel Cascade Diagram

The Smooth Automatic Transmission (SAT) QFD in the figure below (Figure 21) helps define the characteristics of a 'good shift'. The QFD identifies the relationship between voice of the customer (wants) and the voice of the engineer (Technical System Expectation).

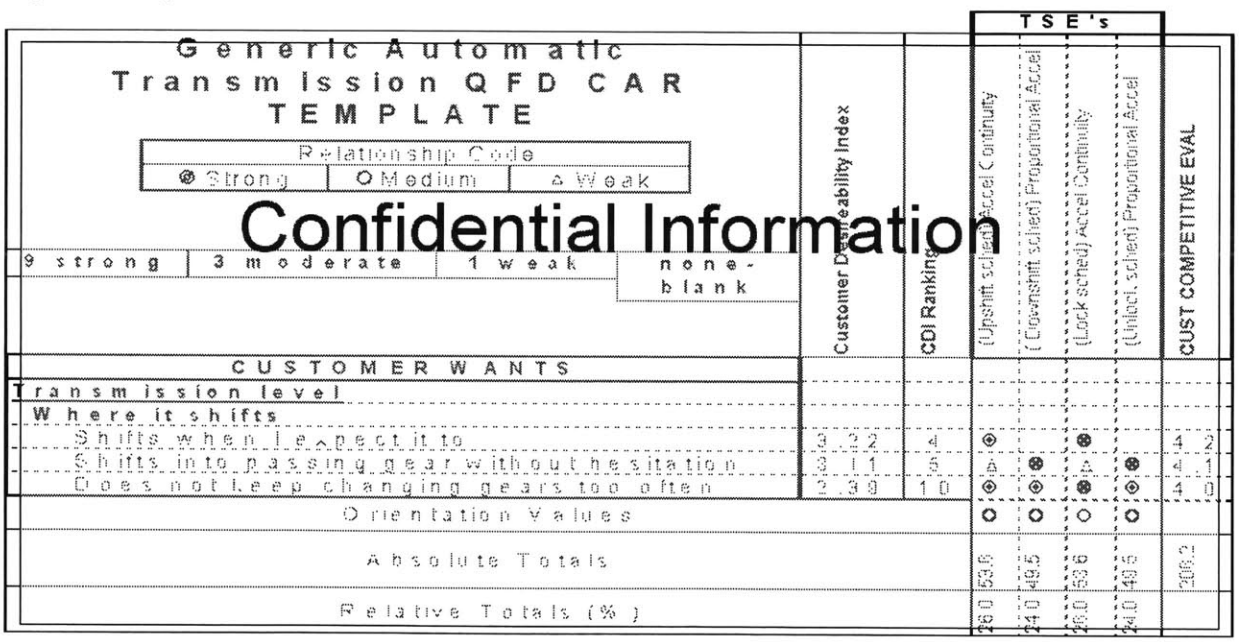

Figure 21 - Smooth Automatic Transmission QFD

The last three examples are also formats Ford Motor Company uses in order to share knowledge on the attributes and interactions.

The P-Diagram as developed by Taguchi [4]shown below (Figure 22) shows all forms of inputs and outputs to a system. This includes customer inputs, noises, control factors,

4

Clausing, Don, Robust Design SDM, March 22, 2002 ideal function and error state. In this format, an interaction can either be a noise or a control factor. Consequently, this makes it difficult to use for our documentation, since we don't know which category to put the interaction. Additionally, this format only covers one attribute or feature at a time. So finding the desired chart showing the interaction of interest may be difficult.

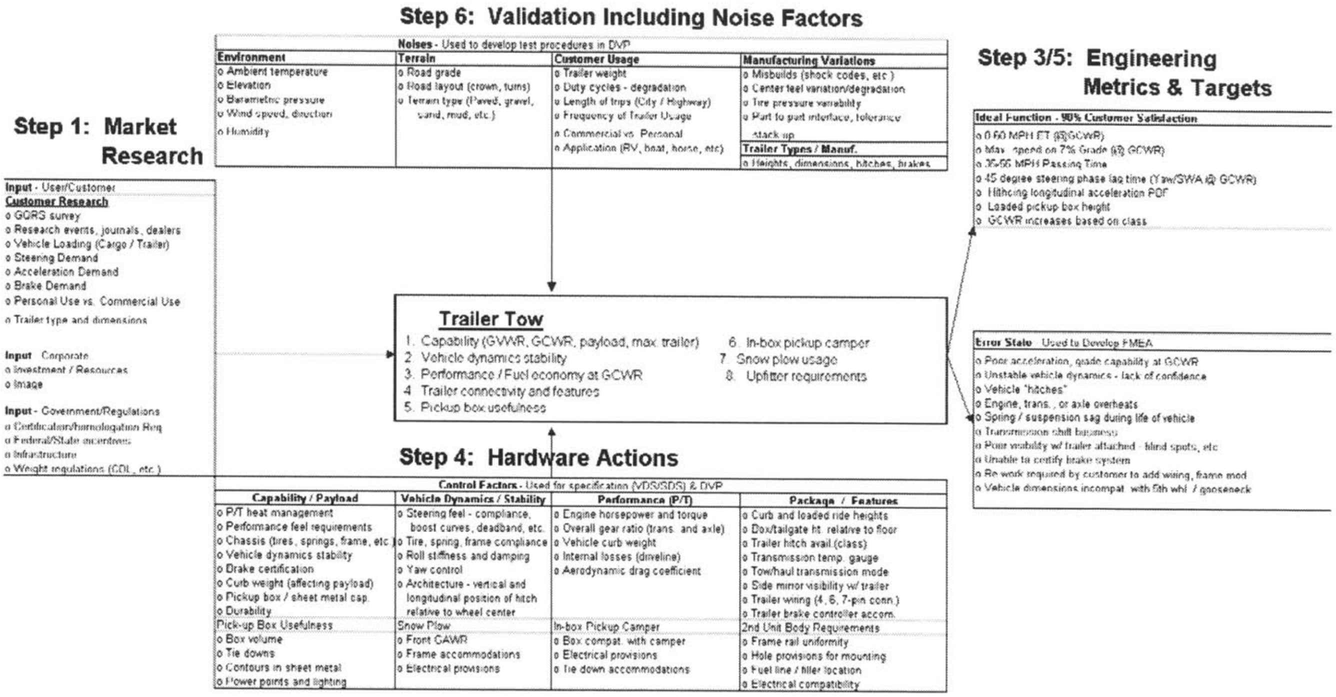

Figure 22 - Trailer Tow P-Diagram

The next interaction tool example is an Ishikawa diagram (Figure 23). This shows a decomposition of influences on the system. It's useful for troubleshooting systems issues. However, it is not useful as an interactions document tool since it doesn't show potential interactions between contributing factors.

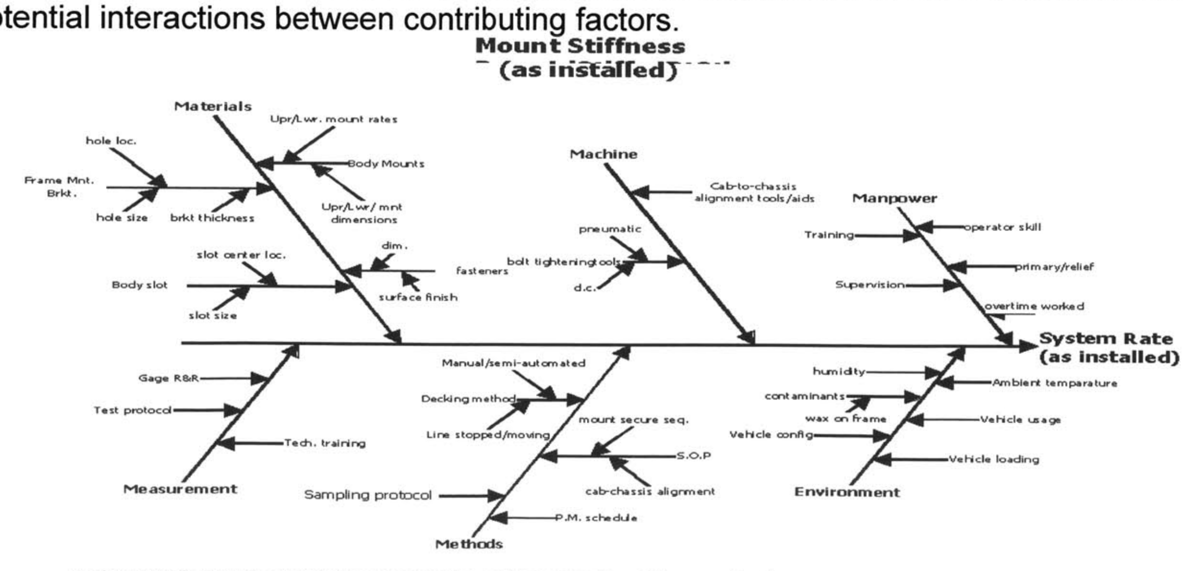

Figure 23 - Ishikawa (Fishbone) Diagram

The next chart (Figure 24) is the newest form of communicating our key attribute DNA metrics and the target ranges. DNA metrics are used to define the brand from a subjective evaluation standpoint. Although this format is good in displaying the vehicle character defining attributes, it doesn't communicate the tunable design parameters that need to be tuned to obtain these requirements. So this is of limited value in our goal of documenting interactions.

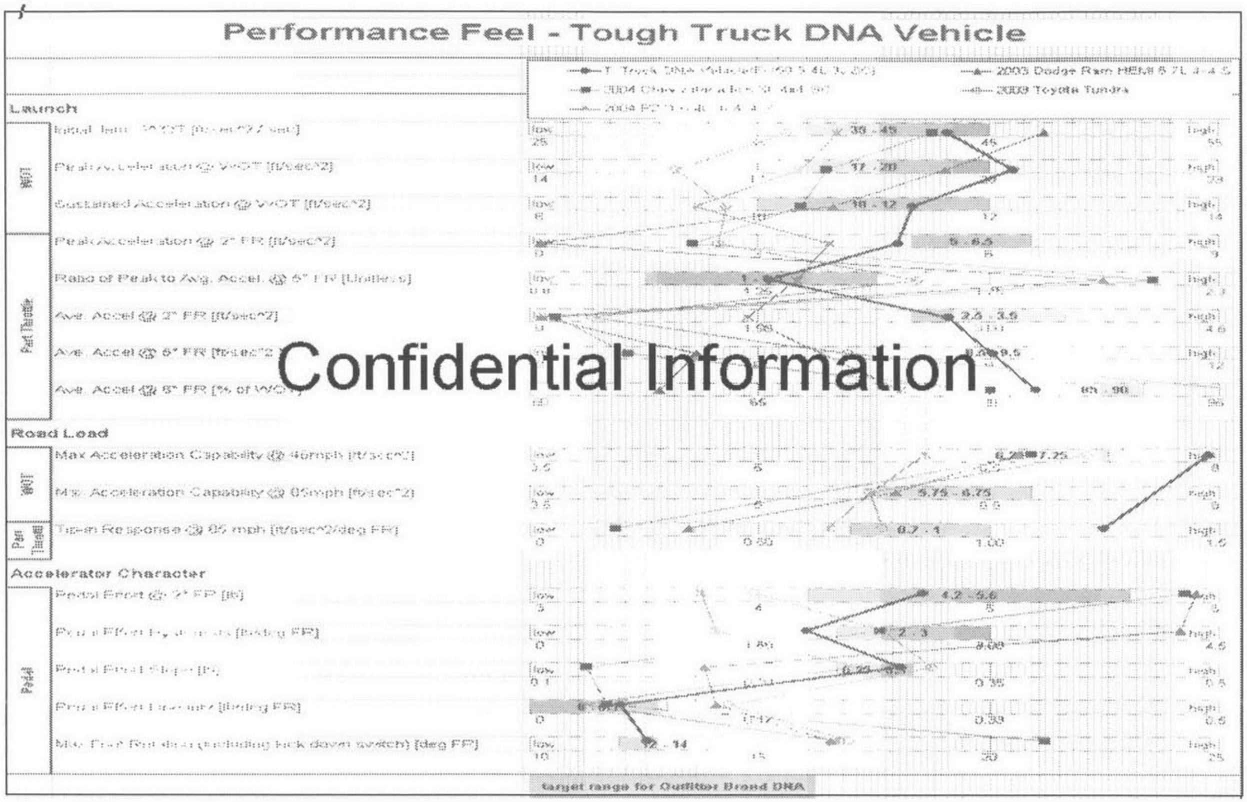

Figure 24 - Performance Feel Brand DNA Metrics and Targets

The last couple of charts (Figures 25 and 26) in the following pages are used by the Vehicle Dynamics group. This is a typical Form vs. Function interactions diagram. This Form vs. Function Interactions Matrix is unique in that there are web links to the attribute and sub-attribute descriptions. Each interaction shown in the matrix is also linked to a page of the subsystem design guide for added details on the interaction. This matrix is used in Ford's intranet local website specific to the Vehicle Dynamics community. This is a good example of how linking can add a significant amount of information that the engineer needs to effectively understand and handle an attribute interaction. These charts also provide some indication of how well staffed and organized vehicle dynamics is when compared to powertrain attributes.

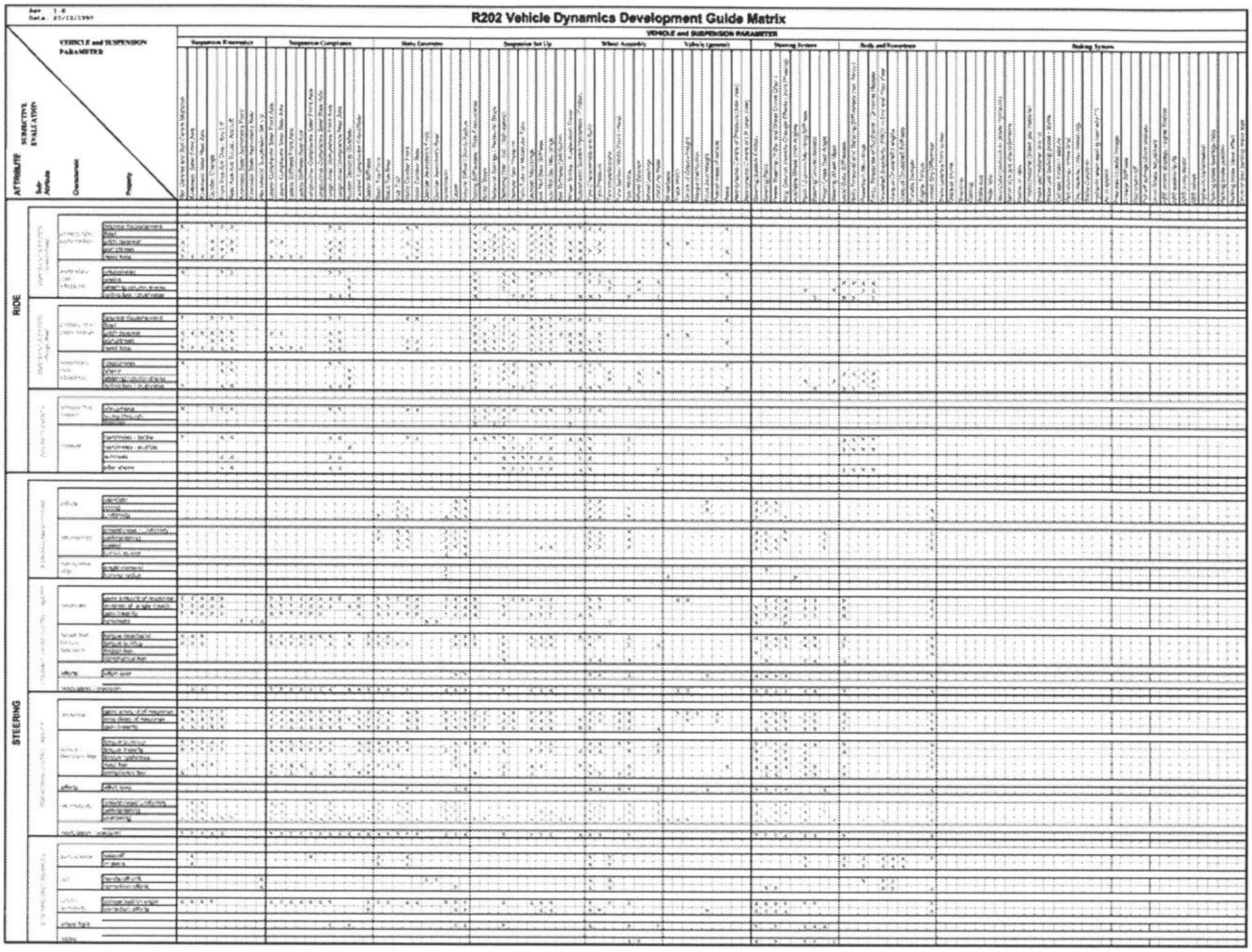

Figure 25 - Vehicle Dynamics Form vs. Function Interactions Matrix (Ride and Steering Attributes)

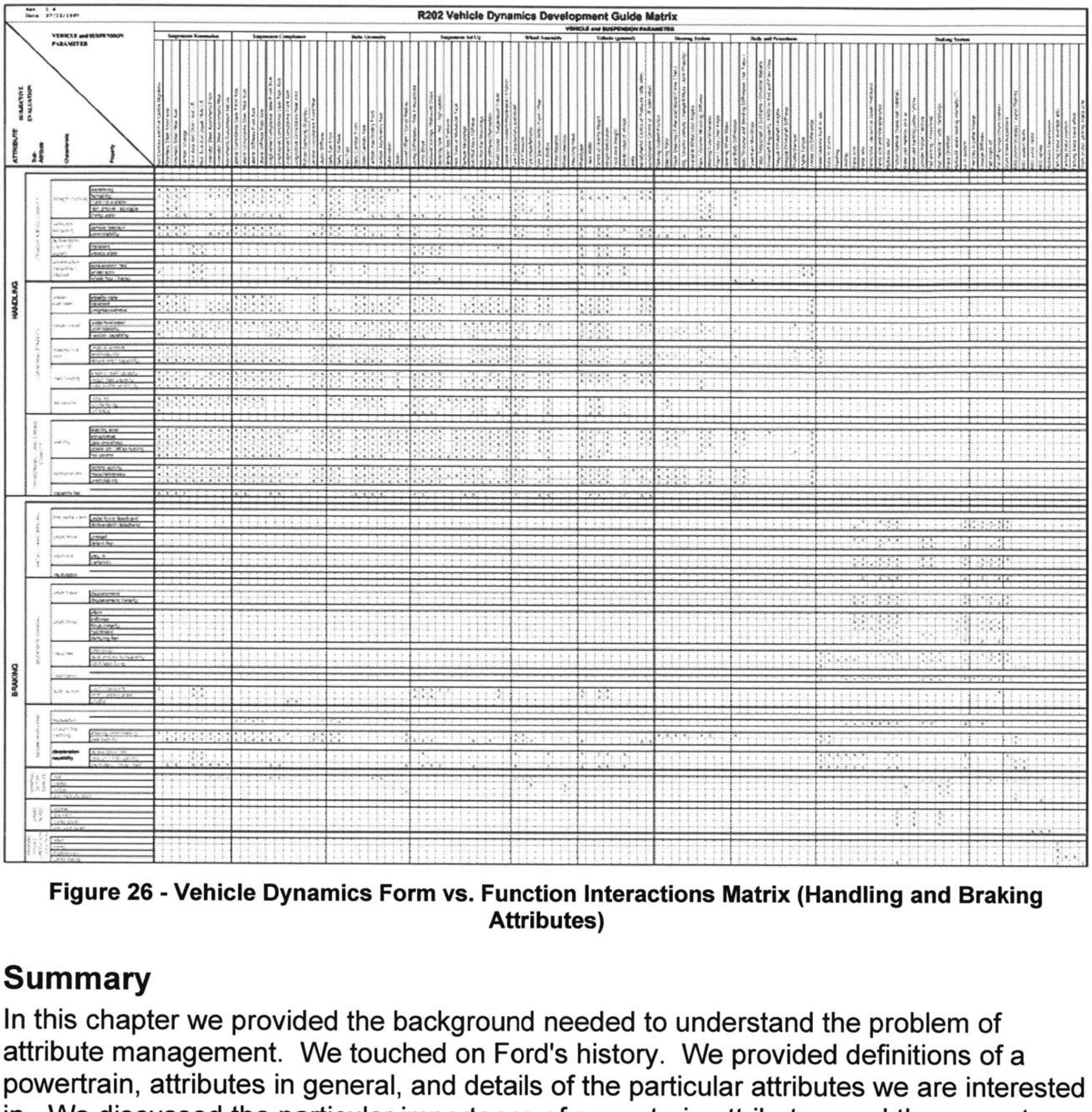

Figure 26 - Vehicle Dynamics Form vs. Function Interactions Matrix (Handling and Braking Attributes)

Summary

In this chapter we provided the background needed to understand the problem of attribute management. We touched on Ford's history. We provided definitions of a powertrain, attributes in general, and details of the particular attributes we are interested in. We discussed the particular importance of powertrain attributes, and the current organizational structures that handle those attributes. We also looked at the current CAE tools and their capabilities. Finally, we looked at existing methods of documenting attribute interactions, and compared them to the DSM format.

Now that we are armed with the generalities, let us take a deeper look at some of these items. In Chapter 3 we will delve into the organizational challenges that help lead to the issues we are seeing.

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Chapter 3 - Organizational Challenges to Attribute Engineering

Introduction

In this chapter we are now ready to look at the current organizational challenges in handling of attribute interactions, and compare the importance of powertrain attributes to the customer versus what the current emphasis is at Ford. In Chapter 1 we identified the issues we are trying to help with and the hypothesis that we are trying to prove. Then in Chapter 2 we gave some general background needed to understand the issues. Now lets take a closer look at the organizational challenges to the handling of powertrain attributes.

Powertrain Organizational Challenges

To the vehicle team, Powertrain is intended to appear to act as a unified body, led by the PMT representative. However powertrain is far from being a single organization. Powertrain is divided into 3 main areas:

- Powertrain Operations (PTO)
- North American Engineering - Core and Advanced Powertrain Engineering (NAE-CAPE)
- Powertrain Systems Engineering (PTSE)

Powertrain is organized to ensure engine and transmission commonality and allows relative uniqueness with the installation components. The organizational structure is shown in Figure 27. The responsibilities of these organizations are outlined below.

PTO

Powertrain Operations designs and manufactures the engines and transmissions. PTO has a reporting structure that reports up to a very high level through the manufacturing organization. This separateness is also compounded by the long lead times required to develop engines and transmissions. Additionally, the engines are designed in Dearborn and the Transmissions are designed in Livonia, which are about 15 miles apart.

NAE-CAPE

NAE-CAPE (North American Engineering – Core and Advanced Powertrain Engineering) engineers the Fuels Systems, Powertrain Control System and the Engine Calibration. This organization is part of the main engineering backbone for North America and supports all program team CAE work for performance and fuel economy. This organization also has the corporate technical specialists for powertrain attributes, which create attribute development methodologies and support performance metrics development.

PTSE

Powertrain Systems Engineering (PTSE) engineers the Air Induction System, Exhaust System, Powertrain Mounts, Axles, Driveshafts, Accelerator Control System, and Transfer Cases. There is a PTSE "backbone" organization within each vehicle cluster. The Powertrain PMT is also located in this organization.

The PMT and PAT leaders must work at a variety of management levels across multiple organizations with varying goals, situated in different locations to pull together a complete, functioning vehicle powertrain.

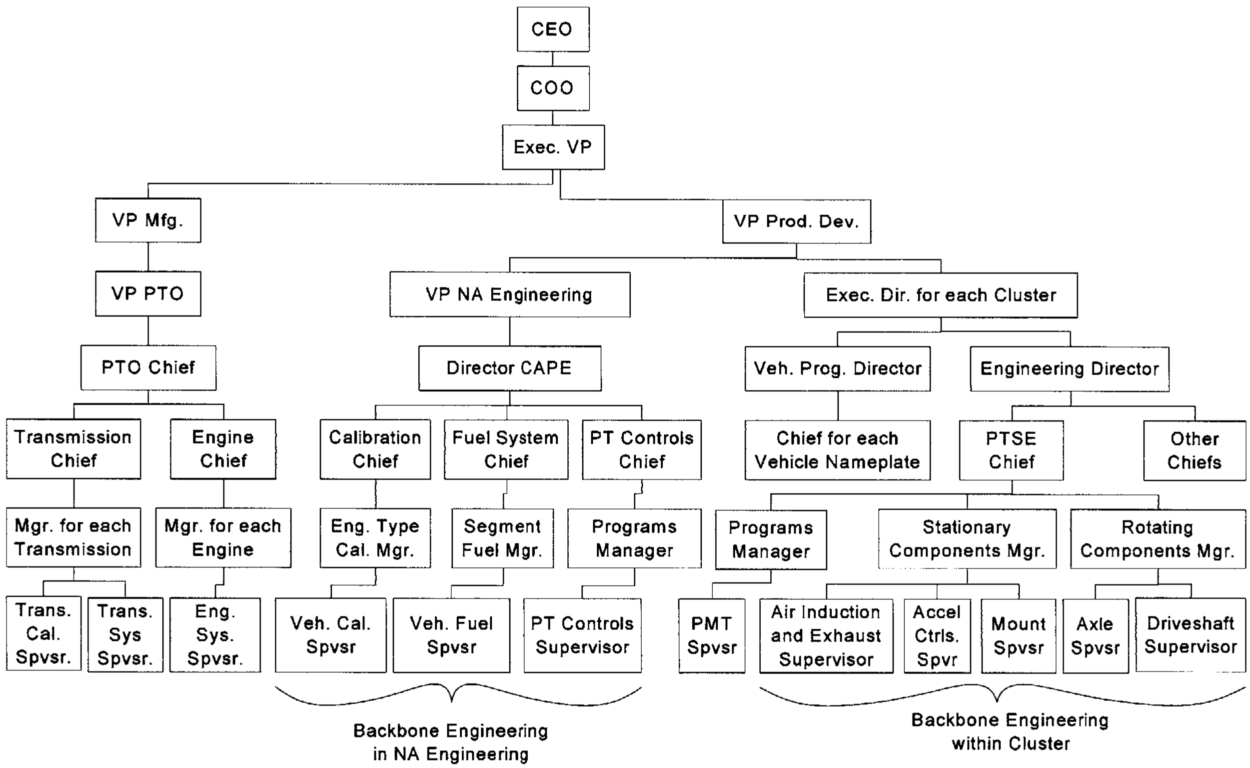


Figure 27 - Powertrain Organizational Structure

Vehicle Engineering Organizational Challenges

Vehicle Engineering handles the vehicle level powertrain attributes of Performance Feel, Shift Quality, Fuel Economy and Trailer Towing. The vehicle engineering organization is divided into two areas:

- North American Engineering (NAE) backbone
- Cluster Specific

The organizational structure is shown in Figure 28 on the following page. Further details on the two areas follow.

North America Vehicle Engineering

The backbone segment of the organization is smaller and covers items that go across all vehicles such as Brand DNA, a drive team that evaluates all Ford vehicles, and a product information group responsible for providing accurate information for the marketing literature and engineering specifications for dealership training.

Cluster Specific

The cluster specific portion of the structure handles the powertrain attributes as well as most other vehicle attributes. An enlargement of the cluster specific organization structure is shown in Figure 29. The responsibilities are divided up between departments: NVH (Noise, Vibration, Harshness), Package, Vehicle Dynamics and Vehicle Integration.

The powertrain attributes are all placed within Vehicle Integration. The Vehicle Integration Manager is not as focused as the other attribute managers.

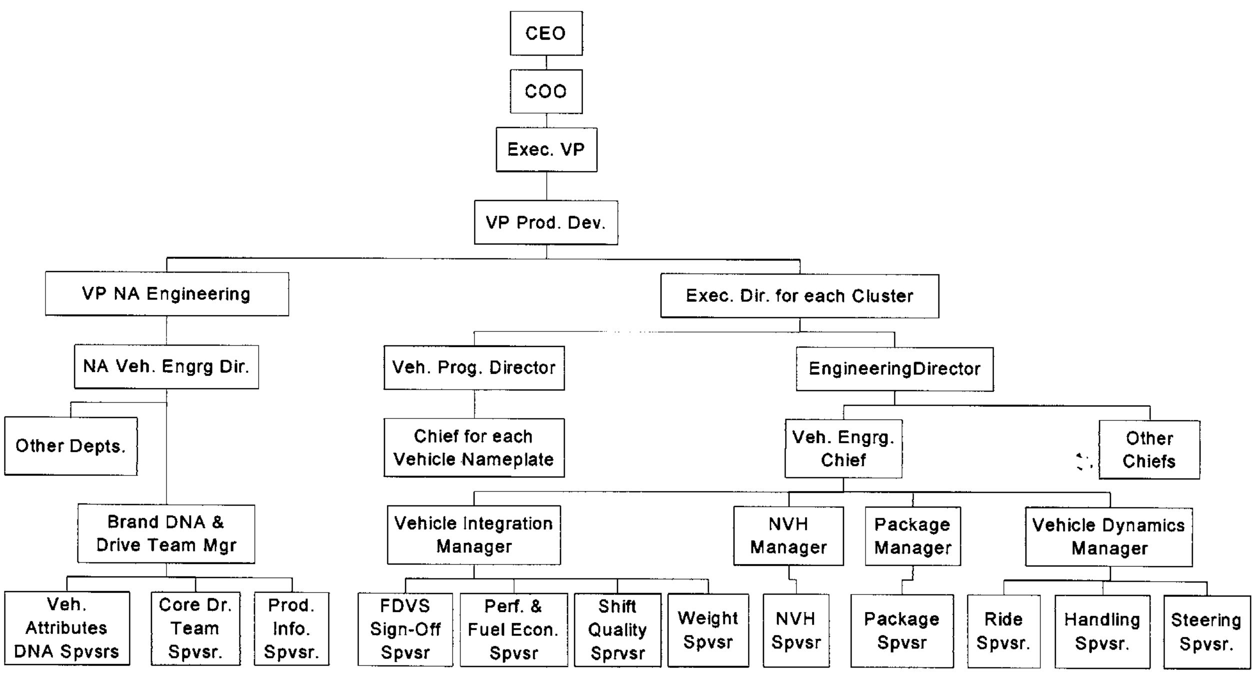


Figure 28 - Management Structure of Vehicle Engineering

Figure 29 in the following page shows that Performance Feel and Fuel Economy are handled by a single group within Vehicle Integration, and Shift quality is handled by another group also within Vehicle integration. There are several other groups that the powertrain attributes groups need to compete with for management attention. Conversely the groups for Ride, Steering and Handling are all consolidated under vehicle dynamics, and NVH and package have departments of their own. The Vehicle Integration Manager's multiple duties does not reflect the emphasis needed per the

DNA items shown in Figure 7, which shows that Driving Dynamics, Powertrain and Package are the key areas.

This also conflicts with the customer satisfaction data we saw in Figures 5 and 6 which indicated that Engine and Transmission Performance correlate to 23% of the total vehicle satisfaction while the attributes of Ride, Handling and Braking constitute 13% of total vehicle satisfaction. Also note that Braking is not handled by vehicle dynamics, but is a very important portion of this 13%, contribution to overall vehicle satisfaction.

Weight is a big driver for powertrain attributes. The busy Vehicle Integration Manager has little time to drive vehicle weight down. Consequently, this vehicle level attribute is typically handled as a tracking item, or low priority, rather than actively managing it.

The overburdened Vehicle Integration Manager also has little time to devote to help solve the issues of the powertrain PAT leaders. Additionally, the reporting structure of the powertrain PAT leader is not within the Powertrain organization. Therefore the PAT leader has no management to take problems to within the current powertrain structure.

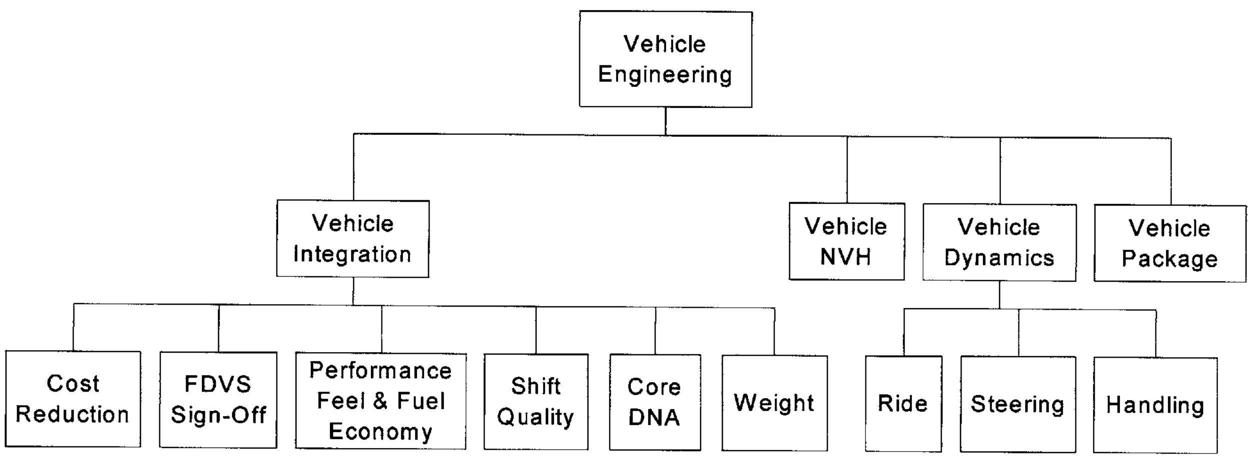


Figure 29 - Cluster Specific Vehicle Engineering Organizational Structure

Drive-by-Wire Technology brings New Challenges

The change to Drive-by-Wire or Electronic Throttle Control (ETC) has changed the delivery of attributes. Traditionally the Performance and Economy (P&E) group has provided specifications for throttle opening as a function of foot rotation. The accelerator controls group then designed the throttle body cam profile to achieve this requirement.

Today with Electronic Throttle Control, the driver's foot rotation is fed into the PCM. The PCM (Powertrain Control Module) then adjusts a variety of parameters to achieve the desired torque at the rear wheels, using what is known as "Driver Demand" tables. This Shifts the method of tuning the Performance Feel attribute from the Accelerator Control Hardware to Engine Calibration.

Shift in Roles and Responsibilities with ETC

The engine calibration group now handles programming the Driver Demand tables for the ETC instead of the accelerator controls group designing hardware. This change in responsibility can be seen in Figure 27, where the responsibility was with the accelerator controls supervisor (bottom row, 4th from right), it now lies with the vehicle calibration supervisor (bottom row, 4th from the left). This is a new challenge to achieving the best throttle control for the customer, since the calibration group is very hands on. The calibration team may have an opinion on how to calibrate the throttle control, which may be different than the specifications from the Performance and Economy (P&E) group. The driver demand table settings from the P&E group are based on customer research and Brand DNA. If the P&E recommendations are not followed, the customer perception of the powertrain may be adversely affected.

Two very different examples of handling of this feature are highlighted on the 2004 Explorer and 2004 F150. These two vehicles were among the 1st truck programs to adopt Electronic Throttle Control (ETC). The calibration groups from both programs did not agree with part throttle targets provided by the Performance Feel PAT. But the way each team handled the disagreement led to significantly different results.

The F150 calibration team tuned the calibration to what they thought the customer wanted in vehicle response, a very smooth and controllable response. This calibration remained in the vehicle and went into production. The results were as the Performance Feel PAT predicted; the F150 will loose performance feel. The media had only one complaint about the vehicle; the powerful 300 horsepower engine seemed to lack power.

The Explorer team on the other hand went out of their way to prove the targets provided by the Performance Feel PAT were not what the customer wanted. The calibration team provided demonstration vehicle with the requested part throttle performance to upper management for review. The management review was an attempt to prove the Performance Feel PAT wrong. This plan to prove the attribute experts wrong backfired. The program and management team (including multiple Executive VP's) praised the vehicle's performance feel attribute. Although this vehicle is not in production yet, it is expected to receive accolades from the public, since it is tuned to meet targets based on actual customer desires.

Challenges to Rolling Out

Getting the engine calibration group to trust the part throttle performance targets provided by the Performance PAT will take some effort since the two groups report into different organizations. The current reporting structure (see Figure 29) for the P&E group also tends to weaken their management's ability to focus on this important issue.

Powertrain Attributes (The Ugly Duckling)

Management priorities also contribute to poor handling of Powertrain attributes. Vehicle Integration Managers have to balance a large number of competing priorities. This demand on management's time results in the most noticeable issues being resolved first, leaving smaller issues unnoticed.

Design Reviews

In a typical design review there are a large number of issues that need to be discussed and resolved. We have observed in several Design Reviews that management is spending several hours on Vehicle Dynamics and Vehicle NVH. Typically, design reviews will run behind schedule due to the complexity of the issues. Powertrain attribute presentations are often shortened to 10-15 minutes or sometimes overlooked due to NVH and vehicle dynamics issues. Better time management of design reviews is required to ensure the highest priority issues in the customer's eyes are resolved first.

European Handling in North America

Prior to Richard Parry-Jones' promotion to Group VP of North American Product Development (NAPD), he was VP of the Small Car Vehicle Center in Europe. European side roads are typically narrow and twisty. Consequently, Vehicle Braking, Steering and Handling sub-attributes are extremely important in the European market. Seeing a strong market desire, he significantly improved vehicle dynamics in the Europe starting with the 1997 Fiesta, and then taking to the Puma, Ka and Focus and remainder of the European lineup with a great deal of success. This improvement to vehicle dynamics was then brought from Europe to North America to help increase customer satisfaction. The North American organization was then significantly strengthened in this area to try to achieve the same level of vehicle dynamics in NAPD.

The increased emphasis being placed on vehicle dynamics in North America can be seen in the latest versions of SUVs. As an example, the 2003 Expedition was significantly modified to replace the solid axle rear suspension with an independent rear suspension, which is the norm in European vehicles. Significant time and money was used to incorporate independent rear suspensions on our SUV products. Unfortunately, the improvement in overall customer-satisfaction for the vehicle does not reflect the cost associated with this change.

