Internalization of Robust Engineering Methods in Automotive Product Development

A Study of Corporate Quality Change in a Large, Mature Automotive Company

By

John W. Fallu

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

Massachusetts Institute of Technology

February 2004

Signature of Author ______________________________

John W. Fallu
System Design and Management Program
February 2002

Certified by ______________________________

Jan Klein
Senior Lecturer
Sloan School of Management

Accepted by ______________________________

Thomas J. Allen
Co-Director, LFM/SDM
Howard W. Johnson Professor of Management

Accepted by ______________________________

David Simchi-Levi
Co-Director, LFM/SDM
Professor of Engineering Systems

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ABSTRACT

It is broadly recognized in the automotive industry, as well as many others, that those organizations that can deliver timely new products or existing product upgrades at desired cost and quality targets will produce higher levels of customer satisfaction, higher profits and a significant competitive advantage.

In an attempt to improve the product development process and the quality of engineering, many automotive firms have implemented, and continue to implement, numerous initiatives designed to increase the discipline within the engineering process with the expectation of meeting cost, timing, and customer satisfaction/quality targets. Improved product development systems, 6-sigma, reliability methods, and 8-D's, are some of the initiatives that have been utilized in attempts to improve the quality operating systems of the organization and tie engineering improvements to customer needs.

While these initiatives have been successful within certain areas, there continues to be a shortfall between required performance and actual quality levels in some large, mature firms. While there has been substantial quality and cost improvement in the past few years, increasing competition continues to demand higher and higher value for the customer.

Satisfying market requirements and permanently improving the quality of vehicles developed requires a complete understanding of the demands on the engineering system, including the enablers and roadblocks to the full utilization of robust engineering practices.

This research examines one automotive company's product development process to determine how and why short cuts in the product development process are typically made. Through studying the progression of cultural change in the organization as related to the utilization of robust engineering tools, the roadblocks and the causal factors for lack of internalization and application of robust practices are identified. Finally, based on the study's analysis and results, effective corrective actions are identified and recommendations for their incorporation are made.

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LIST OF KEY OBSERVATIONS

OBSERVATION PAGE

OBSERVATION 1: Proper application and positive verification of robust tools requires the engineers and the auditors involved have an in-depth knowledge of the part and system function which are being studied. 48

OBSERVATION 2: Information and knowledge generated through robust processes must be stored in and easily accessible and searchable locations for future team usage as issues or design change requirements arise. 48

OBSERVATION 3: Engineering experience and knowledge of the system and components being developed is absolutely critical to successful application and utilization of robust tools. 51

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1 CHAPTER 1: INTRODUCTION

1.1 Motivation

It is broadly recognized, in the automotive industry, as well as many others, that those organizations that can deliver timely new products or existing product upgrades at desired cost, and quality targets will produce higher levels of customer satisfaction, higher profits and a significant competitive advantage. In an attempt to improve the product development process and the quality of engineering, many automotive firms have implemented, and continue to implement numerous initiatives designed to increase the discipline within the engineering process in the hopes of meeting cost, timing and customer satisfaction/quality targets. Initiatives such as 6-sigma, Reliability methods, 8-D's, and improved product development systems are some such initiatives that have been utilized in attempts to improve quality operating systems of the organization and tie engineering improvements to customer interests. While these initiatives have been successful within certain areas, there continues to be a shortfall between overall desired performance and actual quality levels.

Satisfying market requirements and permanently improving the quality of vehicles produced requires a complete understanding of the demands on the engineering system, including the enablers and roadblocks to the full utilization of robust engineering practices. Continuing with reactionary quality improvement initiatives that do not fully model the dynamics of the engineering process and work requirements will only continue the unsatisfactory quality improvement initiatives. This research examines one automotive company in which the specified product development process is not completely utilized and short cuts are typically made. Through studying the progression of cultural change in the organization as related to the utilization of robust engineering tools and establishing the shortfall between desired quality performance and actual quality levels we can substantiate the theory that attributes the incomplete application of robust engineering tools to less than desired product performance. By then identifying the roadblocks and the causal factors for lack of internalization and application of robust practices, affective corrective actions can be identified and understood and initiated. Through the use of causal loop diagrams and systems dynamics models, future improvement efforts can then be tailored to achieve the desired improvements in engineering practice with a complete understanding in the trade-offs associated with increasing engineering disciplines.

1.2 Business Context-Automotive

Mature North American Automotive firms are now competing in a market where up-and-coming Japanese and now Korean automakers have used lean production techniques and high quality products to eat away at the small, low profit vehicle markets. Upon developing the quality reputation, strength and market presence in the small vehicle market they are now working their way into higher margin markets which have up until recently remained a haven for domestic automakers. Domestic automakers ability to maintain existing markets and profit levels, and to create new markets will demand improved quality and continued flexibility as they struggle to match the newer, more flexible work environments of up and coming firms.

The hyper-competitive automotive market is driving the need for significant engineering actions to reduce costs and improve quality and deliver exciting new product. Market and profitability driven product development programs to identify improvement actions to meet the demands of the market will depend on the thoroughness of the application of the product development process. To ensure continued success of an organization all change initiatives must be identified with the consumer requirements in mind and implemented with impeccable product quality.

1.3 Research Outline

The research begins with a review of market performance and competitiveness for major producers in the automotive market. The market review will include gaps in customer satisfaction performance and cost disadvantage studies since model year 2000. Research will then identify the specified product development process that is considered to be robust and audit recent product development initiatives according to the robust process. Through identification of warranty costs associated with the various product development initiatives the research will draw a correlation between the applications of the specified product development process and quality performance. Upon identifying the value of adherence to the product development process, interviews were conducted to identify rationale for deviation from product development requirements. The primary causes for deviation from the specified process were then examined. Given the identified causes of deviation from the product development process, the topics of learning/training, experience/time on the job, manpower, and management attention are examined in-depth.

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2 CHAPTER 2: AUTOMOTIVE MARKET COMPETITION

2.1 Competitive Share and Incentives

Effective change management depends on establishing value in the change at the time of the initiatives introduction. Establishing this value requires tying the initiative to an aspect of company performance that requires improvement for continued organizational success. The establishment of this need and value will be demonstrated through the study of the hyper competitive automotive market and mature automotive firms performance within that market.

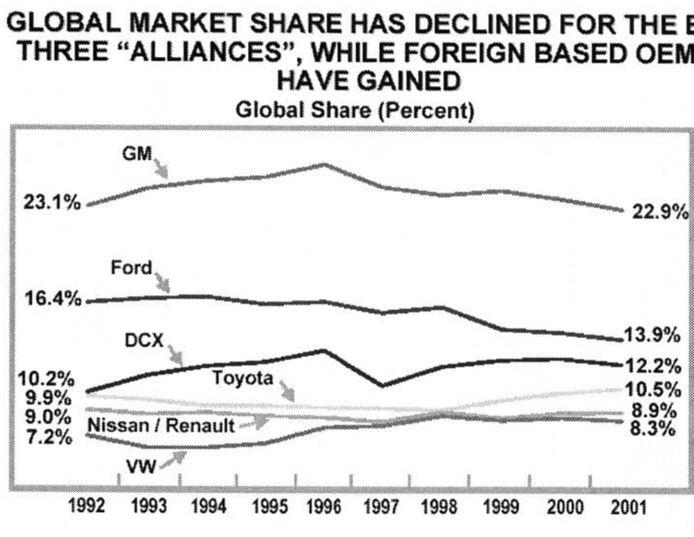

Figure 2-1: Global Market Share

Data taken from publicly available sources, originally compiled for internal presentation.

Automotive market share is an easy and readily available metric used to determine the relative sales growth of a particular company within the automotive industry. By evaluating the market share growth or loss of various companies and comparing the change in market share with the perception of robustness of their products within the market place we can begin to put together the theories for the variability in corporate performance. Historical data shown in the Figure 2-2 depicts the increasing competition that has steadily chipped away market share from most domestic automakers. A combination of increased offerings from new entrant firms and an economic contraction of the market over the past 2 years have further increased the competition for existing customers beyond what is depicted in the chart above. The increase competition for remaining customers has driven automotive firms to increase incentives in order to maintain similar market share.

"Today the Big Three are shelling out an average of $3,389 per unit, discounts needed, in part, because higher quality product is tempering the replacement cycle. "Without incentives, consumers will keep driving their current vehicle," says DesRosiers. Today, Japanese automakers are spending an average $1,062 per vehicle while the Korean brands are doling out $1,371 and the Europeans $1,945. (Special Report: Incentives as Carrot or Noose? By Alisa Priddle and David E. Zoia WardsAuto.com, Jul 21 2003). Despite these actions, global market share has declined for the Big Three while foreign-based OEM's have typically gained. The Big Three's light-vehicle market share has eroded from 66.8% in 2000 to 62.0% through July this year, itself down from 63.4% a year earlier. Meanwhile, the share held by Japan-based automakers has climbed from 25.6% three years ago to 28.7% so far this year, and the German and Korean automakers also have made increases. These shifts represent substantial changes in income for the companies which are gaining or losing share. Projections for future market penetration do not look favorable based on Ward Automotive survey results shown in Figure 2-B. One ray of hope for American automakers, which may not be captured from the survey, is the plethora of new model launches which will begin in 2005. Since market share erosion can be tied to lack of fresh product introductions by

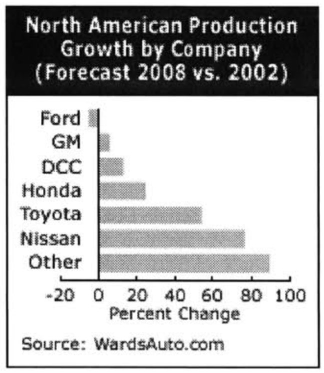

Figure 2-B: Projected Growth by Company

the Big Three in recent years it is possible to generate additional market excitement with new model launches. Of concern though will be the acceptance of the new model offerings within the market. Recent losses in market share may be a signal of a reluctance of larger portions of the automotive consumer market to consider domestic auto manufacturers due to concerns over cost and quality.

2.2 Profitability of Automakers

Not only are domestic automakers losing market share, they are also being forced to offer higher incentives for the vehicles they are selling. The lower incentives being paid by foreign auto manufacturers directly impact the profitability of the manufacturer. Continued higher profits for foreign manufacturers adds to their advantage as they are able to continue to fund new products, continue advanced product development, and upgrade manufacturing equipment to state of the art facilitates. As shown from Figure 2-4 below, foreign competitors hold a significant profitability advantage over domestic manufacturers.

> "Profits equal revenue minus cost," points out Mike Donoughe, Chrysler vice president-family vehicle product team. "If revenue on a transaction is decreased, the only way for corresponding profits to be viable is to address the cost base." Reducing the number of parts in the vehicle cuts down on investment, materials and piece costs and – ultimately – labor. By driving down the manufacturing costs or increasing the desirability of your vehicles directly impacts profitability of an automotive firm. (Will Big 3 Share Sink Below 50%? By David C. Smith WardsAuto.com, Aug 8 2003).

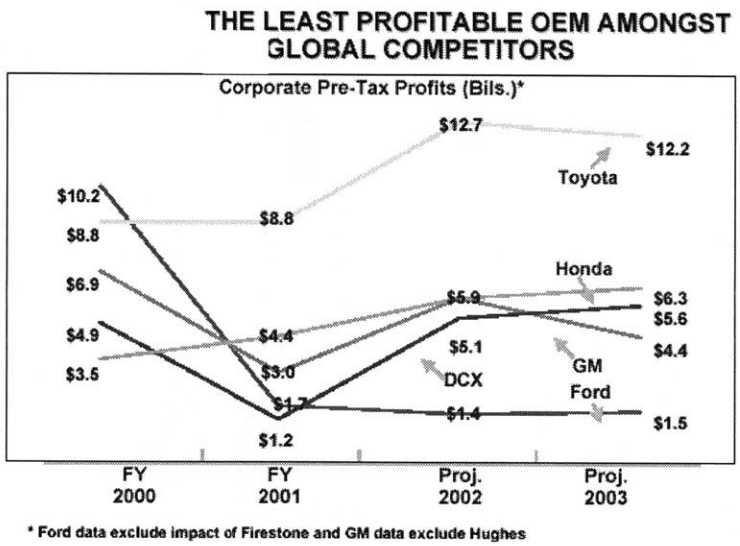

Figure 2-2: Automotive Profitability

The cost competitiveness of a particular firm depends on many factors. Product development plays a big role in how low those costs can go. The cost disadvantage plays a big role in the ability to offer incentives, or collect profit for a particular vehicle line. Without reducing or eliminating the cost disadvantage the poorer performing companies disadvantage will grow as the more profitable companies develop new, exciting, higher quality products which further push the higher cost based manufacturer into an uncompetitive position.

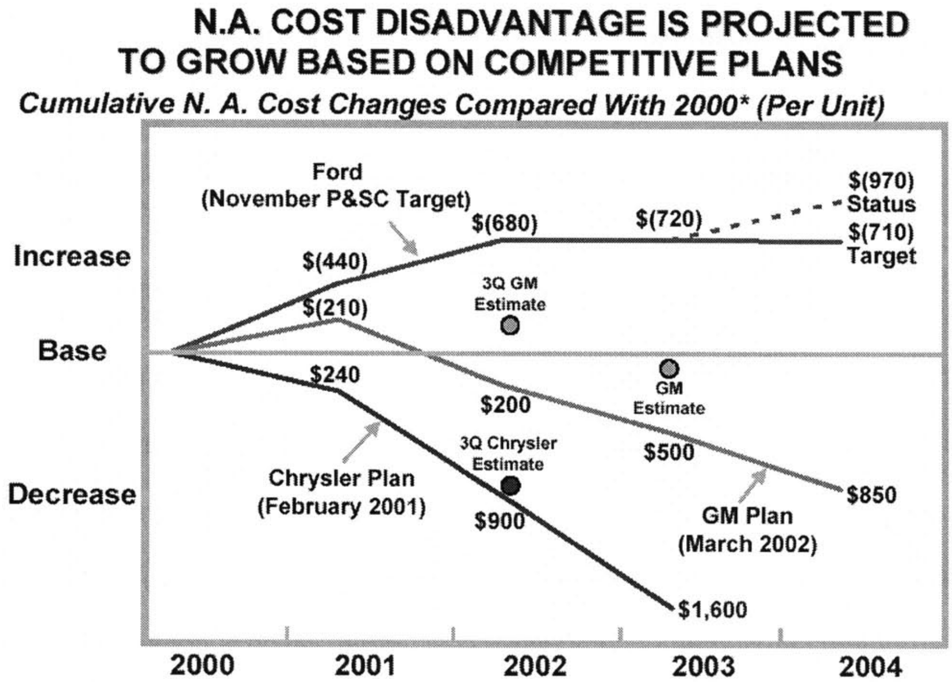

Figure 2-3: Production Cost Disadvantages

Data taken from publicly available sources, originally compiled for internal presentation.

Manufacturing costs from a North American labor perspective are generally fixed due to competitively unfavorable contracts with the United Auto Workers labor union. To pay legacy costs, GM – and Ford and Chrysler – need to keep plants running and cash flowing.

> "They don't have a choice," says Philippi. "They've got to throw money at the market or cut capacity – but (either way) they would still have all the people and all the legacy costs. (They're) in the business of funding pensions, legal plans, health and eye care – with no help from the (United Auto Workers union)." (Will Big 3 Share Sink Below 50%? By David C. Smith WardsAuto.com, Aug 8 2003).

The newer import firms are not currently carrying this significant extra burden associated with over inflated labor costs or legacy costs of retirees. Says Wagoner,

> "In the old days you could lay off people. Today we can't – we carry the cost with (us). It makes more sense to lower the price and try to keep the volume going." (Will Big 3 Share Sink Below 50%? By David C. Smith WardsAuto.com, Aug 8 2003).

Not only do the contracts drive American producers to be uncompetitive in price, it also drives the overcapacity of the industry since it is more cost effective to produce break-even vehicles than it is to temporarily shutdown a facility. While from a "people first" perspective this approach definitely mandates consideration of a companies actions and the impact the actions can have on it's people. At the same time though it handcuffs the manufacturer into carrying an uncompetitive cost burden which is not shared evenly by all players in the market.

Manufacturing costs are also made up of quality of the products and cost to maintain the products throughout the warranted life. This cost also plays a very substantial role in the desirability of the vehicle. A higher quality vehicle that will perform its specified function longer is more desirable. "... all of the cost cutting in the world means nothing without an exciting portfolio compelling customers to pay full price. The ultimate answer is to cultivate a high-quality, "aspirational" image that will encourage consumers to pay top dollar, executives say. "The product's what is going to have the reputation," says Toyota Div. General Manager Don Esmond. "The product's what's going to last in the long run." (Special Report: Incentives as Carrot or Noose? By Alisa Priddle and David E. Zoia WardsAuto.com, July 21 2003).

An "aspirational" image is critical for the desirability and profitability of a product. Just like a Gucci handbag that demands a premium price for their product, a similar aspirational image can be true of some automobile purchase. While most cars don't have the high fashion image as some handbags, a car purchase still says a lot about the consumer. While it can be fashionable showcasing your independence from taste by driving a GM Aztec, it is much more difficult showcasing independence from good sense when driving what is perceived as an unreliable vehicle.

2.3 Automotive Quality

The next important link to make is the tie of Market performance and profitability to quality of the engineering event. Ford Executive Jim Padilla's view is captured in the following quote from a recent internal company publication, the fundamental above all else is great quality.

"The biggest waste we have in our enterprise is the cost of poor quality. And we pay for it many ways. We pay for it in the billions of dollars in warranty bills, campaign bills, loaner cars -- all of that. We pay for it in image. We pay for it in lost loyalty."

The quote above applies for all manufacturers. The ones that will remain competitive and profitable will be the ones that can control their cost of quality. Quality is so fundamental, not only to the purchase equation of the consumer, but to the business equation of the company. Lean thinking initiatives, of which robust processes make up an extremely central part, are based around eliminating all of the quality waste. These changes remain essential for increased profitability.

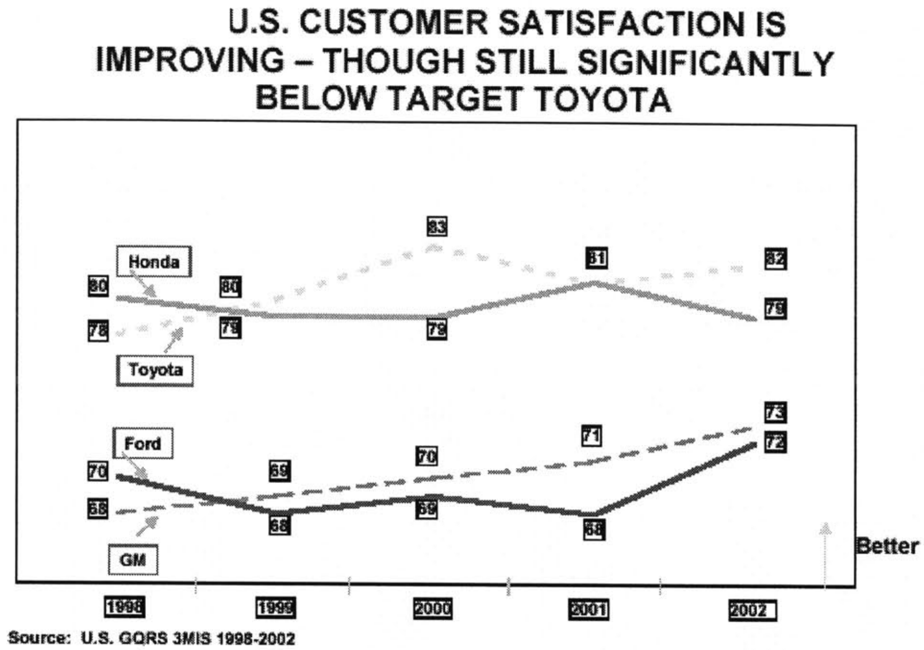

Figure 2-4: Customer Satisfaction Levels

J.D. Power performs market research and publicly reports the results, which rank customer satisfaction of various vehicles. J.D. Power rankings along with reviews in magazines such as Consumers Report represent a large proportion of the research customers perform when shopping for a vehicle. Figure 2-D above shows the customer satisfaction ratings based on customer surveys at 3 months in service. While American manufacturers have been generally improving, Japanese manufactures such as Honda and Toyota maintain the perception of higher quality. This higher perception of quality not only plays into the original purchase equation because of concerns over the durability of the vehicle, but also due to the value of the vehicle 3-5 years down the road. Resale value is one measure of the perceived quality of a product.

Better long-term quality also is key. J.D. Power moved up its Vehicle Dependability Index survey to three years of ownership from five because automakers are eager to match Honda's ability to parlay its durability record into an additional $1,500 per vehicle at resale. (Special Report: Incentives as Carrot or Noose? By Alisa Priddle and David E. Zoia WardsAuto.com, Jul 21 2003).

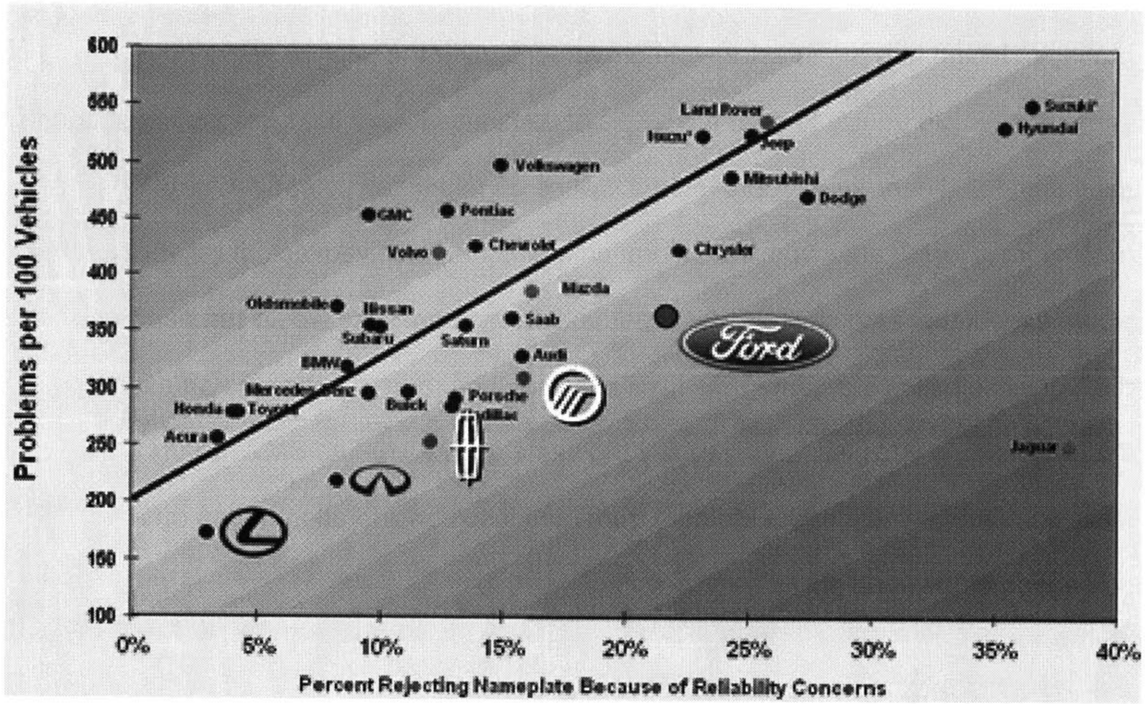

Figure 2-5: Nameplate Quality Rejections

Source: J.D. Power and Associates 2001 Escaped Shopper and Owner Loyalty Study(SM)

Figure 2-E shows the direct relationship between the critical importance of perception of dependability and the likelihood of a consumer to consider a particular vehicle for purchase. Each vehicle that is perceived to hold up well over time receives higher consideration in the purchase equation for new car shoppers. JD powers study showed very similar results as the above study which was conducted by MBG. JD Powers studied the likelihood of customers to reject from consideration a particular vehicle line based on the perceived reliability of that particular family. Unfortunately, when it comes to Rejection Due to Reliability, this consideration is based more on a company's past performance and reputation in the market place than perhaps actual recent

performance. The big standout in this study which shows this truth is Jaguar. While Jaguar has earned a historical reputation of being a vehicle constantly in need of repair, process, design and manufacturing improvements over the past 10 years have improved vehicle quality to near the levels of Japanese luxury competitors. Despite this substantial and consistent improvement, based on past history nearly 40% of possible customers reject Jaguar from consideration based on perceived lack of reliability. One would expect that as actual problems per vehicle increases, so would the number of customers rejecting the nameplate from consideration for purchase. As an example, despite Mercury vehicles having nearly the same quality level as BMW nearly 10% more customers would reject Mercury from purchase consideration based on a perception of lower reliability.

2.4 Brand Management and Pricing Impact

Arguably, some of the lost market share will be re-gained with new product launches. However that market share gain will be shorter and shorter lived as the competition intensifies and the pipeline of new and update product shortens. Differentiation of various automakers will become more difficult as competition intensifies. Recent pricing strategies have even further exacerbated this issue. "Pricing strategies tend to de-emphasize Brand Management that most organizations have been trying to use to generate differentiation in the market. The long-term threat of incentives to brand equity is real, analysts say. The question for the Big Three becomes, how much damage already has been done?

"They're overwhelming the brand image with a distressed-merchandise image," says one multi-franchised dealer. "The bitter byproduct is that incentives tempt dealership sales personnel to sell price more than product," adds a Chevy retailer. "If somebody's buying on price and not on brand, they're more likely to do so again in the future," says Lincoln Merrihew, practice leader-Automotive Group for Compete Inc. "You might have to spend a lot of money to get them again and again." Domestic automakers, in particular, need a more consistent brand and marketing philosophy to fight back. Bouncing between incentives and trying to establish brand equity confuses customers and won't work in the long run, says Merrihew. "It's tough to build brand today," admits Tom Marinelli, vice president-Chrysler brand marketing. The importance of new product means automakers must guard against cuts in new product programs as part of the solution, LaSorda cautions.

A recent study performed by JD Powers looked at the top 10 reasons cited by vehicle owners for rejection particular models. On top of the list and showing up most frequently were affordability concerns.

Figure 2-6: Top 10 Reasons Cited By Vehicle Owners For Rejecting Particular Models

Non-Purchase Reason	Category
1. Total Price Too High	Affordability
2. Total Monthly Payment Too High	Affordability
3. Didn't Like Exterior Styling/Design	Desireability
4. Not Available With Rebates/Incentives -	Affordability
5. Limited Availability on Dealer Lots	Availability
6. Salespeople/Dealer Not Professional	Personal Treatment
7. Not Available With Special Low-Interest Financing	Affordability
8. Concerned About Reliability	Reliability
9. Didn't Like Look/Design of Interior	Desirability
10. Dealers Refused to Discount Vehicle	Affordability

Source: J.D. Power and Associates 2001 Escaped Shopper and Owner Loyalty Study(SM)

As competition continues to stress the cost and discounts of new vehicles the commoditization of the product will continue until price becomes the near sole driver of the purchase equation. This can only happen though when all other factors are considered near equal. A vehicle that is not considered durable or a design that is considered completely undesirable will likely not even be considered in the affordability equation. With affordability being the top concern for most purchasers, profitability becomes a major challenge for most automotive firms. As shown earlier only through increasing the aspiration image of a vehicle or reducing the manufacturing and lifetime costs can current automotive producers remain profitable. The one component that is threaded through the whole purchase consideration is reliability. Reliability affects both the desirability of the vehicle as well as the manufacturing costs and the lifetime costs of the product. Reliable automobiles equates to desirable, profitable products.

2.5 Case for Improvement

As market competition pressures companies to improve quality levels, customer's expectations of quality will also increase. Given the wide range of higher quality vehicles choices available, very soon, if not already, vehicles that leave a question in the consumers mind about quality performance will be dropped from purchase consideration. The intense competition that is prevalent in the automotive market will continue and represents an ongoing challenge for mature automotive firms as they try to change existing operating procedures and cultural norms.

Quality and product engineering performance improvement initiatives have been implemented at all major manufacturers in the past with results depicted in the minor quality improvements shown in the J.D. Powers survey. Understandably these initiatives while marginally successful have not produced the results anticipated at their inception. One senior engineer from a vintage parts and components supplier predicts the Big Three’s share will drop below 50% within five years because they still haven’t learned how to leverage their suppliers like Japan-based auto makers.

> "Purchasing and engineering at the Big Three still are not on the same page. These guys need a lobotomy," he says. (Will Big 3 Share Sink Below 50%? By David C. Smith WardsAuto.com, Aug 8 2003).

While this view is obviously extreme, the message is clear, unless mature firms are able to forget what has made them successful in the past and re-invent themselves for current market conditions and continue to learn and adapt they will go the way of K-Mart, Woolworth and any number of the past fortune 100 companies that have recently met there demise.

Exciting, new, high quality products are the responsibility of the whole organization. Input is required from marketing, finance, service, manufacturing; etc... but at the core of all of this information is product development organization. Meeting higher quality and cost commitments, implementing the changes and product improvements that will meet and continue to exceed the needs of the market lies on the shoulders of product development. Creating and following a disciplined product development procedure that ensures, to the best information available, new products meet the demand of the market is essential for survival in such a fiercely competitive market. Those companies that are not able to adapt and internalize disciplined product development procedures are doomed to repeat errors and marginal performance of the past.

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3 CHAPTER 3: PRODUCT DEVELOPMENT BEST PRACTICES

3.1 Definition of Robust Engineering Practices

We have established the market is more competitive, that low cost producers are moving up market to higher value vehicles with lower priced, high quality product, and at this point they are out performing domestic automakers. The data has also shown that exciting products at the price the customer is willing to pay, with impeccable quality levels will be required for future survival of any automotive company. At this point, we will begin to focus on the product development process and how once an improvement is recognized as required, the improvement is validated to meet customer requirements, both from a reliability and functional standpoint. The study will focus on powertrain components and durability/quality improvement actions. Similar product development processes are followed for both new product development and current model product improvements.

Design related quality improvement projects and verification of the improvement falls primarily to the product development organization and is dependent on their adherence to robust engineering practices. For the purpose of the paper we will define robust engineering procedures, as "an engineering process which ties engineering actions to customer needs with quantifiable, verifiable and demonstrated reliable improvement". Theoretically whether upgrading an existing product or implementing a new product, similar procedures must be followed to ensure a high quality, market accepted change. By analyzing several different product development processes and the requirements in each of the steps of the various processes we can develop a generic list of requirements that represent a generally accepted definition of the steps of a robust engineering procedure.

3.2 Product Development Process Comparisons

In order to better understand and define what is generally considered a robust product development process a comparison can be made between several independent companies generic published processes in order to establish a synthesis of these procedures from which a common product development process can be created. As part of Systems Architecture class in the MIT/SDM program sample product development processes were gathered from four companies, a large automotive company, defense contractor, Aerospace company and automotive supplier. Generic steps which were prevalent in each corporate procedure were identified to compare each specific product development process against. As can be seen from the diagram above, all PD processes followed the same generic steps with the exception that the aerospace and defense companies had a distinct systems level design consideration process. The other two units addressed systems level function and interactions in other process steps. Using the color coding laid out in the Figure 3-A, the Figure 3-B depicts where each one of these separate design steps occurs in each corporate PD process. While the timing and title of each step may occur at different points within the process each companies procedures contains the same basic steps to move a product idea from concept to customer.

STEP NAME	A FEW (<3)	MOST (3-4)	ALL (5)
0. Planning			X
1. Concept Development		X	
2. System-Level Design	X		
3. Detail Design		X	
4. Testing and Refinement		X	
5. Production Ramp-up		X	
6. Operations & Support			X

Figure 3-1: Commonality of PD Steps

Analysis performed as part of Systems Architecture Course group assignment with Engineers form represented organizations

Automotive OEM	Defense	Aero-Space	Automotive Supplier
Program Input	Business Strategy Planning/Execution	Business Capture	Project Proposal Authorization
Define Architecture	Project Planning Management & Control	Requirements Review and Defintion	Plan and Define Program
Product/Process Design	Requirements & Architecture Development	Preliminary Design Phase and Review	Product Design and Development
Design/Mfg. Confirmation	Product Design & Development	Detailed Design Phase and Review	Process Design and Development
Launch Mass Production Confirmation	System Integration, Test, Verification & Validation	Qualification and Testing	Product and Process Validation
Update Corporate Memory	Production & Deployment	Flight Unit Fabrication and Testing	Feedback, Assessment and Corrective Action
	Operations & Support	Mission Increment	
		Post-Mission	

Figure 3-2: Initial Synthesis of Product Development Process

Analysis performed as part of Systems Architecture Course group assignment with Engineers form represented organizations

Drilling slightly deeper into the generic steps, a list of more specific tasks can be created which partially describes each of the detailed and specific steps contained within each of the synthesized process steps. Table 3-C below represents a summation of each of the individual companies PD process steps synthesized into a generic product development process which encompasses the actions of all four corporations.

SYNTHESIZED TEAM 1 PDP	
Business Entrance & Planning Phase	Systems Detail Design Phase
Perform Strategic/Business Planning	Technical Tracking Simulation & Models
Project Start-up and Initial Planning	COVT Planning & Preparation
Preliminary Concept Definition	Component Preliminary Design
Preliminary Architecture Definition	Detailed Design
Project Detail Planning	Component Implementation
Project Management	Component COVT
Project Performance Assessment	System Confirmation, Qualification and Validation Testing Phase
Project Control	Prototype System Integration
Program Capture/Proposal Development	System COVT
Concept & Architecture Phase	Factory Test Development
Concept Definition	Factory Test Verification
Architecture Definition	Systems Production Phase
Preliminary System Requirements Definition	Production Program Material
Systems Requirements Deifinition Phase	Production Program Assembly & Test
System Requirements Definition	Production Program Pack & Ship
System Preliminary	Production Program Acceptance/Demonstration
Product Requirements	Post Delivery Phase
Product Preliminary Design	Warranty & Post Delivery Requirements Analysis
Component Requirements Definition	Product Support
	Systems Deactivation
	Product Development Life Cycle Lessons Learned Capture
	Project Transition and Shutdown

Figure 3-3: Fully Synthesized Product Development Process

Analysis performed as part of Systems Architecture Course group assignment with Engineers form represented organizations

What is apparent through this comparison is the similarities these various industries have in their product development process. Somewhat surprising is the near uniformity of the requirements each separate company has deemed critical to delivering high quality, highly desirable products. While there are differences between each corporation's specific requirements, and timing of the requirement, almost all of the differences can be synthesized into a generic process which is made up of major elements contained within all four organizations processes. Using these four independent, multiple industry corporate PD processes we can begin to make loose assumptions of about what constitutes a robust PD process. While there may be something still better out there, some new methodology or software that will better track and control product development, the generic system described here represents current accepted best practice for developing new products. Assuming that most product development processes fit into this generic framework, one begins to consider, why then the difference in reliability results attained by different organizations.

3.3 PD Shortfall Focus

Given the commonality established through this high level process comparison it becomes apparent that the differences in product development success are not likely to be a result of a companies declared product development process. The similarities which have been demonstrated suggest that most well established companies would have similar product development processes. All companies have demonstrated procedures which are designed to identify and capture customer wants and needs and require the use of robust engineering principals to deliver and verify those requirements. We have shown earlier however that not all companies enjoy the same level of market success and profitability, even when utilizing similar product development processes. While there are a multitude of factors outside of strictly the product development process which plays into the success of a product or company we will maintain focus here to the identification of the shortfalls associated with the PD process as it is utilized to determine the factors which can contribute to reduced market performance.

Determining the differences in performance is not easily revealed without a thorough understanding of the details of the implementation and utilization of the processes and the internal functioning of the organizations themselves. The product development processes which were compared here are from separate industries so the success in the market is difficult to directly compare. For the remaining portion of this study we will however choose the automotive sectors performance to do a deep dive to establish the affect of utilization of the declared processes on actual market success. Having already demonstrated that similar best practices are already employed by automotive firms, it is unlikely that specifying high level change to organizational structure or rewriting the procedures will have an effect to improve corporate performance and adherence to the processes. It is within the current operating practices, despite the declared procedures, of the organization we will investigate for opportunities of improvement.