Attribute Priorities

Based on the results of the questionnaire that we distributed it was clear that Ford is currently placing more emphasis on vehicle dynamics attributes than powertrain attributes (see Figure 30 on the following page). The customer satisfaction data taken from Figure 6 shows that the highest emphasis needs to be placed on the powertrain attributes. Further information on how Ford's emphasis was determined is covered in Chapter 6.

Attribute Group	Ford Emphasis	JD Powers Weighting
Engine and Transmission Performance	18%	23%
Vehicle Styling/Exterior	18%	18%
Ride, Handling and Braking	19%	13%
Cockpit and Instrument Panel	10%	12%
Seats	9%	10%
Comfort and Convenience	11%	10%
Sound System	7%	8%
Heating, Ventilation and Cooling (HVAC)	8%	8%
Total	100%	100%

Figure 30 - Questionnaire Results vs. JD Powers

Quality Data

Ford's internal quality data also points to the relative importance of powertrain attributes. The chart on the following page (Figure 31) shows this importance of powertrain attributes, while comparing a prior model F150 pick-up truck relative to Toyota Tundra. The horizontal axis indicates the relative advantage that one vehicle has over another. The items toward the right are F150 advantages over Tundra, and toward the left side are Tundra advantages over the F150. The vertical axis indicates the relative importance of these advantages to affect the vehicles overall customer satisfaction. Items at the top of the chart are very important and items at the bottom of the chart are of low overall importance. So the F150 team should focus on improving items that are toward the left edge and near the top left corner of the chart to get the maximum advantage for their efforts.

Figure 31 shows that Engine Power and Pick-up was an area where customer satisfaction could be improved from the previous F150. Consequently the engine power output was increased from 260 to 300 horsepower on new 5.7L V8 engine in the F150 truck.

Figure 31 also shows smoothness of transmission as an attribute that is of high importance and that the F150 enjoyed a significant advantage in over the Tundra. Changes were made to the transmission to improve this already strong attribute since it was also important to the customer.

More Power

The recently introduced 2004 F150 truck was stated to have sports car like handling by popular automotive magazines and the Detroit News. However, the main complaint was the lack of powertrain performance for such a powerful engine. This was despite the power being increased significantly on the 5.4L V8 engine. Fuel consumption was a major issue distracting the Performance and Economy group from optimizing performance feel. Fuel Economy, while an important metric for meeting the legal requirement for Corporation Average Fuel Economy (CAFE), is not a high driver of overall customer satisfaction for a vehicle. Figure 31 shows Fuel Economy towards the bottom of chart verifying its relative low importance to the customer.

The complaint of poor performance can be traced to a number of the concerns discussed earlier. Separating the Performance and Fuel Economy groups and putting them in an area where more management attention can be placed as shown in Figure 99 would help this. Further mitigating this issue, the calibration group did not agree with the part throttle performance targets proposed by the Performance Feel PAT. The driver demand calibration was instead optimized for smoothness and controllability of the throttle, which imparted a sluggish feel to the vehicle.

F-Series Under 8500# GVW vs. Toyota Tundra
Potential Attribute Effect on Overall Vehicle Quality Satisfaction

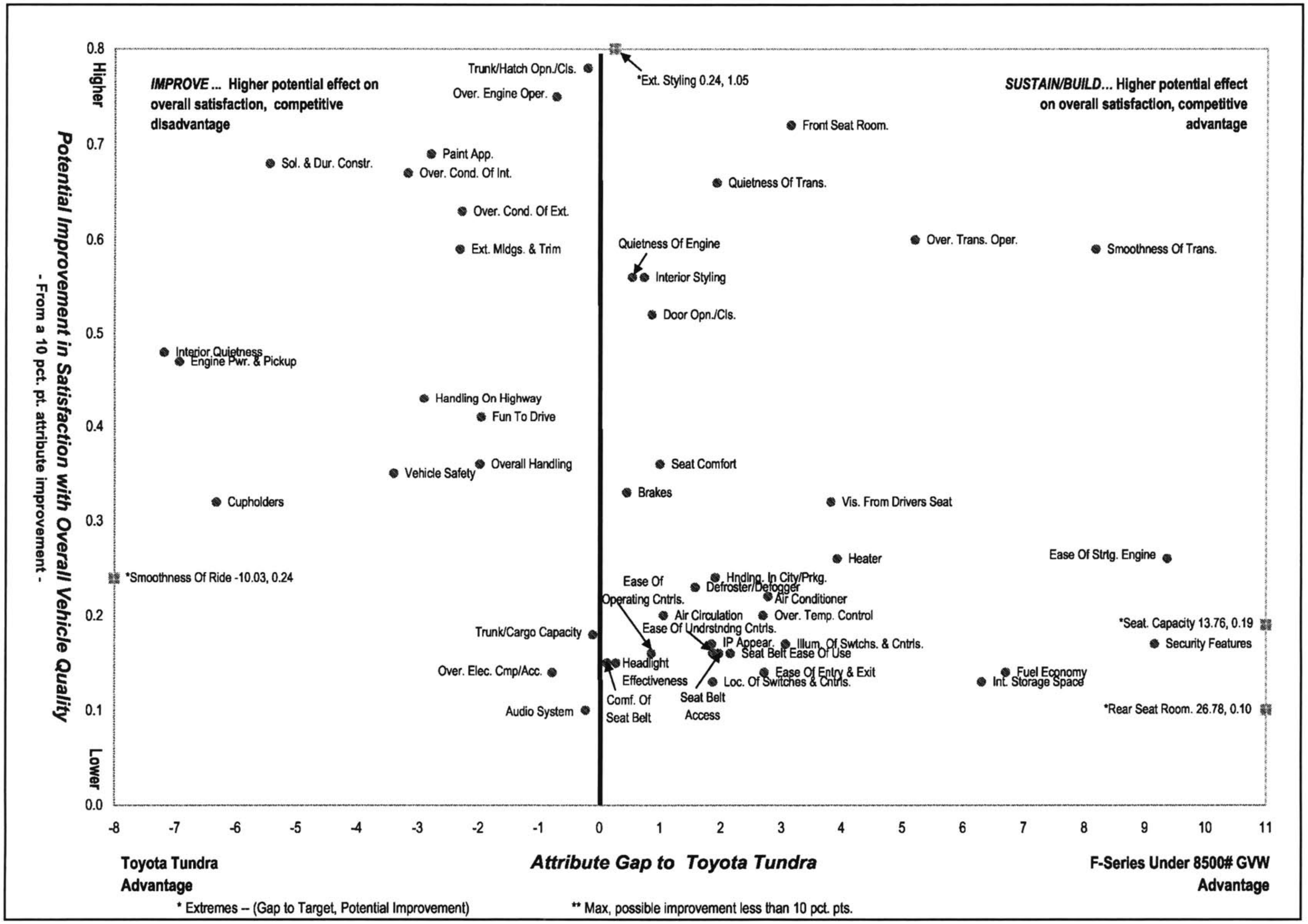


Figure 31 - Potential Satisfaction Improvements

Attribute Interactions

The interaction between attributes is also an important driver in the discussion of F150 performance. The performance could have been improved by specifying a higher final drive ratio in the differential gears of the axle. However, there is a trade-off with fuel economy for changing to a higher gear ratio. Since Fuel Economy was critical to meet CAFE, other means of improving performance feel needed to be taken. The ability to quickly focus on other drivers of performance feel such as accelerator pedal sensitivity is critical to balancing the attributes. This points to the need for documentation of all interactions.

KANO Model

A review of quality data was done to determine if the over-emphasis on vehicle dynamics was being seen in the customer responses to vehicles. The Kano model (in Figure 32 below) of the current model Explorer SUV shows that the powertrain attributes are at the bottom of the linear curve indicating dissatisfaction. Meanwhile the vehicle dynamics attributes were at the high end of the scale indicating high satisfaction. Note that Trailer Tow is the powertrain attribute that is an exception to this coming in at 3^{rd} from top on the linear satisfier. Since the powertrain attributes are high leverage these all need to be at the top of the list to lead to customer satisfaction. We believe the reason for Trailer Tow to be close to the top is the known fact that most customers do not load their vehicles to maximum capacity. We conduct all our testing at our advertised maximum trailer capacity while our customers evaluate at mean trailer weights usually less than half of our vehicle trailer tow capacity.

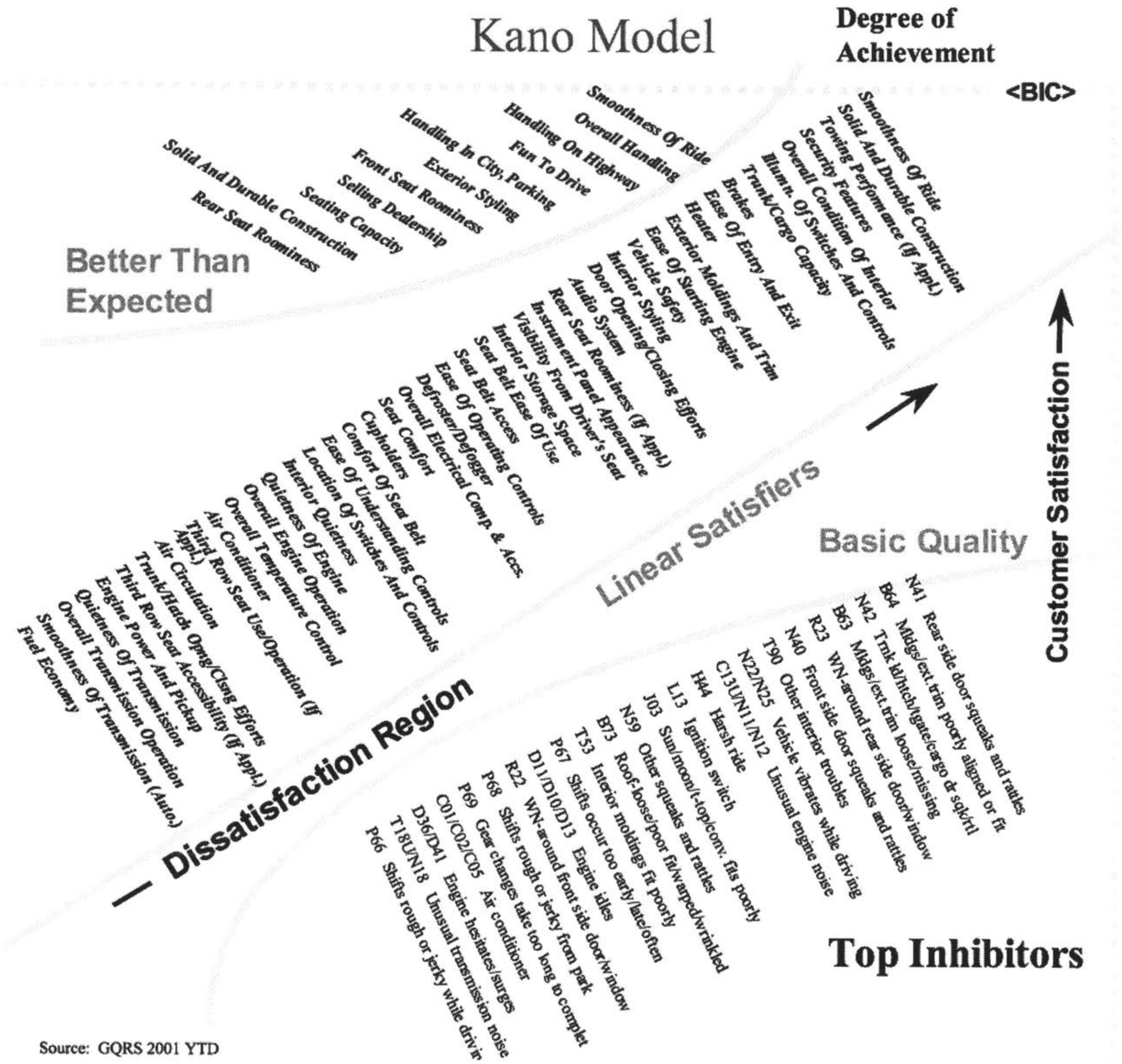


Figure 32 - Kano Model of a Popular SUV

Tech Clubs

Tech Clubs are an organizational recognition tool that allow cross-linking to take place and to ensure flow of information from one team to another. These have been enacted in NVH area and the Vehicle Dynamics area to ensure the flow and adoption of best practices from one program to the next. These Tech Clubs do not currently exist in the powertrain attributes area. This lack of a Tech Club relates to the low level of resources put on powertrain attributes. Based on the customer satisfaction information it can be assumed a powertrain Tech Club for is needed more than any other vehicle attribute.

Summary

We have shown that there are significant organizational challenges to managing functionality in general, particularly when it comes to powertrain attributes. These include the way the hierarchal structure of the organization is set up, the lack of interlinking through tech clubs, and the relatively low priority given to powertrain attributes relative to other features.

Additionally we have seen that there are attribute interactions that may result in the inability to achieve all design goals unless alternative interactions can be found and used as control factors instead.

In the next chapter we will look at various product development models that are generally available and the limitations that they have. We will introduce the Design Structure Matrix (DSM) and explain how it can help fill in some of the holes in the current models.

Chapter 4 - Product Development Models and the Need for DSM

Introduction

We have seen in previous chapters that powertrain attributes and interactions between them are very important. We have seen that they are a challenge to handle from the perspective of tools capability as well as an organizational perspective.

Now let's take a look at how various product development models try to help provide order to the chaotic development process and the shortcomings that they have. Finally we will introduce the DSM and look at how it can help in dealing with the issues left unresolved by these models.

Need for Product Development Models

Today's vehicles are very complicated. With the use of numerous mathematical formulas describing the trade-space available, one could conceivably design the optimal automobile. However, the knowledge of the trade-space is in people's heads and develops over time as technologies change, and so is difficult to put into equations. Consequently one could also conceivably build a mathematical model proving that the probability of getting all the right people to provide the correct data at the right time to develop the perfect automobile is extremely unlikely to happen. While either of these studies would be interesting, it does not directly help to resolve the dilemma of how one actually gets something as complicated as an automobile developed. The product development model is the map for getting through this process.

Principles to Practice

Some of the principles of systems architecture are; that "Form and function are intrinsically linked." Function can be mapped to form. Form and function can be decomposed and further mapped to each other. Emergent properties develop when elements of a system are brought together. While these principles of systems design are good to know, they are still not the map sought after. Let's take a closer look at what these principles mean.

Function can be specified in engineering terms as a list of attributes and sub-attributes. These attributes can be verified by as series of tests. Form can be specified in engineering terms as well. Form generally gets specified in engineering drawings and material specifications and performance specifications.

Design is Chaos

Design is an iterative process whereby form and function are intertwined to give the best mix of desired properties. Since different variations of form will produce different emerging properties, the design process is one of searching for the correct form to deliver the desired function, or best balance of desired functions. The design process therefore looks like Figure 33.

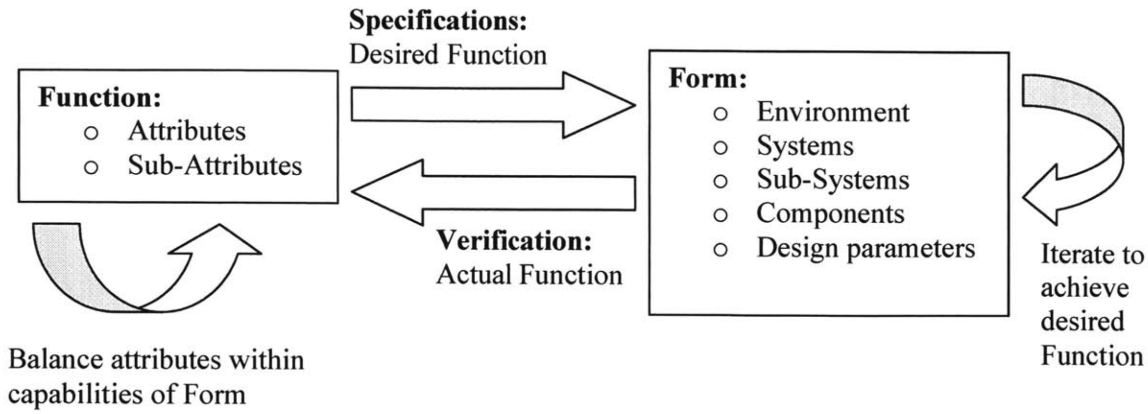


Figure 33 - How Design Happens

Project Management

Project Management provides methods for lining up logical sequences of tasks, and tools for tracking to ensure that they happen on time. While this logical sequence makes perfect sense for a manufacturing or assembly processes, it does not deal well with the numerous amount of rework encountered in product development.

We are particularly interested in the DSM format because it acknowledges that there are potential iterations in the product development cycle, and that there is likelihood that things will need to get revised as development progresses. This acknowledgement allows us to predetermine the order we do things to best reduce the iterations. It also allows us to predetermine how we need to handle remaining potential iterations to reduce disruptions in the product development process.[5]

Product Development Processes

There are numerous product development processes. While each of these try to help map a way through the product development process, they all fall short in dealing with attributes in a vehicle. Ford's FPDS process is a staged gate approach that many companies use. The staged gate process divides the development effort into distinct time-sequenced stages separated by management decision gates. See Figure 34 for an example of a typical staged gate process.

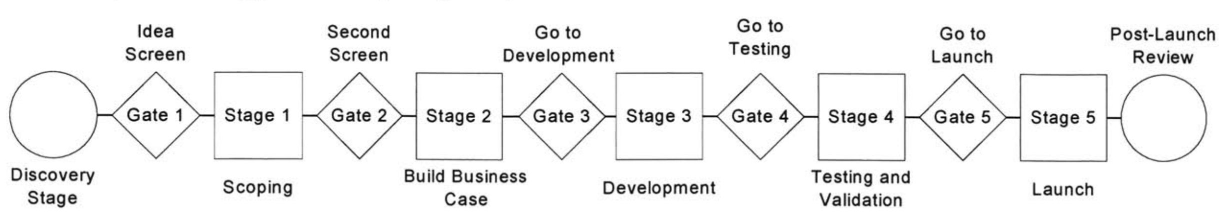


Figure 34 - Typical Stage-Gate Program Process

5 Eppinger, Steven D., Whitney, Daniel E., Smith, Robert P., and Gebala, David A., A Model-Based Method for Organizing Tasks in Product Development.

The staged gate process is intended to give go/no-go direction to the development process by giving the project manager a set of deliverables at each gateway (Figure 35).

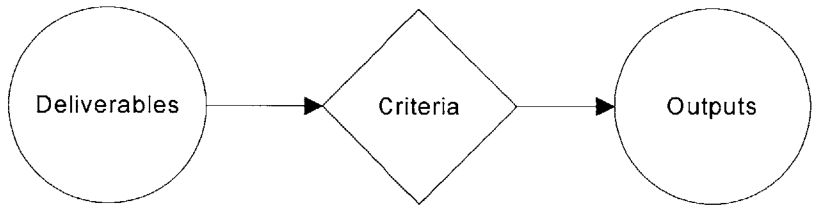


Figure 35 - Decision Making at Gateways

Unfortunately the staged gate process does not give clear direction on what to do if one of the deliverables is not met. This is a real possibility with the numerous holes in the powertrain attribute modeling process, and general lack of understanding of potential interactions. A no-go decision is often not a viable option at a gateway, since many changes to vehicles are linked to regulatory changes, which need to be incorporated by a certain date to allow the legal sale of vehicles.

Similar to the stage gate approach is the waterfall product development process. This is shown in Figure 36. The waterfall development process plans for iterations. These iterations are clearly delineated to happen only within each block of work, and there is relatively little chance to fix things once a block of work is done. This is an issue for a complex system that has many interactions like an automobile, since a late discovery of an unexpected interaction would in effect delay or stop planned design changes. This is critical since many changes are required to happen by a given date to meet legislative requirements for safety, emissions and etc.

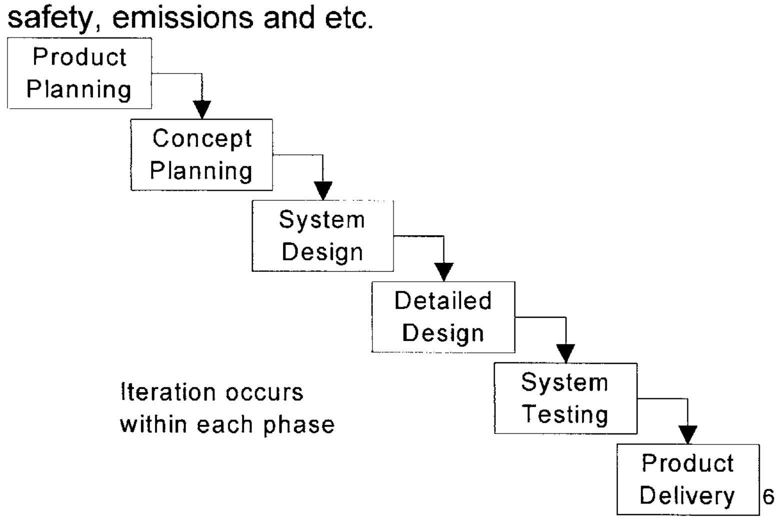
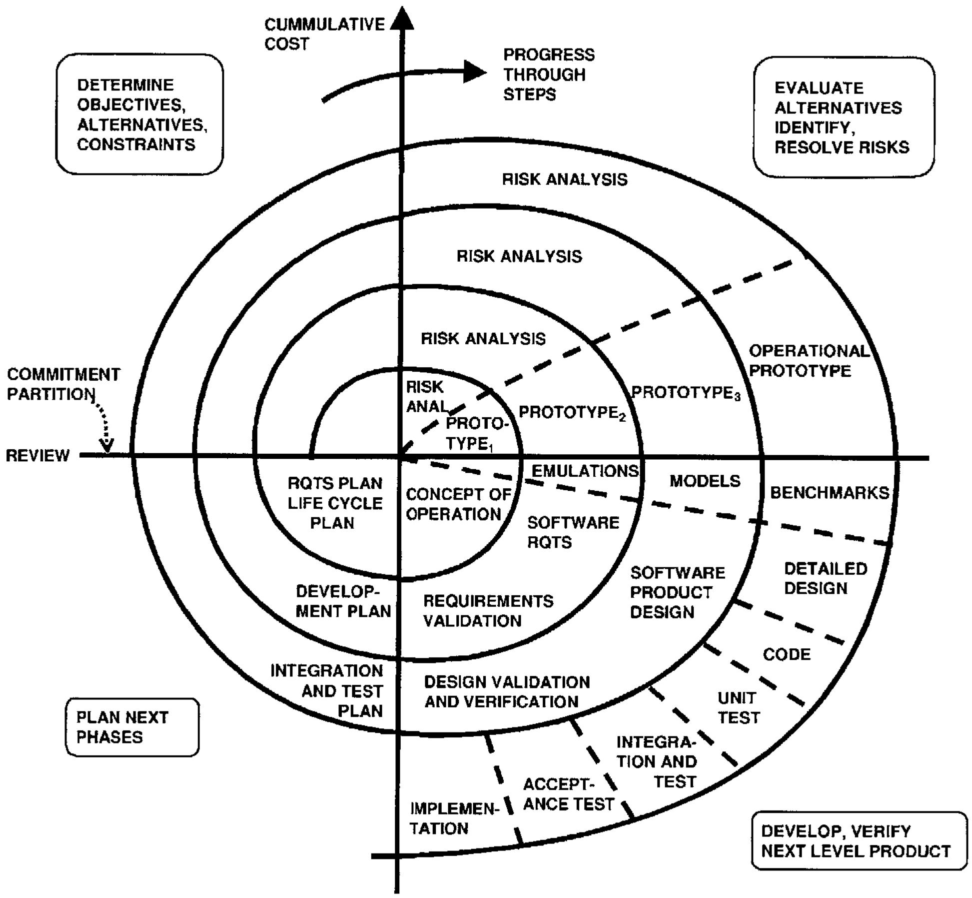


Figure 36 - Waterfall Product Development Diagram

The development of complex systems in regards to attributes needs to resemble a spiral development process like that used in software. This process is depicted below in Figure 37.

[6] Bobak Ferdowski, Evolutionary Strategies in Product Development, presentation to Lean Aerospace Initiative / MIT, March 26, 2003



[7]

Figure 37 - Spiral Development Process

The spiral development process cycles through several iterations of the product increasingly bringing in more real world concerns to ensure that not only are the attributes met, but they are met robustly including all the noises seen in production, sales, usage, etc. Unfortunately, this process is extremely expensive to use in making the numerous prototypes that are needed to ensure all customer and legal requirements are met in automotive development. Prototype vehicles can cost up to $250,000 each to make and a typical development program may require up to 100 vehicles depending on the level of changes. Incorporating four prototype phases like shown in Figure 37 is simply not affordable.

Since a Spiral development process is very expensive, Ford superimposes a Systems V development process over the staged gate approach. The Systems V clearly shows some of the interactions within the systems. This is shown in Figure 38.

[7] Barry Boehm, edited by Wilfred J. Hansen, Spiral Development: Experience, Principles, and Refinements, Spiral Development Workshop, February 9, 2000, SPECIAL REPORT CMU/SEI-2000-SR-008, July 2000

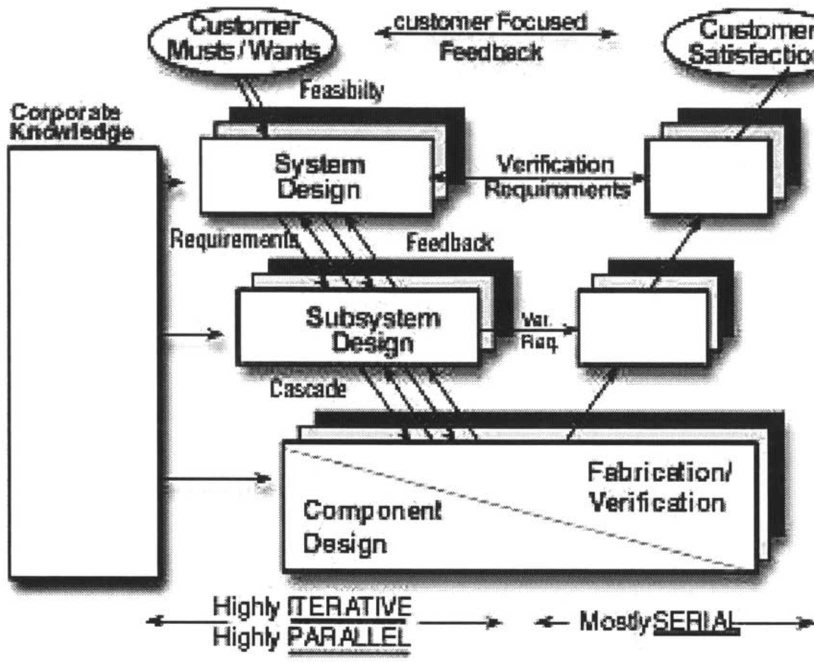


Figure 38 - Detailed Diagram of Systems "V' Product Development Process

The systems V, while acknowledging that these interactions exist, does not give specific guidelines on specific interactions. This is where we will use the DSM.

DSM Background

The Design Structure Matrix (DSM) was developed twenty years ago, and is intended to record all the interactions inside a system in a single square matrix. Its principle use is to analytically determine an improved design/development task sequence from these interactions. Different types of interactions can be modeled in a DSM:

- o Interactions between subsystems or elements of the system,
- o Between design parameters,
- o Tasks to be performed
- o Actual people working in the design of the system.[8]

Interactions are represented by marks in the matrix. A mark indicates that an item in the column has an impact on the item in the associated row. Figure 39 shows a pert diagram juxtaposed to a DSM.

[8] http://web.mit.edu/dsm

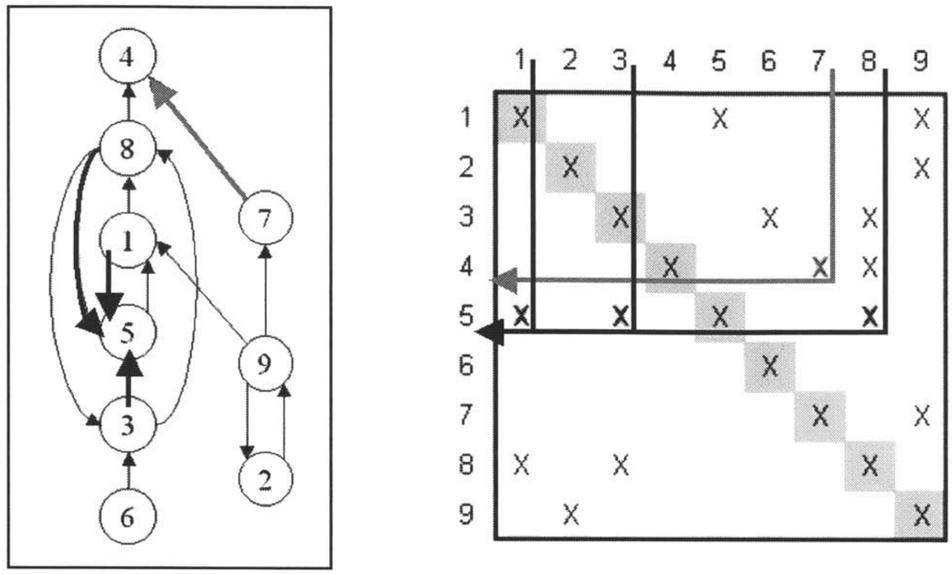


Figure 39 - How DSMs are Constructed and Read (A Simple Example)[9]

On the DSM if the tasks are completed from top to bottom or correspondingly from right to left, the triangle below the diagonal represents feed forwards (information that flows from earlier to later tasks that are sequential in the design process), and the triangle above the diagonal represents feedbacks (information flows that flows in the reverse order of the design process). Figure 40 shows these two distinct sets of information flow.

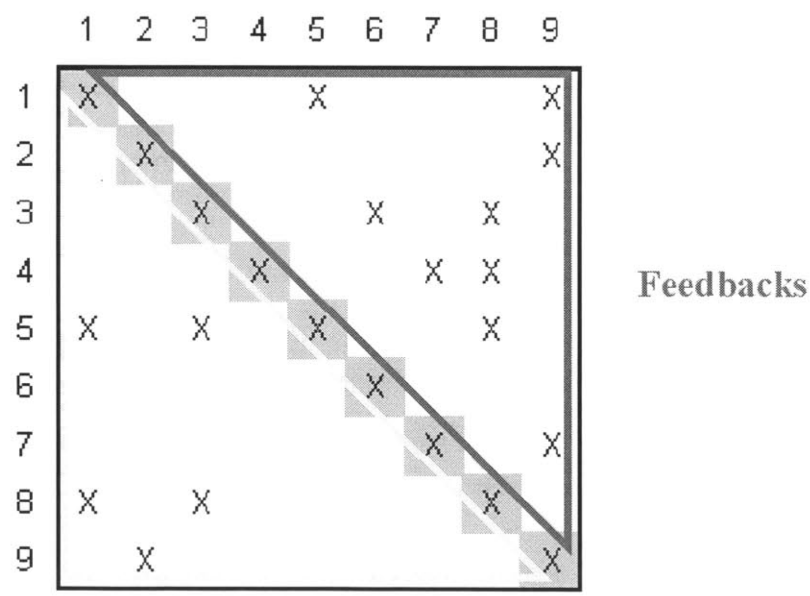


Figure 40 - Feed Forwards and Feedbacks in a DSM

[9] Antione Guivarch, Research on Knowledge Management at the Center for Innovation in Product Development (CIPD) of MIT: Design Structure Matrices

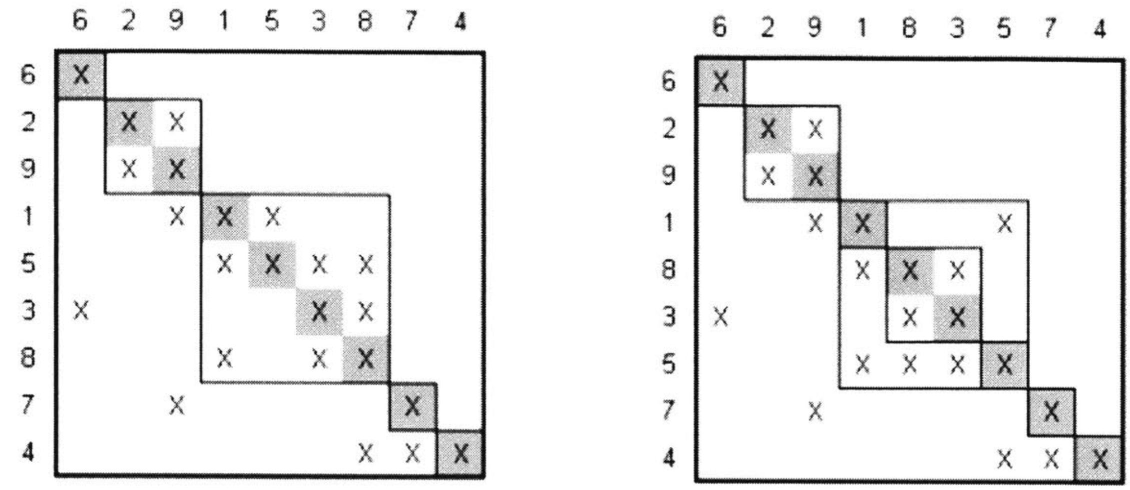
Feedbacks indicate that an assumption needs to be made to complete a task and that there is a possibility of rework in the design process if this assumption is not correct. For example in Figure 40, task 1 requires information from tasks 5 and 9 which have not been completed, so assumptions need to be made on the likely outcomes of these steps to complete task 1. When task 5 is finally completed, it is possible that the estimations made earlier on its outcomes were incorrect. Consequently rework on task 1 might be required, delaying completion of the entire project. These iterative loops are quite common in engineering and can result in significant delays if they were not predicted in the initial plan. Additionally investment costs can increase if unexpected changes happen after production equipment is started and needs to be reworked.

A DSM helps project managers to identify these loops, and possibly reorder the tasks or elements of the system in the process so as to minimize the effect of feedbacks. DSM reorganization is performed in a two-step process.

1. **Partitioning**
   A mathematical algorithm is used to rearrange the process so as to reduce the effects of feedbacks by getting feedbacks as close to the diagonal as possible without any implicit knowledge on the particular process. More precisely in mathematical terms, it will change the order of the elements in lines and columns so as to reduce the matrix to a block triangular one, if possible. See the result of partitioning of the DSM in Figure 40 in the left picture in Figure 41.

2. **Optimizing Cycles**
   This second step reorganizes the tasks within the cycles identified during partitioning. Integrated teams are used to accomplish the cycles to minimize the unavoidable feedbacks. This step consists in selecting the information flows that are most acceptable as feedbacks using tacit knowledge of particular process, (that is those for which assumptions on the outcome are easy to make, or for which the intensity of the influence on other elements is lowest). Tearing is one of several possible options used to further simplify the DSM.[10] Since, it involves knowledge on the particular process, this step cannot be accomplished automatically using mathematical formulas. The right picture in Figure 41 shows one possible re-organization of the DSM.

[10] Steward 1981



Partitioned DSM
DSM in block triangular form: i.e. there are no feedbacks outside the diagonal blocks

One Possible Reorganized DSM
Tasks 5 and 8 were permuted so as to finally keep two acceptable feedbacks only

Figure 41 - Partitioned DSM and One Possible Reorganized DSM

A DSM has other uses and benefits as well:

- DSMs help one visualize the complexity of a system or process
- DSMs record system-level knowledge on a single document. This allows information to be made available for less experienced people. This helps them to learn the complexity of a system more easily and quickly.
- DSMs make a very useful project management tool, since they account for iterative loops. This helps ensure more accurate time and cost planning. DSMs can also help portray the consequences of a modification of one aspect of a system on the development process.
- DSMs allow the design process to be viewed on a task / information exchange basis rather than on a physical, structural, cultural, historically inherited decomposition or ad hoc basis.
- DSMs remove unnecessary design loops and rework from processes, and identify the causes of unavoidable ones, which is a good starting point for further effective process modification and improvement.[11]
- DSMs can be updated, if the system is modified

Use of the DSM method is typically completed using the following 9-step process:

1. Define the system and its boundaries
2. List all the system elements / process tasks
3. Study the information flows between the elements or tasks. This is typically done utilizing requirements documents and via interviews with experienced engineers
4. Build a matrix to represent the information flow,
5. Verify the matrix with engineers
6. Partition the matrix
7. Optimize inside cycles using knowledge on the system or process

[11] Whitney et al 2000.

8. Give the matrix to the engineers and managers
9. Consider a reorganization of the process and eventually implement it.

If a system is highly coupled the DSM may not be able to be adequately partitioned. So manual clustering, or manual reordering of the elements in rows and columns, may be the only viable method to achieve a matrix that is close to block triangular form. This is one of the drawbacks of the DSM method. Below are a couple additional drawbacks that derive directly from the rigid implementation process.

- Totally new and innovative systems (in which there is no previous experience such as Hybrid Electric Vehicles) are difficult to analyze with the DSM method. This results from the lack of understanding of the systems interactions needed to piece together the information collected. Qi Hommes' thesis (formerly Qi Dong) tied together the principles of Axiomatic design by converting design matrixes extracted from the specifications documents into DSMs[12]
- There may not be enough time to complete a DSM. The DSM process is time consuming, particularly the data gathering process. A typical system will require a minimum of several weeks to complete the documentation.[13]

Summary

In this chapter we looked at how the development process is rather chaotic and how project management tools are not truly suitable for mapping out this process. We also looked at a number of product development processes and the issues that each has in relation to being a truly adequate map of the design process. While the product development process used by Ford is an excellent adaptation, it still lacks the detail needed to have a clear map. This is where we believe the DSM is an excellent addition to help better sort out the steps where iterations are likely to take place and to plan specific actions to mitigate risk or to recover quickly from iterations.