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4 CHAPTER 4: ROBUST PRACTICES WITHIN PD PROCESS

4.1 Robust Practices

To this point, the need for improving the product development process, demonstrated through the review of the automotive market, is apparent. Identifying the increasing competitiveness of the market, the lack of profitability of established firms, the growth of hungry newcomers and the importance of dependable, desirable affordable and enjoyable vehicles all underscore the increasing competitiveness that exists in today's automotive market. Further data has shown the importance of a healthy product development process which is required to deliver the products that are required to meet the needs of the market. Additional work then established the similarities in product development processes which exist between leading companies of various industries. The surprising similarities of product development process of the four studied companies, gives further insight into state of the art in product development. It is at this point we will begin to focus down to one specific company's performance, the procedures specified, audit to the usage of those procedures and draw conclusions to corporate performance. Due to the large scope of auditing a full product development program the study will focus primarily around smaller engineering projects which are designed to address specific customer related issues.

Within the details of the product development process are the requirements of developing a systems level understanding of the product, its function and its past performance. The knowledge generated by this type of work is then used to create and validate functional improvements. Several tools have been designed to help with each step of the process. The flow chart in Figure 4-2 below depicts the flow of information used at a particular automotive firm. The process begins with a component boundary level diagram which is used to quantify the relationships between various components and interacting sub-systems within the full system. The next step is to develop the interface matrix. The systems level interface matrix identifies and quantifies the strength of the various systems interactions. For newly designed systems or prior undefined systems, each of these steps and the quantification of the interactions can be a difficult challenge. In the absence of prior test or field data these steps are left primarily to engineering judgment. It is in this judgment, especially the first time through the process that errors can exist. From the interface matrix information flows into the P-diagram which adds the noise and control factors to the systems performance. These three tools are the primary tools used to demonstrate an understanding of the system and the factors that control and affect performance. From the P-diagram information is then fed into the design FMEA for consideration of possible failure modes and the development of robustness and reliability testing that is required for design verification. The testing, failure modes and noise factor management strategies identified in the earlier steps and then fed into the robustness checklist. The robustness checklist is used to summarize the above information and provide mapping or traceability of each of the items to one another. The design verification plan is used to track and capture results of the verification testing identified. All of the information is then fed into the Reliability & Robustness Demonstration Matrix which is a summary of the actions and test results that were taken for all robustness candidates. The diagram below shows the flow of data for this process. Shortcuts in the linkages of these systems or within each step will lead to an incomplete product development process. Without a complete following and transfer of data through each step, the product is at risk for quality issues when it reaches the field due to incomplete validation of performance.

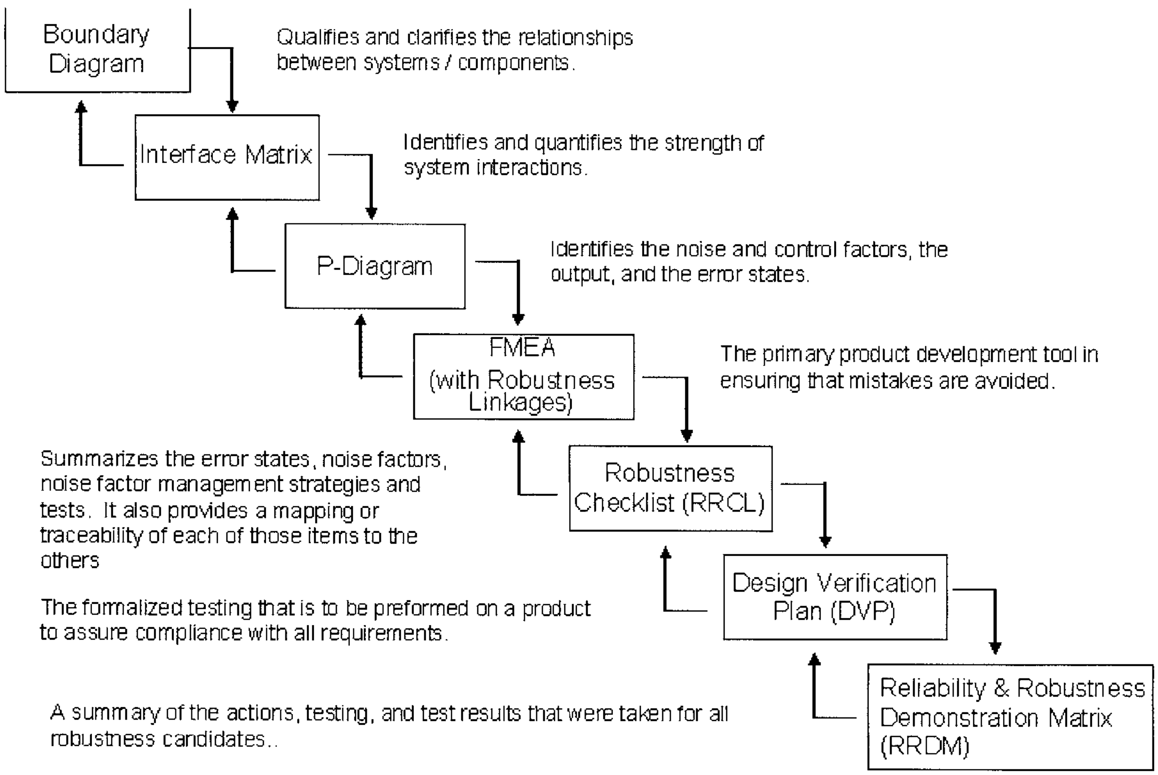

Figure 4-1: Robust Engineering Information Flow

4.2 Full Development Process and Audit Results

Audits of six, approximately 2-year-old PD projects will be used to show some typical shortcuts taken in the product development process and some rough financial loss numbers associated with each of the products. Examples will be then given of additional specific projects along with interviewed comments from the team leaders as to the systemic issue that drove them to deviate from the specified process. The projects selected for in-depth review will focus primarily around transmission development projects. Further interviews covered a wide range of responsibilities throughout the organization, at several different levels to establish common concerns throughout the organization and to begin to develop the systems level understanding required to make true improvements.

Figure 4-B encompassing the full development process starting with identification of a cross functional team, through the critical steps laid out above and on into completion of an evidence book of successful, robust development, capture of lessons learned for applications to future products and an assessment of risk upon release. Six separate product development projects were audited according to their completion of each of these steps. The red bars indicate areas where either the information was incomplete, inaccurate or did not exist. The data shown in the table was taken from "Clean Green" audits which occurred in an attempt to identify the shortfalls in the product development process. The projects audited were projects completed and implemented on new vehicle programs. The percentage of red events depicts an alarming picture for the thoroughness of the product development event. Systems were chosen over a wide range of vehicle attributes. Engine functional components body components and transmission systems were all included within the systems audited. While there are minor differences in the successfully completed steps the same actions or lack of action exist across all applications studied.

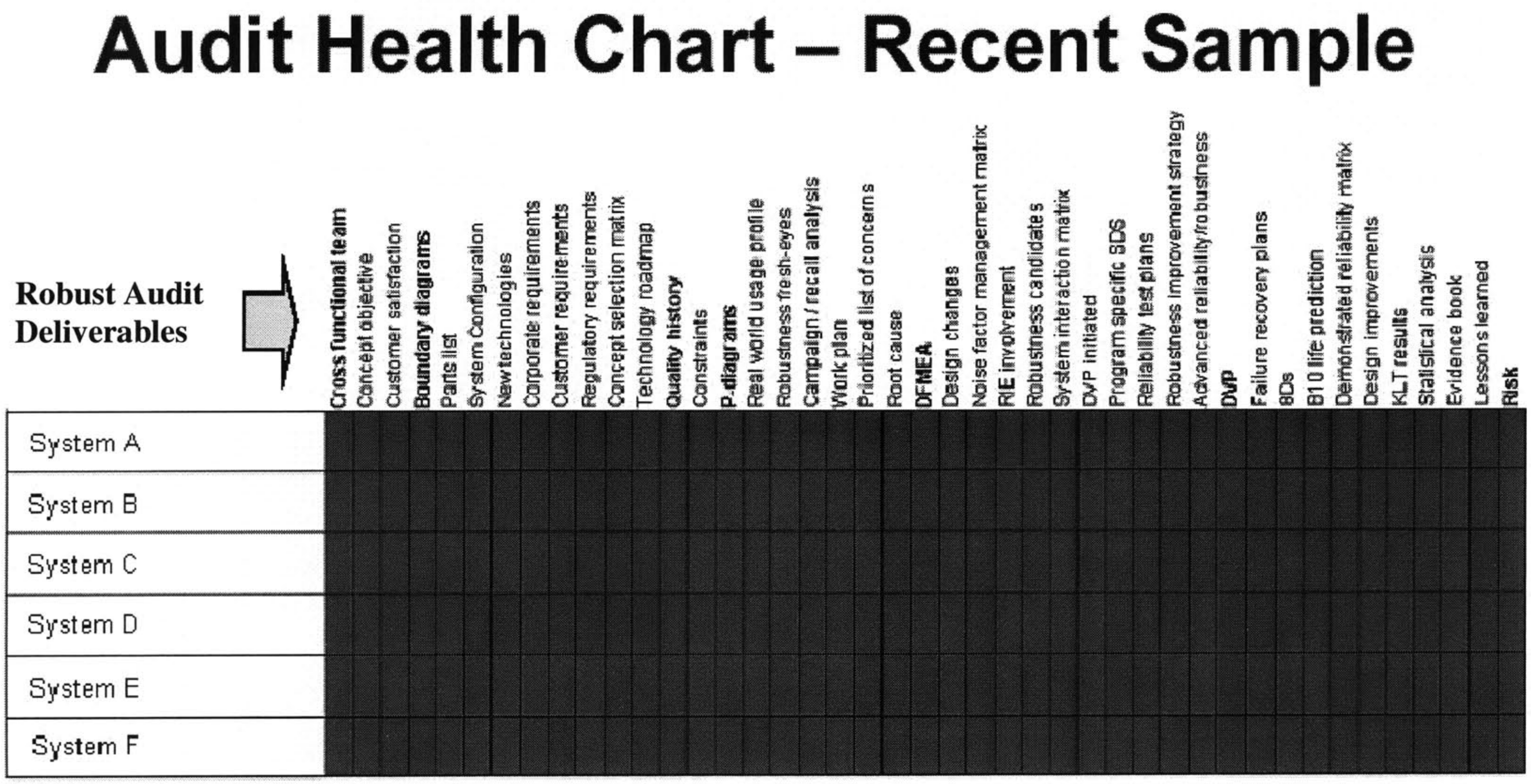

Figure 4-2: Robustness Audits of 6 Engineering Projects

Figure 4-C below depicts the low time in service warranty spending associated with each of the systems presented. Due to variability in cost to repair each system, a direct correlation between the numbers of steps of the robust process completed to warranty cost incurred can not be performed.

Correlation to Warranty Spending

System	Warranty spending ($)
System A	6.8M
System B	4.7M
System C	4K
System D	2K
System E	1K
System F	1K

Figure 4-3: Robustness Performance Affect on Warranty Costs

4.3 Criticality of Robust Process Steps

Some of the steps are more critical to successful engineering process and have a larger effect on component performance than other steps. In addition, solely because a step was missed does not dictate that there will be an issue, it only increases the possibility that there could be an issue. Demonstrating the value and correlation to performance is one of the great difficulties in enforcing adherence to this sometimes difficult and initially time consuming, stringent process. It is very interesting to note that 4 out of 6 systems audited above had very low warranty claims. These four systems could be considered robust, at least to the time in service at which the warranty was audited. Loosely analyzing this data approximately there is a 66% chance of properly engineering a system with incomplete application of robust processes. While not directly correlated, it is interesting that current high quality performance of vehicle things gone wrong according to customer survey's (TGW's) is about 72%. Since there is a certain level of quality associated with historical engineering processes, projects can be completed and function properly without following the robust engineering process. Also, through faults in logic or unforeseen failure modes which are not considered based on incomplete engineering judgment, projects which do completely follow the process can still fail. Bottom line is the risk of failure is significantly lower with adherence to robust engineering practices.

The other advantage of following robust procedures and defining the system based on current knowledge and experience levels is the documentation of the current level of understanding of system function. If issues do arise, the knowledge previously documented provides an enormous stepping-stone to problem resolution than if starting from scratch. Adhering to robust processes during early product development can be the difference between quickly fixing an issue and having it affect field performance for months into the future. An example of this advantage comes in the next section.

4.4 Example Benefits of Robust Process

Early in the development of the transmission full system level maps of pressure and lube capabilities of the transmission were generated at various speeds and operating conditions. The areas identified as critical through the use of robust tools were fully mapped to ensure a complete understanding of the performance capabilities and limitations. Initially, when questions arose about the possibilities of reducing the operating speeds at idle conditions, this descriptive data was used to identify limits to performance based on the new operating conditions. Fortunately the team responsible for lowering idle limits followed a fairly robust process in establishing the testing and the concern areas for transmissions performance. The process followed identified the same flow concerns which were mapped during the early development process of the transmission. Using the previously generated data and the documented development process the team was able to quickly and confidently develop new performance limits. Without this data being readily available, the decision would have taken significantly longer and been much more costly due to the time and manpower required to re-generate the test data.

Unfortunately, a second team did not follow the required robust guidelines and implemented changes in clutch lock-up schedule without fully considering the hydraulic performance of the full transmission system. When this change reached the field it took approximately 3 years for the issue to surface as a warranty concern. Warranty costs for the repairs were projected at over $3 million for each of the three years of the product in the field prior to issue identification. The team responsible for fixing the warranty issue, followed a robust process, identified the shortcomings, utilized the information generated in the early phases of program development and was able to implement a service fix within 70 days of issue identification. The service fix was able to reduce the cost of repair to a total annual warranty bill of about $1 million dollars. The team was also able to quickly implement a production fix which gave additional performance capability at reduce production costs! None the less, this substantial quality issue could have been avoided if proper engineering procedures were followed with the initial considerations for the design change. In the end, not only did this issue cost the company in terms of warranty costs and vehicle confidence levels, but also in engineering costs and possibly in future program performance. The issue required a team of up to 10 engineers, plus test and development facilities, to focus for almost 3 months specifically on this issue, putting forward model plans on hold until this current model issue was resolved. Given the tight time frame of new model programs, this was valuable time that will be nearly impossible to recover without additional short cuts to maintain program dates. As already shown, despite the best of intentions, these short cuts can lead to higher new program risk, and even higher future workload.

4.5 Engineering Audit Results Analysis

By evaluating the performance of the product development team to the required product development process we can see some very substantial quality gaps in the actual performance of the organization. These gaps, while they are nearly impossible to tie directly to poor quality outcomes, are indicative of possible quality issues. The very loose correlation of quality performance in the field to the application of robust tools which was presented earlier can lead to the conclusion that the lack of following disciplined, robust engineering practices has led to sporadic poor quality performance in the field. Given that correlation is not causation, directly tying the two is very difficult. Taking this logic to the limits though, it is possible to design certain systems without any testing or analysis, on simple systems minor engineering calculations can be adequate, on more complicated systems, dumb luck helps play a role. The bottom line is the more you study , the more you know, the more you know, the more you understand, the more you understand, the lower the possibility of missing performance requirements of the operating system. Like the warranty cost table shown earlier, results could be considered adequate by some, but not acceptable for the current market conditions.

Given the quality performance shortfall, of particular concern is that the execution of engineering disciplines does not always comply with procedures or guidelines set forth according to company standards. The audit showed that despite requirements for up front planning and failure mode avoidance most product development programs are still operating under a predominance of build and test / find and fix activities. This type of incomplete engineering performance occurred despite the direct involvement of reliability engineers who are fully trained in the usage and application of robust tools. The audit also showed that numerous engineering disciplines were deficient and several were not executed at the appropriate level (system vs. component) to guarantee a quality outcome to the process. Part of the reasoning demonstrated during the audits for this lack of discipline revolves around a superficial understanding of robustness methodology. This outcome is perplexing given the direct involvement of reliability engineers with each of the audited projects. At some level, for some reason, the reliability engineers involved were ineffective in playing there role in the team.

OBSERVATION 1: Proper application and positive verification of robust tools requires the engineers and the auditors involved have an in-depth knowledge of the part and system function which are being studied.

OBSERVATION 2: Information and knowledge generated through robust processes must be stored in and easily accessible and searchable locations for future team usage as issues or design change requirements arise.

4.6 Priority Concerns and Paradigm Errors

Close investigation of the individual projects also showed that even projects that did complete the required steps, a lack of engineering understanding of the system and failure to identify all system interactions can lead to an invalid selection of priority concerns. An example of this failure can be demonstrated in the review of a high mileage bushing wear issue that plagued a particular automatic transmission. The failure mode of the transmission in this case was loss of drive function due to loss of internal transmission pressure. Inspection of failed transmissions consistently showed a particular bushing to be worn. Testing was successfully performed to show that excessive wear in this bushing could cause loss of line pressure. From that point onward, an outstanding, robust, detailed engineering job was performed to implement and validate a needle bearing for the application. Unfortunately, the loss of line pressure issue returned, without damage to the needle bearing. The initial attribution error, which caused the mis-diagnosis of the problem, was attributing the loss of line pressure to the bushing wear issue, and not the other way around. While the straightforward cause and effect relationship was a possible valid explanation, because of an incomplete system understanding root cause was not identified and the issue returned. This particular issue had a high mileage warranty bill of about $1 million annually; the cost to high mileage quality image of the company was much more substantial. At issue in this problem resolution was the identification of the root cause for bushing wear. This is where time, experience, attitude and attention to detail derail so many projects. Testing was conducted on the bushing to show that at worst-case mis-alignment loads bushing wear could occur. Based on these results the decision to implement a needle bearing to increase the load carrying ability at that interface was made at a cost of $1.50 per transmission. The use of a simple P-diagram at this point and some simple additional testing would have shown that while load into the bushing is a factor, a much more critical concern is lube flow through the bushing. After the field issue returned, subsequent testing showed a very heavy reliance on lube flow to maintain bushing life. Due to a paradigm stated by the engineer at the time; "Needle bearings are just better, we should have a needle bearing at that critical point to handle the load", and the evidence that load can affect wear, the data pointing to more in-depth understanding of lube flow was dismissed. True root cause to loss of line pressure was eventually identified as a result of a plugged filter that restricted flow delivery to the transmission. In this case, by developing a full systems understanding of the loads and the fluid distribution system, the replacement engineer was able to uncover that the filter restriction gradually increased, and hydraulic flow delivery gradually decreased as the filter plugged. The first component to lose lubrication flow was the worn bushing. As the filter continued to absorb wear debris (a high percentage of which was the bushing), all flow became blocked and the transmission failed due to loss of line pressure. Unfortunately, the filter was not considered a possible root cause or inspected in the original investigation.