In previous chapters we showed that there are significant organizational challenges to managing attributes and particularly when it comes to powertrain. These include the current hierarchal structure of the organization, the lack of interlinking through tech clubs, and the relatively low priority given to powertrain attributes relative to other features. We have also seen that attribute interactions may result in the inability to achieve all design goals unless alternative interactions can be found and used as control factors instead.

Convinced that our first hypothesis was verified (i.e., a complete understanding of all powertrain attribute interactions is needed to prevent needless rework.), we developed a Design Structure Matrix to actually document the interactions relating to powertrain attributes. This work is in Chapter 5.

[12] Dong, Qi, 2002, Predicting and Managing Systems Interaction in Early Phase of Product Development Process, MIT Mechanical Engineering, Doctor of Philosophy Degree Thesis
[13] Antione Guivarch, Research on Knowledge Management at the Center for Innovation in Product Development (CIPD) of MIT: Design Structure Matrices

This leaves the second hypothesis still to be verified (i.e. The DSM format, may not be the ideal method of displaying attributes for engineers needing to understand them.) We will look at this in Chapter 6, which relates to a series of surveys and analysis to further understand what engineers really want.

Chapter 5 – Design Structure Matrix

Introduction

In this chapter, we will discuss the Powertrain Attributes DSM, how it was developed and the methodology followed to construct the chosen format for PAT and PMT usage. We will also look at the company's ability to support the interactions using existing CAE tools. Finally, we'll discuss the partitioned and reorganized DSM, rearranged in the order of attributes development in FPDS. In this timing overlay, the interactions that cause work iterations (planned and unplanned) are revealed. We will then present ways to mitigate the amount of rework.

DSM Methodology

We wanted to mix attributes and design parameters together in a DSM. However in reviewing the DSM website we noticed that there were 4 types (see Figure 42):

DSM Data Types	Representation	Application	Analysis Method
Component-based	Multi-component relationships	System architecting, engineering and design	Clustering
Team-based	Multi-team interface characteristics	Organizational design, interface management, team integration	Clustering
Activity-based	Activity input/output relationships	Project scheduling, activity sequencing, cycle time reduction	Sequencing & Partitioning
Parameter-based	parameter decision points and necessary precedents	Low level activity sequencing and process construction	Sequencing & Partitioning

[14]

Figure 42 - DSM Data Types

None of these quite fit what we wanted to do: Attributes seemed to match closely to Parameter-based DSM type, and Design Parameters seemed to match the Component-based DSM type.

We discussed this with Qi Hommes (formerly Qi Dong, former MIT student and current Ford employee), and she recommended we separate the items in the DSM into Attributes and Design Parameters (see Figure 43: Format of Powertrain Attributes DSM).

[14] http://www.dsmweb.org/Tutorial/DSM_types.htm

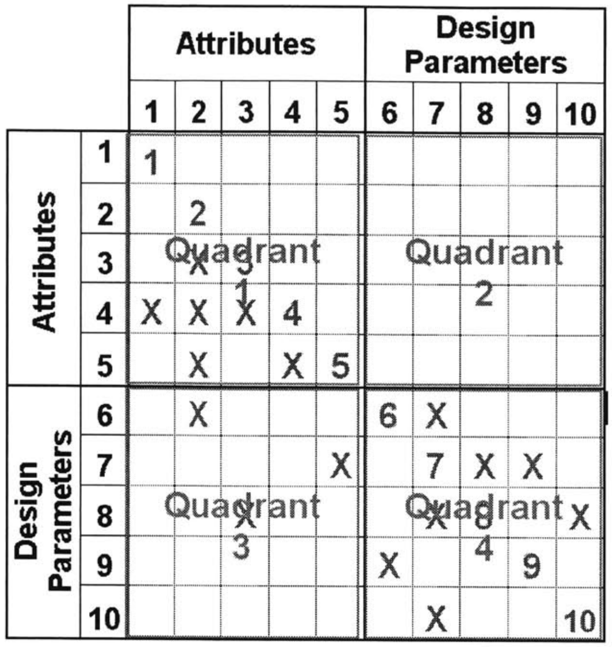


Figure 43 - Format of Powertrain Attributes DSM

Then we could view each quadrant separately (see Figure 44):

		Attributes 1	2	3	4	5
Attributes	1	1				
	2		2			
	3		X	3		
	4	X	X	X	4	
	5		X		X	5

Figure 44 - 1st Quadrant Example

There are 4 main types of interaction that can be shown in the component based DSM. Since we are dealing with functional attributes we will deal only with the design parameters that directly affect these. Some representative interaction types are shown in the table in the following page (see Figure 45). [15]

[15] Pimmler, Thomas U. and Eppinger, Steven D., "Integration Analysis of Product Decompositions", Proceedings of the ASME Sixth International Conference on Design Theory and Methodology, Minneapolis, MN, Sept., 1994. Also, M.I.T. Sloan School of Management, Cambridge, MA, Working Paper no. 3690-94-MS, May 1994.

Spatial	Associations of physical space and alignment; needs fort adjacency or orientation between two elements
Energy	Needs for energy transfer/exchange between two elements
Information	Needs for data or signal exchange between two elements
Material	Needs for material exchange between two elements

Figure 45 - Simple Taxonomy of System Element Interactions

Our DSM will deal only with Information exchange simply because of its sheer size. We thought this was enough to start the communication between the PAT leaders and design engineers, and other vehicle attribute leaders. This will ensure the development process is better planned; and help minimize the unplanned iterations.

DSM Development

The DSM was constructed from the results of numerous discussions with corporate attribute experts and technical specialists. Attribute experts from Performance Feel/Trailer Tow, Shift Quality/Transient NVH, Driveability and Vehicle Dynamics were interviewed to determine the design parameters that affect the powertrain attributes of interest, attribute interactions with other powertrain attributes and other vehicle attributes. The data gathering from all the interviews and discussions took approximately eight weeks to complete. There were eight attribute experts and technical specialists involved, two attribute specialists were consulted for Shift Quality, two were consulted for Performance Feel, one calibration specialist for Driveability and three attribute experts from Vehicle Dynamics (Ride, Steering and Handling).

The result was a 157 x 157 matrix shown in the following page (see Figure 46). The DSM is shown in a user-friendly format for the PATs and PMTs. The first 58 rows and columns are the vehicle attributes for the PAT members and the last 99 rows and columns are the design parameters that impact the vehicle attributes for the PMT leaders and Design & Release engineers.

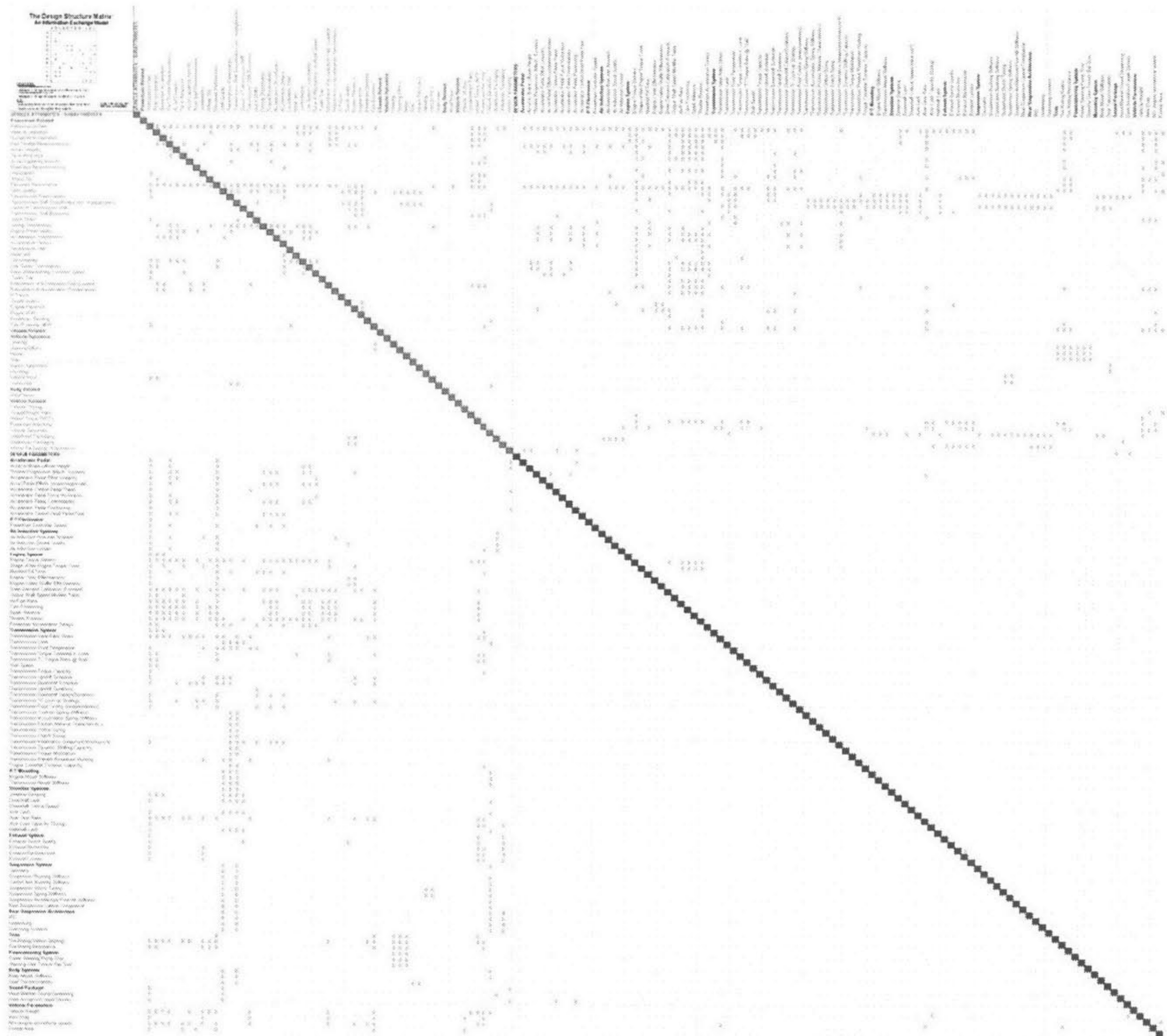


Figure 46 - DSM in PAT / PMT Presentation Format

DSM Findings

High Level Conclusions on Interactions Matrix

There are a significant number of interactions in Quadrants 1, 2 and 3 as expected, and only a few interactions in Quadrant 4. This can be seen in Figure 46 above. The 157x157 DSM has a total of 1487 interactions, which translates to an average of approximately 9 interactions per line.

Powertrain attributes are truly interdependent and in many cases impossible to separate. A simple example is shown in Figure 47.

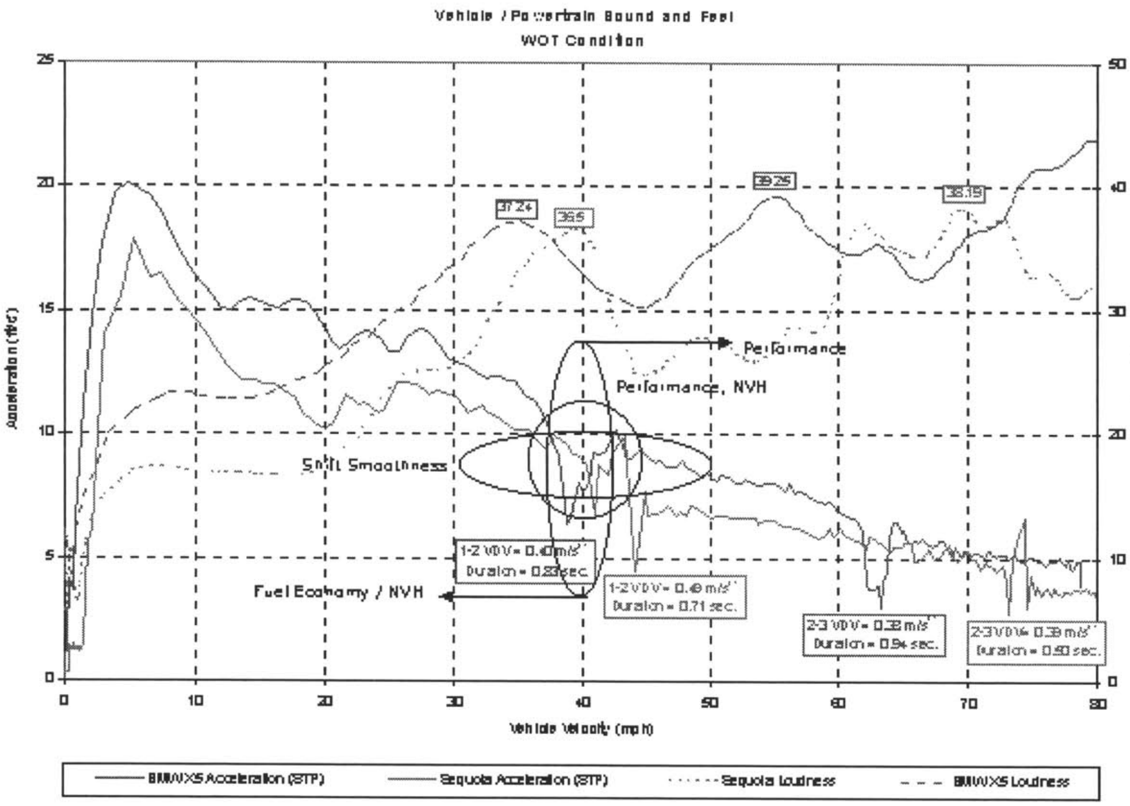


Figure 47 - Example Demonstrating Interdependency of Powertrain Attributes

The above chart demonstrates the interdependency of powertrain attributes. The solid lines plotted are acceleration versus vehicle speed and dashed lines represent engine sound loudness versus vehicle speed. A simple 1st to 2nd gear transmission upshift event (identified by the circle above) can affect performance feel, shift feel/shift duration, engine presence (powertrain NVH), and fuel economy. The key is to find the right balance.

If the 1-2 upshift was positioned for an earlier shift (moved to the left), it would positively impact fuel economy and powertrain NVH. However, an earlier shift may also negatively impact performance feel and shift quality if moved too early. The effects would be the complete opposite if the shift were positioned later (moved to right). The 1-2 upshift can also be calibrated to be very smooth, extending the transmission shift duration (long and drawn out) and increasing powertrain NVH. If the engine is very loud, the trade-off for smoother shifts may be difficult. As mentioned earlier, the key is achieving the right balance. Therefore, a powertrain attributes integration PAT is recommended. This is further explained in the upcoming partitioned and re-organized DSM in the section named DSM Timing Overlay.

Many powertrain attributes interact with other vehicle attributes (i.e., Vehicle Dynamics). Shift feel interacts with understeer and impact harshness (vehicle dynamics sub-attributes) through common tuning components. Later on in the chapter, in the DSM Timing Overlay section, an example of this interaction is discussed in much greater detail.

There were only a few interactions within Quadrant 4 (the design parameter vs. design parameter quadrant). The only interactions are lower-level (or subsystem) design parameters affecting higher-level design parameters (within the same function), for example, air/fuel ratio, cam positioning, throttle position, and spark advance affecting engine torque delivery. Another example would be, tire rolling radius, transmission gear ratio, axle gear ratio all affect vehicle N/V (engine speed/vehicle speed ratio).

As expected, there were significant interactions in Quadrants 2 and 3. Quadrant 2 represents the attributes and the design parameters that affect them, making quadrant 2 useful in the attributes development phase (Confirmation Prototype <CP> Phase to Change Cut-off <CC>) of FPDS (see Figure 14). Quadrant 3 represents the attributes and the design parameters they affect, making it useful in the target-setting phase (Kick Off <KO> to Program Approval <PA>) of FPDS.

The ideal users of our DSM are PAT/PMT Leaders, and the Design/Release Engineers supporting both PAT and PMT. The teams that are expected to use the DSM are the Performance Feel/Fuel Economy/Trailer Tow PAT, Shift Quality PAT, Powertrain PMT, and the new group we recommend forming, the Powertrain Attributes Integration PAT. Other engineering activities or procedures that could use the DSM are Engineering Change Management or Program Change Control, Material Cost Reduction actions or Program Steering Team meetings.

In the next sections, we will discuss each of the four quadrants in more detail. We will cover items such as who are the intended users, when it would likely be used and special considerations of each quadrant.

1st Quadrant (Attributes/Sub-attributes Subset of DSM)

Quadrant 1 represents all interactions that are included in vehicle level attribute trade-offs. There are 58 rows and columns in quadrant 1, some of which are categorical descriptors for the intended users as an attempt to making the DSM more user-friendly and easier to read and follow. These categorical descriptors will be eliminated in the partitioned DSM, later in this chapter.

From an FPDS targets cascade perspective, the attributes targets will be set first, and then the attribute and sub-attribute interactions in quadrant 1 will be studied prior to dropping down to attribute versus design parameters shown in the 2nd and 3rd quadrants.

The ideal user would be a program team's Vehicle Engineering Manager and Vehicle Integration Program Supervisor. Vehicle Engineering is responsible for delivering a balance of all vehicle attribute targets, including powertrain attribute targets.

One of the key findings in this section is that there are numerous interactions between Vehicle Dynamics and Powertrain attributes. For example, Vehicle Pitch (Handling sub-attribute) and Perceived Performance, Understeer (Handling sub-attribute) and Smoothness of Transmission Shift/Transmission Shift Predictability, and steering efforts

(Steering) and Fuel Economy or NVH. As expected, vehicle level attributes (i.e., Vehicle Weight, Aero Drag, Vehicle Sensitivity, etc.) have a major impact on Powertrain attributes. (see Figure 48 below) These interactions are linked by design parameters shown in Quadrant 2 or 3.

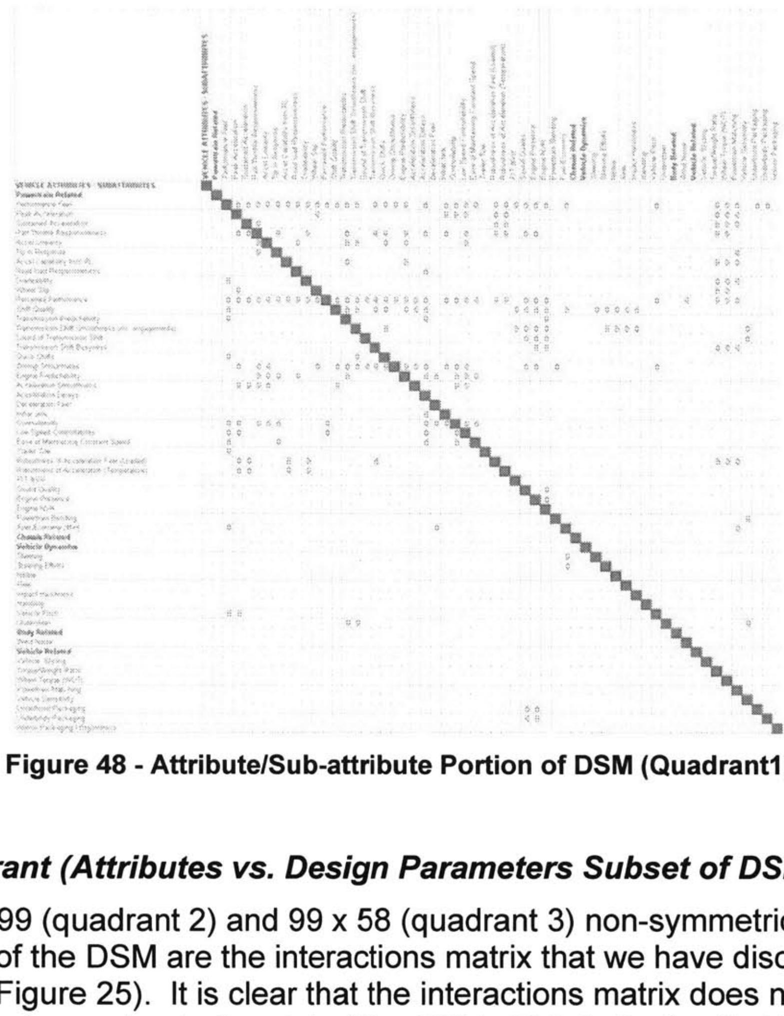


Figure 48 - Attribute/Sub-attribute Portion of DSM (Quadrant1)

2nd & 3rd Quadrant (Attributes vs. Design Parameters Subset of DSM)

These are 58 x 99 (quadrant 2) and 99 x 58 (quadrant 3) non-symmetrical matrices. These portions of the DSM are the interactions matrix that we have discussed in Chapter 2 (see Figure 25). It is clear that the interactions matrix does not include the interactions seen in quadrants 1 and 4 of the DSM. This indicates that the interactions matrix is not as good as the DSM for showing *all* powertrain interactions.

The primary users of quadrants 2 & 3 (see Figure 49) will be the PAT leader and team members (powertrain calibrators and design/release engineers) for attributes development. This matrix reflects the impact of hardware choices and actual hardware function on the attributes. This is very useful from a development perspective since many of these interactions are the source of design iterations. Quadrants 2 and 3 are basically mirror images of each other; that's why they are being addressed in one section.

A very interesting finding is to see significant design parameters outside of powertrain contributing to vehicle sensitivity. Vehicle sensitivity is a major contributor or inhibitor to transmission shift feel. Vehicle sensitivity (or the vehicle transfer function) is a measure of how sensitive the vehicle is to powertrain inputs (i.e., transmission torque inputs). If the vehicle response or acceleration disturbance measured at the driver's seat track is high during a transmission shift event, the vehicle is considered to be sensitive. This is a function of the powertrain, chassis and body mounting systems and how well they isolate the powertrain inputs to the vehicle. See Figure 55 on page 81. The mounting systems of powertrain, chassis suspension and body are considered potential paths of the powertrain inputs.

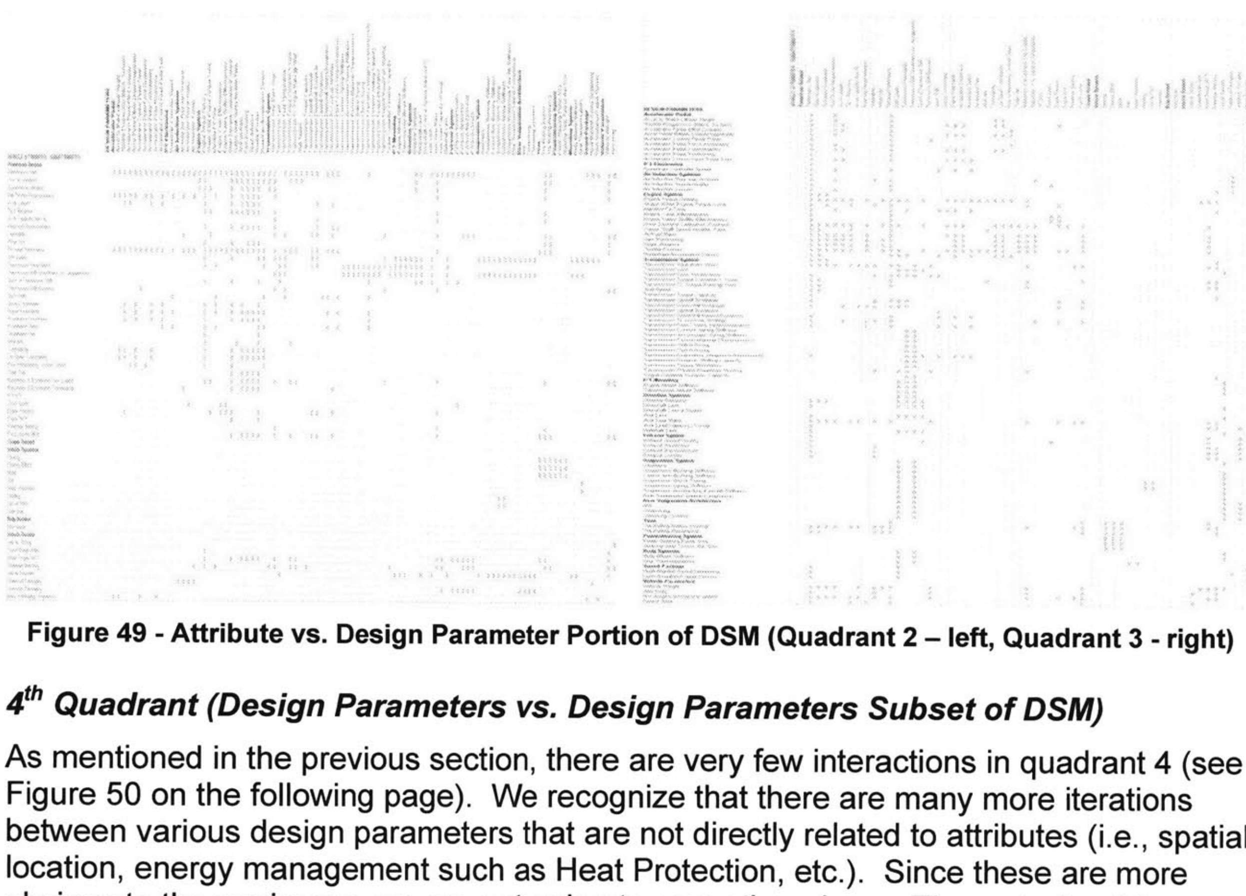


Figure 49 - Attribute vs. Design Parameter Portion of DSM (Quadrant 2 – left, Quadrant 3 - right)

4th Quadrant (Design Parameters vs. Design Parameters Subset of DSM)

As mentioned in the previous section, there are very few interactions in quadrant 4 (see Figure 50 on the following page). We recognize that there are many more iterations between various design parameters that are not directly related to attributes (i.e., spatial location, energy management such as Heat Protection, etc.). Since these are more obvious to the engineers, we are not going to cover them here. The majority of the interactions are lower-level (or subsystem) design parameters affecting higher-level design parameters (within the same function.

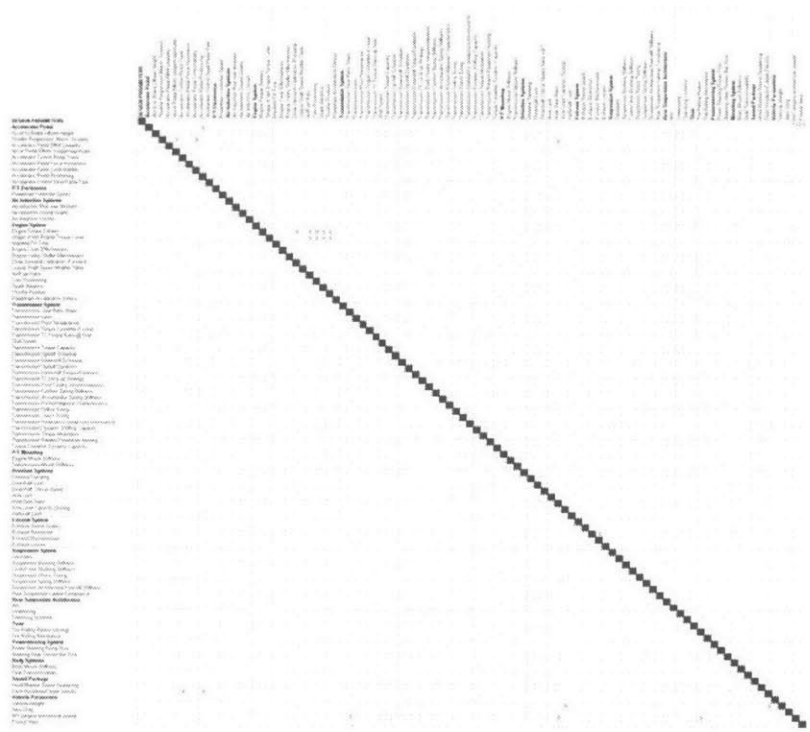


Figure 50 - Design Parameters vs. Design Parameters Portion of DSM (Quadrant 4)

Computer Aided Engineering Overlay on DSM

We are interested in understanding what CAE tools cover which attribute interactions. Understanding the coverage of these tools can help point out interactions that might be missed, causing rework.

We began the overlay of determining how much of our DSM interactions are supported by CAE analysis tools. We completed the Performance Feel attribute and sub-attributes, which is the most important and best supported with CAE tools of all powertrain attributes.

After starting this task, we recognized that this seemingly small task was on the scale of creating a new DSM and halted work. However, we believe this task has value. We then took the total number of interactions supported by CAE and divided by total number of interactions and determined 29% of vehicle performance feel and it sub-attributes were supported by CAE tools.

CVSP (Corporate Vehicle Simulation Program) is the biggest contributor for total CAE support of 29% coverage. The other CAE tool that supported the 29% coverage was the Excel-based Driver Demand Table Development tool which is mainly used to determine the appropriate transmission output shaft torque for ETC (Electronic Throttle Control) Calibration based off driver (or accelerator pedal) input. CVSP, as mentioned earlier is the main CAE model for Performance, Fuel Economy and Trailer Tow for Ford Motor Company. The reason the coverage percentage is so low is because many of the sub-attributes included in the DSM are not traditional performance attribute metrics like 0-60 mph time. They are customer-correlated character defining sub-attributes and DNA metrics.

The remainder of the DSM interactions will have less than 29% coverage with CAE tools. We believe Performance Feel is our upper limit for coverage as modeling of other powertrain attributes (i.e., Shift Quality and Driveability) is not as advanced as Performance Feel.

Since a significant amount of the interactions are not covered by CAE, this indicates a need for a dedicated Powertrain Attributes Integration (PTAI) PAT. This PTAI team is needed to create a holistic viewpoint to cover the typically missed cross-powertrain attribute interactions, since a single attribute PAT will only be concerned with the interactions affecting their own attribute. The PTAI team can then communicate cross vehicle attribute issues to the Program Steering Team (PST) or a higher level Powertrain Attributes manager so that he/she can elevate to the PST.

As mentioned previously, although Ford may have many CAE tools for supporting the design process, none are adequate to support a holistic view of powertrain attributes from a customer's perspective. The closest means we have in capturing the customer's driving experience is the chart on the following page (Figure 51). Unfortunately this is based on actual data, since CAE tools are not capable of modeling the dynamics of transmission shifts.

From this chart, one can view what the customer is experiencing from an acceleration level (and character; peak and sustained), engine sound loudness (and character; linearity) and transmission shift character (Shift Feel, Shift Duration, Schedule and Sound) standpoint.

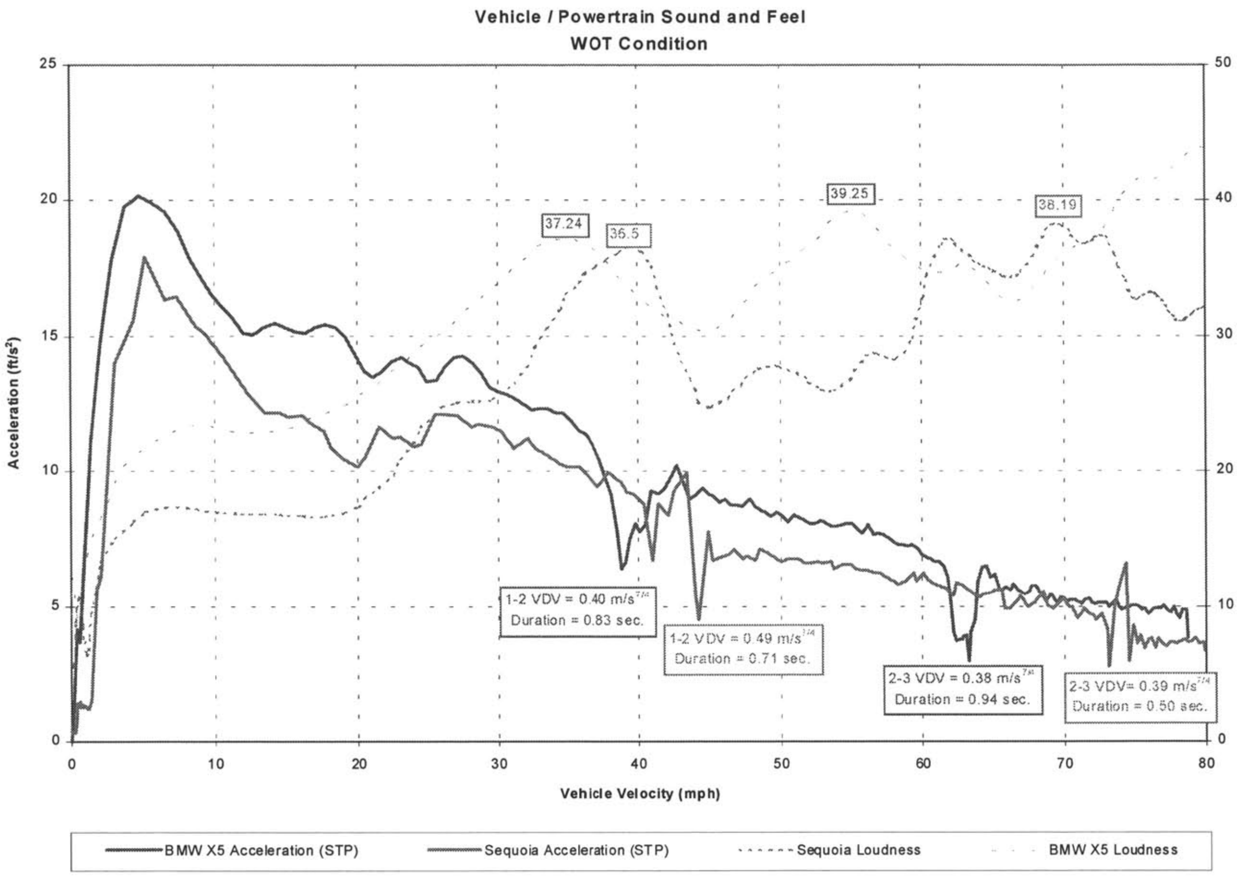


Figure 51 - Representation of the Customer's Driving Experience from a Powertrain Perspective

DSM Timing Overlay

We took the Design Structure Matrix (DSM) in Figure 46, removed the categorical descriptors intended for making the format user-friendly for the PAT/PMT users and then partitioned and re-organized to Ford's attribute development process. The DSM below (see Figure 52) contains the same interactions in the previous four-quadrant DSM, however, it is now a 132 x 132 matrix instead of the 157 x 157 matrix. The only difference being the high-level descriptors were removed so that the vehicle attributes, sub-attributes and design parameters were left to partition, and tear the DSM in order to try to move all interactions below the diagonal and to reorganize the elements in the sequence of the attributes development process.

There are 132 rows and columns (132 x 132 matrix) with a total of 1225 interactions, this translates to approximately 9 interactions per line.

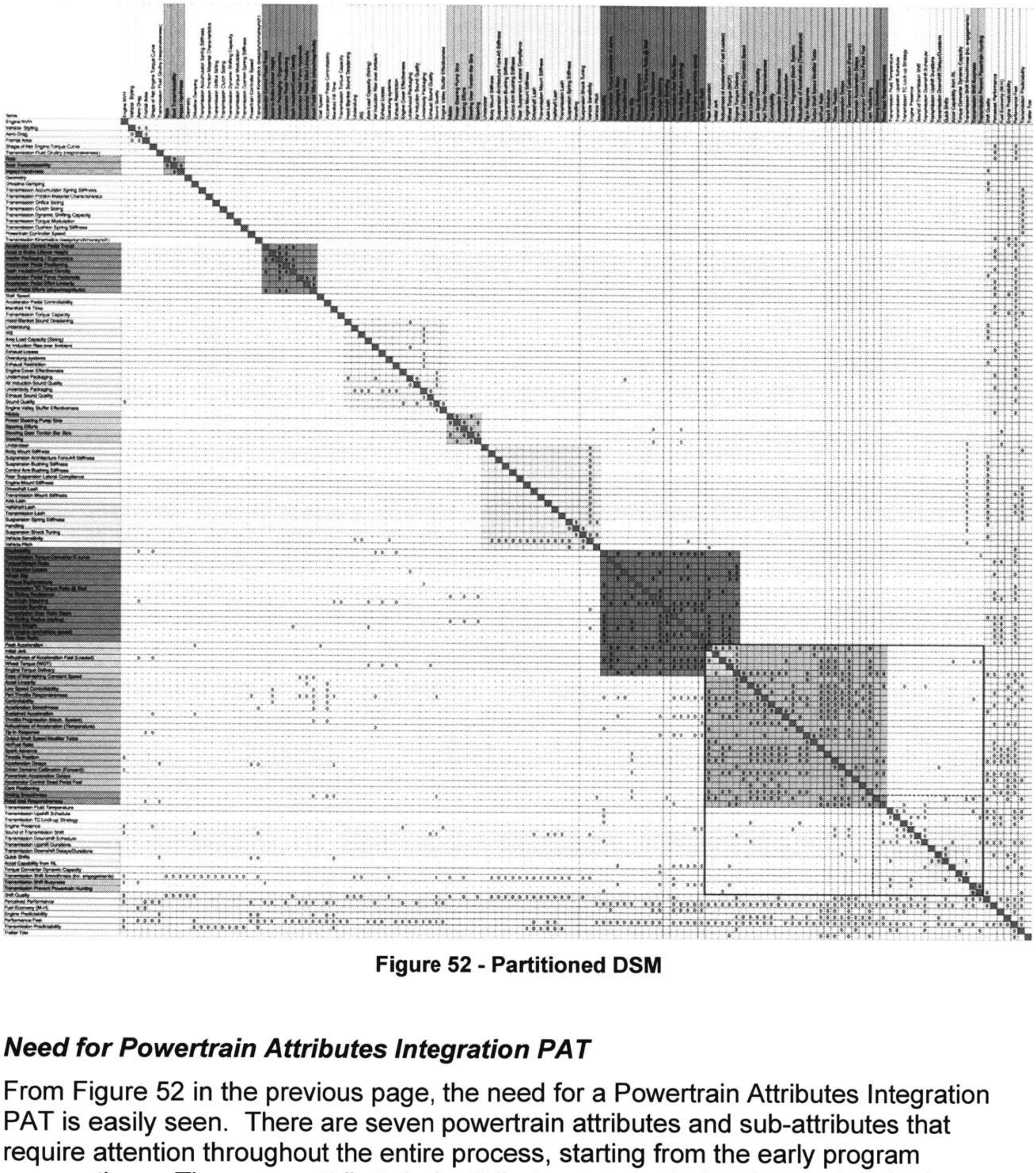


Figure 52 - Partitioned DSM

Need for Powertrain Attributes Integration PAT

From Figure 52 in the previous page, the need for a Powertrain Attributes Integration PAT is easily seen. There are seven powertrain attributes and sub-attributes that require attention throughout the entire process, starting from the early program assumptions. The seven attribute/sub-attributes are shaded and moved to the bottom rows (furthest columns on the right). The attributes/sub-attributes are: Shift Quality, Perceived Performance (sub-attribute of Performance Feel), Fuel Economy, Engine Predictability (sub-attribute of Driveability), Performance Feel, Transmission Predictability (sub-attribute of Shift Quality) and Trailer Tow.

Interactions above the Diagonal

For each of the marks in the upper feedback section of the DSM (see Figure 52), we have included examples. These examples help to validate the DSM and highlight the need to take extra precautions for these interactions.

Underhood Package affected by Air Induction Losses

This interaction is rather obvious and affects many vehicle programs. The main reasons programs underachieve on air induction targets are typically because of poorly correlated CAE modeling (filter restriction or turbulent flow, tight bends or unknown resonances in the system) or changes due to tuning for powertrain sound quality.

To resolve this issue, Ford needs to improve its modeling capabilities to better understand early assumptions in order to achieve induction loss targets, as well as other functional objectives required of the air induction system, for example its contribution to powertrain sound quality and rise-over-ambient temperature requirements. Applying lessons learned from prior programs should also minimize severity of this potential iteration. For example, the next generation F150 pick up truck should have a more direct path for fresh air versus going through the inner fender sheet metal.

Tire Rolling Radius and Rolling Resistance affect Steering

Tire design parameters affect many attributes, probably more so than any other sub-system. The two design parameters that have interactions above the diagonal are tire rolling radius (size) and rolling resistance. Both affect steering, performance and fuel economy among others. A change in tire design can be initiated by the tire design/release engineer, vehicle dynamics engineer (for handling or ride performance) or vehicle performance/fuel economy attribute engineer. This change will affect steering and performance/fuel economy and may trigger a chain of events to get back on track to achieve target performance.

A recent example of when tires changed mid-program was the recently launched 2004 F150. The design change was not initiated by either Vehicle Dynamics or Powertrain Attributes engineering. The change came from vehicle design (Styling). During a program review with Richard Parry-Jones, Richard commented on how the wheel openings looked too large for the vehicle or tires. Instead of changing the wheel lip size, the tires were increased to 18-inch wheels/tires. But this change also came with a significant increase in weight as the new tires were much heavier; additionally impacting Powertrain attributes (performance and fuel economy). A typical response from a powertrain attributes standpoint is to propose a change to regain the loss in N/V (engine/vehicle speed ratio), for example changing to the next higher numerical axle gear ratio, which in turn may cause another change to regain the fuel economy loss from the higher axle ratio. This is typically the scenario, but in the case of the 2004 F150, they were granted performance and (Engine Power and Pickup) customer satisfaction target relief. The performance targets were revised and Engine Power and

Pickup customer satisfaction reductions accepted, hopefully to be made up with an equal improvement in Overall Customer Satisfaction due to styling improvements.

Very large styled wheels are currently very popular with customers. Consequently, Marketing pushes for larger wheels and tires throughout the program. Unfortunately they don't always understand of all the implications, not only with vehicle performance, but also of the large amount rework required to implement the change. The solution to this is to add a freeze date on tire changes in our development work plan and enforce the cut-off date by requiring VP-level (at least Director level) authorization for any changes in tire design.

Vehicle Sensitivity is affected by Vehicle Weight

The addition of mass to dampen unwanted NVH (Noise, Vibration, Harshness) late in a program is a common practice. These late additions of weight adversely affect performance feel (and all powertrain attributes). With the need achieve overall vehicle NVH performance to ensure competitiveness, and quality perception, this will not likely change.

Attention needs to be brought to both vehicle level attributes (Weight and Sensitivity). Improvements in capabilities to handling vehicle sensitivity issues are being made. Less dependence on mass dampers is also needed. These improvements in capability are key to reducing rework.

The weight engineering function (roles and responsibilities) and processes to support programs require major changes. Improving the way we *control* weight in the development process can eliminate or minimize a significant amount of rework by almost all activities. Currently, weight engineering's role is basically a weight tracker providing status of vehicle weight to the program team. The engineering change process needs to improve to reject changes with inaccurate weight information and changes without detailed analysis of all change implications through the approval process. As a minimum, weight provisions should be incorporated upfront in the vehicle-level targets. This will prevent the typical late weight additions from causing the powertrain attributes to be an inhibitor to customer satisfaction.

Vehicle Pitch is affected by Peak Acceleration

Vehicle pitch is the change in vehicle angle, relative to the horizontal axis as the vehicle is accelerating or decelerating. It is a function of the chassis' suspension stiffness and geometry, vehicle weight distribution and the amount of wheel force applied. In our case, we are concerned about vehicle pitch when accelerating as it affects the customer's perception of vehicle performance (see Figure 53).


Launch from a stop;

Vehicle pitching (exaggerated)

Figure 53 - Vehicle Pitch

Once the peak acceleration is known (see Figure 54), vehicle pitch is measured and depending on the vehicle pitch target, chassis tunable items may be modified, changing the vehicle transfer function. As the vehicle transfer function is changed, the shift quality sub-attributes may need to be modified to achieve shift feel targets. If the vehicle is made less sensitive, it is likely shift durations may be shortened which is desirable. In the case of Lincoln Town Car, anti-squat features were added to the vehicle for minimizing pitch. To reduce vehicle acceleration pitch, the anti-squat features lift the rear end as the vehicle accelerates (as shown in the cartoon, Figure 53) to reduce overall vehicle pitch angle.

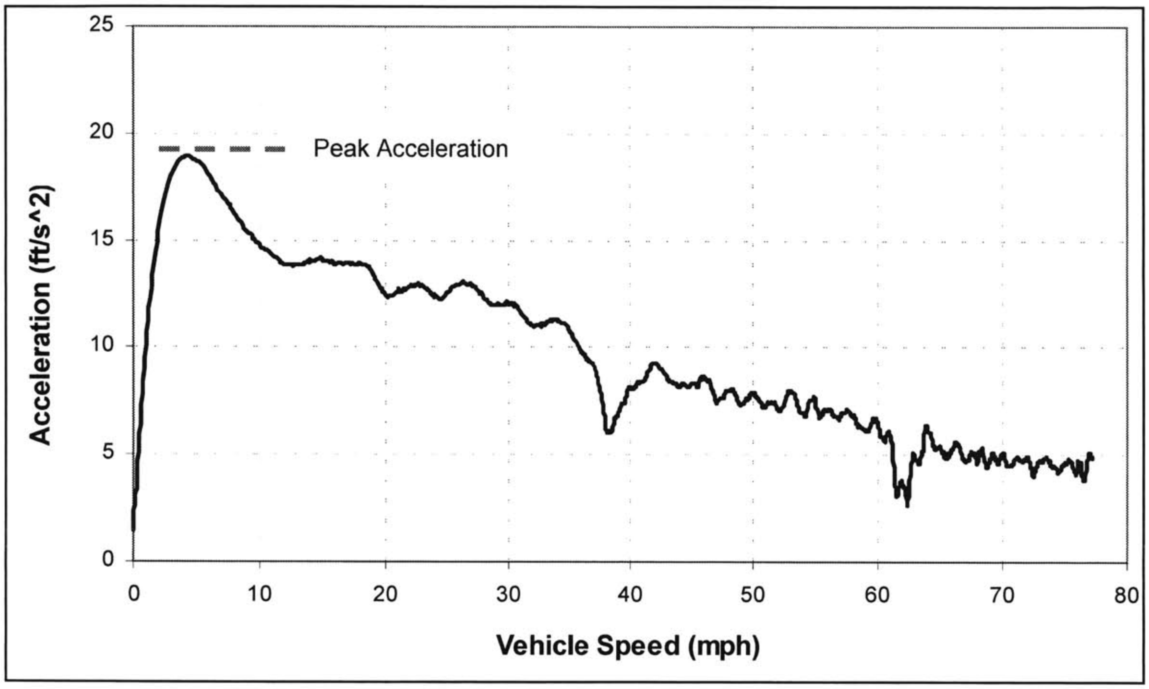


Figure 54 - Acceleration vs. Velocity Chart showing Peak Acceleration

Transmission Shift Smoothness is affected by anything that impacts the vehicle transfer function or vehicle sensitivity.

Shift Quality is a very complex attribute comprising of a few critical sub-attributes, shift sound and feel (NVH), shift duration (length of shift), shift delay (time lag before shift command and actual shift), and shift scheduling (positioning of shifts affecting performance and fuel). We will concentrate on shift feel (smoothness). Shift feel is a product of a complex system or subsystem interactions between the transmission / powertrain, suspension, and vehicle where loads from one subsystem may have a significant impact on the behavior of another.

Shift Feel is measured by vibration at the seat track. The vibration is contributed by both torque output at the powerplant (source) and the vehicle systems (path) the torque travels through. The sensitivity of the vehicle systems path is represented by the transfer function (TF = Vibration/Torque). The Torque and Vibration can be measured at various points in the system to give system/subsystem specific transfer function data.

The figure below (Figure 55) shows the vehicle subsystem parameters that affect shift feel. These parameters address the portion of the DSM with the 16 design parameters affecting shift feel (Smoothness of Transmission Shift). These parameters can be categorized into 3 major categories: Mounting Systems, Chassis Suspension Systems and Driveline Lash.

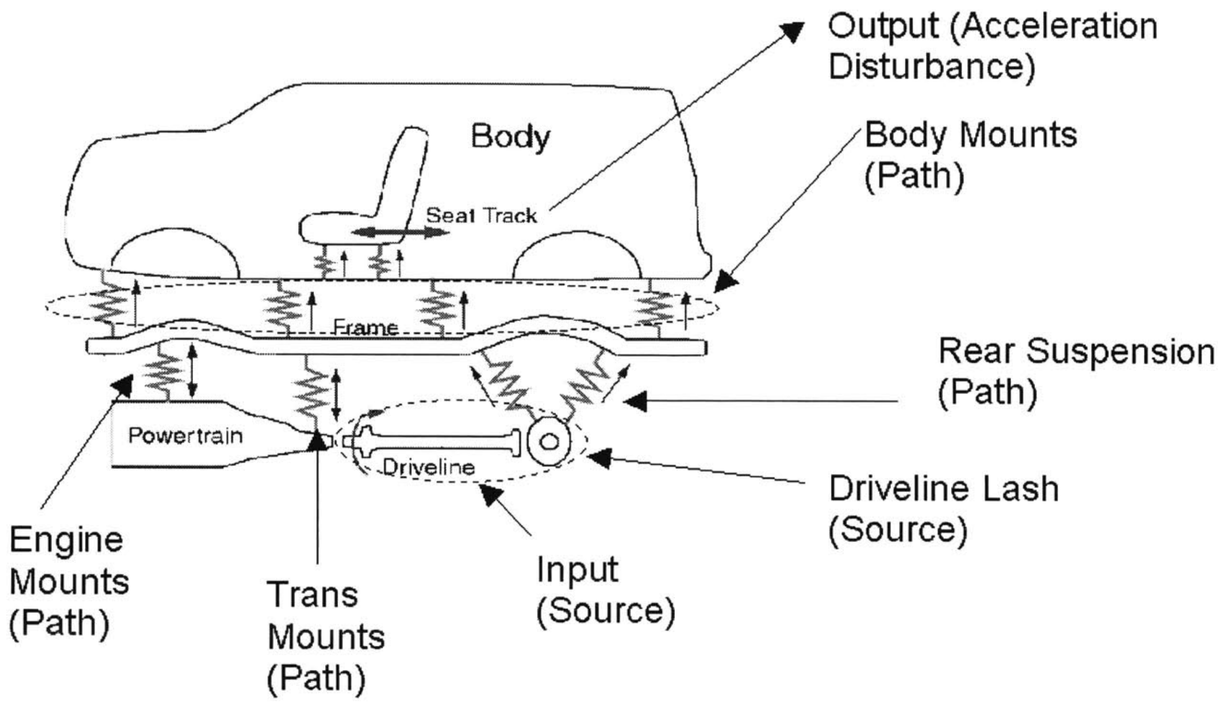


Figure 55 - Interactions Affecting Shift Feel

These interactions are not well known or documented. This results in significant rework and design iterations. Program teams typically stumble across these, and handle them inefficiently.

Mounting Systems

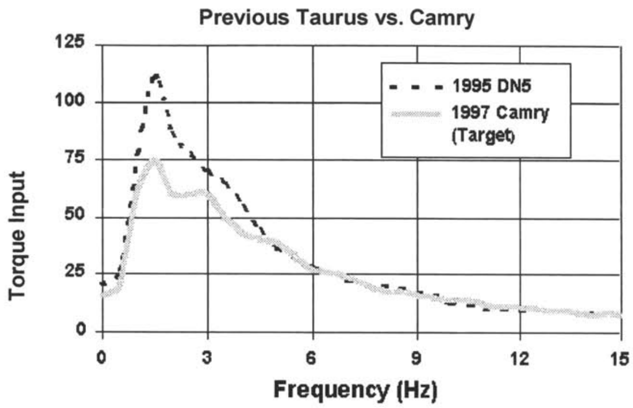
Historically, transmission shift feel was thought to be solely affected by transmission calibration. It was realized a few years ago that mounting systems, in particular powertrain mounts play a significant role in shift feel.

Powertrain mounts secure the powertrain components to the chassis and isolate high-frequency vibrations. Stiffer mounts provide better Shift Quality performance, but adversely affect overall NVH performance. So these attributes need to be balanced together.

The following example displays the effect powertrain mounts has on shift feel. Figure 56 (chart on right) shows the torque input into the system is similar between Taurus

(DN101) to Camry, a significant improvement to the prior model Taurus (DN5), which is the chart on left of Figure 56. A lower torque input to the vehicle is better for shift feel; higher torque input will require more dampening from the mounting system.

Note: Objective metrics for Shift feel and Torque input were intentionally omitted. These are regarded as Ford Motor Company trade secret.



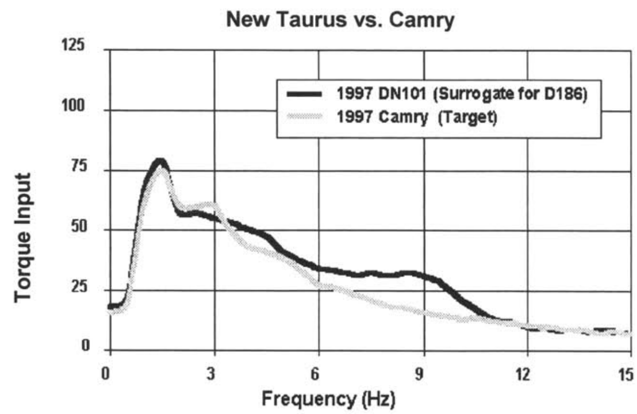
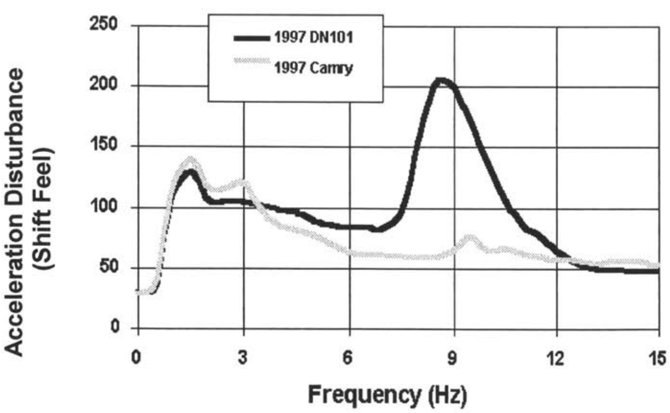


Figure 56 - Torque Input of Taurus (DN5) vs. Camry (left) and Torque Input of Taurus (DN101) vs. Camry (right)

Despite equivalent torque input, the acceleration disturbance or shift feel was much higher on the Taurus than the Camry (see Figure 57 - chart on left). A lower acceleration disturbance results in better shift feel. The Taurus is more sensitive in the 7.5 to 12.5 Hz frequency range. This can be seen in the chart on the right of Figure 57, which represents the vehicle sensitivity or vehicle transfer function. It's the output (shift feel) divided by the input (transmission torque) plotted in the frequency domain.



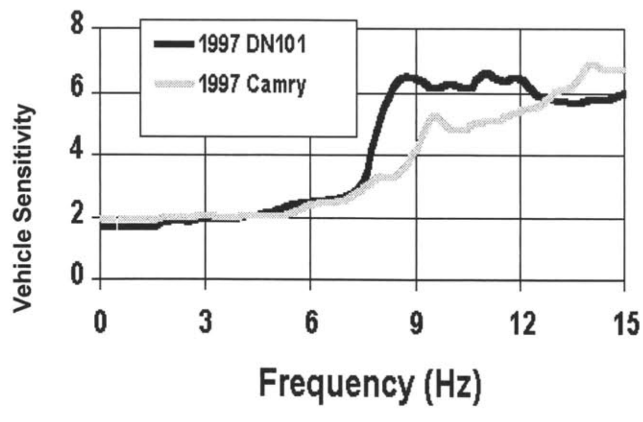


Figure 57 - Comparison of New Taurus vs. Camry - Acceleration Disturbance (left) and Vehicle Sensitivity (right)

By modifying the powertrain mounting system, the transmission shift feel can be greatly affected as shown in the Figure 58 below. As mentioned earlier, lower acceleration disturbance results in better shift feel.

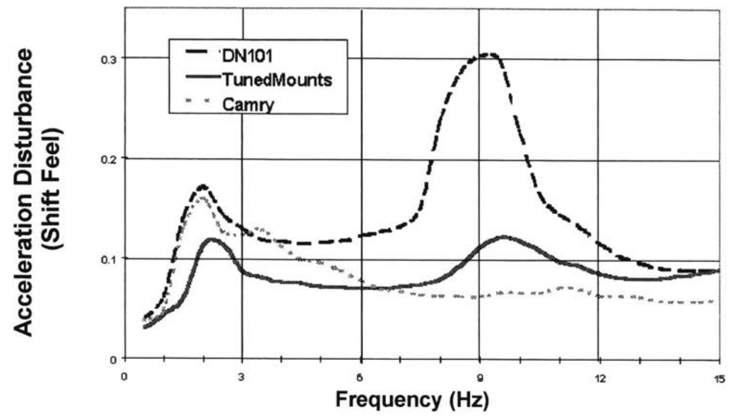


Figure 58 - Shift Feel with Tuned Mounts

In general, for front wheel drive (FWD) vehicles like Taurus, powertrain mounts are one of the most important subsystems impacting Shift Quality. Mount locations and stiffness in all directions control the roll motion of the powertrain during the torque disturbance of a shift event.

Chassis Suspension Systems
The contribution of the chassis to shift quality is relatively new knowledge. The suspension system holds the wheels to the frame/body and provides a reaction path for the tractive effort (wheel force during an acceleration) driving the vehicle. The chassis architecture and ability to dampen input torque into the vehicle greatly impacts vehicle sensitivity, therefore impacting shift feel.

The primary configuration used in most front wheel drive vehicles is the McPherson strut design. This front suspension usually has very little impact on Shift Quality because the front suspension is well designed to handle other vehicle attributes (such as ride and handling). Thus shift feel is generally acceptable for front wheel drive vehicles.

On rear wheel drive (RWD) vehicles, the rear suspension is an important factor in shift feel. Think of the rear suspension as a longitudinal spring system. This longitudinal "spring" is compressed by the tractive effort as the wheels push on the suspension to drive the vehicle. During the shift, some of the torque (tractive effort) being used to drive the rear wheels is used in the transmission to make the gear ratio change. When the level of tractive effort is decreased, it allows the suspension system "spring" to release. It will then oscillate close to the suspension system's natural frequency until the shift is completed. When the shift disturbance is over, the system will return to a compressed equilibrium state.

Driveline Lash

Because lash affects Shift Quality, the amount of lash needs to be minimized as much as possible. Lash is the amount of free play that is allowed in joints and gears within the driveline system. When torque is applied or removed, the joint will move. The joint movement has a hammer effect as parts move in the joint, introducing disturbance into the system. Because no joint can be a perfect fit, there will always be some amount of lash.

Joints between the differential and wheels are most critical since they encounter the highest level of torque, which in turn equates to significant impact disturbances. Consequently, on RWD vehicles, solid axle applications will typically have lower lash than independent differentials because there are fewer CV (Constant Velocity) and spline joints. The trade-off for joints with low lash is cost. Low lash joints are more expensive and difficult to manufacture/assemble.

An example of suspension and lash contribution comes from the 2003 Navigator program when they experienced a Drive-to-Reverse static engagement clunk issue. The charts below (see Figure 59) shows the 2003 Lincoln Navigator prototype while having average torque input relative to competition (left chart) during a Drive-to-Reverse shift event, it has the highest acceleration disturbance or shift feel (right chart). In contrast, the 2002 Lexus LX470 despite having the highest torque input into the system (left chart) have one of the smoothest shifts or lowest acceleration disturbances (right chart).

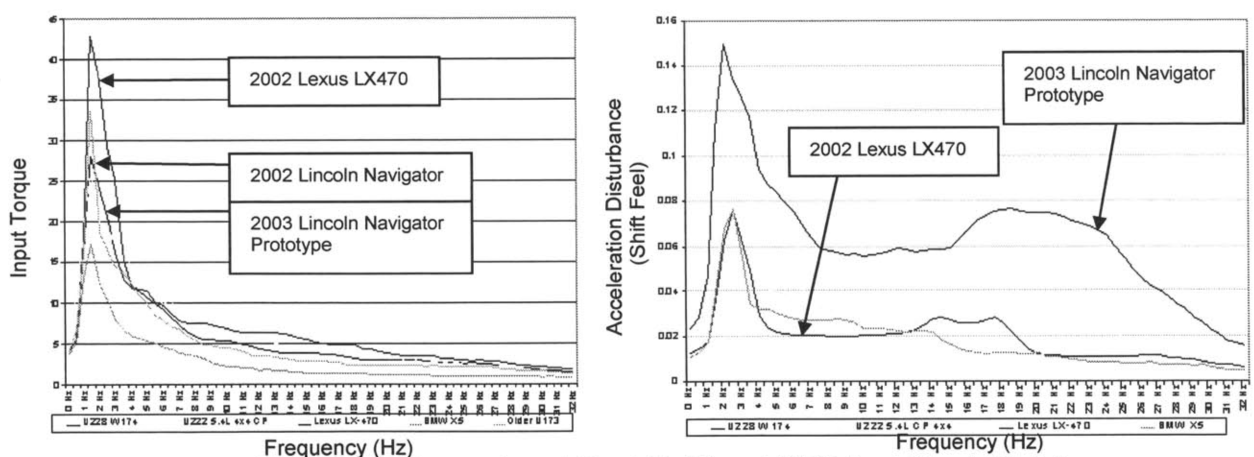


Figure 59 - Torque Input Chart (Left) and Shift Feel Chart (Right)

An investigation of the problem revealed a significant increase in vehicle sensitivity with the new model prototype. As can be seen in Figure 60. This was mainly due to the redesign of the rear suspension from solid rear axle to independent rear suspension. As you can see from Figure 59 (right chart above) the 2002 Navigator and 2003 Navigator have similar torque input, as it should. The powertrain was planned to be carryover engine and transmission (same hardware).

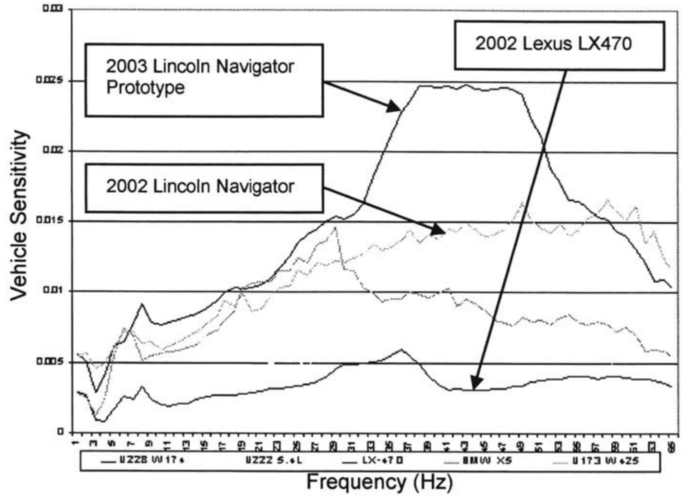


Figure 60 - Vehicle Sensitivity Chart

It was discovered late in the development process through a Design of Experiment with CAE and verified with testing, the major contributors were both the rear suspension bushing stiffness and driveline lash.

The chart below (Figure 61) shows the Acceleration Disturbance improvement (Shift Feel) by stiffening a rear Upper Control Arm chassis bushing.

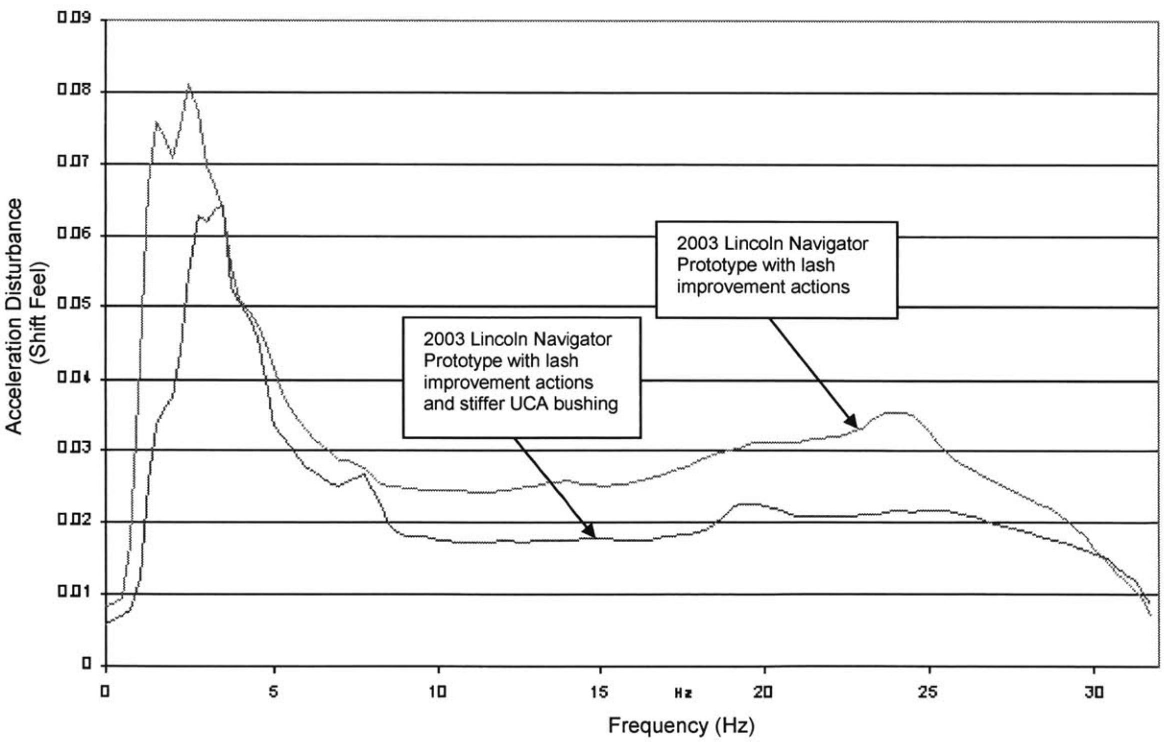


Figure 61 - Shift Feel Test Results with Retuned Chassis Bushing

The results of the CAE analysis and verification testing correlated well. Stiffer suspension bushings and reduced driveline lash resulted in significantly improved shift feel (see Run4' in the Figure 62 below).

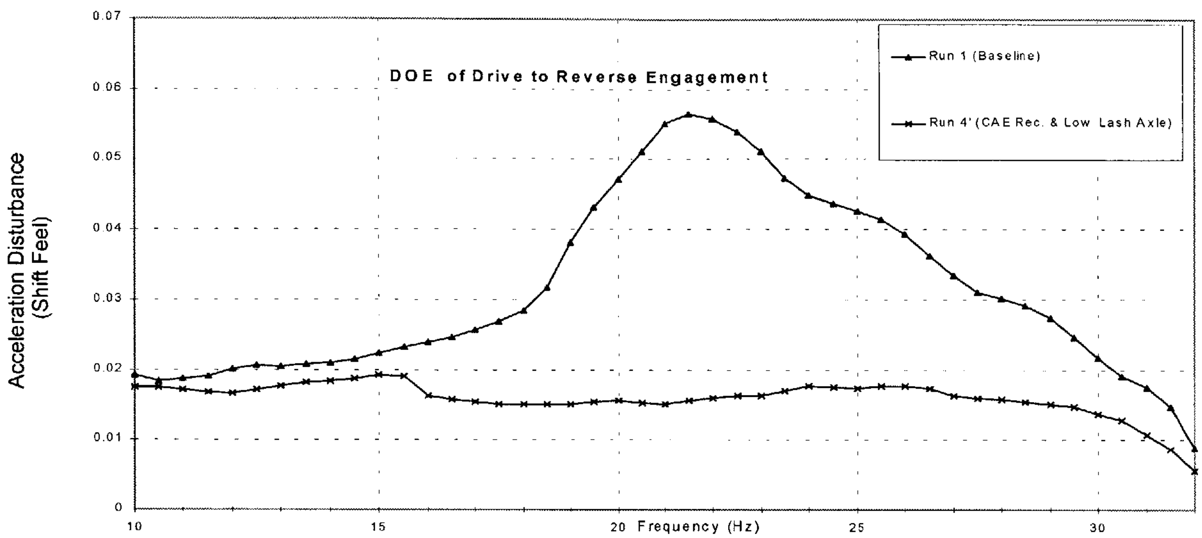


Figure 62 - DOE of Drive to Reverse Engagement

This example also points out the issues mentioned in Chapter 3 with respect to organizational issues. The DOE was completed in ample time to make the changes to the upper control arm bushing. However, the vehicle dynamics team disregarded the Shift Quality PATs recommendations to change the upper control arm bushing tunings as it affected Vehicle Dynamic sub-attributes of impact harshness and understeer Instead, the Shift Quality PAT changed internal transmission components and significant transmission calibration rework was required to help resolve this issue. This affected other shift quality sub-attributes like shift duration. This example also illustrates the high relative importance of Vehicle Dynamics attributes versus powertrain attributes for a given program team. This supports the need for a higher-level Powertrain Attributes Manager.

To minimize rework, we recommend better communication of lessons learned about attribute interactions from prior programs to build our engineering knowledge base. The DSM is an excellent tool for documenting these interactions.

Gradeability is affected by Transmission Prevent Powertrain Hunting (PPH)
Gradeability is the vehicle's ability to climb grades, typically in a loaded condition as most of our requirements and testing is at maximum GCW (Gross Combined Weight).

Transmission PPH is a design parameter for minimizing transmission shift busyness (shift frequency) or powertrain hunting. Powertrain hunting is a condition that occurs when the automatic transmission is shifting between gears in order to maintain a constant speed typically induced by grades or sinusoidal road conditions.

PPH works by delaying the upshifting or downshifting of the transmission, even when the vehicle has reached the desired speed or a crest of a hill as the transmission does not know whether or not another hill is just ahead. PPH strategies are easier to achieve with vehicles equipped with electronic throttle controls.

A successful PPH calibration should enable a vehicle to be able to maintain constant vehicle speeds while driving up commonly encountered grades without excessive shift cycling during both manual (foot operated) and cruise control conditions regardless of weight being hauled.

Interactions Above the Diagonal Inside the Double Lined Box

The large double lined box in the lower right portion of the DSM represents the powertrain calibration process (see Figure 63) from an attribute's point of view. There is slight overlap with the preceding box that represents the Powertrain Matching process. The preliminary engine and driver demand calibration process represents the development of the vehicle acceleration response transfer function relative to driver input or pedal travel. The following process begins the transmission calibration process with the upshift/downshift and torque converter lock/unlock scheduling. Shortly following is the shift feel and shift duration/delay calibration process. This step in the process should deliver the shift quality attributes assuming the right vehicle design parameters. The final step in the powertrain calibration process is the shift refinement step, considering shift busyness and transmission prevent powertrain hunting design parameters. Interactions inside the overall powertrain calibration process are relatively normal as the calibration process is highly iterative.

The following seven interactions are valid and have been documented by numerous programs. Since the calibration process is highly iterative and these interactions are well known, we will not cover in detail as the prior interactions. We will simply discuss at a high level the strategy to address these known interactions.

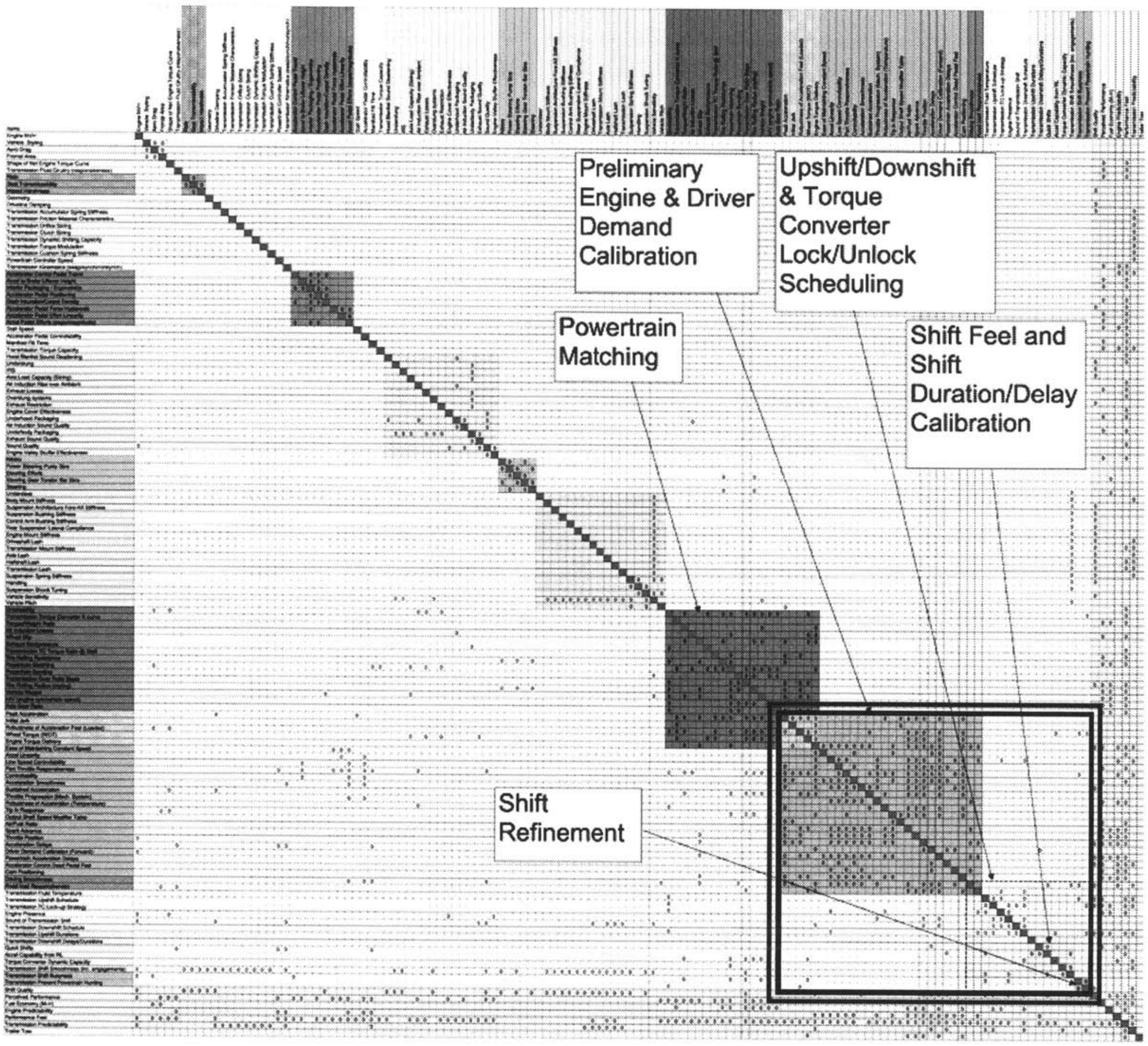


Figure 63 – Partitioned DSM with Labeled Powertrain Attributes Development Processes

Robustness of Acceleration Feel (Loaded) is affected by Acceleration Capability from Road Load

This is being addressed through the Brand DNA targets through improved Powertrain Matching process. Within the Performance Feel and Trailer Tow DNA targets are acceleration target levels that delivers the appropriate levels of acceleration for the brand under laden conditions. Prior vehicle programs mainly focused on launch metrics like 0-60 mph acceleration times with the vehicle in the unloaded condition.

Robustness of Acceleration Feel (Loaded) is affected by Transmission Shift Busyness

This interaction almost falls under the same category as the above. There is a unique metric with the Trailer Tow DNA that addresses this interaction. This metric is mainly an acceleration level at transmission top gear minus 1 gear (meaning the acceleration after 1 downshift event), rather that the wide open throttle capability (top minus 2 or 3 gear performance, based off shift scheduling).

Robustness of Acceleration Feel (Loaded) is affected by Transmission Prevent Powertrain Hunting
This interaction is related more to the shift busyness effect on performance feel. If the transmission is constantly shifting up and down, the impression is that the engine is underpowered and it needs help from the transmission to deliver the power. This is where a robust PPH calibration can minimize this issue.