The conclusion from this work is that, at the time the audited projects were implemented, the Product Development organization was functioning in a non-robust manner and providing an ambient level of quality. Full utilization of the product development processes that will deliver the company to the next higher quality level still needs completion. Until the cultural shift occurs that will require full utilization of the process, repeat issues and new concerns will continue to occur. An example of this inbred cultural mindset comes from one Manager interviewed who offered the following perspective: "We are not suppose to be a paperwork pushing organization, the value engineering adds to the organization and the output of product development is a print." While it may be true that a print is the current measurable output, it is this measurement and the culture that currently values the measurement that has to change. A print can not be considered complete until all robust engineering actions have been satisfied and rather than a print, a dynamic map of product function has been generated.

Also included in this cultural shift is the experience level and technical knowledge base of those reviewing the problem must be capable of identifying the fine details of attribution errors as depicted in the above filter example. Until the disciplined processes required to consistently deliver high quality products are adhered, despite new procedures, and added constraints, the company is doomed to remain at current levels of quality issues. The continuous declining market share will only grow as other organizations continue to improve quality and reduce costs through the use of robust processes and lean manufacturing techniques.

OBSERVATION 3: Engineering experience and knowledge of the system and components being developed is absolutely critical to successful application and utilization of robust tools.

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5 CHAPTER 5: ROBUST ENGINEERING IMPLEMENTATION

5.1 Applicability of Robust Processes

While this study focuses primarily on the application of robust engineering processes to hardware changes, the results can apply to any system level change. Typically, a critical fault that exists in many organizational improvement actions revolves around an ineffective use of robust processes when developing or deciding on the improvement action to undergo. In an article in the July 2003 issue of **Harvard Business Review** entitled "*What Really Works*",[1] the authors find:

> "Most of the management tools and techniques we studied had no direct causal relationship to superior business performance. What does matter it turns out is having a strong grasp of the business basics. "

What becomes apparent from the article is, it isn't about the implementation of the management flavor of the month, it is about taking the time and effort to truly understand how the organization is operating and uncovering the cultural forces are that drive performance. These hidden forces drive quality issues in hardware and they drive performance issues in organizations. Churning weather it be people, product changes or procedure changes inhibits the ability of participants to understand the basics of the system in which they operate or engineer.

As an example, the robust tool performance audits discussed earlier demonstrated the ability of the current product development system to deliver high quality products approximately 66% of the time. Based on these results, we can see that as the more changes implemented, the higher the likelihood of future quality issues. The more

[1] "What Really Works", Harvard Business Review, July 2003

product churning, the higher the probability of failure. If for example, an organization takes on 10 actions to reduce material costs, based on the actual audited results, each change has a 33% chance of being non-robust. Choosing the failure rate here is a difficult task, but if one of the three non-robust systems fails only ½ of 1% of the time (five repairs per 1000 vehicles), the vehicle could incur a noticeable increase in failure rate and warranty costs. The additional warranty cost per vehicle sold is calculated utilizing a sample cost per repair of $2500 per vehicle. Calculating the cost per vehicle (5 repairs / 1000 vehicles * $2500 / repair) of the added warranty equates to an additional $12.50/vehicle in additional warranty costs alone. Without taking into account the reduction in customer satisfaction and the hit on corporate quality image, a company would be losing money in the end with added churning actions if the cost reduction actions were less than the cost to repair the warranty associated with the changes. What will likely happen, are measurable short-term costs will come down, with a long-term increase in warranty and engineering spending. The more changes implemented, the higher the churning, the higher the future costs. To get the engineering system as well as the organization under control, the use of robust analysis tools is required to develop an in-depth understanding of function of the organization prior to implementation of changes.

Taking a find and fix approach, which results from the inability or disinterest to fully understanding of the system, usually results in missing the true root cause of an issue and the implementation of an ineffective solution. This type of fault exists both within an engineering organization and in the business practices that focus on fixing them. One of the challenges that confound this practice is the paradigm created by solving similar issues in the past. Even when working on the same general type of issues, complex systems tends to have different robust resolutions. While many factors remain very similar in problem resolution steps of similar issues, it is typically in the details involved in generating an understanding of each individual system that means the difference between success and failure. The Product Development Process comparison performed in Chapter 3 is a perfect example of how despite apparent similarities in the implemented procedures, actually success varies greatly according to the details of implementation. These details that affect success are dependant on the organization that is implementing the changes. To improve how a system works, be it organizational or product related, it is imperative to understand how the system is functioning before the implementation of improvement actions; otherwise, the actions may not address true system function. In order to ensure the changes made are effective, whether they are hardware changes or organizational changes, we have to change how we work to include a robust systems level understanding of the issues.

5.2 Cookie Cutter Solutions

Applying cookie cutter changes to a complex operating system, gives cookie cutter results. Application of cookie cutter methodology to engineering or hardware related problems is usually visible in poor short-term product performance. Unfortunately, the results of cookie cutter solutions in organizational improvement actions are more deceptive. Time delays typically hide the true outcome of the actions. By the time the results are seen, it becomes unclear if the new operating issue is a result of the old action or a new issue. Typically, it is deemed time to apply the next, newest cookie cutter solution to the new problem that has arisen. This is the improvement process that has plagued both product and process improvements for years. Random cookie-cutter process improvement actions applied in the past have not provided the aspirational high quality products required to drive future market, or organizational success. For true improvement to the product development process the same robust problem solving techniques must be applied to organizational issues as those prescribed for use in driving to root cause of hardware issues. Without this type of in-depth analysis of the functioning and shortcomings of the current operating system, the organization is doomed to continue to repeat the mediocre results of years past.

5.3 Self Confirming Attribution Errors

In their paper "Capability Traps and Self Confirming Attribution Errors in the Dynamics of Process Improvement", Nelson Repenning and John Sterman of MIT discuss how "management's attribution to the root causes of low performance in the product development process will determine how they choose to respond. Management theory suggests if they conclude the problem is poor process, the solution is to invest more resources and worker time in improvement. If, however, management concludes workers are shirking responsibility or undisciplined they should focus on worker effort and compliance with standards. Attribution theory says that due to complexity of the operating system, management is more likely to blame the people that work for them or around them and not the system itself (a dispositional bias)." In their paper, Repenning and Sterman go on to show

> "*How the outcome feedback managers receive tends to **reinforce** rather than **correct** their initial attributions, even when they are erroneous, leading to self-confirming attribution errors.*"

This is similar to a parent creating undesirable attributes in their own children. Criticizing a child for being an undisciplined slacker and constantly following him/her around to point out the errors in their way, both affirms the parents attributions and drives the child to accept what he/she is expected to be. By over constraining the system in which professionals are operating similar habits can form. Adding overbearing constraints and audited requirements form the same narrow-minded thinking in hard working professionals as it can in aspirational children. Actual performance actions taken are a direct result of the systems requirements and the demands recognized as most critical based on management feedback. Human nature is to fix what hurts. The problem becomes when all you are trying to do is stop the pain due to an over audited, over constrained, and over worked system all that begins to matter are meeting the requirements. Going the extra step to make better more enjoyable product becomes an unattainable goal. Interviewing one manager who was trying to enforce the use of robust tools offered the following quote:

> 'It got to the point where rather than trying to engineer the system himself, the engineer would just come back to me and ask what he should do next."

The engineer in this case had given up trying to understand the system or develop an understanding for the requirements of robust engineering tools his only concern was satisfying the exact requirements of the manager who was pushing for tool usage.

5.4 Attribution Error for PD Improvement

The audit results of the product development process shows significant improvements in the operational procedures are required in order for declining automakers to remain competitive with up and coming firms. These necessary improvements focus around the product development process, which based on earlier audits appears out of control. The challenge now becomes identifying the root cause for inadequate adherence to the product development process.

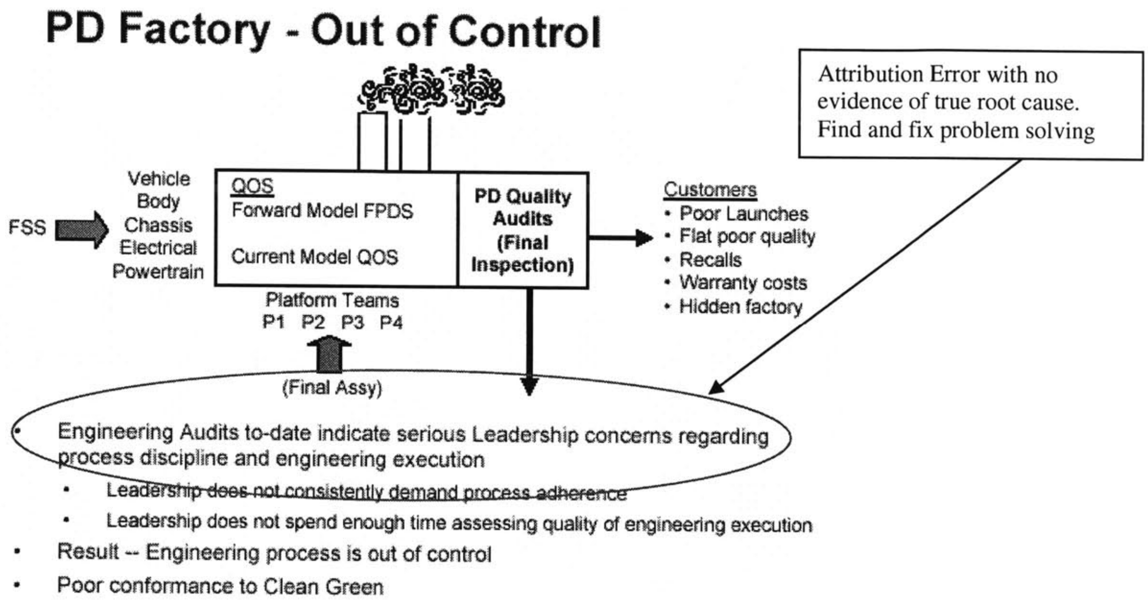

Figure 5-1: Robust Process Break-down Attribution Error

Figure 5-A above, published by the reliability group, which is a part of the Quality Office of the organization studied, shows typical attribution error for the root cause of PD process out of control. This is very interesting evidence showing how deep the issue with adhering to robust engineering tools exists within the organization. Just like an engineering project which fixes the blatantly visible problem and fails to address the true cause for the failure, this particular reliability organization is following the same find and fix mentality. Rather than looking for the systematic reasons driving ineffective PD leadership, the reliability office attributes failure to slacking leadership. As was seen by the engineer that gave up on engineering, excessive constraints in the system can drive

managers to satisfy higher-level requirements at the expense of perceived lower priority robust engineering actions. Just like the managers' influence over and engineers' performance, the priorities of the system force leaders to act according to what is valued by the organization. If local leadership is not following a prescribed process, it may not be because local leadership does not value the initiative, but because the organization as a whole does not support its value. Even though the organization may preach a robust product development process, do the actions of the organization support their use? For example, when it comes down to the hard choices of delaying a program or following the process, the organization shows it's priority by the choices it makes. Irrespective of local leadership's commitment to following the PD process, if following the process pushes a system beyond the promised date, no matter what the cause, the actions taken to ensure the hardware is on time will define future performance of the organization.

OBSERVATION 4: Reactionary engineering results from over constraining and tracking of engineering performance and drives behavior based solely on meeting immediate requirements. Over constrained systems prevents empowered engineering efforts focused on delivering the best product.

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6 CHAPTER 6: CURRENT STATE OF THE ORGANIZATION

6.1 *Application of Robust Tools for True Root Cause*

As with most systems issues, be they engineering systems or organizational systems, the complexity of the function & process interactions, both hidden and visible, make it nearly impossible to understand the full system dynamics and thoroughly diagnose and eliminate root cause of issues. The benefit of disciplined robust processes is it gives a framework to identify system function, categorize it, describe it, analyze it, improve it, and verify the improvement. Incorporation of robust procedures into a large mature organization that has survived for 100 years or so without verifiable robust processes constitutes a major cultural shift in normal operating procedures. Despite upper management desires and edicts, a shift like this does not happen overnight. This type of change can be so complex, so prone to failure, a library of books have been written on this type of change management. Accepting that cultural, political and technical change takes time, to determine if, or where implementation of robust processes may be stumbling we must first determine where in the change process the organization currently resides. The demonstrated best way to identify and resolve complex systems issues is through the application of robust problem solving methods. Since the goal should be to identify root causes and verify methodologies for improvement, it should not be necessary to check the box for complete tool usage. Just like a hammer or a screwdriver, robust tools should be treated and used as they are designed, not for every job imaginable.

6.2 Problem Identification – Problem and Objective

Problem Statement: Changes in the product development process to include robust processes have been implemented and corporate performance results are not being observed fast enough. Continued incorporation of non-robust projects is leading to uncompetitive costs and undesirable warranty performance.

Objective: Empower the organization to utilize the best tools available to facilitate delivering the highest quality, lowest cost products on time, with verified performance.

Process: Identify where in the change process the organization is currently operating with respect to utilization of robust tools and determine the leadership actions that will guide the company to full integration to the use of robust tools.

Theory: Utilization of robust processes is a direct result of demonstrated and observed value. Demonstrated value refers to the ability to deliver improved performance at lower cost through the utilization of robust processes. Observed value refers to the perceived emphasis and recognition given by an individual's direct supervision, be it engineering level or manager level or higher, to the application and deliverables of robust tools.

6.3 Historical Data Review / Failure Rate

The audits performed earlier in the study, and summarized in Chapter 4.2, were completed to establish the current state of the use of robust processes throughout the product development organization. The audits were conducted on completed projects implemented approximately 1-2 years ago, so while the results are valid for the time the audits were conducted, they may not capture improvements to operating procedures since that time. The audits also do not identify the cause for poor application of robust tools, only that there is a shortfall. What can be concluded is, based on the audit results the product develop system is not performing to its desired or designed function. While awareness of the tools appears prevalent, thorough application of the tools appears lacking. It is this critical disconnect that is leading to the high failure rate in the product development system, and the item which needs identification and resolution.

6.4 Generic Issues Identification

In order to generate possible root cause theories to test how the system functions, interviews and questionnaires were conducted throughout various levels of the organization to establish a "universal" consensus on the state of product development. The thought tree in Figure 6-A summarizes generic responses gathered during some of the interviews, but primarily through multiple additional conversations with various engineers and managers in more informal settings. The items identified and discussed during these conversations are broken down according to the 3-strands of change; "Political" issues, "Cultural" issues and "Technical" issues. While there is significant overlap between some of the categories the different aspects are shown in the various branches. The tree is shown primarily to portray the complexity of the issue and to demonstrate the wide variety of issues that can derail critical change initiatives. While it is easy to pick one branch of the tree and declare addressing one particular issue, such as failing leadership, will drive to a solution is equivalent to taking a find and fix approach in an engineering change project. Addressing the whole picture in terms of the use and avoidance of the process change is required if true change is to be internalized. While fixing each individual issue shown above becomes far to complex, all of the concerns listed must be understood and considered in the final solution. The goal needs to be to dig down to the root of the issue and re-grow a new organization built around the desired robust behaviors.

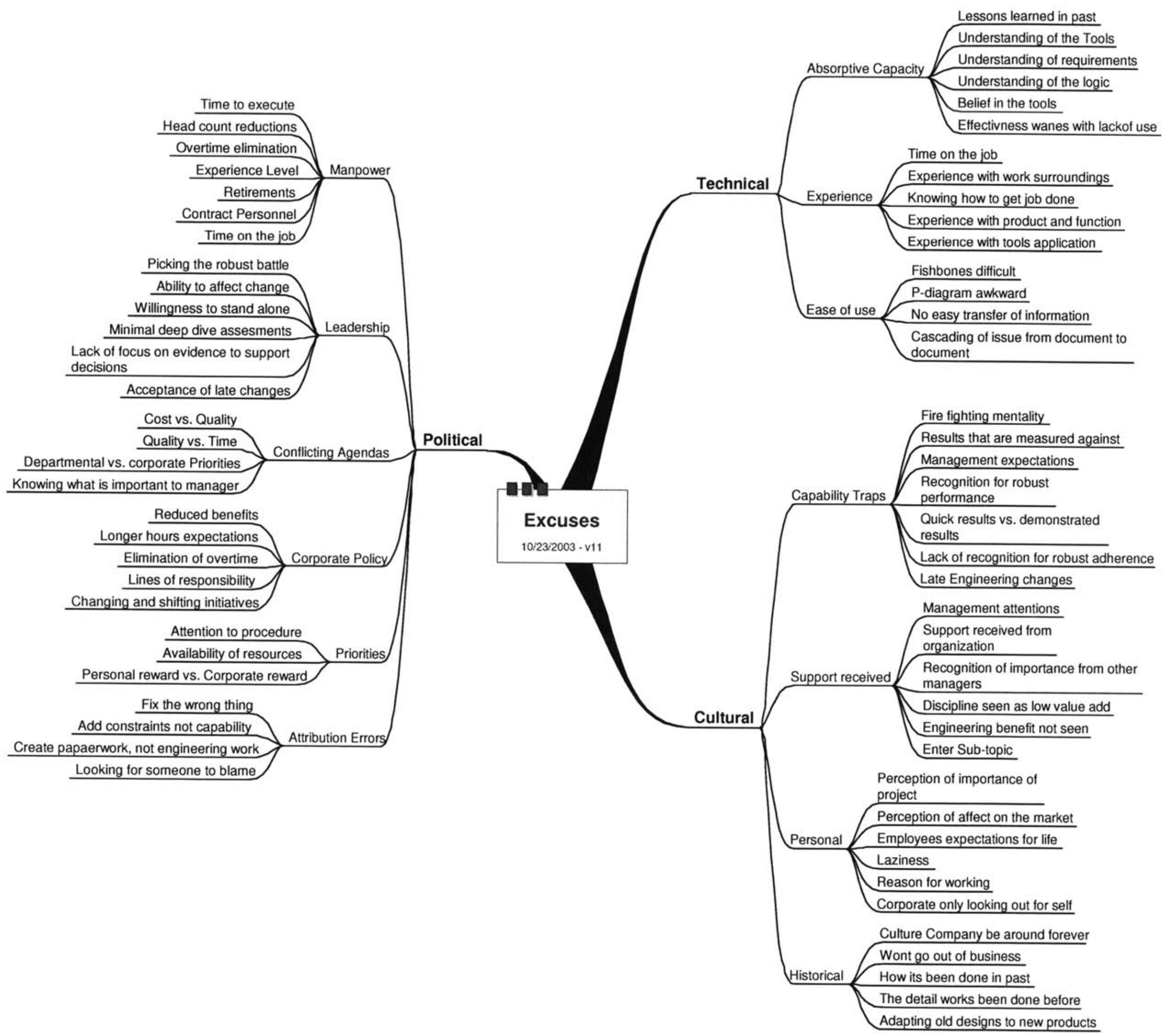

Figure 6-1: Excuses for Failure to Apply Robust Tools

6.5 Performance and Data Analysis

To generate needed data for accurate analysis of the state of the organization, a series of interviews were conducted and survey questionnaires sent out to specific areas throughout the organization. Interviews were conducted with management level personnel with responsibilities ranging from entry level supervisor up to vehicle powertrain director level. Survey questionnaires were sent to 42 engineers throughout the transmission design organization with equal emphasis put on forward model program and current model programs. Twenty seven engineering questionnaire responses were returned for analysis. In general, similar results were collected from all levels of the organization and throughout responsibilities in the organization.