Acceleration Linearity is affected by Transmission TC Lockup Strategy and Acceleration Linearity is affected by Transmission Downshift Schedule
These two interactions are also being addressed by Performance Feel DNA metrics. The downshift scheduling (positioning of downshifts) and torque converter lock/unlock (positioning of torque converter locks and unlocks) strategy is key to delivering the feeling of linear acceleration. One has to be very careful with downshift scheduling and torque converter lock/unlock scheduling as they both affect a sub-attribute of Performance Feel (Acceleration Linearity) and Shift Busyness (Shift Quality sub-attribute). Spacing the transmission events (shifts and locks/unlocks) closely improves Performance Feel, but moving too closely may result in Shift Busyness. The Performance Feel DNA and PPH will significantly reduce the severity of rework if rework is even required.

Part Throttle Responsiveness is affected by Transmission Shift Busyness
The more aggressive the driver demand and downshift scheduling becomes, the higher the probability of transmission shift busyness. Additional design requirements in the powertrain selection process are required to better match the powertrain to the vehicle. These additional design requirements can overcome this issue. The Performance Feel DNA metrics mentioned earlier should minimize this concern of shift busyness enabling more responsive part throttle performance.

Acceleration Delays is affected by Transmission Downshift Delays/Durations
Transmission hardware (hydraulic capacity) significantly impacts transmission downshift delays, thus affecting acceleration delay, therefore Performance Feel. This has been demonstrated in a couple of customer research clinics with actual customers driving instrumented vehicles. Vehicles with more downshift delay were perceived to have less performance. This error state is a significant contributor to customer dissatisfaction and is a being addressed in all future transmission development programs.

Although we didn't cover the last seven interactions in great detail, these points still supports the validity of the DSM. These issues are well known and Ford has developed Brand DNA metrics as a means to address many of these interactions.

Benefits of Using DSM

We believe the DSM is the best tool for complex systems management. It easily communicates the system interactions like the Interactions Matrix (Form vs. Function Interactions) and in a Functional QFD. The DSM can also display the strength of relationship or interaction similar to QFD. We did not rate strength of interaction for our

DSM mainly because of its sheer size although it could have been done. Gaining consensus on the strength of relationship for each interaction would have been too much to handle and outside of the scope of our project. Strength of interaction may vary due to program hardware and assumptions. For example, a program with an independent rear suspension will be more concerned with driveline lash than one with a live axle (less lash in systems with a live axle). Another example is the strength of relationship of powertrain mounts to shift smoothness is much higher with front wheel drive vehicles than rear wheel drive.

There is another benefit of using DSM that is not available in any of the other system management tools shown. The DSM can capture work iterations. The DSM can be partitioned and rearranged to reflect the product development process flow. All interactions left above the diagonal represent potential work iterations. Unplanned iterations can derail program teams from meeting cost and timing objectives. Knowing interactions above the diagonal exist, one can better manage by developing a strategy to minimize or possibly eliminate the potential for rework. An example would be to have the Shift Quality PAT and Vehicle Dynamics PAT work with CAE upfront to develop alternative suspension bushings or the Shift Quality PAT to work with Powertrain NVH to develop compatible engine mount tuning.

This points to the need for a task based DSM for attributes development. We attempted to line up the partitioned attribute DSM with FPDS timing. This was difficult as it included timing of only finished attributes. Engineers do many tasks to complete the development of a single attribute.

There are a significant amount of vehicle attributes in the DSM. These attributes are being developed simultaneously with the powertrain attributes. Changes in other attributes will affect powertrain attributes. This points to the need for a total vehicle attribute DSM.

Summary

In this chapter, the Powertrain Attributes DSM was presented in the format we thought would be best suited for the intended user (PATs and PMTs). We partitioned the DSM and discussed all the interactions above the diagonal and provided recommendations of how to minimize potential for iterations. The partitioned DSM showed many feedback loops that need to be managed.

The DSM clearly showed interactions between multiple powertrain attributes, powertrain attributes and other vehicle attributes, powertrain / vehicle attributes and design parameters, and design parameters interacting with other design parameters.

We showed that the CAE tool coverage of attribute interactions is sparse and that program teams struggle with unknown interactions causing significant rework through design iterations. We then provided recommendations that will help manage the interactions to minimize rework.

In the next chapter, we will look at how engineers would like the knowledge from the DSM to be documented, and made available.

Chapter 6 - Survey Results

Introduction

In the previous chapters we have proven the first hypothesis (i.e. a complete understanding of all powertrain attribute interactions is needed to prevent needless rework.). We then developed a Design Structure Matrix to actually document the interactions relating to powertrain attributes in Chapter 5.

In this chapter we will prove or disprove the second hypothesis (i.e. The DSM format, may not be the ideal method of displaying attributes for engineers needing to understand them.) We will look at this via a series of surveys and analysis to further understand what engineers really need in terms of better understanding attributes and interactions between them.

Surveys

We conducted 3 surveys to help understand what the engineering community felt about attributes management and to determine what help/changes they would like to see in this regard. The first survey was a broad questionnaire and left intentionally vague. The 2nd questionnaire was a more detailed follow up to the first, but unfortunately suffered from a low response rate. The third questionnaire encompassed the types of questions we asked in the first and second questionnaires, but in a more specific format, which better allowed statistical data collection. The surveys are included in Appendix B.

1st Survey Results

Survey Responses

Figure 64 shows the Survey response ratio for the first questionnaire. The first round was simply sending out the questionnaires. Second round was resending the questionnaire and personally asking for a response. The persistence got a fairly high response rate despite the low number that we sent out.

Survey Counts	Number
Surveys Sent	31
Received 1st Round	5
Received 2nd Round	11
Total Received	16
Response Ratio	52%

Figure 64 - First Survey Response Results

Importance of Attributes

We asked the question: "On a 1 to 5 scale, how significant of an issue do you think effective attribute management is at Ford?" The responses seen in Figure 65 were right at the high end signifying that the engineers believe attribute interactions are extremely important.

	Average	4.33		
	Standard Deviation	0.82		
Answer	**Rating**	**Qty**	**Percent**	
1	Not significant	0	0 %	
2		0	0 %	
3	Average	3	20 %	
4		4	27 %	
5	One of the largest issues	8	53 %	

Figure 65 - Importance of Effective Attribute Management Responses

Help Desired

We asked in the questionnaire, " What kind of help would you like available in regards to help in understanding systems/attribute interactions?" Figure 66 shows the broad types of help desired. From this we concluded:

1. People really want an expert. (i.e., Someone to help them and guide them)
2. Second to an expert people want a reference guide.
3. Tied for third, people want training and improved testing and training
4. And lastly, people would like CAE tools to help

Recommendations	**Number**	**Percent**
Tech Spec	10	63 %
Design Guide/Data Base	7	44 %
Training	3	19 %
Quick & Easy Tests	3	19 %
CAE Tools	2	13 %

Figure 66 - Recommendations of Help Desired

Since companies are in need of doing more with less people, the option of a technical specialist to help is not a possibility. But it does show the need for Ford to build added technical expertise.

People's second choice requesting a "Design Guide/Data Base" confirmed the first part of our thesis, that a complete study and cataloging of the attributes is necessary to prevent needless probing for interactions.

Detailed Help Desired

The data was then gleaned for further details on the type of information being sought (see Figure 67). Three items stood out:

1. People want an easy to follow Table or Chart.
2. A web-based tool would be great for easy access and updating.
3. People need to know the details so that they know how to handle the relationships. Simply stating that something affects something else just begets the questions:

- If I change this by X% how much does Y change by?
- And in which direction does it change?
- Rules of thumb or links to information would be very helpful.

Detailed Recommendations	Number	Percent
Interactions Table or chart	5	31%
Detailed Explanation of effects and magnitude	5	31%
Web based	5	31%
P-Diagram	1	6%
Systems Interface Diagram	1	6%
Search engine	1	6%
Cascade Diagram	1	6%

Figure 67 - First Survey Detailed Recommendations on Help Desired

The detailed recommendations indicated that a DSM was clearly lacking in the third aspect of providing detailed knowledge. This is the detailed knowledge that a technical specialist could help with. This justified the additional research we did on how they really want this laid out.

2nd Survey Results

The results of the 2nd survey were disappointing. Although a fairly good percentage of the people responded, we had very few responses in total. See Figure 68 below.

Survey Counts	Number
Surveys Sent	31
Received 1st Round	6
Received 2nd Round	6
Total Received	12
Response Ratio	39%

Figure 68 - Second Survey Response Results

Format Preferences

We asked which of 5 different formats that people preferred:

1. **P-Diagram** - A single page diagram showing: Attribute, Inputs, Noises, Control Factors, Ideal Function, and Error States
2. **Cascade Diagram** - A diagram showing how high level attributes are cascaded down to sub-attributes. The cascade diagram shown in the surveys included a fair amount of text explaining what each sub-attribute meant.
3. **Design Structure Matrix** - A matrix with the relevant attributes, sub-attributes and design parameters, where the item in a given column affects an item in a given row if there is a mark in the corresponding location of the matrix.
4. **Interactive/Web** - Links on a given page lead one to the affected item on another page. This allows space for details of the interactions to be shown on the pages. These pages do not include this extra information.

5. **Interactions Matrix** - A chart showing how various components relate to a given attribute.

The example formats shown in the surveys are contained in Appendix C.

The responses indicated that the DSM and cascade diagram were the favorite first choices. The second was the interactive/web format. However the responses were very few and we suspected a preponderance of people choosing the format that they were familiar with. See Figure 69 below.

	Respondents answering this question	Number having a preference	Cascade Diagram	DSM	Interactive / Web	P-Diagram	Interactions Matrix
1st Choice	11	6	2	2	1	1	1
Combine with:	8	3	2	1	3	2	2

Figure 69 - Format Preferences

Responses included:

- They all have their benefits
- Format must include interactions (seems to rule out cascade diagram). I don't have enough experience to choose one over the other otherwise.
- The Interactive/Web format seemed to include the best information. It was not too cluttered
- My Second choice was for the cascade diagram because it had some explanation along with the diagrams, so it was easier to follow.
- Different formats work for different people. Since the files are not that large, make all of them available.
- I would like to combine the interactive web base with live interactions between the P-diagram and cascade diagram.

Based on the very few responses we received it appeared that the Cascade Diagram and the DSM were equally good candidates. The good news about this is that the Cascade Diagram is a subset of the DSM. So it appeared that the DSM was a good primary choice. The respondents were interested in connecting these formats to additional information via the interactive/web method.

However we were very concerned about the low number of responses. So we didn't want to jump to conclusions from this limited data.

Training

We asked if people had taken the online Vehicle Shift Quality Training and Assessment of Prior Experience and Learning (APEL), since that was indicated as an area where people wanted help in the first questionnaire. If people actually took the training and wanted more, we could conclude there was a true need for this. It would also indicate that people didn't just want to have a technical specialist. It turned out that not many of the people had taken the training. See Figure 70 on the following page.

	Qty	Percent
Yes	2	18%
No	9	82%

Figure 70 - Number of People that has taken Vehicle Shift Quality Training

Comments included:

- Did not take it. (other FTEPs have not been of much use)
- It was a good overview and the resource guide was at a decent level. I had a fairly good understanding going in and was able to complete the first half of the questions based on current knowledge. But the last half of the questions were over my head and I had to read the guide and learn new stuff, which is what I wanted.

We asked people "Would you recommend additional powertrain attribute classes?" The responses included:

- Powertrain Matching Seminar
- PT Matching, Engine Performance (ED 200 series)
- Powertrain matching would be interesting (and something this company is weak at), combining the effects of torque converter matching w/ an overview of key performance metrics (0-60, gradeability, shift delay, downshift scheduling) and key DNA metrics. Fuel economy may be also useful, though I'm concerned that it's really the VI and VEMs (Vehicle Engineering Managers) that would need this and they may not have the time to take it.
- I'd recommend a Vehicle Fuel Economy class explaining the parts of the vehicle that contribute to fuel economy and percent of each. P/T gets gigged all the time and it's time to educate the world.

Additional powertrain attributes classes were recommended despite not many people having taken the currently offered class. Since the original question was vague we couldn't tell if people were recommending the class for themselves or to get others to be able to better understand their issues.

We asked, "Is there some other training that you would like to have? (i.e. Complex systems management)"

- NVH Information seminar. Shift Quality Seminar - so we can know what effects each attribute.
- Yes, I personally could use more technical training to better understand A/T transmissions and torque converters.
- Complex systems management is probably the most important in the company. Key systems interactions and vehicle trade offs (components that interact to help one attribute and hurt another but that can be optimized as a system.

We concluded that there is probably a need to have classes for the powertrain attributes including:

- Fuel Economy

- Powertrain NVH
- Powertrain Matching / Torque Converter matching/ Gears & Gear Ratio selection
- Engine Performance

Computer Aided Engineering Tools

For CAE tools we asked 3 questions. The first one was, "In regards to CAE tools, what would you like to see improved?"

- Part throttle performance in CVSP.
- CVSP is a great tool. I have a ton of respect for it after working with it and am very impressed with its accuracy of prediction. Continuing to evolve this tool is absolutely critical to my task of Performance, Fuel Economy and Trailer tow.
- CAE for Mazda and Volvo products, compatible with FNA models.
- Possible axle whine concerns cannot be assessed in CAE when choosing axle-bushing rates.
- I am not familiar with the tools currently available. I have heard that GM has mandated this type of training for all engineers.
- Target setting process

Based on the few responses that we received it appears that not many people understand the capabilities of Ford's current CAE tools. In the information tool that we are looking to provide, it would be useful to indicate if an interaction is handled by a modeling tool. In discussions with Dan Whitney he suggested that we mark on the completed DSM the current CAE capabilities for handling interactions. We addressed this in Chapter 5.

The second CAE question we asked was, "What additional CAE tools do we need?"

- A better way to model vehicle weight.
- With Trans. Out based ETC strategy we had an excellent tool to populate the driver demand table (the calibrate-able performance of a vehicle). As we've shifted to Engine out based ETC strategy this tool is useless. We have no way other than trial and error to develop a driver demand table that meets DNA. This is a serious delay to product development, creates less robust calibrations that don't meet DNA and therefore give away Power and Pickup Satisfaction/Engine Satisfaction/Overall Vehicle Satisfaction. This lack of a CAE tool to create this, as we had on the '04 Explorer, means we're giving Sat. away for no benefit to other attributes.
- Driveability target setting tools

Handling of vehicle weight is a continual issue. Additional regulatory and customer driven features tend to drive vehicle weight up. Weight is typically passively tracked on programs. As weight increases powertrain attributes of Fuel Economy and Performance Feel are negatively impacted. Better handling of this sub-attribute is needed.

There is a need for another CAE tool, which is needed to develop driver demand tables for applications where an ECM (Engine Control Module) and TCM (Transmission

Control Module) are used in lieu of a PCM. A Powertrain Control Module is more cost effective and therefore more commonly used. A tool currently is available for developing driver demand table for a PCM. A new tool is needed to achieve an equivalent functionality with an ECM/TCM.

And the last question was, "Would you see any value in integrating the current models to look at all the attributes at once?"

- Yes, that would be a complex model!!
- All powertrain attributes as CVSP does, yes. Data plots of performance to include NVH at WOT; possibly, as we've done in the past.
- However, the data print out from CVSP is already verging on "too much information." So unless it is a critical trade off info (NVH) I think adding any more to the page will just bog people down and make it less useful than today."
- Only if they save effort
- Absolutely, this is one of the larger issues facing program teams. Unfortunately conflicting objectives, management "MANDATES", and inexperience is creating content churn due to improperly assessed attribute impacts of changes.
- I don't know if the overall attribute analysis would be too much data, and how system interactions would affect the given models. But again, I'm not familiar with the current tools and their capability.

Combining all the powertrain attributes into a single model is not recommended due to sheer complexity of the model. Model complexity appears to already be a challenge to getting accurate and timely results.

3rd Survey Results

Due to the poor response on the second survey we took several steps to increase participation of the 3rd Survey:

1. We sent this survey out under Steve Von Foerster's name (Director)
2. We put the actual survey online.
3. We sent the survey to a much wider audience
4. We made a shorter subset survey for managers

This helped us get an increase in responses. The response ratio fell as no follow-up nagging was done to elicit increased responses. The results are shown in Figure 71.

Item	Qty
Requests	144
Responses	33
Response Ratio	23%

Figure 71 - 3rd Survey Response Results

This gave us much more information and a better understanding of users needs.

Engineering Emphasis

We have correlated data from JD Powers (Figure 6) showing the attribute grouping that customers think is important for customer satisfaction. It is important to pay the most attention to the items that customers notice most to ensure high customer satisfaction. However getting an actual headcount on each of the areas is difficult, and furthermore the relative level of effort needed to develop each is very difficult to estimate in comparison to each other. So we simply asked engineers what emphasis the company places on each of the areas. The summary of their answers is listed in Figure 72.

Category	Averages
Ride, Handling and Braking	19.2%
Engine and Transmission Performance	18.5%
Vehicle Styling/Exterior	17.9%
Comfort and Convenience	11.2%
Cockpit and Instrument Panel	10.3%
Seats	8.7%
Heating, Ventilation and Cooling (HVAC)	7.6%
Sound System	6.6%
Total	100%

Figure 72 - Engineering Emphasis Placed on Each of the Vehicle Attribute Groupings

There were a couple of key areas where engineering emphasis did not match customer needs. The results of this question versus the customer satisfaction correlations are further reviewed later in this chapter under the heading of Emphasis.

Engineering Process

An established process is a key enabler to consistent quality. With the numerous interactions seen in vehicles we did not expect to have a consistent process. However one could envision consistent methodologies and tools being used as a goal. Since we want to provide a tool for understanding interactions, we want 2 things:

- Engineers to consistently pick that tool as first choice
- Have high effectiveness when using the tool to minimize rework

We simply asked engineers what tools that they used to discover interactions and how effective they believe that method to be. The results are listed in Figure 73 in the following page.

	Answer		Effectiveness	
	Avg (%)	StDev (%)	Avg (%)	StDev (%)
a. No particular process	7	12	16	28
b. Discuss with co-workers	30	15	47	27
c. Use modelling to understand	24	19	37	32
d. Look on web	6	7	13	19
e. Review books / technical papers	9	8	21	26
f. Ask boss	12	11	18	25
g. Other ___________	12	25	11	27
Total (must equal 100%)	100			

Figure 73 - Methods Employed to Ensure there are no Unexpected Interactions

For "other" the following items were given:

- Personal Experience
- Ask the experienced engineers or management
- Review in Systems PAT / Use formal Attribute PAT
- Change Control using the right tools for the problem. We designed this process for our program.
- Supplier interaction/ Data acquisition
- Internal design guides / Use interaction diagrams

The most popular choices by far were discussing with co-workers (30%) and modeling (24%). Note that these most popular choices are ranked at 47% and 37% average effectiveness.

The use of a particular process appeared to directly relate to its effectiveness. We tested this by building a regression model. A regression analysis of the data showed that there was a clear relationship between effectiveness and usage. Three regressions were tried a fit of each variable was verified statistically using t-stat where a low P-value indicates that a variable clearly affects a response:

- Avg Effectiveness * X1 + StDev *X2 + X3 = Avg Usage *(StDev had high P-value indicating that it should be removed from the model)*
- Avg Effectiveness * X1 + X3 = Avg Usage *(Non- Zero constant X3 had high P-value also indicating that it should be removed from the model)*
- Avg Effectiveness * X1 = Avg Usage *(Avg. Eff. had extremely low P-value indicating a good fit)*

The graph of the final model indicates a good fit with R^2=90%. It is shown in Figure 74 in the following page.

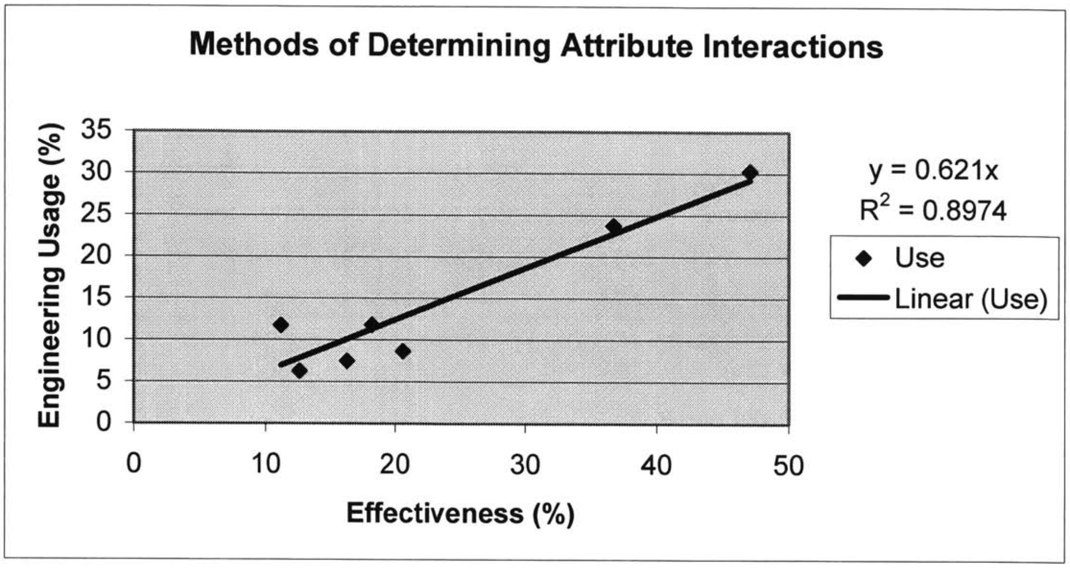


Figure 74 - Engineering usage of Detection Methods Follows Effectiveness

The conclusion from this is that any new tool needs to be perceived to be extremely effect to ensure adoption. Note that this simple model indicates that a tool, which is perceived as 100% effective will likely only enjoy a usage of 62%.

Constant Change

With a great deal of interactions and very low effectiveness at finding the potential interactions, we would expect to have a lot of iterations and rework. So we asked, " Do any of the outputs you provide potentially result in design changes?" And the answer was overwhelmingly "Yes". See Figure 75.

	Responses	Percentage
Yes	30	94 %
No	2	6 %

Figure 75 - Respondents Indicating their Efforts Result in Design Changes

So we asked, " What percent of the time does this happen?" and the answer was a little over a third of the time on average as can be seen in Figure 76.

Average	36 %
StDev	28 %

Figure 76 - Percentage of Time an Output Causes a Design Change

If an individual's work is changing the design a third of the time, they must be subjected to a lot of change from other people as well. So we asked, "Do any of the design assumptions you use change during or after your work is started?" The answer again was overwhelming that they are experiencing change from others. See Figure 77 on the following page.

	Responses	Percentage
Yes	30	94 %
No	2	6 %

Figure 77 - Respondents Finding That Assumptions Change After Work has Started

We again asked, " What percent of the time does this happen?" and the answer was a little over half the time on average. See Figure 78.

Average	54 %
StDev	30 %

Figure 78 - Percent of Time There Are Changes in Assumptions After Work is Started

We expected similar answers between Figures 76 and 78. We suspect that this difference may be due to human nature to think that one's own work is of higher quality that other's work. However, further research would need to be done to determine why these numbers vary. This data is useful in building systems dynamics models, like Tony Zambito did in his thesis.

It is important that all the interactions are known and addressed before a vehicle goes into production. So prototype vehicles are built to ensure that any undetected interactions are identified and resolved. Ideally one would like to have as many of the potential interactions worked out before a confirmation prototype vehicle is built. So we asked the question, " What percentage of all powertrain interactions do you think are addressed by existing processes prior to vehicle builds?" The answer we received was not very encouraging with only about half of the interactions known before the vehicles are built. See Figure 79.

Average	52 %
StDev	23 %

Figure 79 - Percentage of Interactions Known Before Vehicles are Built Responses

Relative Priority

Clearly improved tools to address interactions are desirable as the existing ones are not overly effective. However we need to be cognizant that there are numerous competing priorities. So we asked how significant of an issue attribute management is compared to others the company faces. Figure 80 lists the answers that we received:

Answer	Rating	Qty	Percent
1	Not significant	0	0 %
2		4	12 %
3	Average	7	21 %
4		15	45 %
5	One of the largest issues	7	21 %

Figure 80 - Importance of Attribute Management Responses

This is the same question that we asked in the first questionnaire with the words slightly differently worded to remove the word "effective" before "attribute management". In that survey we got a lot more responses that were rated 5. Combining the results from the 1st and 3rd surveys we got (see Figure 81):

Answer	Rating	Qty	Percent
1	Not significant	0	0 %
2		4	8 %
3	Average	10	21 %
4		19	40 %
5	One of the largest issues	15	31 %

Figure 81 - Sum of Importance of "Effective Attribute" and "Attribute" Management" Responses

Clearly the powertrain engineering community thinks this is an important issue, regardless of how the question is phrased. So improving management of attributes is vitally important.

Particular Concerns

Since engineers are very concerned about attribute management, we asked them "What attribute interactions are you most concerned about that are not currently addressed sufficiently by current processes?" We got a variety of answers that spanned the gamut of powertrain attributes:

- Shift Quality vs. P/T NVH; Shift Quality vs. Ride & Handling
- Performance feel, smoothness in shifting, and fuel economy.
- Vehicle to subsystem cascade methodologies. This ties to vehicle sensitivity changes and driveline NVH performance. Every program I have been on has seen this change and generates issues at or near launch. The vehicles become more sensitive.
- My concern is avoiding error states where the vehicle does something unexpected...a loud noise, vibration, clunk, hesitation or surge. As the level of electronic controls increases, the possibility for error states increases.
- Engine / Transmission calibration and Shift Quality
- What are our current processes? Each program has very different processes. SO, I am not sure how to answer, but here goes:
    - Diagnostics/Service
    - Regenerative Braking
    - High Voltage Battery Life/Performance/Drivability
- Cost, Weight
- Powertrain NVH
- Affects of transmission disturbance on the overall shift quality rating.
- Durability
- Driveline NVH and fuel economy
- Performance vs. Fuel Economy vs. Shift Quality vs. NVH tradeoffs
- All attributes are treated as subordinate to cost. As an example, even affordable fuel economy actions are eliminated based simply upon cost.

- Assembly feasibility is held hostage to last minute opinion at the plant. VO can force changes that affect attributes.
- Performance Feel, Driveability
- NVH, Vehicle Dynamics (Ride & Handling)
- Dynamics late changes, Shock tuning, jounce bumper stiffness.
- Build combinations that are not tested due to vehicle count reductions.
- Weight and everything else.
- Calibration interaction to fuel economy and performance
- There is very poor management of Vehicle and Powertrain natural frequency modal alignment. The Vehicle frequencies change significantly from one model to another in the total line-up and not all of these frequencies are monitored or even tested, especially
- The ones we do know and have no tools to predict. They end-up eating resources late in the program when is difficult and more expensive to make changes.
- Fuel Economy & weight interaction and perception of powertrain performance.
- Vehicle level clunk and vehicle sensitivity are not managed well. They are always after thoughts. Modal separation is needed to improve our vehicle NVH (structure and airborne) and shift quality.
- Fuel Economy; Weight; Aero.; Heat Management; NVH; Performance; Shift Feel; Aftermarket use of vehicle; Alternate Fuels.
- Any interaction that this not a simple one dimension.
- Safety Attribute's impact on fuel/evaporative system and subsequent impact on calibration (R00/R05) and system durability verification.

Help Desired

We learned from the first survey that people overwhelmingly want a technical expert to rely on. However the need to reduce engineering costs does not make this practical. So we did not include that as a possibility in the 3rd questionnaire. Also we asked the question based on the broad categories identified in the first questionnaire. We gave people 3 choices for the types of help desired. The responses indicated a fairly even distribution of the choices, with a bias towards quick and simple testing. See Figure 82.

Answer	**Qty**	**Percent**
Design Guides or Data Base	17	52 %
Attribute Training	15	45 %
Quick & Simple Testing	23	70 %
Additional CAE Tools	18	55 %
Other	4	12 %
Respondents	**33**	**100 %**

Figure 82 - Type of Help Desired in Managing Attributes

The 4 other answers were:

- More attention by the pre-program team
- Reliable CAE Tools
- Vehicles to test
- Better Modal Alignment control processes

We then asked whether these choices were the first, second or third choice. The answer that appeared the most popular 1st choice was Design Guide or Data Base Followed by Attribute Training. The favorite second choice was clearly "Quick and Simple Testing". This further verifies the first part of out hypothesis that all the interactions need to be cataloged and made available. See Figure 83 on the next page.

	1st Choice	2nd Choice	3rd Choice	Total
Design Guides or Data Base	11	4	3	15
Attribute Training	8	2	4	19
Quick & Simple Testing	3	14	3	13
Additional CAE Tools	2	6	6	19
Other	4	0	0	29
Respondents	28	26	16	

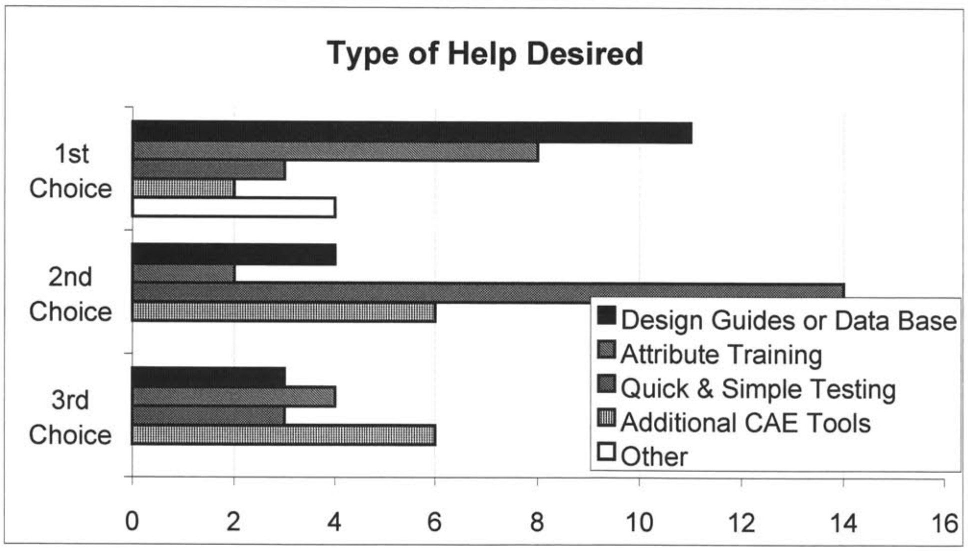


Figure 83 - 1st, 2nd and 3rd Choices of Help Desired in Managing Attributes

How Often

We wanted to know if a design guide or database was available how often people would use it. We asked, "If documentation of all powertrain attributes existed and was easy to use, how often do you think you would use this information? See Figure 84.

Frequency	Qty	Percent
Once per day	5	16 %
2 - 3 times per week	7	23 %
Once per week	10	32 %
Once every 2 - 3 weeks	4	13 %
Once per month	2	6 %
Less than once per month	3	10 %

Figure 84 - Frequency Engineers Would use Design Guide / Database

Over half the people said that they would use this information more frequently than once per week.

What is the Best Tool?

We asked what tool people thought was the best choice in the 2nd questionnaire. But we were concerned about the possibility of people picking a method of showing interactions simply because they were familiar with it. So we asked about people's familiarity with various options that we were considering for display formats, as well as their choice.

In choosing which type of format people liked the Interactions Matrix appeared to be the clear choice, and the P-Diagram as a second choice. The DSM did not make it into the first choice at all. See Figure 85 on the following page.

	1st Choice	2nd Choice	Worst Choice
Design Structure Matrix	0	5	3
Interactive / Web	3	3	3
Cascade Diagram	2	4	4
Interactions Matrix	10	4	1
P-Diagram	8	5	4

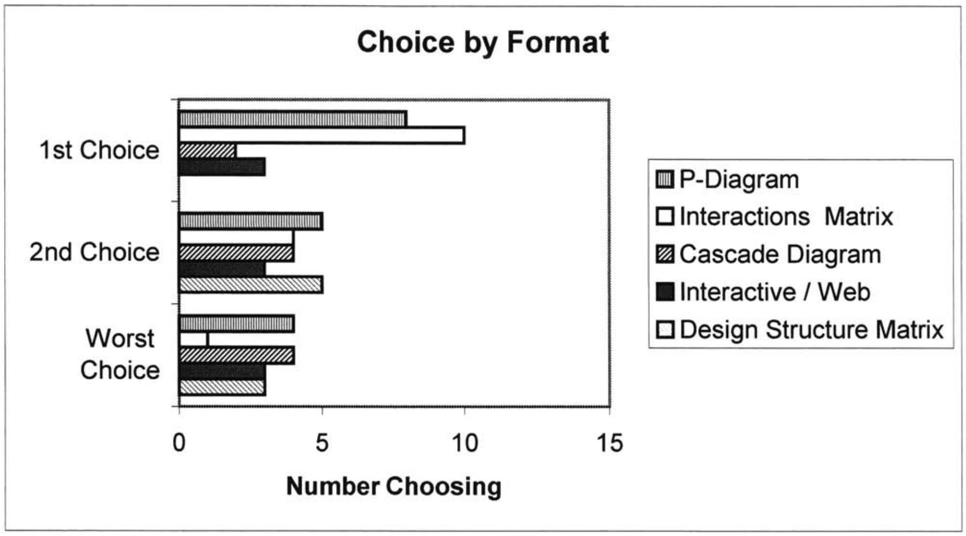


Figure 85 - 1st, 2nd and 3rd Choices for Interactions Presentation Method

We wanted to determine if the respondents were predisposed to a particular type of format based on their familiarity.

It can be seen in the following diagram (Figure 86) that the highest familiarity was with the P-Diagram, which correlated with the first choice.

	DSM	InteractiveWeb	Cascade	InterMatrix	P-Diagram
New to me	14	13	7	4	1
Have seen before	6	7	6	9	1
Am familiar with how to read	7	8	9	9	10
Have created / modified before	4	3	9	7	18
Have taught others how to create / modify	0	0	0	2	2

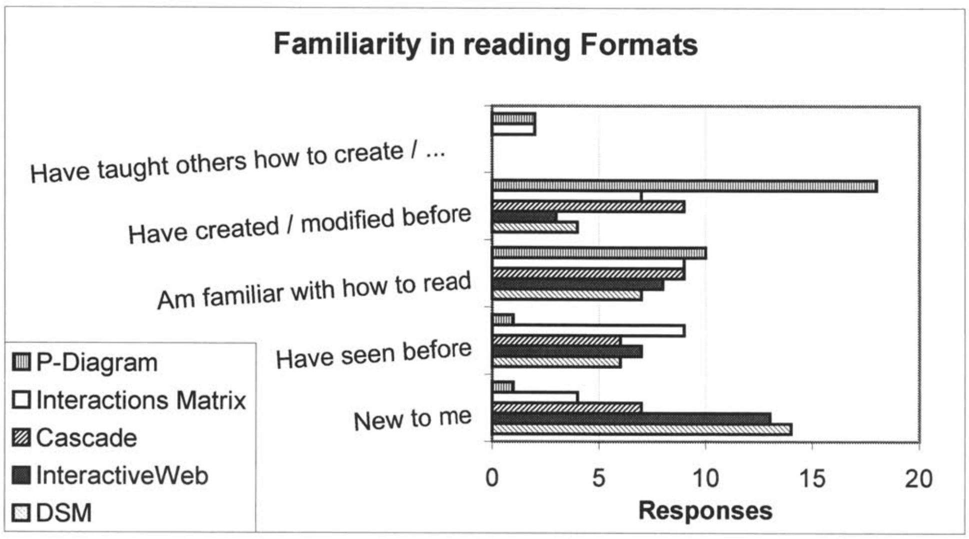


Figure 86 - Respondent's Familiarity with Each Interaction Documentation Method

To test the possibility that people were choosing a format based on familiarity, we built a model of format choice as the output and familiarity as the input. The choice of 1st, 2nd or worst choice was only slightly a function of familiarity with this format.

As can be seen from the chart below a large number of the responses for 1st and 2nd choice were for formats that either the engineers had either created/modified before or were familiar with how to read. Additionally there appeared to be a tendency for the formats that were new to be selected as the worst choice. See Figure 87 on the following page.

	1st Choice	2nd Choice	Worst Choice
New to me	2	2	3
Have seen before	5	1	4
Am familiar with how to read	6	8	3
Have created / modified before	9	10	4
Have taught others how to create / modify	1	0	1

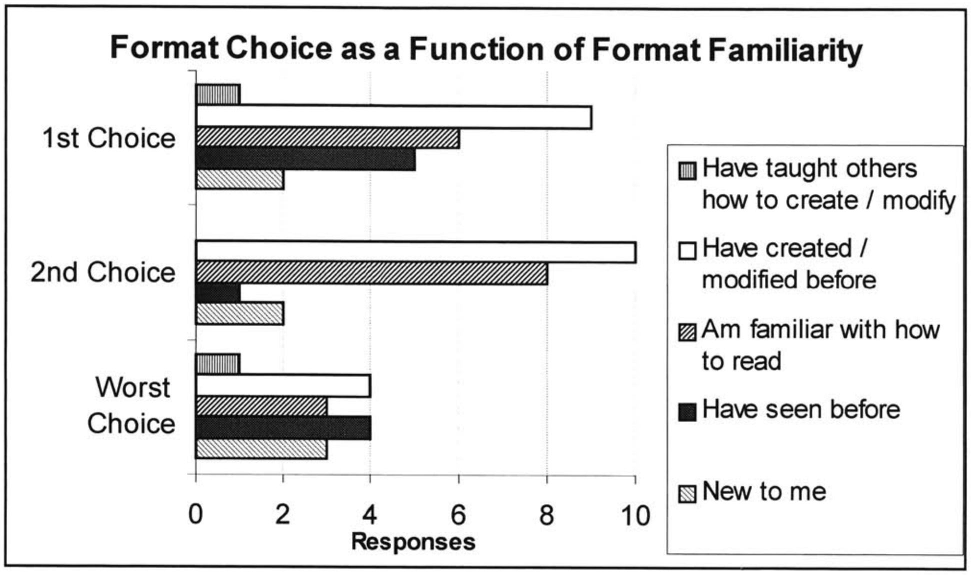


Figure 87 - Format Choice as a Function of Format Familiarity

A simple model predicting the number of individuals choosing format has only a slight interaction based only slightly on familiarity (see Figure 88 on next page):

$$\text{No. Responses} = -4.53 + 7.48 \times \text{Familiarity} - 1.167 \times \text{Familiarity}^2 - 0.14 \times \text{Familiarity} \times \text{Choice}$$

		1	2	5
		1st Choice	2nd Choice	Worst Choice
1	New to me	2	1	1
2	Have seen before	5	5	4
3	Am familiar with how to read	7	7	5
4	Have created / modified before	6	6	4
5	Have taught others how to create / modify	3	2	0

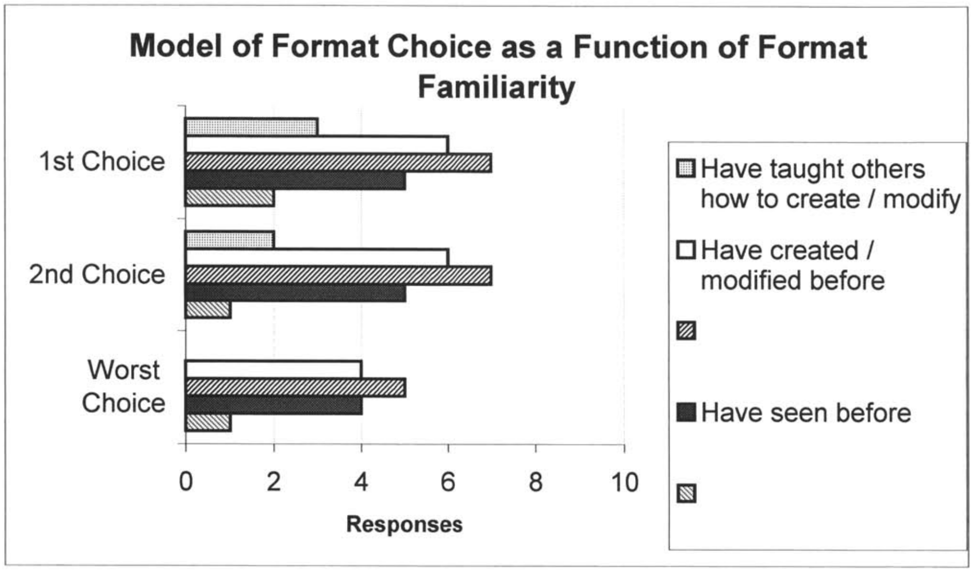


Figure 88 - Equation and Resulting Table of Correlation Between Familiarity and Choice

We concluded from this study that there probably was a significant bias towards picking a format that was familiar; however, this bias was not the only cause for the choices. So we believe the data to have some merit.

With that in mind let's look at some of the reasons people picked something for best, second or worst choice:

Design Structure Matrix

Here are the reasons why people selected the Design Structure Matrix:
Best Choice

2nd Choice
- Helps drive the DVP and identify interactions. Similar to the Red Pepper tool.
- Gives design impacts
- Shows trade offs.
- It helps to put a priority on strong relationships

Worst Choice
- Doesn't exist in enough detail to drive a robust target cascade.

- Have never witnessed this used effectively.
- This helps the least with priorities and recognizing strong relationships.

Interactive Web

Here are the reasons why people selected the Interactive Web Format:
Best Choice

- Can also point you to all of the other ways to view it. Can provide links to more information or technical specialists in the field. Etc.
- Have been useful in the past.
- I find it easy to use web tools etc. and like the point and click feature to find answers. As long as the interface is easy to navigate.

2nd Choice

- Ability to "intelligently" search for answers to specific issues

Worst Choice

- Too complex
- It is redundant to more explicit cascade tools.
- No new information.

Cascade Diagram

Here are the reasons why people selected the Cascade Diagram:
Best Choice

- Easiest to read
- "You can see all the things a particular item affects.

2nd Choice

- It ties to the responsibility of every attribute engineer to cascade to his or her respective PMTs.
- Reveals expectations

Interactions Matrix

Here are the reasons why people selected the Interactions Matrix:
Best Choice

- Shows all interactions
- Clearly identifies where tradeoffs are required.
- Shows what is required to achieve good attribute performance.
- The interactions matrix helps to put a priority on strong relationships.

2nd Choice

- Contains all of the components and noise generators for a particular attribute.
- Easy to read, conveys more information that some of the others, etc.
- Good at capturing all levels of interactions, although, can become complex to manage.

Worst Choice

- Don't know what it is.
- Shows how different systems react to each other, but it is not as easy to understand and read.

P-Diagram

Here are the reasons why people selected the P-Diagram:
Best Choice

- Contains all of the components and noise generators for a particular attribute.
- Analysis of error states
- Most clearly shows the interactions and noise factors.
- Begins with the basics of the system.
- It teaches the rudiments of an attribute, which enables the development of interfaces and FMEA.
- Visually describes boundaries

2nd Choice

- Easy to read, shows inputs/outputs
- You can see all the interactions.
- Key in development of noise factors and DVP reliability matrix
- Contains a lot of useful information on a one page document

Worst Choice

- Least amount of info
- Not enough detail

Training

Since a number of people in the first survey had recommended additional training to help with attribute interactions, we asked some questions about this subject.

Vehicle Shift Quality Training

Online vehicle shift quality training and competency testing is available to all engineers and is required training for powertrain personnel. So this class seems like an appropriate test of the need for and effectiveness of training that was brought up in the 1st questionnaire.

We started out simply by asking, " Have you taken the online Vehicle Shift Quality Training and APEL?" See Figure 89.

	Qty	Percent
Yes	7	21 %
No	26	79 %

Figure 89 - Respondents that has taken Vehicle Shift Quality Training

A majority of the respondents had not taken the training. There is a push to develop similar classes for the other attributes. So we asked those that had taken the training what they found to be most and least useful.

Most useful:

- Gives an overview of the entire attribute and what drives it.
- Understanding Subsystems that Impact Shift Quality

- The training was great, but in practice, we violate many of the "best practices" that are contained within.

Least useful:

- Target Cascade
- APEL and training do not improve understanding of vehicle level interactions for shift quality.

Other Training

We asked, " Are there other powertrain attributes training classes that you would like to have available?" and gave a list to choose from including:

- Drivability
- Fuel Economy
- Performance Feel
- Trailer Tow

The responses included a fairly even distribution of attributes in the list. The respondents penciled-in two additional attributes:

- Durability (1)
- Powertrain NVH (5)

See the chart (Figure 90) below for further details:

Training Desired	Qty	Percent
Performance Feel	23	27 %
Driveability	22	26 %
Fuel Economy	20	23 %
Trailer Tow	15	17 %
Powertrain NVH	5	6 %
Durability	1	1 %

Figure 90 - Additional Powertrain Attribute Training Classed Desired

Who would benefit most?

Knowing the desired classes that people wanted we then asked who they thought might benefit most from taking them. They were allowed to select up to 3 groups from a list of:

- Component Engineers
- Management
- PAT Engineers
- PMT Engineers
- Vehicle Program Engineers

Their choices are tallied in the following chart (see Figure 91 on the following page):

Who Would Benefit Most?	Qty	Percent
PAT Engineers	16	21 %
Management	15	20 %
Vehicle Program Engineers	16	21 %
PMT Engineers	14	18 %
Component Engineers	13	17 %
Program Planning	1	1 %
Software Designers	1	1 %

Figure 91 - People that Would Benefit Most from Additional Attribute Training Classes*

* Note that Program Planning and Software Designers were write-ins.

We were also curious if people would choose their own group as needing the training. Slightly over half of the respondents included themselves in the 3 choices that they were allowed. Yes means that they included themselves. See Figure 92.

	Qty	Percent
Yes	15	54 %
No	13	46 %

Figure 92 - Those that Thought Their Group Would Benefit from Additional Classes

Computer Aided Engineering

There was some interest in increased CAE capability.

"Are there improvements that you think are needed in CAE tools? Please provide the name of the tool and the improvements needed?"

- "Shift Quality CAE tools are currently undergoing several needed enhancements. For example, models which include hydraulic control system of the transmission, as well as strategy and mechanical systems ... to show overall system interactions."
- Yes.
- ADAMS shift quality: need to integrate VDM & HCS models w/ ADAMS shift quality for a fully calibrate-able system.
- From the vehicle program engineer side, the CVSP model does not seem accurate or very good. We should be able to make better estimates or not put so much emphasis on that number.
- No specific changes. Would like to see better driveline modeling tools.
- Yes - all CAE tools need better correlation to real world customer usage
- Yes, CVSP accuracy in the Performance & FE areas would help.
- The largest improvement needed is time and resources to correlate the models. This is not always supported well within the FPDS timing and the manpower to support correlation is often not available.

"Are there additional tools needed? Please outline what the tool needs to do."

- "It would be nice to have a CAE tool which could predict the audible aspects of Shift Quality."
- I think Ford should develop a tool that would allow a virtual drive of the vehicle, similar to a video game or driving simulator. Proposed changes and/or features could be compared immediately rather than demonstrated in a graph or matrix presented in a meeting. Management needs to see and feel the changes faster!!!
- Need better design guides for shift quality.
- Give a more accurate fuel economy and 0-60-time estimate. Based on the hundred years of history, we should be able to figure something out.
- Yes
- It would be helpful to have an improved hydraulic control system-modeling environment.

"Would you see any value in combining and expanding the current modeling capabilities to look at all the attributes at once?" See Figure 93.

	Qty	Percent
Yes	6	86 %
No	1	14 %

Figure 93 - Respondents that Would like to see Current Modeling Capabilities Expanded

What don't you want to lose if the CAE tools get revised?
- I want to keep the ability to run each attribute, where appropriate, with simpler, single-attribute CAE models."
- I would be reluctant to loose CVSP.

Emphasis

There appeared to be a significant gap in the customer importance and the emphasis that the company places on a couple of groups of vehicle attributes, so we did further analysis of the data. We were concerned particularly about discrepancies in the following areas:
- Engine and Transmission Performance
- Ride, Handling and Braking

Based on the averages, Engine and Transmission Performance showed that the company was placing 4% too little engineering effort on it relative to the level of importance to customers. Meanwhile 6% average overemphasis was being placed on Ride, Handling and Braking relative to the importance seen by customers.

We did a two-tailed t-test on the data and found there was an 85% probability that there was indeed a difference in means for Engine and Transmission Performance. So it is highly likely that the company is placing an under-emphasis on these attributes. The same test showed that Ride, Handling and Braking conclusively had a difference between the emphasis that customers place and the engineering organization places on these attributes. The company appears to be placing a higher emphasis on Ride, Handling and Braking than the customer thinks is warranted.

Based on this finding we highly recommend that a portion of the engineering emphasis currently being placed on Ride, Handling and Braking be refocused on improving Engine and Transmission Performance. This shift in emphasis should improve the customer overall perception of the company's vehicles.

The following chart (Figure 94) juxtaposes in the value a customer places on each of the attribute groupings against the emphasis that the company places on these attribute groupings. The delta column is the difference between the two averages. The T-Test column indicates the probability (from 0 to 1) that the 2 data sets have the same mean. Based on this test; Ride, Handling and Braking and the Sound system conclusively have differences in the mean, and the Engine and Transmission Performance has an 85% probability of having a different mean.

	Customer Importance			Engrg. Emphasis				
	Avg	**StDev**	**Count**	**Avg**	**StDev**	**Count**	**Delta**	**T-Test**
Engine and Transmission Performance	23%	4%	8	19%	15%	33	4%	**0.15**
Vehicle Styling/Exterior	18%	2%	8	18%	9%	33	0%	0.82
Ride, Handling and Braking	13%	3%	8	19%	9%	33	-6%	**0.00**
Cockpit and Instrument Panel	12%	2%	8	10%	5%	33	1%	0.30
Seats	10%	3%	8	9%	3%	33	1%	0.35
Comfort and Convenience	10%	3%	8	11%	6%	33	-2%	0.24
Sound System	8%	1%	8	7%	3%	33	2%	0.01
Heating, Ventilation and Cooling (HVAC)	8%	1%	8	8%	4%	33	0%	0.58

Figure 94 - Customer Value of Various Attribute Groupings vs. Engineering Emphasis.

Analysis of Needs

Looking at all of the data from the questionnaires we couldn't make any clear decisions on the best format based on people's comments. So we attempted to glean the desires from the comments. We came to 3 basic needs:

1. Documenting all the interactions
2. Understanding the significance of the attribute
3. Ease of use of the documentation

So we put a chart together showing the various aspects of each of these formats in Figure 95 (next page).

Desires	Cascade Diagram			Design Structure Matrix			Interactive / Web			P-Diagram			Interactions Matrix		
	Yes	No	Add	Yes	No	Add	Yes	No	Add	Yes	No	Add	Yes	No	Add
Interactions Shown															
All interactions on 1 chart		X		X				X			X			X	
Attribute to Attirbute Interactions	X			X			X			X				X	
Attribute to Design Parameter Interactions		X		X			X			X			X		
Design Parameter to Design Parameter Interactions		X		X			X			X				X	
Attribute Significance															
Probability of interaction is significant			X			X			X			X			X
How to detect interaction			X			X			X			X			X
How to measure interaction level			X			X			X			X			X
Quick analysis Methods			X			X			X			X			X
Provides correlated modeling accuracy on interaction level and magnitude		X			X			X			X			X	
Provide detailed explanation of interaction including magnitude and direction			X			X			X			X			X
Ease of Use															
Web based for easy to access	X			X			X			X			X		
Map-like navigation	X			X				X			X		X		
Includes search tool			X			X			X			X			X
Totals															
	3	4	6	6	1	6	4	3	6	4	3	6	3	4	6

Figure 95 - Analysis of Needs

In documenting the interactions, there was a great diversity in the ability to capture all the interactions. The poorest were the Cascade Diagram and the Interactions Matrix. These diagrams simply are not set up to capture a lot of the interactions that we found. The cascade diagram is useful only in breaking down high level attributes to low level attributes. The Interactions matrix only covered the Attribute to Design Parameters, which will be discussed further in the DSM findings. Both the P-Diagram and the Interactive/Web format can capture all of the interactions but do so on many pages. So the DSM was the clear winner in this category.

In the category of understanding attributes significance, all of the formats were fairly equal. None of them provide any real understanding in the chart. It is in this area that engineers really wanted help. This is why they want technical specialists. We are particularly interested in providing this kind of in-depth knowledge. We found two methods of better providing this:

1. Provide references to documents in a book.
2. Provide active links to more information in a computer-based document.

References to documents in a book are shown well by a typical diagnosis or troubleshooting chart. The example shown in Figure 96 refers the reader to a separate page in the document based on the information needed.

Active links were used in Form vs. Function Diagram in Figures 25 and 26. These active links in a spreadsheet are an excellent method of providing the information engineers need in regards to attribute interactions.

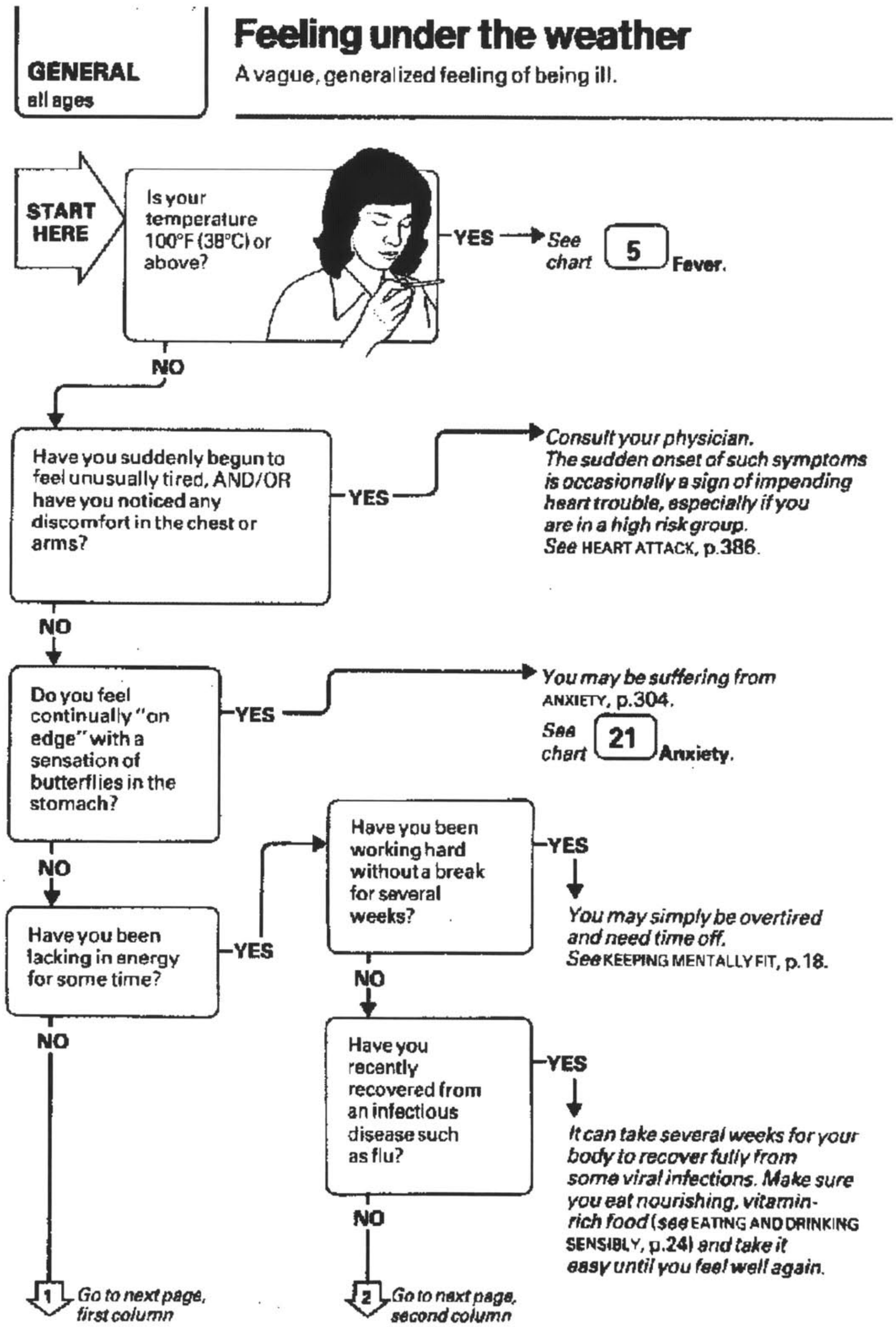


Figure 96 - Example of Diagnosis Chart with References to Added Information[16]

[16] The American Medical Association, edited by Kunz, Jeffrey R. M. and Finkel, Asher J., "Family Medical Guide", p70, 1987

Inter-Company CAE Tools Comparison

We compared CAE tools between sister organizations within Ford Motor Company to determine if some of the companies are doing things better than others. We surveyed powertrain attribute technical specialists in the powertrain area of:

- Ford
- Jaguar/Land Rover
- Mazda
- Volvo

We asked 5 questions pertaining to each of the 5 powertrain attributes we were investigating. The questions were:

1. Do you have the appropriate CAE tools to aid in program powertrain selection and attributes development? Do you have CAE tools available to address all the powertrain attributes listed above?
2. Are you satisfied with the level of accuracy? Why?
3. Are they integrated with other powertrain attributes or other vehicle attributes (i.e., vehicle dynamics, NVH, etc.)?
4. Do you use other process tools (i.e., P Diagrams, Cascade Diagrams, Design Structure Matrices, etc.) to help facilitate the communication of potential attribute/design parameter interactions to minimize unwanted emergent properties (minimizing unplanned rework)?
5. Do you have process tools that address cross attribute integration (i.e., chassis bushings that affect both shift quality and vehicle dynamics)?

The high level answers to these questions are shown in Figure 97 on the following page. It can be seen that there are varying levels of capabilities between the companies. Jaguar appears to have a good feel for attribute interactions and is worth studying. Ford and Volvo appear to rely more on in-house tools while Mazda is using more commercially available tools such as MatLab and EASY5.

QUESTIONS	A. Do you have the appropriate CAE tools to aid in program powertrain selection and attributes development? Do you have CAE tools available to address all the powertrain attributes listed above?				B. Are you satisfied with the level of accuracy? Why?				C. Are they integrated with other powertrain attributes or other vehicle attributes (i.e., vehicle dynamics, NVH, etc.)?				D. Do you use other process tools (i.e., P Diagrams, Cascade Diagrams, Design Structure Matrices, etc.) to help facilitate the communication of potential attribute/design parameter interactions to minimize unwanted emergent properties (minimizing unplanned rework)?				E. Do you have process tools that address cross attribute integration (i.e., chassis bushings that affect both shift quality and vehicle dynamics)?							
Attributes	**Ford**	**Jaguar**	**Mazda**	**Volvo**	**Ford**	**Jaguar**	**Mazda**	**Volvo**	**Ford**	**Jaguar**	**Mazda**	**Volvo**	**Ford**	**Jaguar**	**Mazda**	**Volvo**	**Ford**	**Jaguar**	**Mazda**	**Volvo**	Yes	Some	No	
1) **Performance Feel** (WOT Performance and the customer's perception of vehicle performance)	Yes	Yes	Yes	No	No	Yes	No		Yes	Some	No		No	Yes	No		Yes	Yes	No		8	1	7	4
2) **Driveability** (Acceleration Smoothness, deceleration feel)	Some		No	No	No		No		Yes	Yes	No		No	Yes	No		No		No		3	1	9	7
3) **Shift Quality** (Shift Feel, Shift Scheduling and Shift Delays and Durations) or Manual Shiftability	Yes		Yes	No	No		No		Yes	Yes	No		Yes	Yes	No		Yes		No		7	0	6	7
4) **Trailer Tow** (Determining optimum trailer weight, Gradeability in loaded conditions)	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Some	No		Yes	Yes	No		Yes	Yes	No		12	1	4	3
5) **Fuel Economy** (M-H and City/Suburban fuel economy)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Some	No	Yes	Yes	Yes	No		Yes	Yes	No		14	1	3	2
Yes	4	3	4	2	1	3	2	2	5	2	0	1	3	5	0	0	4	3	0	0				
Some	1	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0				
No	0	0	1	3	4	0	3	0	0	0	5	0	2	0	5	0	1	0	5	0				
	0	2	0	0	0	2	0	3	0	0	0	4	0	0	0	5	0	2	0	5				

Summary	**Ford**	**Jaguar**	**Mazda**	**Volvo**	**Total**
Yes	17	16	6	5	44
Some	1	3	0	0	4
No	7	0	19	3	29
	0	6	0	17	23

Figure 97 - Inter-Company CAE Tool Capability Analysis

Summary

In this chapter we disproved the second hypothesis (i.e. The DSM format, may not be the ideal method of displaying attributes for engineers needing to understand them.) We initially tried via a series of surveys to understand what engineers really need in terms of better understanding attributes and interactions between them. We found that the respondents tended to prefer a format that was familiar to them. Frustrated with this we did a comparison of the different formats based on what the engineers said they really needed from the initial open-ended surveys. Our analysis showed that the DSM format was overall the most useful as a base format.

The DSM and all of the potential formats shown needed some additional support to be truly useful to engineers. We showed a couple of good examples of how this additional information could be referenced either via web links or page references. This documentation is expected to be used at least once per week by vast majority of the respondents.

The surveys also indicated a high amount of rework actually happening in the development process today. This data on rework is excellent input to systems dynamics models like that done by Tony Zambito.[17]

Engineers also desire additional powertrain attributes training similar to the online Vehicle Shift Quality training currently available. These classes are seen as useful for both the direct users, and the folks that they deal with to help them better understand attributes and interactions. Despite the desire for additional classes, very few had taken the one currently available. We need to find a way to increase the number of engineers who will take this class.

As indicated in previous chapters, the surveys also indicated that engineering emphasis is being directed disproportionately at vehicle dynamics attributes rather than at powertrain attributes in comparison to customer related importance. The same high-level focus that significantly improved vehicle dynamics attributes needs to be directed towards powertrain attributes.

The improvement of CAE tools is desired in specific areas. The improvement of these tools to look at all attributes at once is not desired if it is at the expense of ease of use.

The comparisons between companies showed that Jaguar appears to have a particularly good understanding of attributes and interactions. It is worthwhile looking at the processes that they use further to determine if methods can be transferred.

Now that we have proved the first hypothesis and disproved the 2^{nd} hypothesis, let's wrap up our findings and conclusions in Chapter 7.

[17] Zambito, Antonino Paolo, Using the Design Structure Matrix to Streamline Automotive hood System Development, Masters Thesis for Systems Design and Management Degree at MIT, 2000.

Chapter 7 - Findings and Recommendations

Introduction

In this chapter we will review what we have discovered and present recommendations for next steps. The chart below (Figure 98) shows a high level summary of the recommendations. The body of this chapter covers these findings in more detail.

Finding	Recommendation
Powertrain attributes are highest on customer Pareto. Powertrain attributes are 3rd on Ford process Pareto.	Adjust thinking and organizational structure to better align with customer wants.
The organizational structure does not give powertrain attributes enough visibility.	Restructure organization to give powertrain attributes a separate structure
CAE does not support attributes or their interactions well.	Determine all areas of weakness by marking the effectiveness of each tool on mark on the DSM. Define coping strategies for each area where tools are weak. Coping strategies may include more CAE tool coverage of attribute interactions, or other means.
Jaguar appears to be more advanced in handling of attribute interactions	Investigate what tools Jaguar is using to understand attribute interactions.
Engineers need more training on attributes and the interactions between them	Develop more web-based courses like the Vehicle Shift Quality course.
Powertrain Optimization is needed to improve the powertrain attributes	Ensure this is a deliverable for FPDS by <SC> by the CVSP group. Develop a Torque Converter Design Optimization tool to support designs coming from Powertrain Optimization.
A DSM showing interactions between components would be useful for D&R engineers	The PMT/PAT friendly DSM should be squared to determine how design parameters are interrelated via the attribute interactions.
All formats looked at have limitations, when it comes to detailed information, such as likelihood, direction and strength of interactions; and how to handle the interaction from a development perspective.	A DSM with web links would be a powerful tool to help PATs and D&R engineers to better manage attributes.
Attributes are strongly coupled to each other, making design and attribute management difficult.	Create a DSM for all vehicles attributes.
Attributes based DSM cannot be compared to program timing due to numerous tasks needed to develop each attribute	Create a task based DSM for all vehicles attributes.
The DSM portrays attributes and attribute interactions clearly. It also shows attributes and design parameter interactions.	The DSM is the format of choice for showing attribute interactions.

Figure 98 - Summary of Findings and Recommendations

Attribute Priorities

Powertrain attributes are regarded more highly by customers than Ford places emphasis on them. Richard Parry-Jones was a strong leader for Vehicle Dynamics attributes and was able to significantly improve the company's capabilities in this area. We need this kind of dedication to improving powertrain attributes.

Organizational Recommendations

We recommend that vehicle powertrain attributes get addressed by a single department for each vehicle cluster within the core vehicle engineering organizations. This is the way Vehicle Dynamics, Vehicle NVH and Vehicle Package are handled. The resulting organizational structure is shown in Figure 99. Within this revised organization it is recommended to separate performance feel and fuel economy into two distinct groups. This is to prevent issues with either performance feel or fuel economy shadowing issues in the other areas that need to be resolved concurrently.

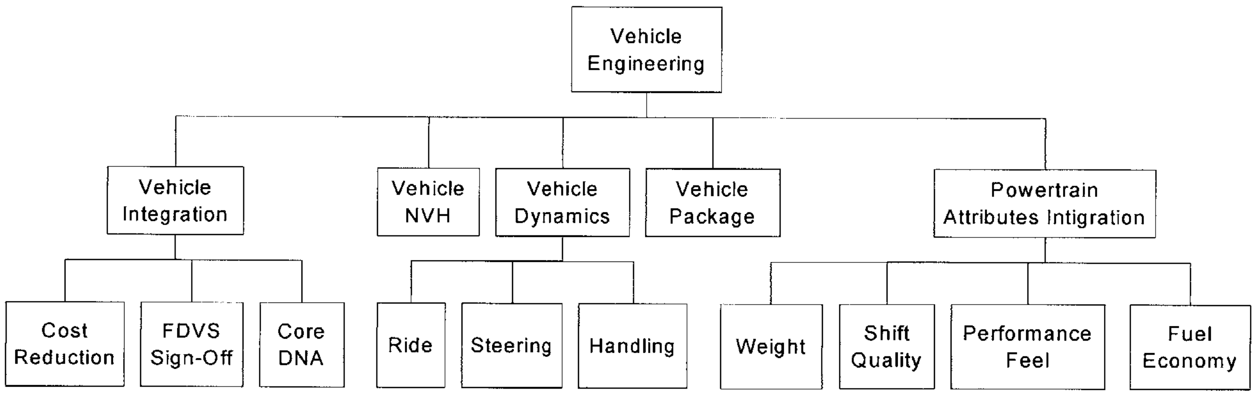


Figure 99 - Proposed Organizational Change

This proposed organization should gain some of the efficiencies; much needed focus and attention to actually start incorporating prior programs lessons learned. With the higher management in place, a Tech Club can be created to support process improvements and best practices and facilitate people development. Within the organization, a Powertrain Attributes Integration Specialist or group should exist in order to balance the attributes with customer wants (Performance, Driving Smoothness) and corporate needs (Fuel Economy). This proposal will give equal weighting to Powertrain Attributes as Vehicle Dynamics, Vehicle Package or Vehicle NVH.

Powertrain Calibration

We recommend the movement of Powertrain Calibration from Core and Advanced Powertrain Engineering (CAPE) to Powertrain Systems Engineering (PTSE) within the Product Clusters (i.e., Trucks, SUV, Sport Car or Family Car). This will remove a layer of disconnect or distance to the program teams. With calibration in the CAPE organization, their priorities don't always align directly with program priorities. They have their own deliverables cascaded down to them, which may put program timing in jeopardy, like material cost reduction actions. Moving calibration closer to the vehicle team will help bring the Powertrain PATs closer to calibration and help eliminate issues like those seen on the Electronic Throttle Control.

Computer Aided Engineering

The CAE tools used to model and develop attributes do not cover attribute interactions very well (less than 29% coverage). Many of the interactions seen in the DSM have happened on numerous programs. The high level of rework that engineers report reflects this. Improvements in the CAE tools or additional tools are needed ensure that interactions are not overlooked. Additional coping mechanisms are needed since developing CAE tools is not always quick. Transfer of knowledge about difficulties with interactions needs to be rapidly passed from program to program. A DSM showing all the interactions is a good start to at least raise awareness. Tech Clubs would also help in this area.

Capability Comparison

Jaguar appears to be more advanced in the handling of attribute interactions based on inter-company surveys of attribute experts. Understanding how Jaguar is able to handle interactions could be beneficial to Ford. It may be possible that they have tools or techniques that can be used at Ford to help manage attributes better. A follow-up on this survey is needed.

Training

Engineering surveys have identified that additional training on powertrain attributes would be helpful. This training would not only be useful for those developing the attributes, but also for those they interface with. Since there is very little time to take formal classes, web-based classes are ideal. The vehicle shift quality class is an excellent example of the added classes needed. The recommended classes are Performance Feel, Driveability, Fuel Economy, Trailer Tow and Powertrain NVH.

Future Research

Powertrain Optimization / Torque Converter Design Optimization

The Powertrain Optimization CAE Model is a tool for determining the proper axle, engine torque target curve and transmission torque converter performance curves that best achieves the desired Performance Feel sub-attributes and fuel economy. Results of some program optimizations have resulted in significant fuel economy benefits without trading off performance, and in some cases, results have shown benefits to both performance and fuel economy. However, torque converter design process is a highly iterative process that usually requires at least a year of design and much longer for building a demonstration prototype, thus making the proposal difficult to sell. We recommend the development of a transmission torque converter optimization tool as a technical enabler for achieving the desired level of powertrain attribute performance. This way if a vehicle program has late changes an optimized torque converter can be provided quickly.

Further DSM Work

There are two recommendations for further DSM work:

Communication Improvement in Current Powertrain Attributes DSM

To better facilitate communication at the working level, we need to determine the design parameter to design parameter interactions without the link to the attributes. Currently, the DSM is set up so that the component engineer needs to speak to the attribute engineer to determine all the other components they may affect if he/she underachieves their target. What we are suggesting is determining where components affect other components directly. This can be efficiently done using a DSM and matrix math. With the DSM organized in the original Attributes (in quadrant 1, Figure 48) and Design Parameters (in quadrant 4, Figure 50) one needs to make all marks on the DSM as 1s and all blanks as zeros and then square the matrix. After squaring, the marks in the design parameters section will be the links through the attributes to the affected design parameters. At this point, the DSM can be partitioned and rearranged to reflect the attribute development process to facilitate more efficient communication. This can be coupled with our next recommendation (Interface Improvement to DSM) to explain the interaction and information exchange that needs to take place.

Interface Improvement to DSM

We recommend that future DSMs should include hyperlinks similar to the Vehicle Dynamics Form vs. Function Interactions Matrix (Figures 25 & 26). Our concern is showing our large matrix and potential users would be intimidated to the point of them not using it. If the DSM were on the Internet and hyperlinked to all the necessary information (design guides, DNA target charts, CAE tools that model the interaction, etc.), its high level of effectiveness would help ensure usage.

The partitioned DSM can also be uploaded and the links for the interactions above the diagonal can lead to recommendations for minimizing the potential for rework (plans for success). It can also include examples of the interaction, how it was handled and lessons learned.

Entire Vehicle Attribute DSM (Vehicle Dynamics, NVH, Package & Powertrain)

On a much larger scale, we are recommending the development of an entire vehicle attributes DSM. It needs to include the vehicle attributes that are known to cause significant redesigns such as Vehicle NVH, Package, Vehicle Dynamics and Powertrain attributes. Since all the attributes are being developed concurrently, a Powertrain Attributes DSM cannot capture the iterations happening in the development of these other attributes. A complete vehicle attributes/design parameter DSM will provide an improved understanding and more accurate view of all potential iterations. It will communicate to the entire vehicle engineering/attributes community what the interactions, more importantly the feedback loops to pay very close attention to, and begin to plan or develop a methodology to work around minimizing rework.

Furthermore this complete vehicle attributes DSM needs to be task based. This is because several tasks may be required to develop a single attribute. This will allow the sequence of the tasks to be rearranged to most efficiently develop a vehicle.

Conclusion on Thesis Hypotheses

A complete study of all powertrain attribute interactions is needed to prevent needless probing for missed interactions. The documented interactions that forced feedback loops are important pieces of information to provide upfront to future model program teams. Knowledge of key commodities and subsystems and their importance to multiple and cross-vehicle attributes should play an important role in program assumptions, sub-system architecture and design to minimize design iterations and rework.

The DSM format, while being exceptionally good at capturing all the interactions is also a viable tool for documenting systems interactions. While it is an imposing document to look at, it importantly captures all the interactions. Additionally this format can be rearranged to show the areas of potential iteration. The DSM format like all engineering documentation methods lacks the detailed information that is needed by engineers, but can easily be strengthened by adding web links to each of the marks in the matrix.

Summary

Powertrain attributes are the most important of all attributes to the customer, but are not considered as important by Ford. Compounding this, the organizational structure does not give powertrain attributes enough visibility. We have provided recommendations to address these issues through a proposed new organizational structure providing increased visibility and process improvements (via the Tech Club) to powertrain attributes.

Attributes are strongly coupled to each other, making design and attribute management difficult. CAE does not support our DSM interactions well. Engineers need more training on attributes. We have recommended both a Powertrain Attributes Integration PAT and the development of a total vehicle attributes/design parameter DSM to address the rework associated with the integration of powertrain attributes and total vehicle attributes development and integration. Additional findings from the total vehicle attributes DSM should feed into training material. The Tech Club mentioned above, through the technical maturity model for a given attribute will also dictate functional training.

The DSM portrays attributes and attribute interactions clearly. It also shows attributes and design parameter interactions, but lack the detail information our engineers require. All other system management methods investigated are deficient to DSM, especially in the area of determining design iterations and rework. We recommend the development of a DSM with web links to help PATs and D&R engineers better manage attributes. This would be a very powerful attributes management tool for all product development engineering (Attributes and Design & Release) and project management personnel.

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Daleiden, Steven A., Chassis Flexibility: Assessing Architectural Differences and Their Effect on managing Derivative Product Development, 2000, MIT Mechanical Engineering Master of Science degree thesis.

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Appendices

Appendix A – Definitions

APEL	Assessment of Prior Experience and Learning – A test to determine an employee's skill in an area gained either through learning on the job or from instruction/classes.
Attribute	An inherent characteristic or quality ascribed to a particular function of a vehicle. Those characteristics by which we judge a vehicle.
Boom	A noise
Brand DNA	Key attributes that people identify with a brand
CAPE	Core and Advanced Powertrain Engineering
Comparator	A vehicle not usually a direct competitor, but has certain desired attributes (BIC attributes) that the program team wants to emulate
CPMT	Chunk Program Module Team – A team responsible for delivering a subsystem that reports to a PMT.
D&R	Design and Release
Deliverable	A task that needs to be completed or information than must be available at a given gateway
DSM	Design Structure Matrix
FPDS	Ford Product Development System
FRL	Ford Research Lab
GQRS	Global Quality Reporting System
MAFE	Model Average Fuel Economy
NAE	North American Engineering
NAPD	North American Product Development
NVH	Noise, Vibration and Harshness
P&E	Performance and Economy
P/T	Powertrain
PALS	Program Attribute Leadership Strategy – The process of determining, which aspects of a vehicle to provide particularly exceptional attributes to win strong consumer acceptance.
PAT	Program Attribute Team
PCM	Powertrain Control Module
PDL	Program Direction Letter
Performance	Relates to basic powertrain power (horsepower/torque) and gearing.