6.5.1 Interview Questions and Interviewee Selection

Within the transmission division of powertrain, thirteen interviews were conducted in total. The interviewee schedule was established to ensure a wide range of job functions and responsibility levels. In general the organization and the interviews were divided by executive engineer. One executive engineer is responsible for current model applications and one executive engineer is responsible for future model applications. Current model applications are those systems which continue to utilize the same basic architecture which was initially launched in prior years, minor design revisions may be incorporated year over year. New model programs represent the engineering design activities which occur to create a substantially new architecture prior to a new program being launched. Both executives were interviewed as well as their boss, the Chief Engineer. Also interviewed of the executive level was a chief powertrain engineer with responsibility over complete powertrain systems over multiple vehicles as well as a vehicle specific powertrain engineering manager. Within the transmission organization, five interviews were conducted with management having current model only responsibility, four interviewees had forward model only responsibility, and the remaining four had a mix of both. The two interviewees with powertrain responsibility had high level responsibility outside of the transmission only field which gave a perspective of performance of other areas of the company. The questions used in the interviews are shown below. ***Bolded*** questions were asked both in the management interviews and in the engineering questionnaires.

ENGINEERING ROBUSTNESS INTERVIEW QUESTIONS

For the purpose of the interview,

Robust tools for new programs: Audited item Requirements

Warranty improvement: A-B-A type testing, Component swap process, root cause verification fishbone diagrams, Is-is not, statistical methods, RDM, in general, high confidence engineering

1. Describe your position
2. Are the projects you review typically new product development following FPDS timing?
   a. If they are new programs, what process (meetings, design reviews, checkpoints) do you use to enforce robust engineering procedures?
   b. How are shortfalls in the complete tool usage (p-Diagram, boundary diagram, etc..) addressed?
   c. Do you run into issues with enforcing tool usage? Why? How do you proceed?
   d. Do other priorities hamper your ability to enforce robust engineering processes? How?
   e. How do you capture the knowledge generated during these earlier design stages for possible future issues?
3. For the projects your involved with that are Warranty/Durability improvement actions,
   a. What process do you typically follow to implement improvement actions (Weekly problem meetings, monthly design reviews,
   b. What drives change, how do you select issues?
   c. What is the typical format for projects you review?– 8-D, 6-sigma, high-mileage
   d. Any concerns about the required format? Is it effective in enforcing robust tool usage?
   e. ***What percent of projects you review fully utilize robust tools?*** How do you proceed?
   f. Do you run into issues with enforcing tool usage? Why?
   g. For projects you are not satisfied with the level of robust process usage how do you manage the risk?
4. ***In what time frame do you feel the use of robust tools has increased (1, 2, 3, 4, 5 yrs)?***
5. ***What has been main driver for the increased usage?***
6. ***On a scale of 1-10 (10 outstanding) how do you rate your knowledge on "robust" practices?***
7. ***How do you rate your ability to enforce use of robust tools (1-10)?***
8. ***At what level of robust tool knowledge are managers overall? (1-10)***
9. ***At what level of robust tool knowledge are supervisors overall? (1-10)***
10. ***At what level of robust tool knowledge are engineers overall? (1-10)***
11. ***What are the primary reasons projects do not completely follow robust procedures?***
12. ***Do you think there is a general resistance to use robust tools? Why?***
13. For each of the 6 initiatives listed, how do you they will affect company performance in the 3 following areas:
    - The use of robust process
    - Company financial performance
    - Employee moral
        1. Increased engineering job requirement stability
        2. Robust tool performance Audits
        3. 6-sigma
        4. Mandatory, computer based training programs
        5. Engineering head count reduction requirements
        6. Material cost reduction requirements
        7. Other?

Figure 6-2: Management Interview Questionnaire

6.5.2 Engineering Questionnaire

Below is the questionnaire which was sent to 42 engineers in various programs throughout the division. The purpose of the questionnaire was to gather key pieces of information very quickly from a larger sample size than what could be gathered through doing interviews alone. Some of the questionnaires were followed up with additional questions to get clarification or expand on some point. Twenty seven responses were received for analysis.

ENGINEERING ROBUSTNESS QUESTIONAIRE

For the purpose of the questionnaire,

Robust tools for new programs: Clean green audit items

Robust tools for MCR/Warranty improvement: A-B-A type testing, Component swap process, root cause verification, fishbone, Is-is not, statistical methods, RDM, 6-panel, P-diagrams

Please type your answer below the question and return the file. All answers are confidential.

1. What percent of projects you work on fully utilize robust tools?
2. What are the primary reasons you may not completely follow robust procedures?
3. Does management sufficiently encourage and support use of robust tools?
4. In what period do you feel the use of robust tools has increased (1, 2, 5 years)?
5. What has been the main driver for the increased usage?
6. On a scale of 1-10 (10 outstanding) how do you rate your knowledge on "robust" practices?
7. How do you rate your ability to influence the use of robust tools in others (1-10)?
8. How do you rate the average Manager's knowledge of robust practices? (1-10)
9. How do you rate the average Supervisors knowledge of robust practices? (1-10)
10. How do you rate the average Engineers knowledge of robust practices? (1-10)

Figure 6-3: Engineering Level Survey Questions

6.6 Common Survey/Interview Results

Two immediately evident finding, which will be discussed in in-depth in future reading were;

1) The difference in robust process applications between forward model and current model programs and
2) The high variability of robust tool application throughout the company.

Forward model programs which have detailed gateways and well timed requirements report a higher level of adherence to robust processes than current model improvement actions or material cost reduction actions. Likewise, through the interviews with high level management which has responsibility for multiple facets of the company, a marked difference is apparent in the use of robust processes from different divisions of the organization. This variability in progress even further complicates the change leadership initiatives required to ensure successful implementation. Process changes required at 70% implementation can be significantly different for organizations operating at only 20% implementation.

6.6.1 Basic Interview/Questionnaire Results Analysis

Ten of the interview/survey questions were asked both of engineers as well as management, as depicted by the bolded questions in the interview questionnaire. Basic analysis of the performance of the overall organization will be performed first for these common questions. Analysis of the common question data will start with the question of "Why robust engineering tools are not used consistently throughout the organization". From table 6-D, the most common excuse given is time, or workload constraints which detract from the ability to put in the work required to perform the upfront robust engineering work. As was shown in the earlier hydraulic flow example in Section 4.4 the prior lack of use of robust tools can be a rather large contributor to the current time available to perform robust processes in new program initiatives. Lack of robust tool usage on current applications drives future workload through the implementation of future quality issues that will need high priority resolution.

Why Robust Tools Are Not Fully Utilized			
Rank	Issue	# Reponses	Percent
1	Time/Workload	28	50%
2	Value	12	21%
3	Seasoned Engineers	5	9%
4	Training	3	5%
5	Accountability	2	4%
6	Priorities	2	4%
7	Cost	2	4%
8	Resources	2	4%

Figure 6-4: Robust Tool Usage Excuses

Statistical analysis of the data does not show any significant difference between managers or engineers, forward or current model programs, in terms of the top reasons for why the tools are not used fully. Unfortunately, time is one of the nebulous excuses that provide an easy reason to explain incomplete performance. Studying how we budget or prioritize our time and why, is really required in order to fully understand what is driving the behavior which makes spending time on other work more valuable.

Based on the high rate of responses of time being a key contributor to poor usage of robust tools, follow-up questions were asked of a few of the engineers which provided initial survey feedback to better understand how time and workload are detracting from robust tool usage. The theory being that the engineers may be avoiding using robust tools due to the difficulty of their use and observed value being placed on other priorities. The follow-up interview question that was asked was "In the survey you listed time/workload as the main reason for not fully utilizing robust tools. What are the biggest time commitments you have that demand higher priority?" The three respondents that were asked the question all answered with "mostly just urgent day to day issues." One of the follow-up interviewees went on to give a recent example of how a typical day that was to be dedicated to data analysis of a robust project was diverted to other issues based on his supervisors urgent request.

> "We received a high priority request to provide a new test sample for a durability test that was to begin in the next week. There were several special test parts required to build the required unit. Since my boss put high priority on getting the job done myself, our technician and one other engineer went to work contacting the responsible component engineers to gather all the parts and establish priority in the system. Because of this upfront work we completed the test sample build in 3 days and had it ready well ahead of the required delivery date."

This particular example the job could have been performed by one person, with a slightly later completion date, but because of the relative ease and urgency of responding to this issue and the ability to participate in a high recognition opportunity three engineers were motivated to pitch in and show great teamwork to address the issue. The engineer went on to say:

> "I new I should be completing the data analysis, but it was easier to chase down the parts and it was what my supervisor had asked be done so I was meeting his needs. Eventually he will be asking for the data analysis results but hopefully I will have them done then."

In this example, most likely the data analysis will eventually be complete, but if urgent issues continue to push of the more difficult and time consuming tasks of robust engineering at some point the engineer will have no choice but to short-cut some of the required process. General avoidance of robust processes requires continued demonstration of value. While most likely the supervisor did not directly know what his request meant for future work, by making the urgent request he was demonstrating value for short term returns over longer term engineering and data analysis and providing the engineer a means to avoid the more difficult work of test data analysis.

OBSERVATION 5: General avoidance of robust processes due to the in-depth technical nature of their requirements requires continued demonstration of value by direct supervision.

Granted, there is a point where not all the work can be accomplished and most organizations strive to operate just above this point, so it is likely that needed work is cascading off of the top. The work that slides from the pile is that which is prioritized lower, or perceived to have less value. It is very interesting to note that the 2nd and 3rd leading reason the tools are not used is "value" and seasoned engineers. Seasoned engineers refer to those engineers with vast experience built up prior to implementation of robust tools who feel they know how to engineer parts and don't need the "paperwork" to prove it. These two excuses point to the level of attention robust tools are assigned. As one engineer stated:

> "For a high workload position, overseen by a responsible, professional engineer, high value work will typically be accomplished first. If the use of robust tools isn't seen as valuable to the engineer, or more importantly, his/her management, they will not be fully accomplished."

Unfortunately, until value to the organization as a whole and can be established, as will be demonstrated, enforcing usage will only result in cursory performance and inadequate compliance.

Accountability and priority as well as a few other contributors round out the list. In general these responses point to the need for a balanced workload coupled with demonstrated value and recognition for proper tool usage. Most engineers when asked reported a high level of satisfaction following implementation of a project they felt was robust, and contained demonstrated results. Following robust processes can shorten the feedback on engineering performance if preliminary testing is completed properly, successfully and with demonstrated improvement. Field data which is generated after significant delay then becomes only a confirmation data point instead of the final prove-out metric.

6.6.2 Management Support of Tools

In his book, Leading Change, John P. Kotter shows the value of vision and the necessity of short term wins to demonstrate value and encourage new initiative success. To determine if the disconnect comes from value or management attention all levels of interviewees were asked if management was giving the use of robust tools adequate priority. The results are shown in the table below:

Management Adequately Supports Robust Tools		
	# Responses	Percent
Yes	29	81%
No	7	19%

Figure 6-5: Management Support

Two possible reasons for the high positive response could be that either management is truly driving the change, or those responding feel that enough attention is being attributed, given the value of robust processes. To attempt to drive down this path a little further, when asked what the primary reason for increases in the use of robust processes, the overwhelming response was management initiative. The key to a management driven initiative such as this is to ensure that while management is driving the usage, they are doing so in an up-front manner that facilitates and encourages on-time application of robust processes. As one chief engineer aptly put it:

> "Applying robust processes after the design and all decisions are done is an empty process. If management is sitting back and waiting for results this initiative will never take off".

Why Experiencing Improvement			
Rank	Issue	# Reponses	Percent
1	Manager Initiative	16	32%
2	6-Sigma	11	22%
3	Audits	8	16%
4	Training	8	16%
5	Quality Focus	7	14%

Figure 6-6: Robustness Motivating Factors

Based on the responses it appears in general management is driving the value of robust tools and it is being recognized within the organization. A the results show, four of the five issues listed on Figure 6-5 above are positive, visionary, change leadership actions which will help foster understanding, demonstrate value and contribute to a positive change excepting culture. As is being demonstrated, anchoring the change in the organization depends on demonstrating value and achieving positive results. The audits on the other hand, depending on the methods used to introduce and perform them, run the risk of becoming a punitive system which forces blanket application despite misunderstood value. Based on interview feedback, it appears that the audits currently being performed have not fully demonstrated value or driven behavior conducive to learning or openness. As one manager of a forward model program put it:

> "The audits are definitely a big bat aimed at our heads motivating adherence, and we'll make sure we are adhering and do what we must to pass the audits, right or wrong."

A supervisor of a similar forward model program also stated:

> "We will fill out all the links and paperwork to satisfy the auditors, but with a blanket process like this and the inability of responsible engineers to judge the value for themselves, the quality of the work won't be what it could be... they are auditing for quantity, not quality because that is all they know. They (the auditors) don't have the technical expertise to understand the documents so they drill down through the linked documents to make sure every box is filled in, whether it is valuable to the design actions or not."

OBSERVATION 6: Based on interview feedback, it appears that the audits currently being performed have not fully demonstrated value or driven behavior conducive to learning or openness.

6.7 Current Organizational Assessment

To establish a baseline of the operating conditions of the organization a series of questions were asked around how various aspects of the organization are performing and when the real change began to emerge.

6.7.1 Time Since Awareness

One key aspect of implementing a new initiative into the organization is the time given for the new knowledge to be absorbed by the organization and time to recognize value. Accordingly, each group was asked about there perception of how long the use of robust tools has been encouraged or enforced. The forward model groups perceived robust tools were in existence for a longer period of time.

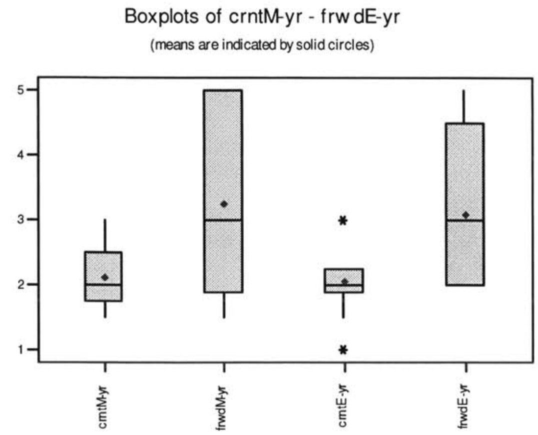

Figure 6-7: Years of Awareness – All Groupings

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers along the y-axis represents the variable which is being studied, in this case, years (yr).

Statistically, current model managers and current model engineers are equivalent to each other as seen in Figure 6-6. Forward model engineers and managers also have an equivalent opinion of time since awareness of robust tools. While there is higher variability in the forward model programs, some of this can be attributed to the time some of the engineers have been located on the new product programs. One of the new programs interviewed had only been in existence for approximately one year with several team members transferred with less experience in the area. The consistency in time aware of the tools fits very well with application of the tools which is occurring first in forward model programs. Gateways and engineering quality operating systems are driving the usage in the forward model applications. Average time since awareness for forward model engineers has, on average been 3 years. This compares to only two years of awareness for current model engineers. As shown below, performing a 2-

sample t-test of current and forward model engineers, we can see based on the p-value of 0.019 these results are statistically significant (a p-value less than 0.05 represents a statistically significant difference between the two samples) and there is a difference in the time of awareness between forward and current model programs.

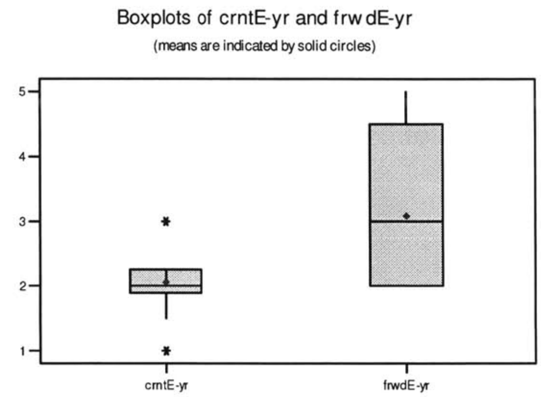

Figure 6-8: Raised Awareness, Current vs. Forward Model Engineers

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers along the y-axis represents the variable which is being studied, in this case, years (yr).

Current Model Engineers vs. Forward Model Engineers – Years Awareness Two-Sample T-Test and CI:

```
Two-sample T for crntE-yr vs frwdE-yr

N        Mean      StDev    SE Mean
crntE-yr  10       2.050      0.599       0.19
frwdE-yr  16        3.09       1.21       0.30

Difference = mu crntE-yr - mu frwdE-yr
Estimate for difference:  -1.044
95% CI for difference: (-1.899, -0.189)
T-Test of difference=0(vs not =): T-Value=-2.52
P-Value = 0.019 DF=24
```

Comparing management's perspective for years of tool usage, we don't get quite as much separation. While there appears to be a real difference in time, because of the high variability in forward model manager's responses the p-value higher than 0.05 which means the difference is not statistically significant. The high variability of the responses again could be a result of the time forward model supervisors have been in their new positions. Additional samples would be required to determine if the difference is truly significant. This factor could also be attributed to an overall roll-out to management level personnel which occurred at a similar time, thus introducing all management to the new requirements, prior to application on actual projects.

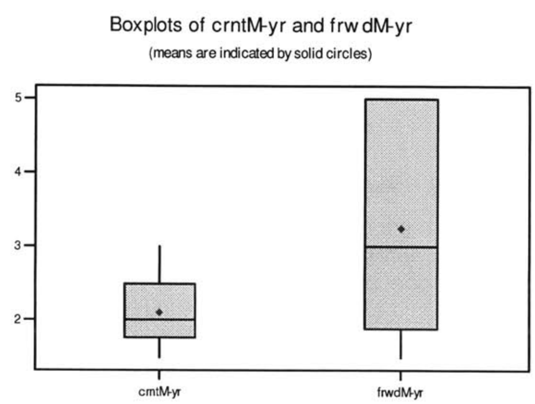

Figure 6-9: Years of Raised Awareness Current to Forward Managers

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers along the y-axis represents the variable which is being studied, in this case, years (yr).

Current Model Manager vs. Forward Model Manager – Years Awareness
Two-Sample T-Test and CI: crntM-yr, frwdM-yr

```
Two-sample T for crntM-yr vs frwdM-yr

          N     Mean     StDev   SE Mean
crntM-yr  9    2.111     0.546      0.18
frwdM-yr  6     3.25      1.47      0.60

Difference = mu crntM-yr - mu frwdM-yr
Estimate for difference:  -1.139
95% CI for difference: (-2.756, 0.478)
T-Test of difference = 0 (vs not =): T-Value = -1.81
P-Value = 0.130  DF = 5
```

OBSERVATION 7: Forward Model programs have been aware, applying, and been successful with robust tools and processes longer than current model programs.

6.7.2 Change Penetration

The second statistic we will analyze is the percent of projects reviewed which follow a robust process. For forward model programs determining percent of tool applications is fairly straightforward since a well documented process exists to control the gateways the project status. For quality improvement actions or material cost reduction based engineering changes with no real cadence the exact steps to follow and when they should be performed was slightly less clear. In addition, the tools or process required to follow on a current model initiative is somewhat variable based on the level of design change or failure mode.

Results are first divided according to forward or current model responsibility. Figures 6-9 and 6-10 are shown comparing the percent of projects completed fully utilizing robust tools based on management's and engineering perspective. As the results show, forward model management believes the usage of robust tools is extremely high while forward model engineers reported actual usage is somewhat lower and much more variable. Current model management puts actual tool usage at a lower level and are more in-line with engineers actual performance. While there is some overlap, the difference in perceived usage is statistically higher for forward model engineers. The same naming convention is used for this series of graphs and statistical analysis as in the study of time since awareness. Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers represents the variable which is being studied, the y-axis in this case percent of projects completed with robust tools (prcn).

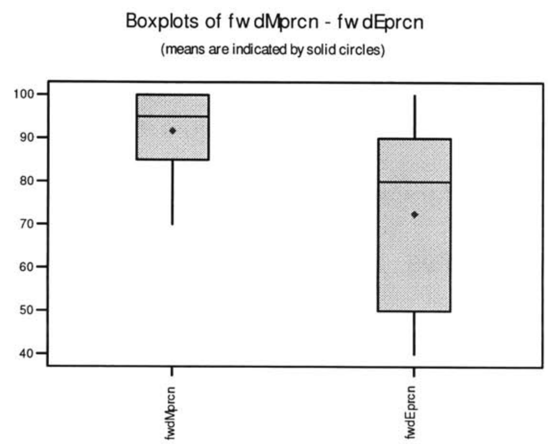

Figure 6-10: Forward Model Percent Robust Process

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers along the y-axis represents the variable which is being studied, in this case, percent (prcn).

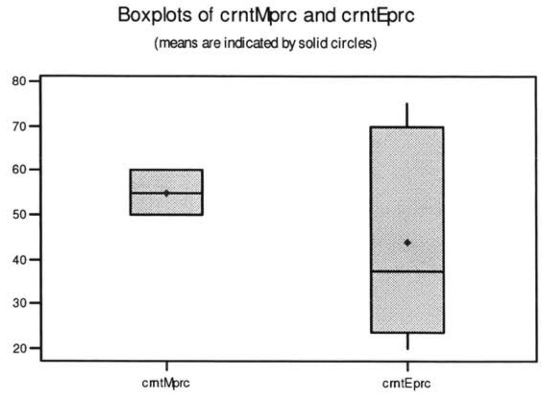

Figure 6-11: Current Model Percent Robust Process

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of numbers along the y-axis represents the variable which is being studied, in this case, percent (prcn).

In order to determine if any of the apparent differences are statistically valid several series of 2-sample t-tests were conducted. The first study compares the percent of projects current model engineers complete using robust tools to those of their forward model counterparts. Based on a P-value of 0.006 there is a statistical difference between applications of the tools in forward model than current model applications with forward model programs being higher.

Current model engineer vs. Forward model engineer
Two-Sample T-Test and CI:

```
Two-sample T for crntEprcnt vs fwdEprcnt

            N      Mean      StDev   SE Mean
crntEprc   10      44.0       23.2       7.3
fwdEprcn   15      72.7       21.6       5.6

Difference = mu crntEprcnt - mu fwdEprcnt
Estimate for difference:  -28.67
```

```
95% CI for difference: (-48.03, -9.30)
T-Test of difference = 0 (vs not =): T-Value = -3.11
P-Value = 0.006  DF = 18
```

Comparing forward model engineers to forward model managers there is a statistically significant difference in the reported use of the tools by the engineers and their management's perception of use of the tools.

Two-Sample T-Test and CI:
Forward Model Manager vs. Forward Model Engineer

```
Two-sample T for fwdMprcnt vs fwdEprcnt

           N     Mean    StDev   SE Mean
fwdMprcn   6     91.7     11.7       4.8
fwdEprcn  15     72.7     21.6       5.6

Difference = mu fwdMprcnt - mu fwdEprcnt
Estimate for difference:  19.00
95% CI for difference: (3.43, 34.57)
T-Test of difference = 0 (vs not =): T-Value = 2.59  P-Value = 0.020  DF = 16
```

As was shown in Figure 6-9, the forward model manager's perspective shows a much higher impression of tool usage than is actually being performed at the engineering level. Given the interview conditions and desire to show high tool usage, these results may be more wishful reporting than a gap in true understanding of the work that is being performed. This is supported by one forward model manager's admission that while they are following the process, the quality of the work may not be as high as it could be.

Comparing current model engineering, in Figure 6-10, while the percent usage is significantly lower than the forward model programs, based on a p-value greater than 0.05, there is not a statistical difference between management perception of the application of robust tools and the reported usage by the engineers. In this case, since audits and requirements are not as stringent as in forward model applications, management level respondents don't risk poor perception by giving a realistic response.

Two-Sample T-Test and CI:
Current Model Manager vs. Current Model Engineering

```
Two-sample T for crntMprcnt vs crntEprcnt
N        Mean       StDev   SE Mean
crntMprc   8      55.00       5.35        1.9
crntEprc  10       44.0       23.2        7.3

Difference = mu crntMprcnt - mu crntEprcnt
Estimate for difference:  11.00
95% CI for difference: (-5.87, 27.87)
T-Test of difference = 0 (vs not =): T-Value = 1.45 P-Value = 0.177 DF=10
```

6.7.3 Knowledge Absorption

The last series of questions covered in both the interviews as well as the questionnaires focused around the perceived knowledge level of the organization. Each respondent was asked to rate their personal knowledge level as well as local managers, supervisors and engineers. A follow-up question was also asked to determine each respondent's perceived effectiveness in influencing others to use robust processes. The results are displayed in the box plots shown below.

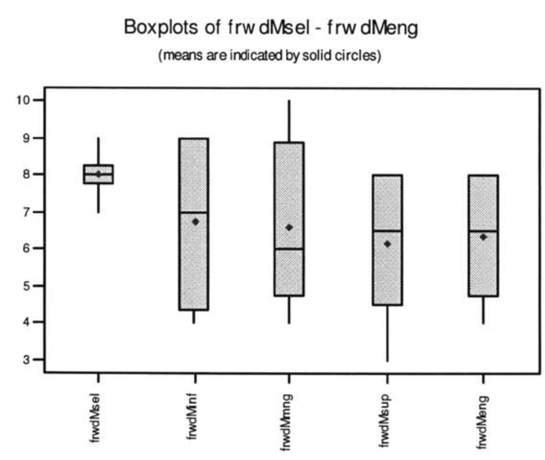

Figure 6-12: Forward Model Managers Ranked Knowledge

Naming convention used for the graphs is as follows: the first three letters represent either Forward Model Programs (fwd) or Current model programs (crnt). The middle capitalized letter represents either Management (M) response or Engineering (E) level response. The final series of letters represents the variable which is being studied, in this case, self, influence, manager, supervisor and other engineer). The y-axis is the scaled ranking from 1-10. Same convention applies for the next 3 plots.

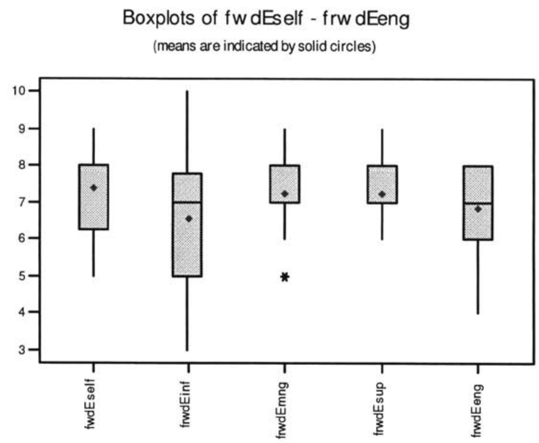

Figure 6-13: Forward Model Engineers Ranked Knowledge

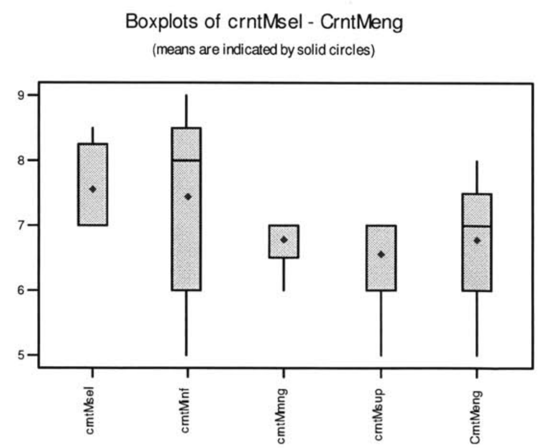

Figure 6-14: Current Model Managers Knowledge Rankings

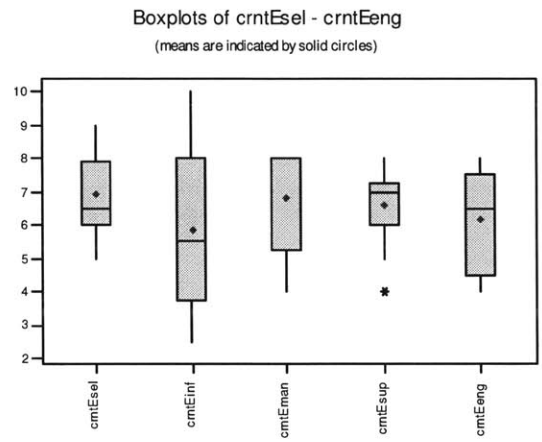

Figure 6-15: Current Model Engineers Knowledge Rankings

In general, the responses were equivalent for all levels of the organization. Even performing paired t-tests to determine if individual respondents showed any statistical difference did not reveal any significant anomalies from one area of ranking to the next. The only real significant difference is the difficulties, as shown by very high variability, some respondents reported in influencing others to implement robust processes.

OBSERVATION 8: Knowledge level in the organization is consistently good with average rankings at about a 7 with experts being a 10.

6.8 Conclusions - Current State of the Organization

Based on the combined survey and interview results the knowledge level and acceptance level of robust tools is at a respectably high level. Management in all cases is seen as driving the initiative and providing the value for increased robust process applications. There still remains some shortfall in the required application of tools and additional metrics are likely required to drive full utilization of the tools. Forward model programs which have been required by the organization to utilize robust tools for a longer period of time show a higher level of understanding and higher usage level. The checkpoint process which is used regularly in the forward model applications is attributed as the primary reason for the increased awareness and usage. Current model applications do not require the same checkpoint or gate approvals for engineering changes, as a consequence, a lower level of awareness and application is reported.

OBSERVATION 9: Current model applications are lagging forward model programs in the use of robust tools due to a lack of quality gateways for engineering change approval.

7 CHAPTER 7: ADDITIONAL CHANGE INITIATIVE ANALYSIS

7.1 Organization Structure and Conflicting Agendas

The demands of the market make it impossible to pursue only one change initiative. As we have been theorizing, typically an employee, be they management or engineering, will support the initiatives which provides him/her the best value. Value in this case is challenging to define since each person has differences in what is perceived as valuable. Value can be defined as anything from time away from work with family, to the ability to contribute to company success to the best of their ability. Support for the initiative will be given depending on if the initiative drives the most value for the employee. For the purpose of this study we will assume for most consciences employees the initiative that defines value is the initiative that provides the most positive recognition from superiors without requiring excessive time from personal interests.

7.2 Impact Analysis of Change Initiatives

Studying alternative change initiatives provides insights to two key areas; first by studying the acceptance and method of implementation of alternative actions we can begin to understand effective change management for this organization. Second, each additional initiative can affect the cultural acceptance and willingness to internalize robust processes. Interviewees were asked to rate the impact; positive, negative or neutral, each initiative has on three separate factors; 1) Use of robust tools, 2) Company performance, and 3) Employee morale. The results are shown in the following sub-sections.

7.2.1 6-Sigma

The 6-sigma is the initiative most related to implementation of robust processes across the organization. While 6-sigma is intended for a highly trained small sub-group within the organization, robust tools are an expectation for the whole company. The 6-sigma program was implemented approximately 4-years ago. Through the use of demonstrated short-term benefits, and upper level management driven expectations 6-sigma has become a recognized asset to nearly everyone interviewed. Comments from those directly involved were showing a drop in morale around the 6-sigma process due to recent increases in the auditing of the process and financial results. Since the auditing is based primarily on financial performance the financial emphasis is detracting from the apparent concern for the quality, customer impact or longevity of the project. Early positive opinions of 6-sigma and opinions of those not directly involved were based primarily on the impression of 6-sigma making a positive improvement to customer satisfaction. It will be interesting to see if the positive opinions continue as auditing and financially based results continue to be the metric used for determining 6-Sigma program success.

Figure 7-1: 6-Sigma Initiative Interview Results

6-Sigma	Negative	Neutral	Positive	Comments
Robust Tool Usage	0%	0%	100%	Increase statistical knowledge Best robust tools supporters Demonstrated benefit
Company Performance	0%	8%	92%	Data supports benefits Depends on behavior driving
Morale	8%	33%	58%	Becoming part of culture Rules and bureaucracy becoming prohibitive

7.2.2 Ongoing Robust Process Audits

One of the methods recently deployed to enforce the use of robust tools is audits of new model programs at each major milestone or checkpoint. The results of the audits are reported to upper management and teams not complying are noted and dealt with accordingly. The benefit of the audit to management is it gives them a number which can be held up and compared, a simple metric, just like dollars saved to judge performance against. Unfortunately, as in the 6-sigma initiative, the addition of audits to enforce the use of robust processes appears to generate the same negative impact in morale and acceptance of the initiative. Interview respondents have demonstrated the impression that rather than allowing the use of robust tools to be about engineering good, high quality reliable parts and systems, using robust processes is now about filling out the paperwork to pass the audits. This message comes through pretty clearly in the results in Table 7-B. The "use" of robust tools is way up, the benefit is neutral and effect on morale is 100% negative. As in the 6-sigma initiative, morale in new model programs was actually increasing with the initiation of robust processes until the new auditing process was initiated.

Figure 7-2: Robust Tool Usage Check Point Audits

Ongoing Robust Process Audits	Negative	Neutral	Positive	Comments
Robust Tool Usage	8%	8%	83%	Can do paperwork and get by Too much unwanted exposure if don't comply
Company Performance	25%	50%	25%	Set-up as punitive doesn't add to motivation or drive to do better.
Morale	100%	0%	0%	Blanket application - non-value added Audits are currently done extremely poorly

7.2.3 Engineering Stability Programs

The next initiative studied is one implemented in an attempt to increase position stability within the engineering communities in order to increase technical proficiency. Corporate culture had progressed to the point where technical depth was perceived as valued. The predominate perception had become that in order to succeed with in the organization a new position must be acquired every 18 months in order to develop a well rounded resume. Becoming to technically proficient or valuable in one area appeared to detract from an engineer's desirability because of focused knowledge. Engineering stability programs are used to promote the value of becoming technically proficient and knowledgeable in a subject matter. In general the impression of this program which is less than a year old has been extremely positive. Encouraging results are seen both in the anticipated use of robust tools and improvements in company performance due to well needed increased technical knowledge. The only detractors from the program were those that were concerned that when it did become time for a rotation to a new position it may be more difficult if the pendulum had swung too far and now prevents rotation. This is a third example of the desire of the organization to engineer good high quality technically confident parts – given the proper opportunities.

Figure 7-3: Engineering Stability Program

Engineering Stability	Negative	Neutral	Positive	Comments
Robust Tool Usage	0%	0%	100%	Increased technical depth, ability to see bigger picture, increase use of more complex tools, increasing absorptive capacity
Company Performance	0%	0%	100%	
Morale	0%	36%	64%	Some like new job challenge Adds to accountability if have to live with product longer Need rewards around stability

7.2.4 Performance Review Required Training

The next initiative questioned was the requirement of ongoing training. On-line training courses are available to all employees to help foster the growth and usage of various problem solving and engineering tools. Due to time constraints from workload requirements and other excuses, engineers were not sufficiently utilizing the available training. Management edict recently required that 3 basic training modules be complete by year end or lack of compliance would be noted on performance reviews. Completion of 5 training courses has also become mandatory for all future promotions. In general, the emphasis put on training was seen as extremely positive. At issue though was the continued expectation for high levels of workload, in conjunction with the additional time required to complete mandatory training. The testing required demonstrating proficiency with the new tool was perceived to be more focused on the terms and buzzwords than actual knowledge relevant to solving customer based issues. In the end, because of the tight time constraints, just like with process audits, the training will likely be completed, but unfortunately the actual impact and benefit of the training may not be seen due to the inability to apply the training to the job at hand. While management emphasis is required to complete the training, it may be driving completion to satisfy the requirements.