Performance Feel	The customer perception of performance that includes the effects of vehicle acceleration, shift character, shift scheduling, sound quality and acceleration control characteristics. These vehicle characteristics should be considered during the following evaluations.
PMT	Program Module Team
PST	Program Steering Team
PT or P/T	Powertrain
PTSE	Powertrain Systems Engineering – An organization responsible for designing and releasing the various components needed to install a powertrain into a vehicle.
QFD	Quality Function Deployment
RVT	Research & Vehicle Technology
SDS	System Design Specification
SUV	Sport Utility Vehicle
TGW	Things Gone Wrong
VDS	Vehicle Design Specification
VEM	Vehicle Engineering Manager
VI	Vehicle Integration
VOC	Voice of Customer

Appendix B – Questionnaires

The following pages show the 3 questionnaires used:

- **Questionnaire 1** – Contains a Hypothetical question as a preface. This survey consists of 4 open ended questions.
- **Questionnaire 2** – Contains a synopsis of what was learned on previous survey. Asks 3 multi-part questions.
- **Questionnaire 3** – Two questionnaires were used. A shorter one was used for management, which contained 8 questions. The longer questionnaire for non-management personnel consisted of 15 questions.

Figures in Appendix B

Questionnaire

Hypothetical Question
Please read the hypothetical question below and then answer the survey questions below the box.

You have been asked to attend the vehicle change control meeting as the vehicle engineering powertrain attributes representative. At the meeting, an engineer brings in a change to soften the chassis bushings to improve NVH. The head of change control asks you whether powertrain attributes are affected. You should answer:

a. **Yes, powertrain attributes are affected**
   The change control leader may follow-up with questions like:
   - What powertrain attributes might be affected?
   - What analysis/testing is needed to determine whether other actions are needed to accommodate this change?
   - What other actions are likely to be needed?
   - What analysis or testing needs to be done to ensure that all of the changes give the expected results?

b. **No, powertrain attributes are not affected**
   - (Not the correct answer.)

c. **I'll need to check**
   - How will you go about this?
   - How long will it take to investigate?
   - How confident are you that you will have the correct answers?

Our questions
1. What kind of help would you like available in regards to help in understanding systems/attribute interactions?

2. What is the most efficient way to provide this help?

3. How often do you think you would use this systems management tool or information?

4. On a 1 to 5 scale, how significant of an issue do you think effective attribute management is at Ford? (1 = Not significant, 3 = Average, 5 = One of the largest issues). Why?

Please return to Dan Rinkevich Outlook: DRINKEVI by Noon Friday Sept 12, 2003

Figure 100 - Questionnaire 1

Results from Last Survey
Thank you for your responses to the last questionnaire. This chart shows the types of help people want on powertrain interactions:

Recommendation	Percent
Tech Spec / Experienced Guidance	63%
Design Guide/Data Base	44%
Training	19%
Improved Testing / Processes	19%
CAE Tools	13%

Clearly help from knowledgeable people is the preferred method of assistance desired. Since the scope of this project does not include adding additional resources we won't cover it in our questions. We will pass this along to management.

Testing was highlighted as an important topic. However, we are currently working to provide more of an upfront attribute engineering tool/model.

Additional Questions
Based on these results I have some follow on questions. We really need your input to these questions to make this project successful:

1. In regards to a design guide /data base please take a look at these various formats:

Type	Example	Comments
P-Diagram	"P-Diagram P131 Trailer Tow Attribute	P-Diagram for Trailer Tow. Shows inputs, outputs, noise factors, control factors and error states.
Cascade Diagram	Microsoft Word Document	Cascade diagram from attribute to sub-attributes and their definitions. This one is for shift quality.
Design Structure Matrix	DSM.pps	A matrix showing interactions between all attributes, sub-attributes, and design parameters.
Interactive / Web	"Powertrain Brand Attributes Interaction	Interactive model showing interactions Note: This particular model has limited active links and no web links at this point.
Interactions Matrix	Vehicle_Shift_Quality_S01L02_sq_Interact	High level Form vs. Function relationship matrix

   a. What type of format do you prefer?

Figure 101 - Questionnaire 2 (Page 1)

b. Are there elements of some of these that you would combine?

2. In regards to training:

   a. Have you taken the online Vehicle Shift Quality Training and APEL?

   b. If so, was this training useful?

   c. Would you recommend additional powertrain attribute classes?

   d. Is there some other training that you would like to have? (i.e. Complex systems management)

3. In regards to CAE tools, we are interested in plugging the holes in current tools/ methodologies.

   a. What would you like to see improved?

   b. What additional CAE tools do we need?

   c. Would you see any value in integrating the current models to look at all the attributes at once?

Please return this to me by noon on Wednedsay (10/1). After a bit of time I will give you some feedback. Thank you in advance for your help.

Figure 102 - Questionnaire 2 (Page 2)

Survey on Powertrain Attribute Interactions

This information will be used to help the company understand how to handle powertrain interactions. All information will be held in strict confidence. No personal identities will be revealed with any information reported out. We would appreciate your candid comments.

Name

Email address

Phone number

Can we contact you to clarify any responses?
- Yes
- No

How would you best describe your role?

Engineer
Tech Spec
Supervisor

- Brand / Attribute Specialist
- PAT Leader
- PMT Leader
- Other

What is your organizational level?

1. How much emphasis do you think the company places on each of the following categories to maximize customer satisfaction? (Please provide answers, which total to 100%.)
Note: These are the categories that J. D. Powers uses to correllate to customer satisfaction.

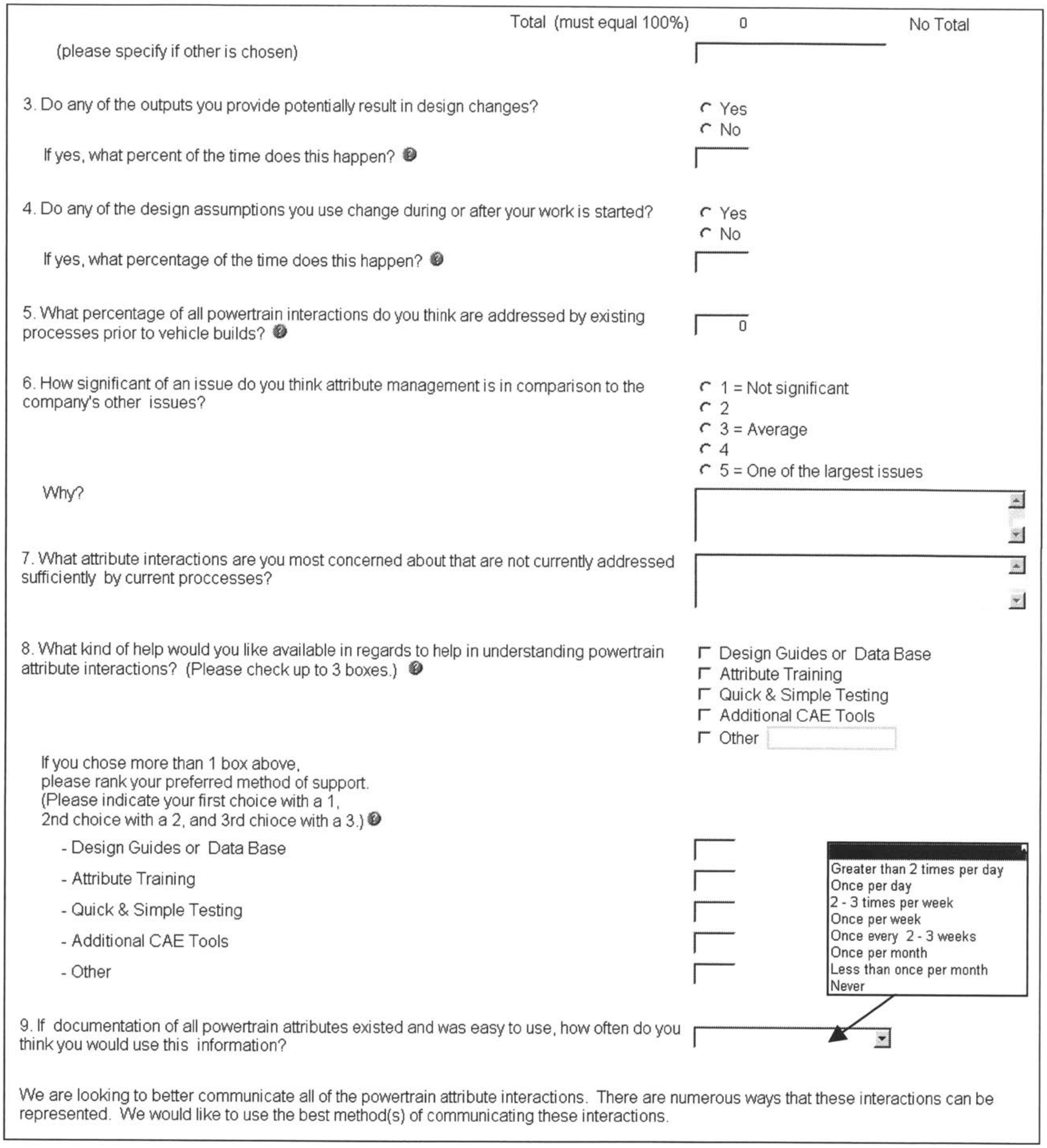
- Engine and Transmission Performance	0
- Cockpit and Instrument Panel	0
- Ride, Handling and Braking	0
- Heating, Ventilation and Cooling (HVAC)	0
- Comfort and Convienence	0
- Sound System	0
- Seats	0
- Vehicle Styling/Exterior	0
Total	0

Are there other categories that J. D. Power should include in their customer satisfaction surveys?

2. When considering a potential change what methods do you employ to ensure there are no unexpected interactions? What percentage of time would you use each of these: (Please provide answers which total to 100%.)

		How effective do you find each method to be?
a. No particular process	0	0
b. Discuss with co-workers	0	0
c. Use modelling to understand	0	0
d. Look on web	0	0
e. Review books / technical papers	0	0
f. Ask boss	0	0
g. Other ____________	0	0

Figure 103 - Questionnaire 3 – Non-Management Page 1



Total (must equal 100%) 0 No Total

(please specify if other is chosen)

3. Do any of the outputs you provide potentially result in design changes?

- Yes
- No

If yes, what percent of the time does this happen?

4. Do any of the design assumptions you use change during or after your work is started?

- Yes
- No

If yes, what percentage of the time does this happen?

5. What percentage of all powertrain interactions do you think are addressed by existing processes prior to vehicle builds? 0

6. How significant of an issue do you think attribute management is in comparison to the company's other issues?

- 1 = Not significant
- 2
- 3 = Average
- 4
- 5 = One of the largest issues

Why?

7. What attribute interactions are you most concerned about that are not currently addressed sufficiently by current proccesses?

8. What kind of help would you like available in regards to help in understanding powertrain attribute interactions? (Please check up to 3 boxes.)

- Design Guides or Data Base
- Attribute Training
- Quick & Simple Testing
- Additional CAE Tools
- Other

If you chose more than 1 box above,
please rank your preferred method of support.
(Please indicate your first choice with a 1,
2nd choice with a 2, and 3rd chioce with a 3.)

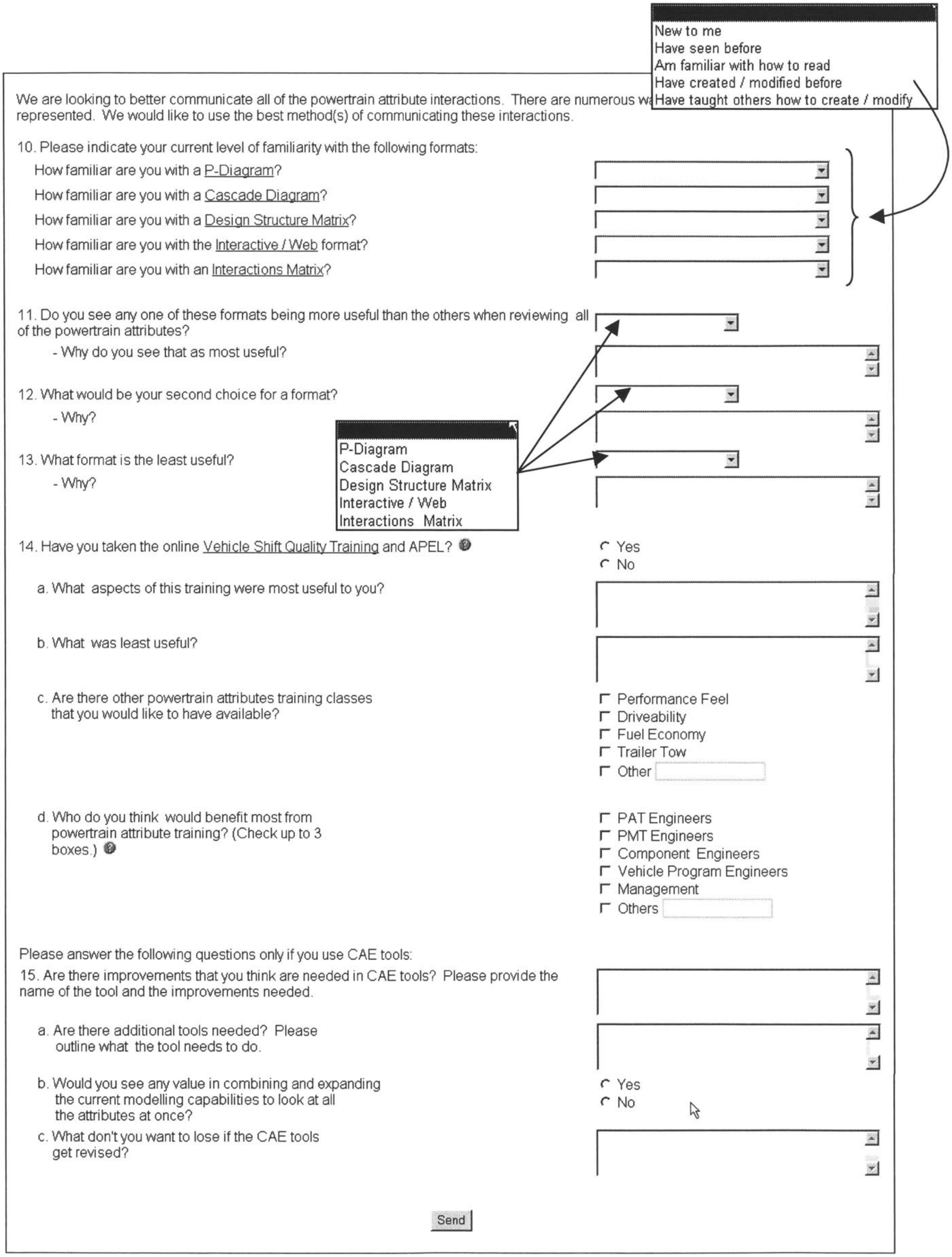
- Design Guides or Data Base
- Attribute Training
- Quick & Simple Testing
- Additional CAE Tools
- Other

Greater than 2 times per day
Once per day
2 - 3 times per week
Once per week
Once every 2 - 3 weeks
Once per month
Less than once per month
Never

9. If documentation of all powertrain attributes existed and was easy to use, how often do you think you would use this information?

We are looking to better communicate all of the powertrain attribute interactions. There are numerous ways that these interactions can be represented. We would like to use the best method(s) of communicating these interactions.

Figure 104 - Questionnaire 3 – Non-Management Page 2


New to me
Have seen before
Am familiar with how to read
Have created / modified before
Have taught others how to create / modify

We are looking to better communicate all of the powertrain attribute interactions. There are numerous wa[ys] represented. We would like to use the best method(s) of communicating these interactions.

10. Please indicate your current level of familiarity with the following formats:

How familiar are you with a P-Diagram?

How familiar are you with a Cascade Diagram?

How familiar are you with a Design Structure Matrix?

How familiar are you with the Interactive / Web format?

How familiar are you with an Interactions Matrix?

11. Do you see any one of these formats being more useful than the others when reviewing all of the powertrain attributes?

- Why do you see that as most useful?

12. What would be your second choice for a format?

- Why?

13. What format is the least useful?

- Why?

P-Diagram
Cascade Diagram
Design Structure Matrix
Interactive / Web
Interactions Matrix

14. Have you taken the online Vehicle Shift Quality Training and APEL?

Yes
No

a. What aspects of this training were most useful to you?

b. What was least useful?

c. Are there other powertrain attributes training classes that you would like to have available?

Performance Feel
Driveability
Fuel Economy
Trailer Tow
Other

d. Who do you think would benefit most from powertrain attribute training? (Check up to 3 boxes.)

PAT Engineers
PMT Engineers
Component Engineers
Vehicle Program Engineers
Management
Others

Please answer the following questions only if you use CAE tools:

15. Are there improvements that you think are needed in CAE tools? Please provide the name of the tool and the improvements needed.

a. Are there additional tools needed? Please outline what the tool needs to do.

b. Would you see any value in combining and expanding the current modelling capabilities to look at all the attributes at once?

Yes
No

c. What don't you want to lose if the CAE tools get revised?

Send

Figure 105 - Questionnaire 3 – Non-Management Page 3

Management Survey on Powertrain Attribute Interactions

This information will be used to help the company understand how to handle powertrain interactions. All information will be held in strict confidence. No personal identities will be revealed with any information reported out. We would appreciate your candid comments.

Name

Email address

Phone number

Can we contact you to clarify any responses? ○ Yes ○ No

What is your organizational level? (Manager / Chief / Director)

1. How much emphasis do you think the company places on each of the following categories to maximize customer satisfaction? (Please provide answers, which total to 100%.)
Note: These are the categories that J. D. Powers uses to correllate to customer satisfaction.

- Engine and Transmission Performance	0
- Cockpit and Instrument Panel	0
- Ride, Handling and Braking	0
- Heating, Ventilation and Cooling (HVAC)	0
- Comfort and Convienence	0
- Sound System	0
- Seats	0
- Vehicle Styling/Exterior	0
Total	0

Are there other categories that J. D. Power should include in their customer satisfaction surveys?

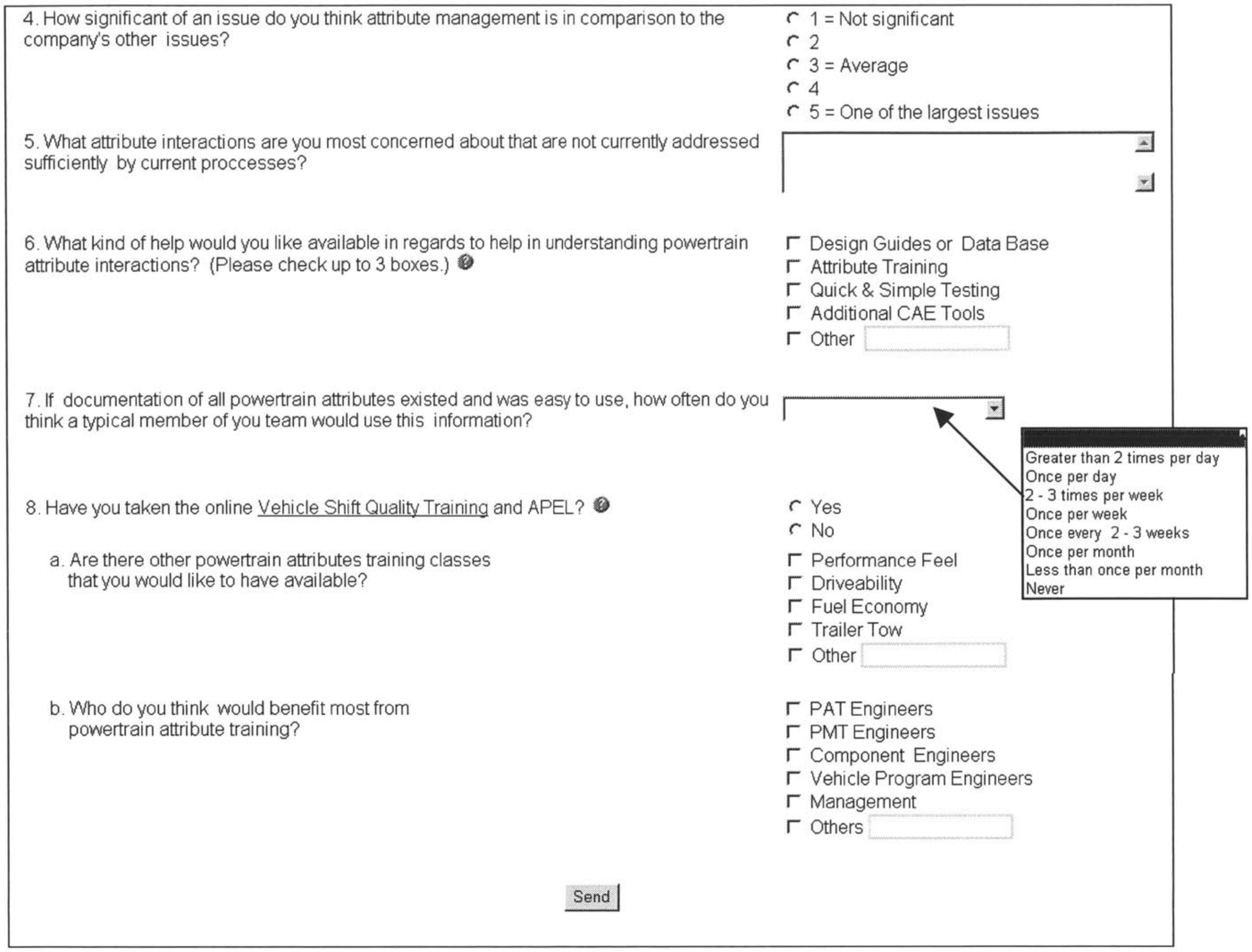
2. When considering a potential change what methods does your team employ to ensure there are no unexpected interactions or issues? What percentage of time would they use each of these: (Please provide answers which total to 100%.)

		How effective do you believe each method to be?
a. No particular process	0	0
b. Discuss with co-workers	0	0
c. Use modelling to understand	0	0
d. Look on web	0	0
e. Review books / technical papers	0	0
f. Ask boss	0	0
g. Other ____________	0	0
Total (must equal 100%)	0	No Total

(please specify if other is chosen)

3. What percentage of all powertrain interactions do you think are addressed by existing processes prior to vehicle builds? 0

Figure 106 - Questionnaire 3 – Management Page 1



4. How significant of an issue do you think attribute management is in comparison to the company's other issues?

- 1 = Not significant
- 2
- 3 = Average
- 4
- 5 = One of the largest issues

5. What attribute interactions are you most concerned about that are not currently addressed sufficiently by current proccesses?

6. What kind of help would you like available in regards to help in understanding powertrain attribute interactions? (Please check up to 3 boxes.)

- Design Guides or Data Base
- Attribute Training
- Quick & Simple Testing
- Additional CAE Tools
- Other

7. If documentation of all powertrain attributes existed and was easy to use, how often do you think a typical member of you team would use this information?

- Greater than 2 times per day
- Once per day
- 2 - 3 times per week
- Once per week
- Once every 2 - 3 weeks
- Once per month
- Less than once per month
- Never

8. Have you taken the online Vehicle Shift Quality Training and APEL?

- Yes
- No

a. Are there other powertrain attributes training classes that you would like to have available?

- Performance Feel
- Driveability
- Fuel Economy
- Trailer Tow
- Other

b. Who do you think would benefit most from powertrain attribute training?

- PAT Engineers
- PMT Engineers
- Component Engineers
- Vehicle Program Engineers
- Management
- Others

Send

Figure 107 - Questionnaire 3 – Management Page 2

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Appendix C - Examples of Documentation Formats for questionnaires.

The following pages show the 5 formats referenced in the questionnaires:

- **P-Diagram** - A single page diagram showing: Attribute, Inputs, Noises, Control Factors, Ideal Function, and Error States
- **Cascade Diagram** - A diagram showing how high level attributes are cascaded down to sub-attributes
- **Design Structure Matrix** - A matrix with the relevant attributes, sub-attributes and design parameters, where the item in a given column affects and item in a give row if there is a mark in the corresponding location of the matrix.
- **Interactive/Web** - Links on a given page lead one to the affected item on another page. This allows space for details of the interactions to be shown on the pages. These pages do not include this extra information.
- **Interactions Matrix** - A chart showing how various components relate to a given attribute.

Figures in Appendix C

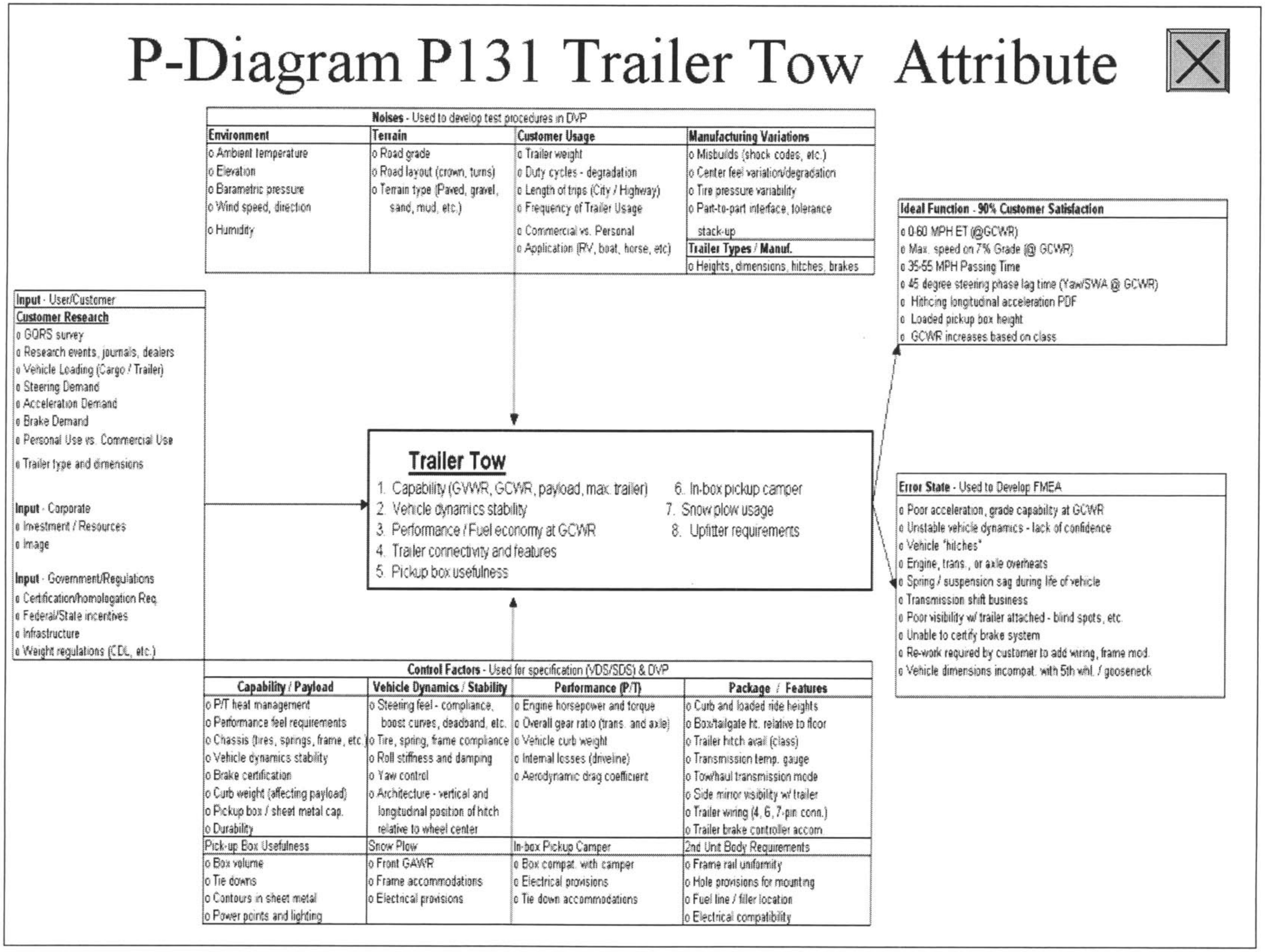


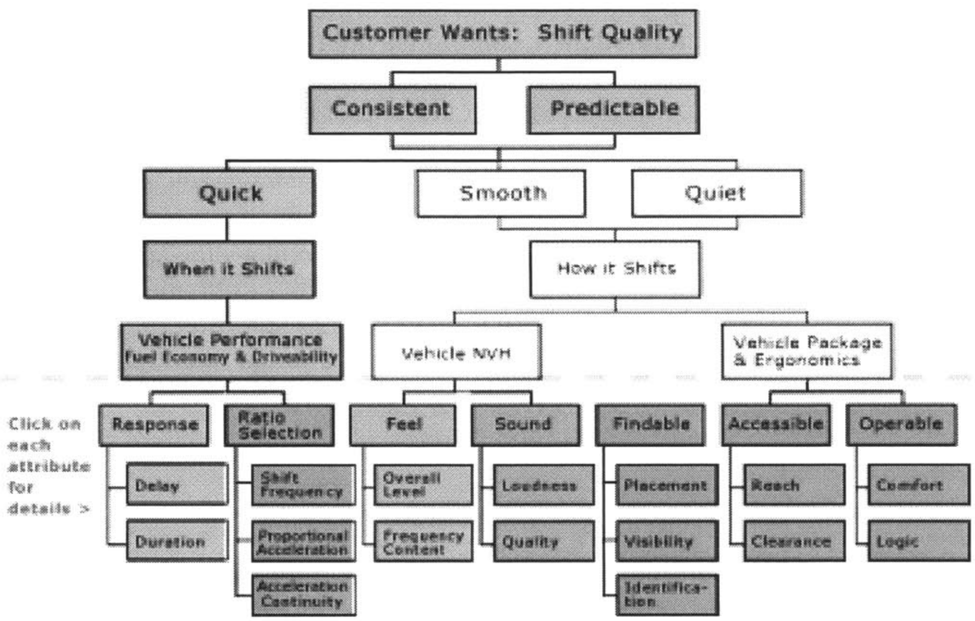
Figure 108 - P-Diagram included in Questionnaires

Customer Wants Correlated to Vehicle Attributes

To successfully deliver the five characteristics customers want in their vehicles' Shift Quality performance, the characteristics must be cascaded down to lower-level sub-attributes as shown in this chart.

When cascading customer wants to specific vehicle attributes, interactions among the sub-attributes must also be considered.

Click on the vehicle level attributes displayed in the chart for a brief description.



Response

Responsiveness is characterized by delay and duration.

- Delay is the amount of time from the request of an action until the beginning of the action is perceived.
- Duration is the amount of time from the perceived beginning of a shift until the perceived shift is completed.

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Ratio Selection

Ratio selection is the choosing of different gear ratios in the automatic transmission. Ratio selection is characterized in terms of shift frequency, proportional acceleration and acceleration continuity.

Figure 109 - Cascade Diagram from Questionnaires (Page 1)

Shift Frequency

Shift frequency is often thought of as "shifts too often" (shifts/mile, shifts/minute, etc.) but many other factors figure in as well. If the shifts are quick, smooth and quiet, the customer will tolerate a lot more of them than if they are drawn out, rough and loud. This is an attribute that requires the measuring and balancing of several interacting characteristics to determine the total impact to the customer.

Proportional Acceleration

Proportional acceleration refers to customers' desire for their vehicle to respond proportionally to their pedal input. If they step lightly on the accelerator, they want a light acceleration (not a downshift followed by a heavy acceleration). Conversely, if they keep depressing the accelerator for increased acceleration, they do not want the pedal to travel all the way to the floor before the transmission responds. The vehicle acceleration as a function of foot rotation can be evaluated to ensure a minimum amount of foot rotation between shift events and to avoid large steps or flat spots.

Acceleration Continuity

Acceleration continuity refers to the customer expectation for acceleration at a constant foot angle. The customer expects a smooth, continuous acceleration as vehicle speed increases, not a sharp drop in vehicle speed immediately after a gear change. This is measured as the percent of change in acceleration from just before the shift to just after the shift. Typically, changes greater than 15 percent are to be avoided.

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Feel

Shift feel primarily refers to the perception of the seat acceleration disturbance. There are two aspects to shift feel: overall level and frequency content.

Overall Level

Overall level refers to the magnitude of the acceleration disturbance associated with a particular shift event. This is measured by applying the vibration dose value (VDV) equation to the driver's fore-aft seat track acceleration. The VDV provides a single number for each shift event that represents the overall acceleration disturbance. VDV is calculated in the 1-32Hz.-frequency range because this is where the customer is most sensitive to shift disturbances.

Frequency Content

Frequency content looks at levels of acceleration disturbance across the frequency spectrum. Even if the overall level is low, significant energy at a particular frequency (typically above 5Hz) can be annoying. For example, a punch in the arm is annoying, especially one with a lot of energy behind it. However, someone tapping on your shoulder for 20 or 30 seconds is annoying as well, even though the overall energy level is low. Back to top

Figure 110 - Cascade Diagram from Questionnaires (Page 2)

Sound

Generally, the sound level of the vehicle is termed by engineers as powertrain presence. There are two aspects of sound: loudness and quality. Loudness is associated with the overall level of the sound. Quality is associated with the frequency content of the sound.

Overall Level

The overall level of sound associated with a shift event is sound pressure measured in decibels or sones.

Frequency Content

As opposed to the overall level, frequency content looks for annoying levels of sound that occur across the frequency spectrum. Even if the overall level is low, significant energy at a particular frequency can be annoying. For example, a clap of thunder is annoying with its high level of energy at many different frequencies. However, a fingernail on a chalkboard can be even more annoying even though the overall level of energy is much lower.

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Vehicle Package & Ergonomics

The Vehicle Package & Ergonomics attribute addresses how customers engage the automatic transmission via the gear selector system.

Customers want the gear selector system to be easy-to-find, accessible and operable. Gear selector systems that are hard to reach or difficult to operate can easily generate customer complaints such as "shifts rough or jerky" or "makes disconcerting noise while shifting."

When assessing customer feedback about Shift Quality performance, it can be difficult to distinguish if their statements apply to the operation of the gear selector system or actual gear changes in the automatic transmission. To help assess this difference from a customer satisfaction perspective, the Global Quality Reporting System (GQRS) now asks for two categories of Shift Quality feedback: "While Driving" and "From Park."

Specific Shift Quality metrics for vehicle package and ergonomics have not been developed. Specific targets for this attribute are the responsibility of the gear selector system.

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Figure 111 - Cascade Diagram from Questionnaires (Page 3)

The Design Structure Matrix:
An Information Exchange Model

<u>Interpretation:</u>

- Items A thru L represent attributes, sub-attributes (i.e. sustained acceleration) and design parameters (e.g. pedal efforts)
- Interactions are represented by marks in Box:
  - Attribute D is influenced by design parameters E, F, and L.
  - Attribute B has an effect on attributes C, F, G, J, and K.