Figure 7-4: Mandatory Training Programs

PR Required Training	Negative	Neutral	Positive	Comments
Robust Tool Usage	0%	25%	75%	Adds to knowledge base
Company Performance	8%	83%	8%	I've rejected change notices based on information I've learned is required through the training.
Morale	67%	33%	0%	Lacks usefulness because of edict to do now - minimal actual learning and application

7.2.5 Head Count Reductions

In order to address the financially uncompetitive position the company has found itself in, two actions are being pursued. The first one addressed here is head count reduction actions. Early retirements and contract personnel lay-offs were used to reduce the overhead associated with carrying a larger staff. These actions are required to reduce short term expenses in order to focus money on needed product improvements. Unfortunately, reducing head count in a time of added product development work means heavier workload for those that are remaining. While the use of robust tools is recognized to benefit long-term workload, the current use of the tools adds to the requirements now. Head count reduction were seen as extremely negative for the use of robust tools, neutral for company performance and generally negative for company morale. One interesting perspective given by executive level manager, and supported by a corporate level survey, was morale increased despite head count reduction actions during this time period. The perspective offered to explain the increase, focused around engineers performing truly value added work and elimination of low performers who detracted from positive contributions.

Figure 7-5: Head Count Reduction Requirements

Head Count Reductions	Negative	Neutral	Positive	Comments
Robust Tool Usage	92%	8%	0%	Added workload something has to give Added workload might drive usage in order to do things better
Company Performance	42%	33%	25%	Will hopefully reduce costs so we survive, may have negative long-term impact due to lost expertise and workload related quality issues
Morale	75%	8%	17%	Getting rid of dead wood so everyone feels as though they are contributing more equally, Higher sense of purpose, common goal. Just more work to go around.

7.2.6 Material Cost Reduction Actions

The final action management interviewees were requested to evaluate were material cost reduction requirements on existing products. When asked about the use of robust tools for these quality critical engineering changes, most interviewees felt these cost actions would detract from the use of robust tools due to the increased workload. This is a very unfortunate opinion given that in order to ensure long-term profitability these engineering changes should be performed in conjunction with, and actually drive, the use of robust tools. A few positive comments did support that sentiment, but the reality of the work being done did not appear to be robust. Interviewees did feel that if the changes being implemented were high quality changes the long term effect to the financial performance of the company would be positive. This sentiment though was tempered by the concerns that the short-term increased workload and heavy cost focus, may hurt overall morale. There was a general opinion that the cost requirements had been well communicated and the impacts to the company if cost requirements were not met were well understood. Despite a general discontent with requiring the actions, overall support seemed positive.

Figure 7-6: Material Cost Reduction Requirements

Material Cost Reductions	Negative	Neutral	Positive	Comments
Robust Tool Usage	42%	33%	25%	May force more experience and application of the tools Able to pick projects to ensure quality implementation and highest cost impact
Company Performance	17%	8%	75%	Short term better, long term questionable, but hopeful
Moral	67%	33%	0%	Shows valuing cost over quality or product Increases workload with reduced headcount.

7.3 Observations of Change Initiatives

Studying the benefits and short-falls of other change initiatives can give a positive indication into what could most benefit the internalization of robust processes. Positive results are consistently reported when the company is felt to be valuing quality over quantity or customer satisfaction over cost, even when it means some short-term personal sacrifice. In general, it appears change initiatives are well received until the desired performance does not match the corporate objectives. Organizational response at that time has consistently been to add constraints to the system through the use of checkers, trackers and auditors. The use of these punitive methods fails to address the root cause for failure to meet initial corporate objectives and as a result typically do not add to the performance of the organization. While they do add a measurable that can be judged, the measurable typically chosen is not one that drives the behavior which will deliver the true end objective of the organization – the highest quality product at the lowest cost.

OBSERVATION 10: Management edicts without shared vision are not well supported and don't add to the overall health, or quality of the organization.

OBSERVATION 11: Despite recognized value to the customer, product development does not appear to fully utilize robust processes unless the value is recognized by the organization as a whole.

OBSERVATION 12: Verification of use of robust processes is a difficult, detailed and technical job that is of no value when completed after-the-fact. In order to be performed properly, the engineer responsible must find personal value in completing the process.

8 CHAPTER 8: DYNAMICS OF CHANGE INITITIVES IMPACT

8.1 Systems Dynamics Model Introduction

The final step of this analysis is to simulate some of the key factors that drive engineering workload, and then simulate some of the initiatives which will affect the quality of work being performed. A systems dynamics model was created to perform this analysis. The models developed below are based on a much larger model developed by Dr. James Lyneis, (JMLyneis@wpi.edu) Professor of the Practice, Worcester Polytechnic Institute. The first step of the model involves engineering workload, and the creation of re-work, or future quality issues. The second step adds an additional model section which represents incorporation of the Engineering Stability Program. This portion is used to demonstrate the effect maintaining longer-term job responsibilities can have on engineering productivity and quality of work performed. A third section is then added to demonstrate the importance of training in robust tool usage and the effect delaying or accelerating training can have on quality and quantity of work to do within the organization.

8.2 The Rework Loop

The model is created around the manner in which work is performed and generated. Using a single program model concept, engineering staff is established based on an initial, finite amount of work which needs to be complete. Rate of work completion (work truly completed and completed properly) depends on the productivity of the engineers performing the work and the quality of the work performed. Low quality work results in future re-work which is typically unaccounted for in initial staff requirement levels. This is due to the fact that while the work is believed to be completed, in actuality it resides in a pool we will label “undiscovered rework”. This undiscovered rework will resurface at some future date as new additional workload, workload that must be completed typically in a very high priority manner. A second factor that is adding to future workload comes from program changes and new corporate initiatives. The same work/rework cycle applies to the discovered rework and late program changes – some work will be completed properly and some will result in additional rework.

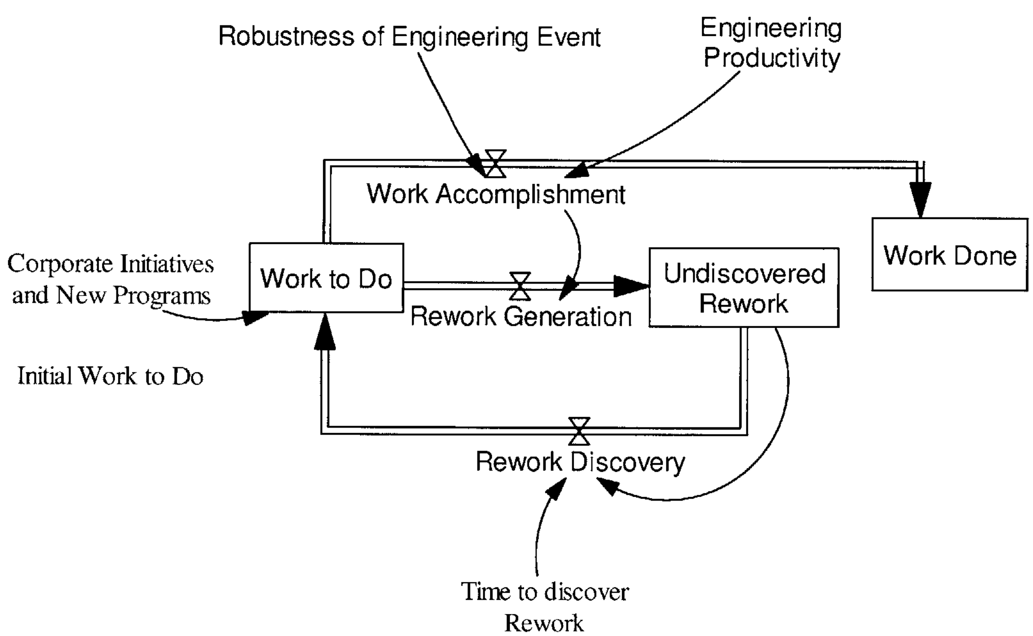

Figure 8-1: Rework Generation Loop

If the incoming work (both original and rework) exceeds the quality output level of the engineering staff the engineering organization can enter into an ever increasing workload environment without ever really accomplishing or fixing the product. Examples of this can sometimes be seen in existing products which seem to have an endless supply of quality issues for the engineering staff to resolve. In a non-robust organization the continuous churning of mediocre engineering changes creates an ongoing supply of future quality issues that can keep the organization working for years to come.

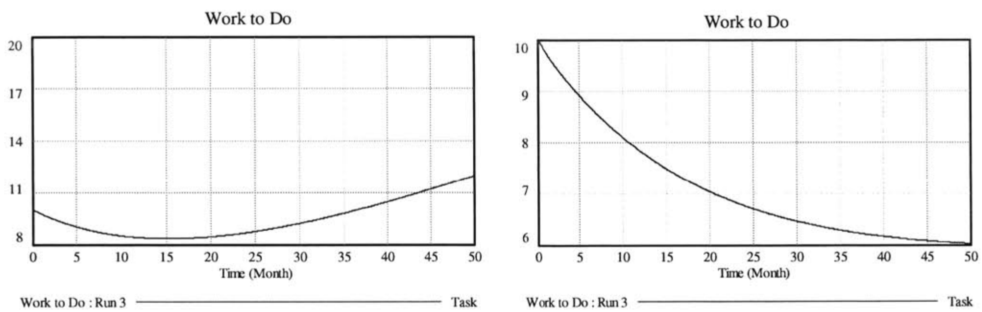

Figure 8-2: Plots of work to do utilizing a 0.75 Robustness Factor demonstrating future work increasing vs. 0.90 Robustness Factor with continuously declining workload.

For a lean, balanced workload organization, the continual occurrence of re-work can drive the organization into an upward spiraling workload as new work requirements continue to come in and prior quality issues return. Future workload can only be controlled by adding staff, or increasing the quality of the initial work performed. Given the extremely tight manpower restrictions most organizations are currently operating under, adding personnel is highly unlikely. The solution must be focused around the quality of the initial work performed.

The other variable available in this model which will affect the work completed is the productivity of the engineering organization. As was demonstrated by the surveys on the engineering stability program, maintaining engineers in current positions in order to increase technical proficiency will increase their productivity. Performing a similar analysis as was done above with robust tools, if we increase the productivity of engineering from 0.75 to 0.9, we can see that work to do initially decrease as the engineers complete tasks more quickly. However, after 25 months, the workload starts to climb since the quality of the high workload was not high enough to prevent excessive re-work.

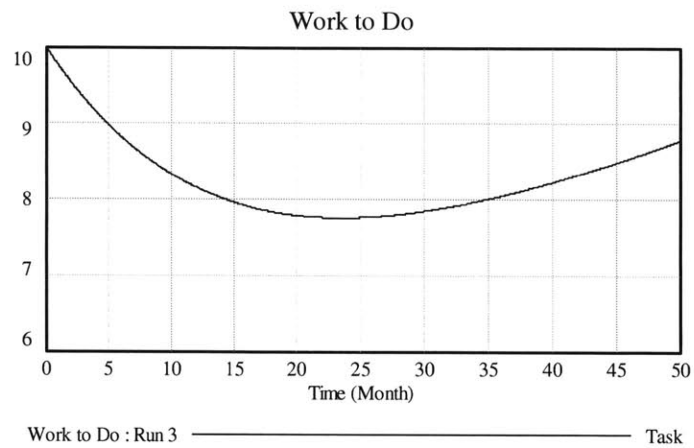

Figure 8-3: Workload Generation with High Engineering Productivity

8.3 The Engineering Stability Loop

As was shown in the model above, there are two main factors which affect the amount of the work actually accomplished; first is the engineering productivity and second, the robustness or quality of the engineering work performed. Both factors effect actual work output and quality of work performed. In order to demonstrate some of the dynamics contributing to productivity an engineering rotation model was added to the rework model. The ESP model assumes that there is no new hiring of employees due to the tight financial times, but that rotation of responsibility is still possible. The model is based on the assumption that experience with the parts engineered will result in higher quality work and faster paced work. As an example, a new engineer to a component will require additional training on the component or use of reference material in order to determine part function and required test procedures. This learning process will prolong the engineering event and reduce work output. In addition, most often there are lessons learned or design changes made in the past that may not be adequately captured in design guides or other locations. Only through experience is the engineer able to recreate some of the knowledge that isn't captured in design documentation. All too often, that experience comes at the expense of program timing, or even worse, customer quality.

The ESP model is based first on the willingness of the organization to rotate the work staff. If the organization is unwilling to rotate staff, then over time all staff becomes experienced and performing at a similarly high level. This high level of performance can deteriorate some if a portion of the staff becomes disheartened by there inability to attempt new challenges. If the organization is willing to rotate staff, the previously experienced engineer now becomes new staff to the new organization. The experience level of the new staff is constantly increasing over the course of the year until the engineer becomes experienced staff. Time to gain experience can be variable depending on the complexity of the job and the habits of the engineer. Overall productivity of the staff is dependent the ratio of new to experienced staff. This ratio will determine the overall work output. But, since in-experienced staff also has the higher possibility of creating quality issues, new staff also decreases the robustness of the engineering event. Even an engineer that is fully trained in robust tools has the possibility of making an error if incorrect assumptions are made about part requirements or performance. In the model, each rotation is assumed to bring the engineer all the way back down to “new staff” engineering level in terms of part experience. In reality, each rotation does bring experience level that should at least improve initial productivity at the new position even if the risk for less robust engineering performance still does exist. A more complex model could have relative productivity affected by the number of rotations experienced. Figure 9-3 below shows the addition of the engineering rotation model.

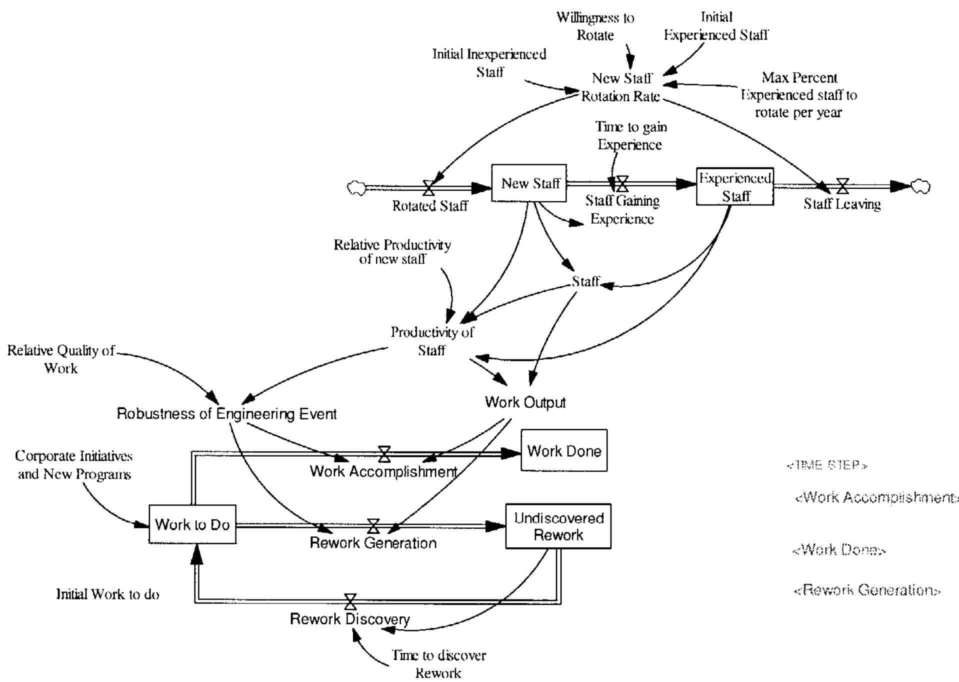

Figure 8-4: Engineering Stability Simulation

Comparing the affect of willingness to rotate staff to a very low willingness we can see the dramatic affect on amount of work to do. The percent of rotation is only valid for this model and is not meant to be an actual organizational objective.

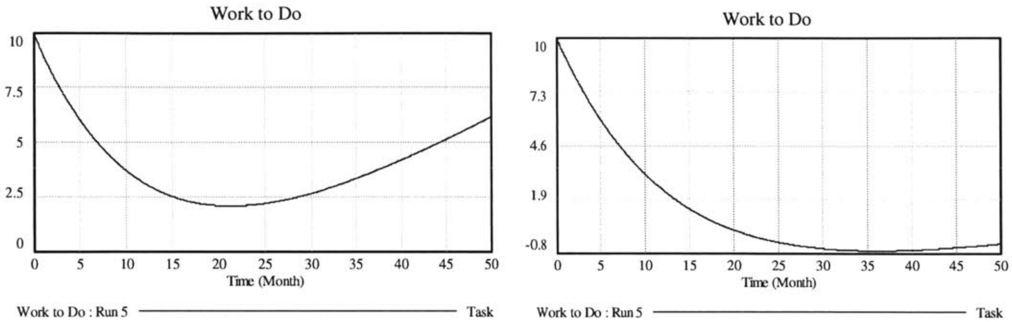

Figure 8-5: Willingness to Rotate Staff - 10% rotation annually vs. 2.5% annually.

OBSERVATION 13: Increasing engineering position stability will increase engineering proficiency and work output but may not sufficiently improve quality without increasing usage and application of robust processes.

8.4 The Training Priority Loop

The final segment of the model to be added and analyzed is the training module. The structure of the training segment is assembled much the same way as the experience module, with the exception that willingness to train is dependant on the workload of the organization. If the organization is in an upward trending workload condition, the willingness to train is decreased, in an attempt to direct resources to completing the required work. The other significant difference is that training is a skill that remains with the engineering despite job rotation. Once trained and experienced in robust tool usage, the knowledge gained continues to contribute to higher quality output independent of the job being performed. The rest of the training section model is essentially the same as the engineering experience model. Once trained, there is a time delay until the engineer becomes completely proficient in the use of the tools. Depending on how proficient the overall staff is determines the robustness of the engineering event.