	A	B	C	D	E	F	G	H	I	J	K	L
A	•		X									
B		•										
C		X	•									
D				•	X	X						X
E					•	X		X			X	
F		X				•			X			X
G		X					•				X	
H	X			X				•	X		X	
I			X			X			•	X		
J		X	X							•	X	X
K		X	X								•	
L	X								X	X	X	•

Figure 112 - Design Structure Matrix from Questionnaires (Page 1)

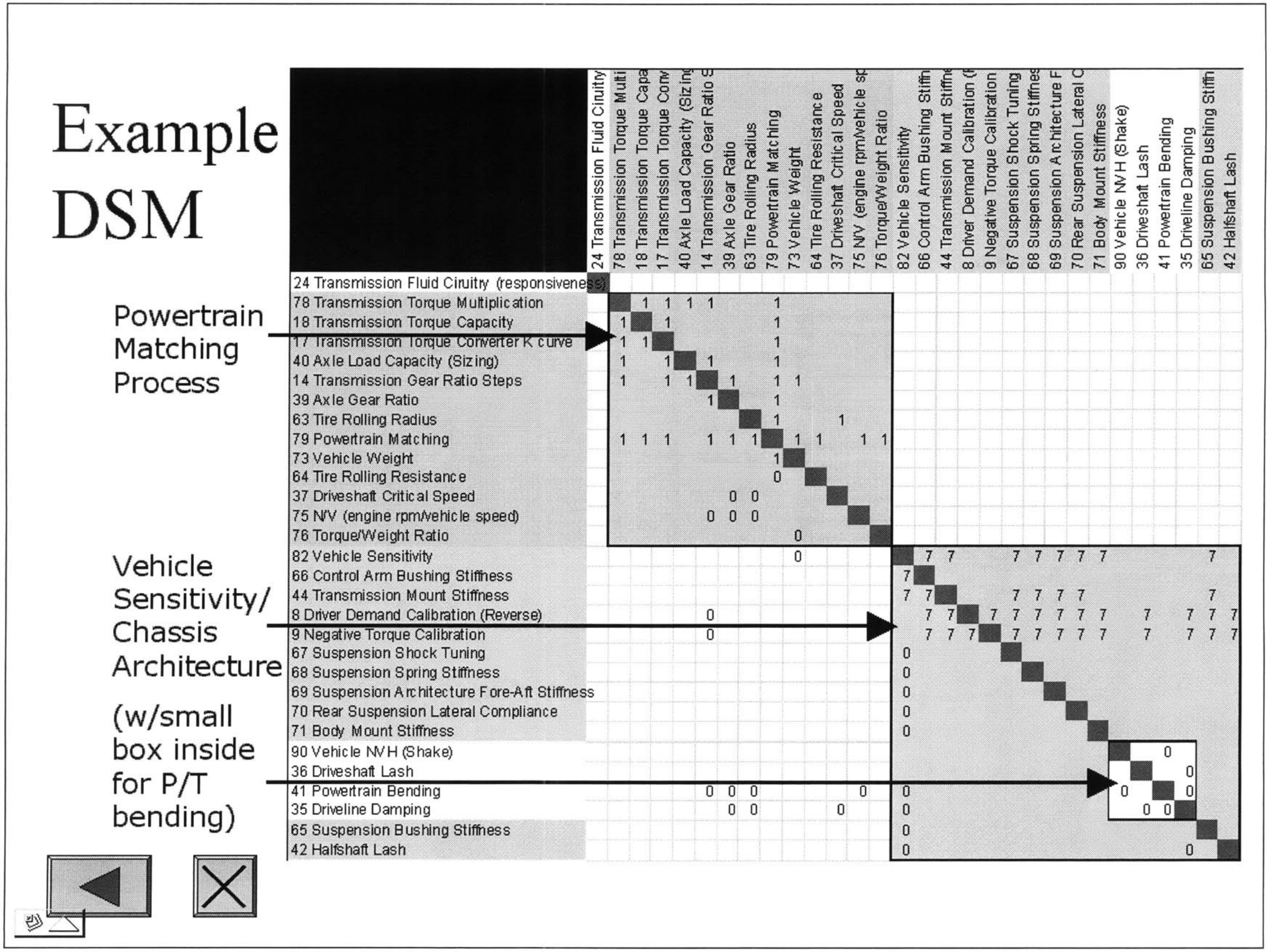

Figure 113 - Design Structure Matrix from Questionnaires (Page 2)

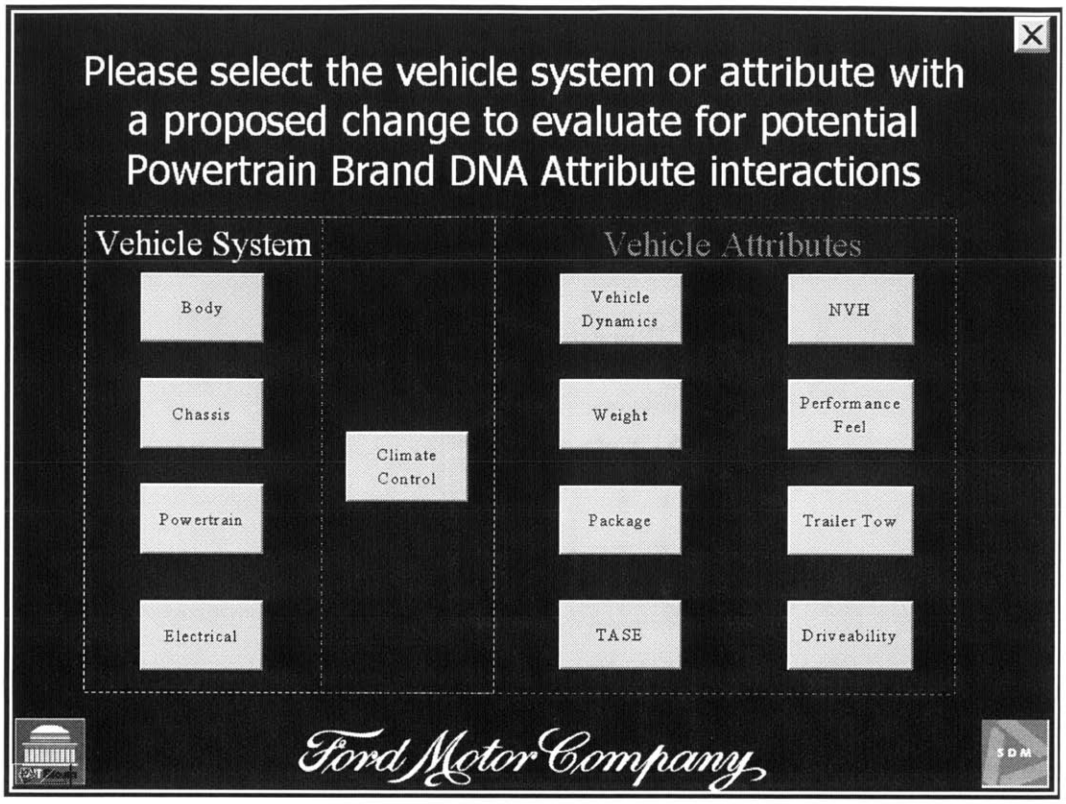

Figure 114 - Web Interactive Format from Questionnaires (Front Page)

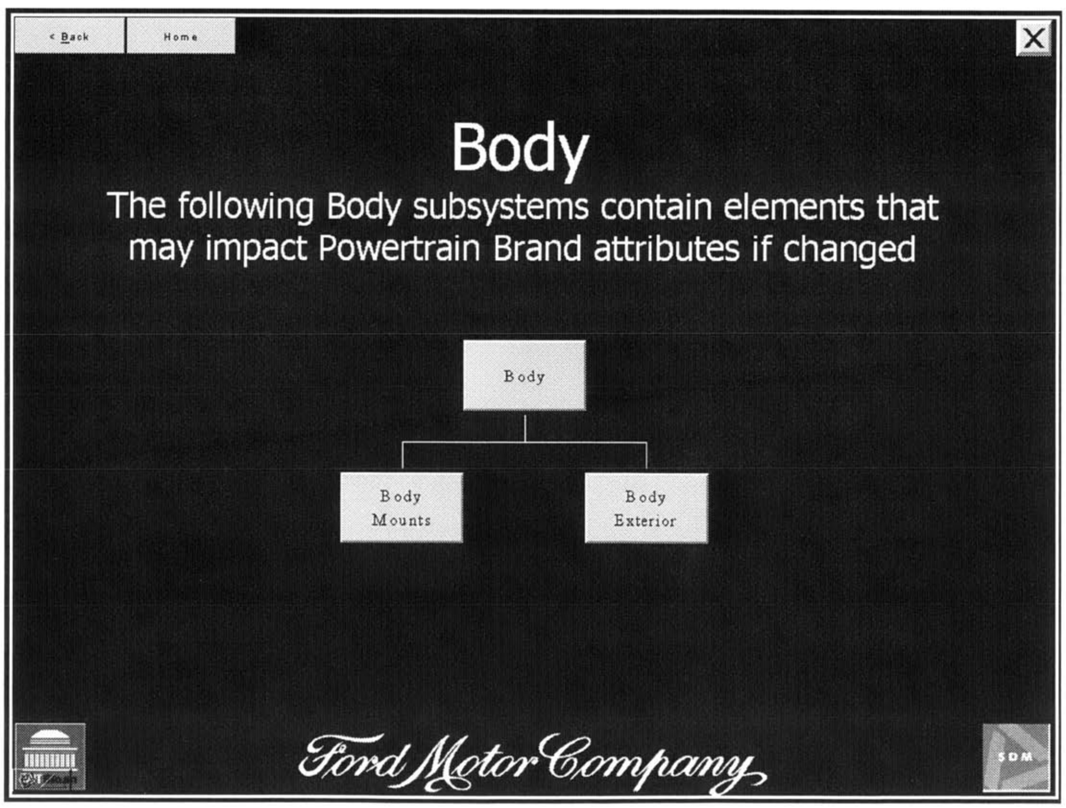

Figure 115 - Web Interactive Format from Questionnaires (Body Page)

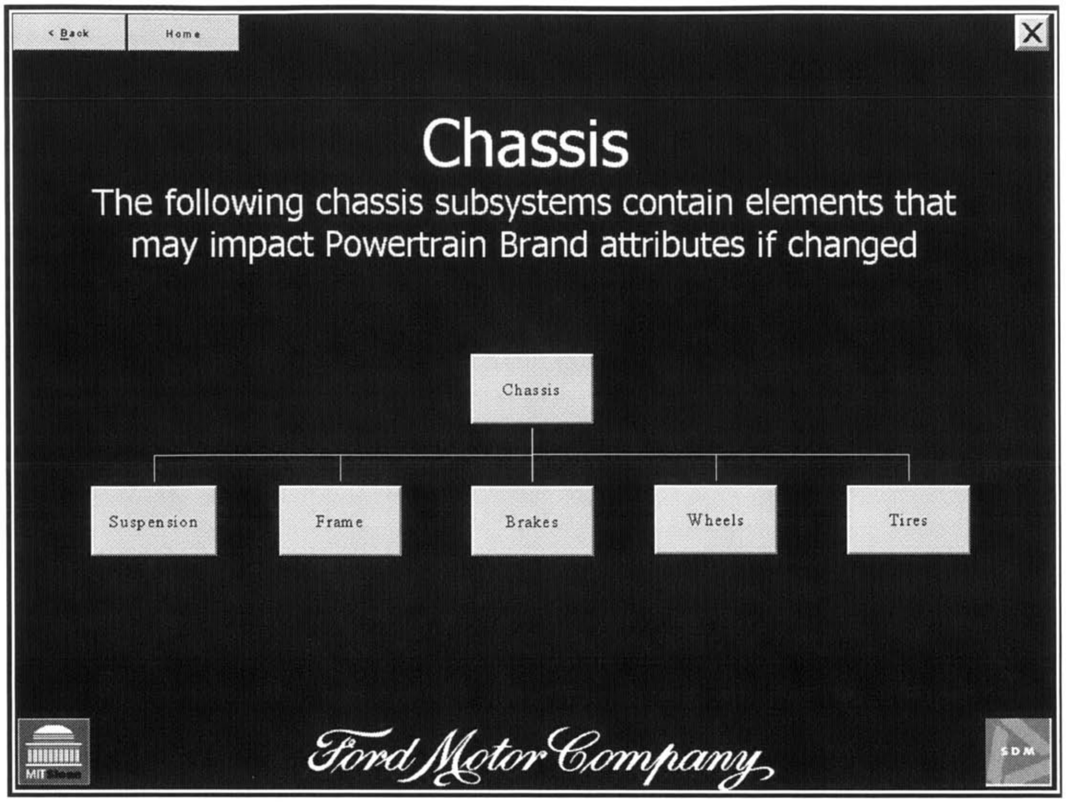

Figure 116- Web Interactive Format from Questionnaires (Chassis Page)

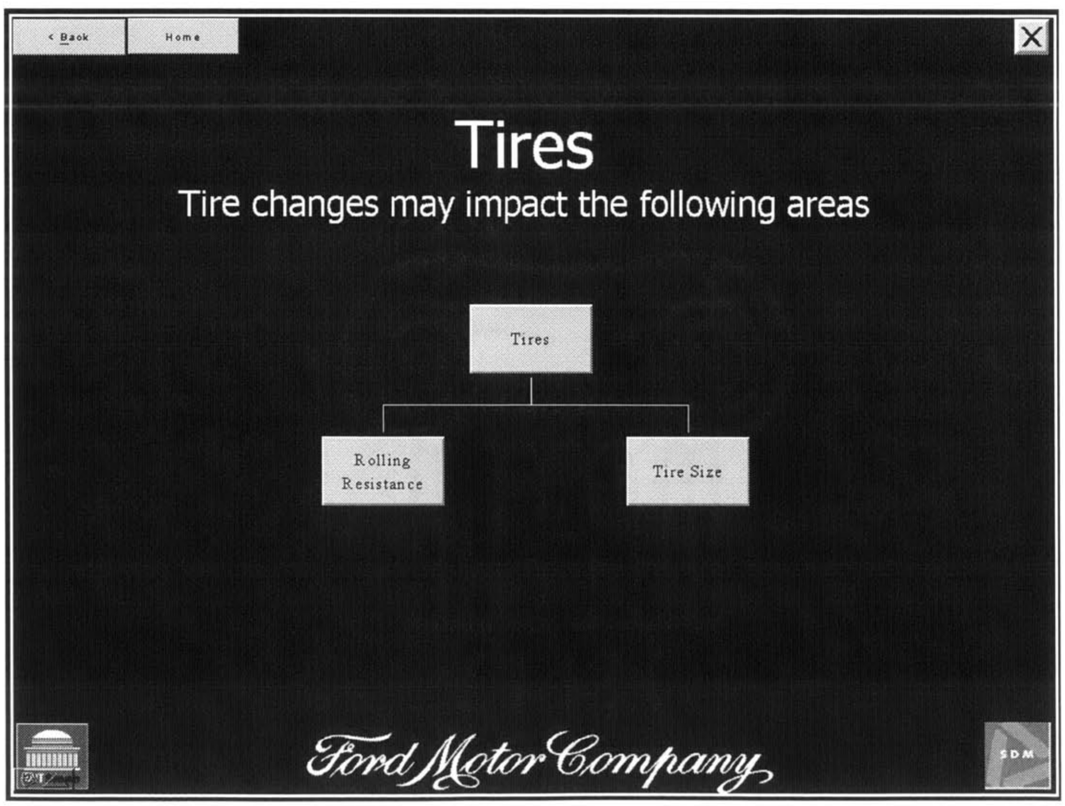

Figure 117 - Web Interactive Format from Questionnaires (Tires Page)

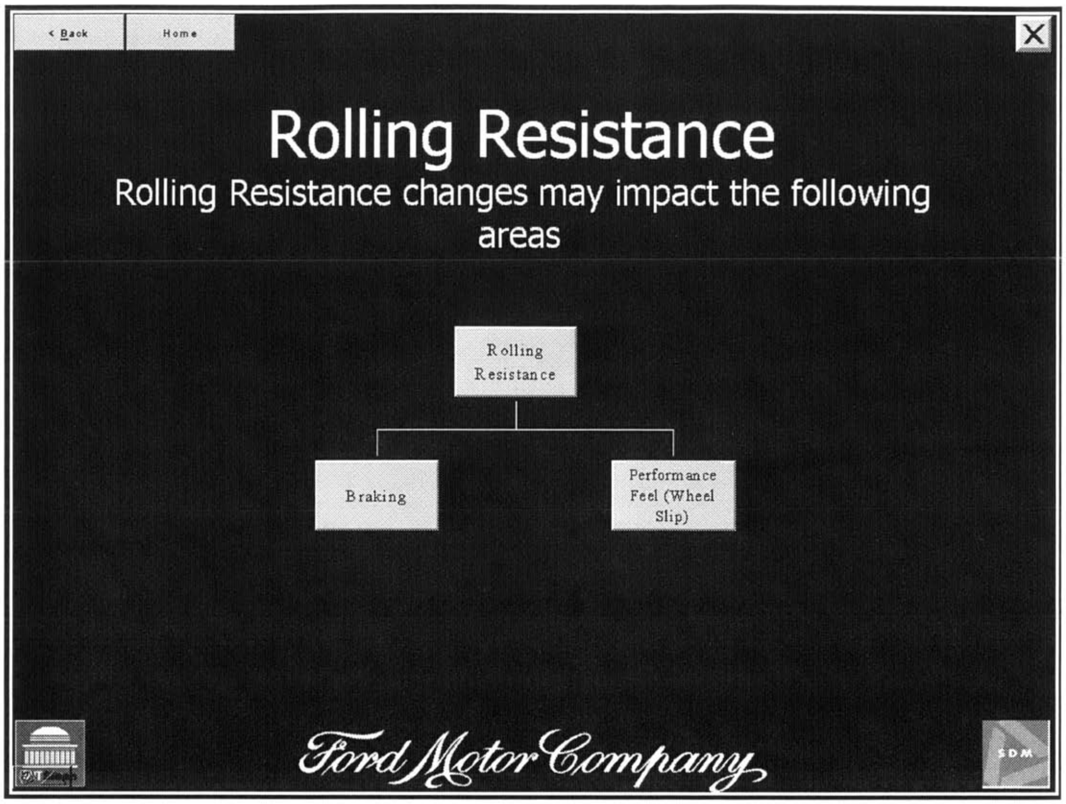

Figure 118 - Web Interactive Format from Questionnaires (Rolling Resistance Page)

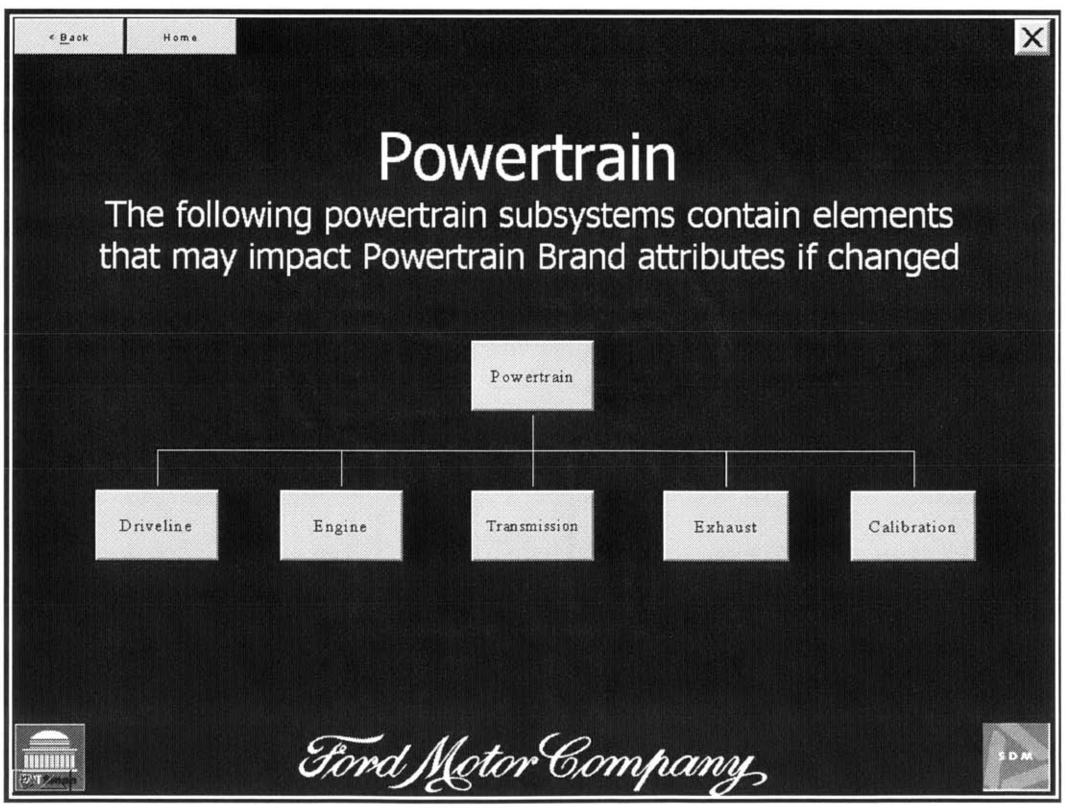

Figure 119 - Web Interactive Format from Questionnaires (Powertrain Page)

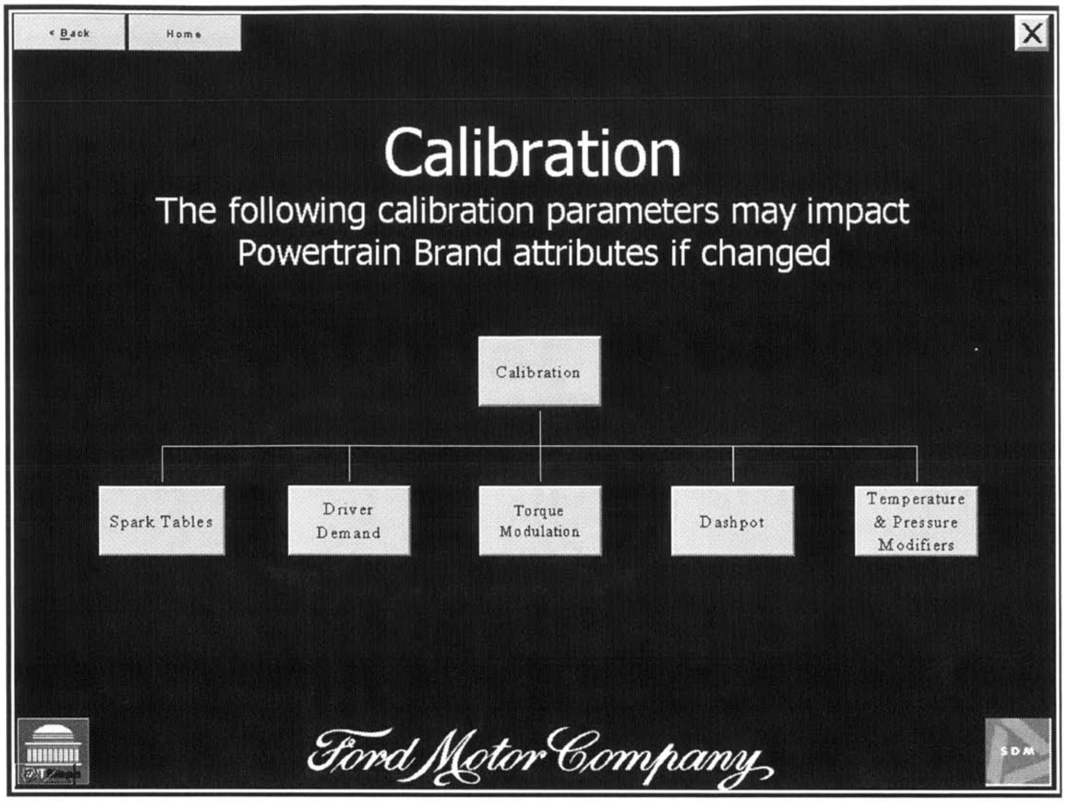

Figure 120 - Web Interactive Format from Questionnaires (Calibration Page)

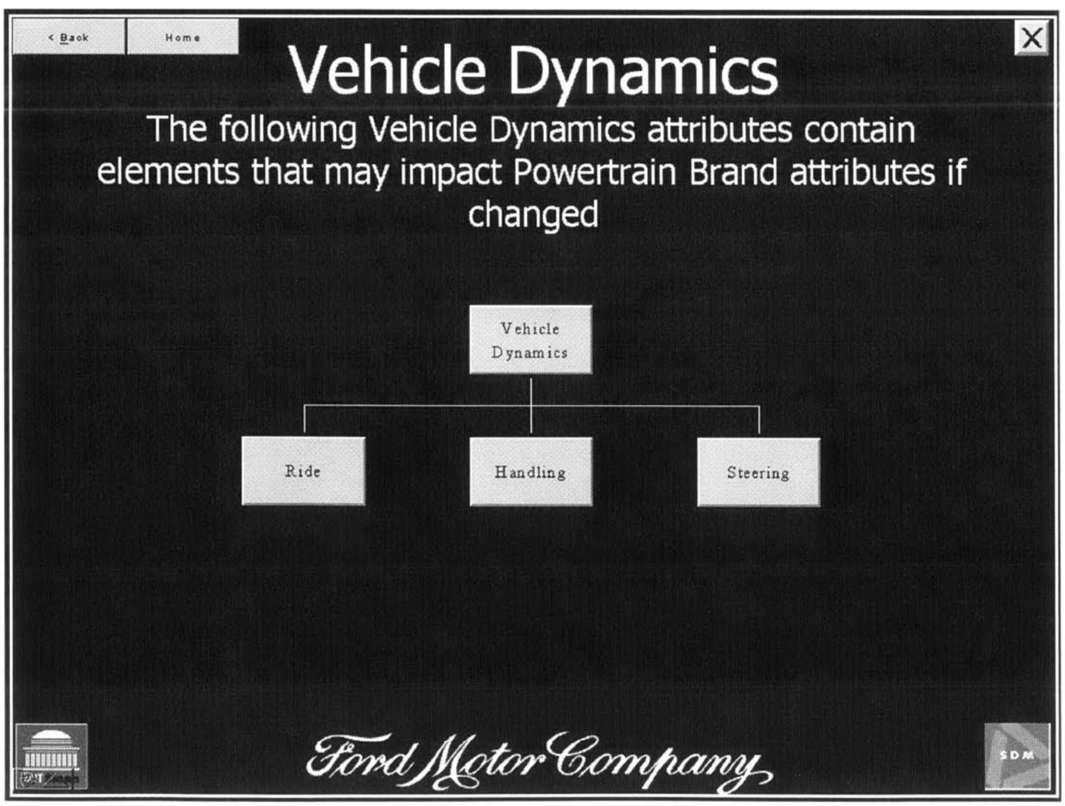

Figure 121 - Web Interactive Format from Questionnaires (Vehicle Dynamics Page)

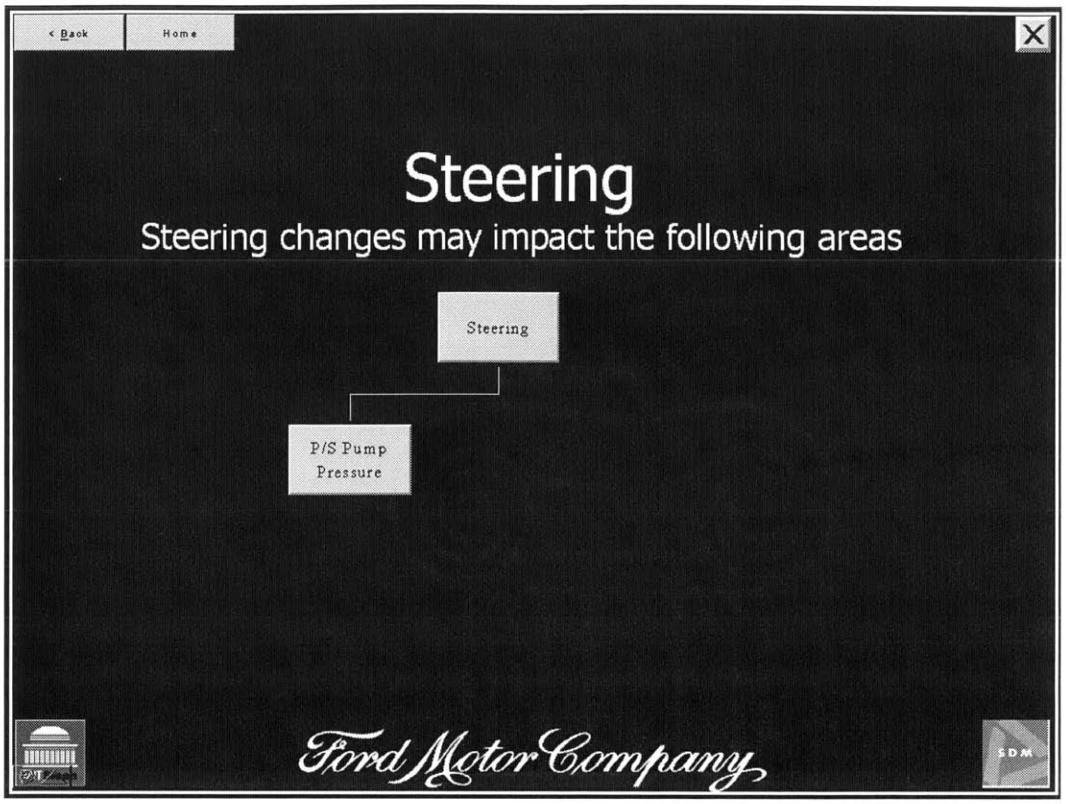

Figure 122 - Web Interactive Format from Questionnaires (Steering Page)

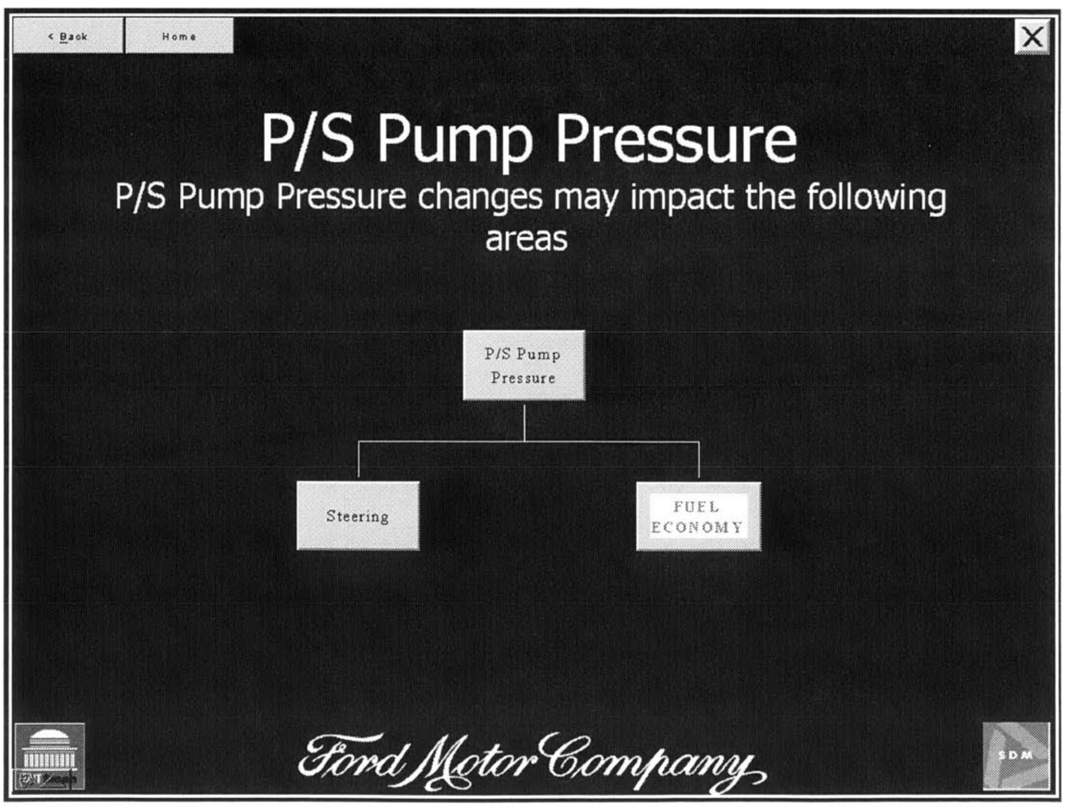

Figure 123 - Web Interactive Format from Questionnaires (Power Steering Pump Page)

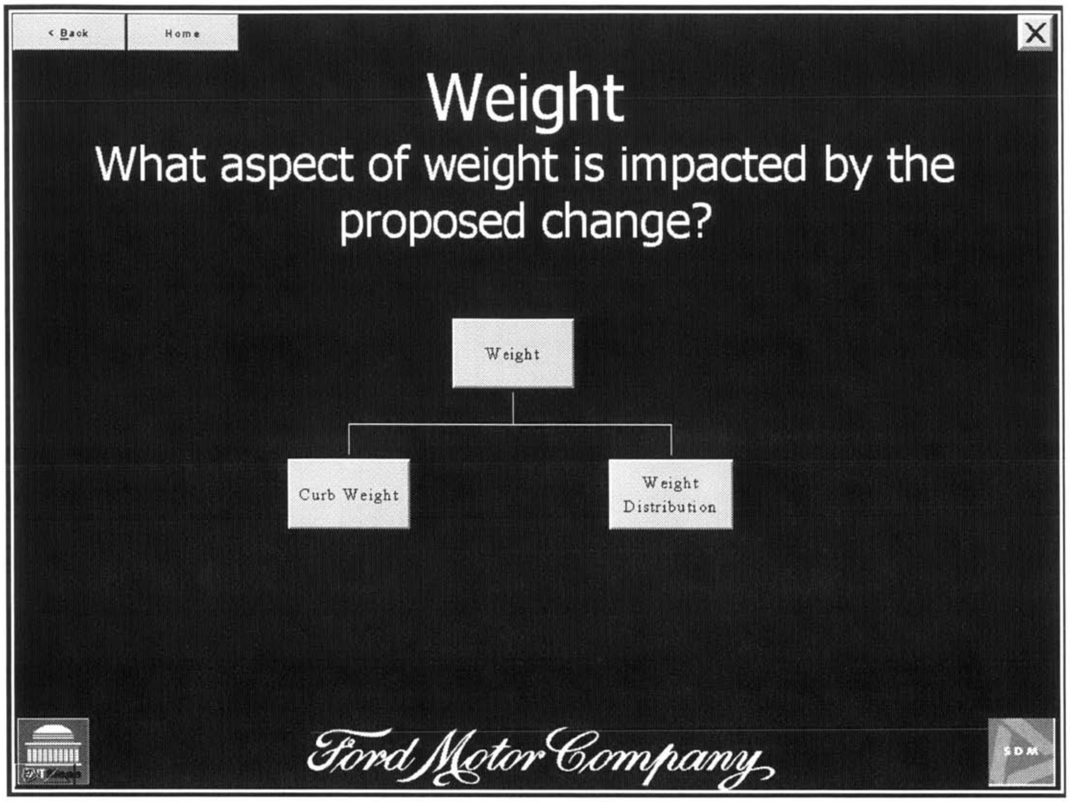

Figure 124 - Web Interactive Format from Questionnaires (Weight Page)

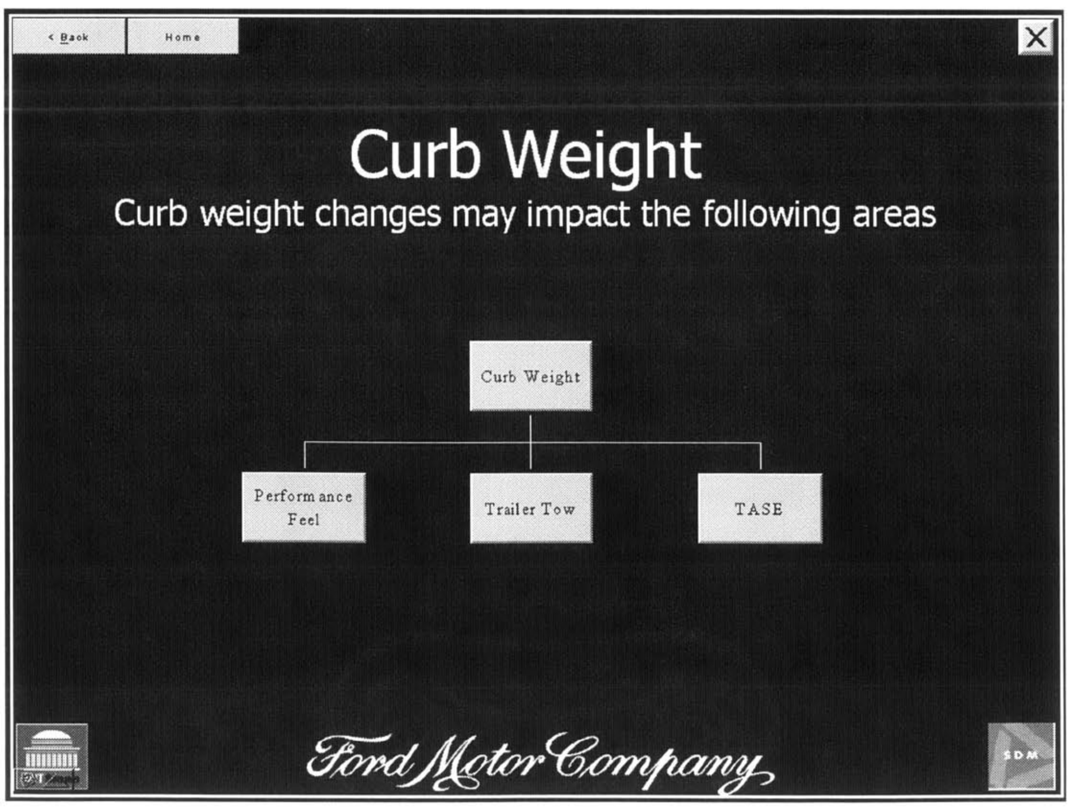

Figure 125 - Web Interactive Format from Questionnaires (Curb Page)

Shift Quality Interactions Matrix
Strength of Relationship

Shift Quality Interfaces			Shift Quality: When it shifts — **Response** (How long it takes to start or finish)	Shift Quality: When it shifts — **Ratio Selection** (How the vehicle selects the ratio)	Shift Quality: How it shifts — **Feel** (Acceleration disturbance)	Shift Quality: How it shifts — **Sound** (In-vehicle powertrain noise)	Shift Quality: How it shifts — **Driver Interface** (Manual selection of ratio/range)
Program Module Teams	Body	Closures				●	
Program Module Teams	Body	Exterior				△	
Program Module Teams	Body	Interior			○	○	○
Program Module Teams	Body	Structure			○	●	
Program Module Teams	Chassis	Frame & Fuel			○	○	
Program Module Teams	Chassis	Brakes, Wheels & Tires		○	○	△	
Program Module Teams	Chassis	Suspension & Steering			●	○	
Program Module Teams	Climate Control			○	○		
Program Module Teams	Powertrain	Engine	●	●	●	●	
Program Module Teams	Powertrain	Auto Trans	●	●	●	●	●
Program Module Teams	Powertrain	Exhaust				●	
Program Module Teams	Powertrain	Cooling		○	△	△	
Program Module Teams	Powertrain	Mounts	○	△	●	●	
Program Module Teams	Powertrain	P/T Electronics	●	●	●	●	△
Program Module Teams	Powertrain	Driveline	○		●	●	
Program Module Teams	Powertrain	Air Induction				●	
Program Module Teams	Powertrain	Accel. & Speed Control	●	●	△	△	
Program Module Teams	Electrical						
Vehicle Attributes	Safety						●
Vehicle Attributes	Security						
Vehicle Attributes	Package/Ergonomics				△	△	●
Vehicle Attributes	Thermal/Aerodynamics						
Vehicle Attributes	Vehicle Dynamics		△		●		
Vehicle Attributes	Emissions		△	○	△		
Vehicle Attributes	Performance/Fuel Economy/Driveability		●	●		●	●
Vehicle Attributes	NVH	Powertrain	●	●	●	●	●
Vehicle Attributes	NVH	Road				○	
Vehicle Attributes	NVH	Wind				○	
Vehicle Attributes	Electrical/Electronic					○	○
Vehicle Attributes	Interior Climate Comfort Environment			○			
Vehicle Attributes	Weight		○	●	○	○	○
Vehicle Attributes	Product/Process Design Compatibility		●	●	●	●	○
Vehicle Attributes	Customer Life Cycle		○	△	○		
Vehicle Attributes	Styling/Appearance					△	●
Vehicle Attributes	Cost		●	●	●	●	●

Key
- ● Strong
- ○ Moderate
- △ Weak

Originator: Lisa Greene/lgreene
sq interactions matrix for course.xls

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Figure 126 - Interactions Matrix from Questionnaires