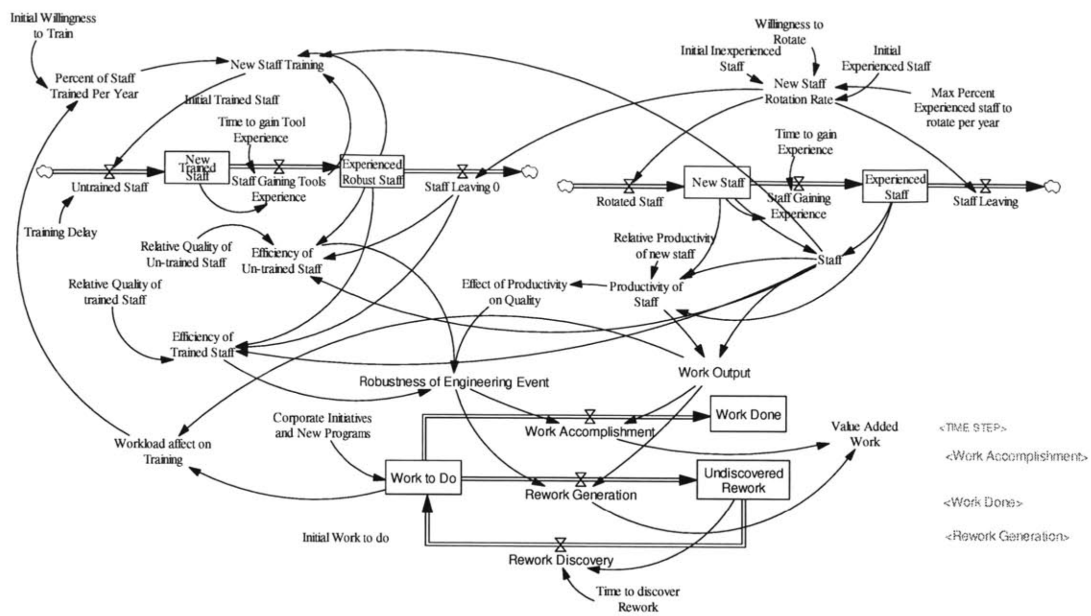

Figure 8-6: Training Model

Analysis of the total model will first start with a comparison of the effect of beginning with a untrained staff, with a low willingness to train compared to having a completely trained staff at the onset of the project. With a completely trained staff, the workload is constantly decreasing as the incoming work is less than the high quality work being performed.

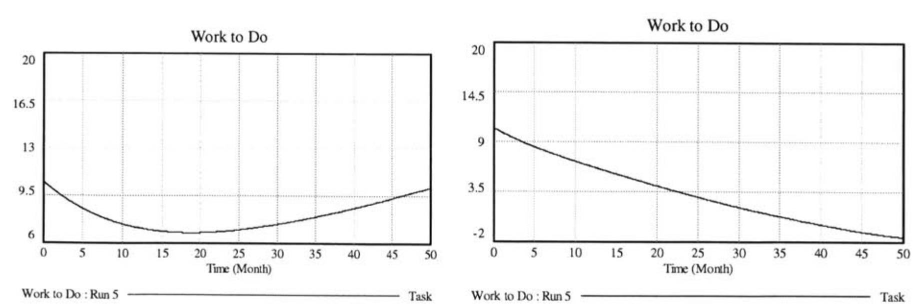

Figure 8-7: Percent of trained staff, 0% with low willingness to train vs. fully trained

Next, a comparison of the effect of training one percent of staff annually versus a willingness to train twenty percent of the staff annually was performed. The same initial decrease in workload is seen through the first fifteen months as the work believed to be complete gathers in the undiscovered re-work bin. After about 15 months in the application with a low willingness to train, the workload begins to climb faster than it can be completed and the organization enters an ever increasing spiral of rework generation exceeding the ability of work to be complete. This increasing workload spiral is not observed when the willingness to train is set to 20% annually. In this case, after 15 months 20% of the staff is fully trained and experienced and the overall quality of the organization has improved to the point where workload does not exceed output. Again, these percentages are used for demonstration purposes for this model. Actual training levels for the organization should be established based on need.

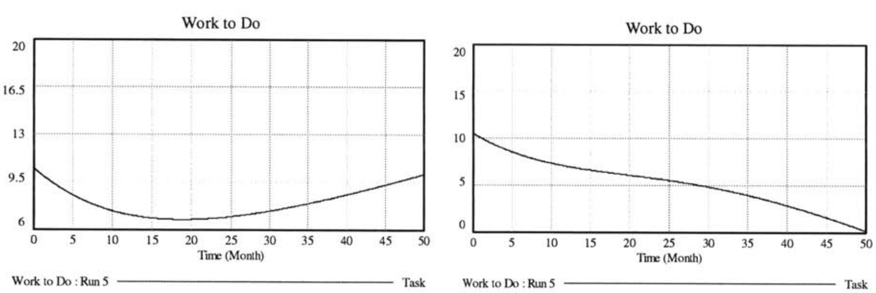

Figure 8-8: Willingness to Train, 1% trained annually in robust processes vs. 20%

Both previous studies were completed with a fixed level of training annually, to closer simulate actual corporate performance, a sensitivity of willingness to train was added based on the workload of the organization. The chart below demonstrates the workload levels when the organization allows higher workload or other initiatives to affect training plans.

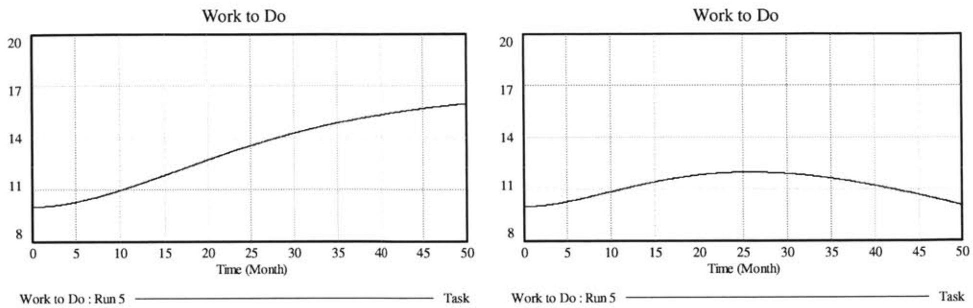

Figure 8-9: Workload Effect on Training and Resultant Rework level Requirements

As can be seen on the chart to the left, allowing workload to effect training just exacerbates the workload problem. The quality output of the organization and the minimization of future rework depend on quality work upfront. Without allowing or requiring training despite the workload, the organization may again enter an increasing spiral of regenerative workload.

OBSERVATION 14: Maintaining robustness process training despite financial or workload pressures will result in reduced future workload and ability to reduce future engineering headcount due to lower rework requirements.

9 CHAPTER 9: PERFORMANCE MEASUREMENT AND CONFLICTING AGENDAS

9.1 Performance Motivation

Establishing the motivating factors required to generate acceptance of any new initiative is one of the central challenges of implementing change. Evaluating the initiatives in the previous chapter gives some indication of the success and acceptance of prior change initiatives and the motivating factors that drove their acceptance. The observations generated based on prior change initiative results suggest one possible way of increasing use of robust processes is to make sure performance measurements and objectives are in line with the use of robust tools. The objective of product development has to be to deliver the highest quality, lowest cost product on the market. Delivering robust tools is not a customer based objective for product development. Robust tools, much like Lean initiatives are a process, a tool box of enablers that allow delivery of the end objective. Auditing for the use of tools only provides a measuring stick for the process used, not for the end product object – high quality low cost parts.

The original roll-out of the 6-sigma initiative provides an example of alignment of these objectives. Original implementation of the 6-sigma program 3 main objectives; deliver a high quality training while maintaining the integrity of the program, quickly develop the knowledge and capability of the black-belt to a critical mass level, and resolve 3-4 customer need driven projects with a specified average cost savings per year. Emphasis at the early stages of 6-sigma implementation was focused on the initial two objectives based around the knowledge and capability of the blackbelt.

Project selection was based on the projected financial savings of the project and annual objectives were established. However, at the early stages the emphasis remained on quality of the program. Measurables for direct engineering management were based more on providing engineers for training and identifying learning projects to be used through the training program. Training and project mentoring was provide through an outside consultant to ensure the quality of the program remained intact. From the interview and questionnaire results shown in Figure 7.3, which suggests near 100% success perceived from the 6-sigma program, engineering is able to adapt their operating habits to the use of higher quality tools given the objectives are set for their usage. Unfortunately, as project financial and completion objectives were missed, additional performance constraints have been added to the system. Key here again becomes why these project completion objectives were missed. We can look outside the organization to determine the external pressures which are driving local leadership to fail in this area or strictly evaluate local management. Granted, at some point the product development organization does have to stand up and claim responsibility for poor performance, but, the organization as a whole needs to be set-up for all functions to succeed in delivering the highest quality, lowest cost product.

9.2 Unfortunate Sequence of Events

The 6-sigma program provides and example of the technical and time challenges of applying robust processes and enforcing their use. Due to the difficulty of measuring the quality of the project, measurement systems are set-up to measure easier to quantify variables such as cost savings and # of projects complete. In doing so, those easier to measure variables may become the motivating performance metric and not the actual use of robust verifiable processes, or the delivery of high quality low cost product.

As an example, cost and quality are two needs that are consistently perceived to constantly conflict with one another. While this may be true for some incremental improvement actions on current model programs, Lean Thinking and the use of robust tools are designed around the knowledge that smart engineering based on a thorough understanding of part function and operating requirements can yield higher quality, lower cost product. However, in a non-lean, non-robust organization, without internal checks and balances to drive improvement on both fronts and ensure a correct and consistent course, the needle can oscillate from one to the other. A balance of responsibility and accountability is required to prevent bias. Two of the management interviewees are directly responsible for implementing demonstrated robust fixes, and delivering annual savings based on those improvements. Having one person responsible for delivering these conflicting agendas can pose a dilemma for the management level employee. As one of the interviewees stated:

> "It can be a real challenge to balance the need for reported cost savings with the desire to provide demonstrated robust improvement. At the end of the year, it is easier (for management) to count closed projects and cost savings than it is to asses the quality or robustness of the project. Even though the company expects both, we only feel pain from our managers when we don't deliver the money".

The technical complexities of the issues and the detailed knowledge required for application of the tools make it nearly impossible for someone without in-depth experience, and interest in the product to verify the quality of the work performed. Given this challenge, Master Black-belts are made responsible for verifying the quality of the problem solving process utilized, and with managing blackbelts to close a specific number of projects per year, with a set financial objective. Due to the ease of measuring financial performance and corporate need of delivering financial results, the challenge of delivering high quality projects has fallen lower on the priority requirements with the organization and hence the master black belts direct supervision. Similar objectives shifts have been seen in other initiatives. Typical shifts move toward metrics that are easy for management or non-technical analysts to measure, understand and verify compliance. Given the relative ease of counting the number of projects closed and the cost savings per project, the system appears to put heavier emphasis on these measurements versus the complex technical aspects of robust tool compliance or quality of the project. Given this pressure to meet the targets of the measurement system is it any wonder some engineering quality operating system requirements may be relaxed in order to meet what is perceived as a higher priority objective?

OBSERVATION 15: **Analysis of the current culture shows the product development organization will deliver results according to the objectives set out and enforced by direct management.**

OBSERVATION 16: **Performance metrics will tend to drift to easy to measure and easy to verify results.**

9.3 Financially Driven Engineering Performance

Economic and competitive position consistently forces companies to evaluate their cost performance on the products they produce. As markets take a down-turn, the pressures to evaluate and reduce the cost of product intensifies. In order to emphasize the importance of reducing product cost, new metrics can be implemented to measure cost performance of the organization and their ability to reduce the price of the commodity. Each part of the organization, including engineering is usually charged with removing a certain dollar value, with the intention of not effecting product quality. As we have demonstrated though, in a non-robust organization, the more the product churning the higher the probability of introducing quality concerns. The last economic down-turn for the automotive industry came in the late 1990's. Since engineering changes take time to design, test and implement, and additional time for the quality issue to emerge in the field we would expect to see a spike in warranty spending approximately 2 years after most of the cost reduced changes have occurred.

Figure 9-1: Warranty Impact of Product Churning

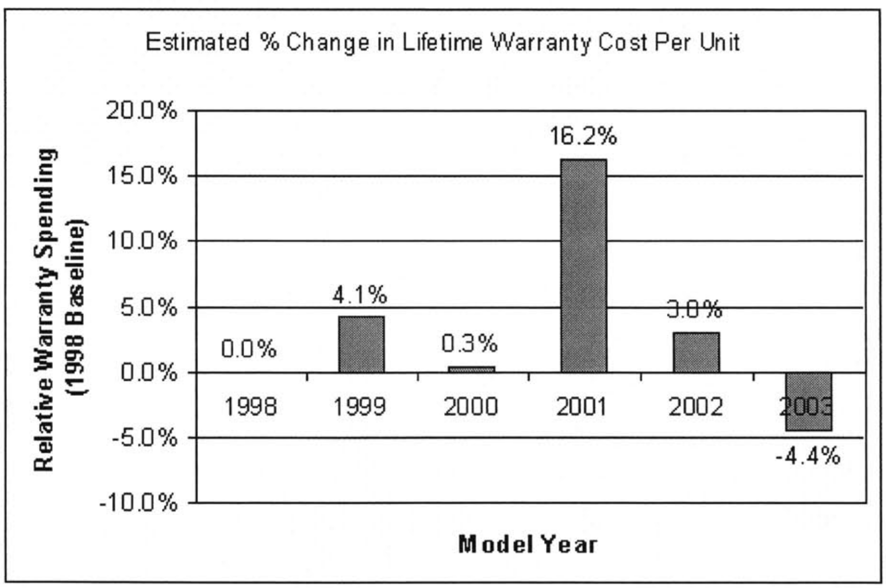

Figure 9-1 above shows the percent change in warranty spending since 1998 on a technically complex automotive system. Quite clearly there is a significant increase in warranty spending in model year 2001, shortly following engineering cost reduction actions that would have been identified in the 1998-1999 time frames and then implemented in the 2000-2001 model years. Subsequent years have seen ongoing reductions in warranty spending as the cost/quality needle has swung back to a quality focus. Typical attribution error at this point would be to once again fault engineering management for poor implementation of cost reduced components. Given that engineering management is responsible for part quality, it is where the responsibility belongs. However, given the corporate directives to cut costs, and cut costs quickly, the measurement systems and priorities of the organization do not support the time and intensity required to completely verify system performance. In addition at this time, the engineering operating system did not include the same level of robust tool applications that could have delivered the desired high level of quality. As cost competition begins again to drive organizational performance maintaining a robust tool focus despite the financial and timing pressures will be critical to the success of the organization. Without maintaining a robust tool focus similar oscillations in the quality performance metrics are likely to occur again.

OBSERVATION 17: **Direct performance measurables will be required to drive and enforce the use of robust tools**

9.4 Audit Driven Engineering Performance

The change in quality performance seen in Figure 9-1 is an undesirable side effect of the implemented cost reduction actions. Improvements in the product development process to include robust procedures were implemented to reduce this type of cost/quality trade-off. Adhered to high quality engineering procedures should be capable of producing high quality low cost product. At issue is how to ensure high quality products are delivered, given that metrics available to verify performance is delayed by 2-3 years.

Audits of the process are one method to provide a metric to measure the use of robust tools. While the audits do provide a check for the engineering system, it has the risk of not being a positive one. Most audits if not based on the technical aspects of the program wont be a check based on the quality of the end product, but on the quality of the paper work delivery. Due to the complexity of the systems being engineered, for the auditor to truly verify the use of robust processes the auditor must be an expert in the system being engineered otherwise it becomes a wasted paper verification process.

As was demonstrated from interviews and questionnaires, the engineering system will only be engineered robustly if there is value. Given the reported acceptance level and recognition of the importance of robust tools, it is easy to see that the engineering activity is finding value in robust processes – when allowed to apply them judiciously. When the performance objectives are set-up to pass the audits, and not based on delivering high quality parts, engineering effort will focus around ensuring the paper trail is completely and neatly delivered. Auditors without the technical background will be unable to uncover the paper trail circles that can be created to satisfy the auditor, but not the quality of the product.

OBSERVATION 18: **Performance metrics must be established based on learning and quality of the end product, not on ability to pass a paper trail audit.**

9.5 New Performance Metrics

At this point, the performance and metric challenge remains. Application of robust tools is required for the delivery of low cost high quality product, but the system does not provide the proper checks and balances to ensure even delivery. Based on interview results, the need is recognized, but, as has been shown, without a direct deliverable priority of management will tend towards objectives which are driven and measured by the organization as a whole. Since direct management attention has proven through other large external surveys to be the largest influencing factor driving the acceptance of new change initiatives, ensuring that management deliverables are in line with delivering robust tools is absolutely critical. The challenge though is not to deliver robust tools, it is to deliver robust product. The tools are the method to verify and demonstrate that robustness. If the focus is only on the tools without the end product in mind, only minor quality improvements will be recognized. The metrics must be established to use the robust tools output to demonstrate high quality, low cost product. Metrics which require simply demonstrating all of the tools are used will not meet the product and market requirements. In order to verify and have confidence in the application of the tools and the end product delivered an experienced team is required to verify the process and testing used.

10 CHAPTER 10: REGROWING A ROBUST PRODUCT DEVELOPMENT ORGANIZATION

10.1 Pulling Change into the Organization

As Klein demonstrates in her book True Change: How Outsiders on the Inside Get Things Done in an Organization[2],

> "Change must be accomplished through working within the current culture to transform the culture to meet new challenges."

It is only through understanding and working within the current culture that we can understand and develop change methods that will be accepted and internalized into the existing organization. Through the knowledge gained in the earlier interviews and surveys we have developed an understanding of the current organization, the successful methods utilized to introduce positive change, and the common pitfall of add-on constraints which derail positive change.

Affective incorporation of robust practices into the product development process requires a fundamental shift in the overall corporate culture as well as a change in the operating procedures of the product development organization. Changes to the product development quality operating procedures have already occurred, but due to pre-existing corporate culture based around policing and external process verification the change has not been internalized within the product development organization. In order for the product development organization to internalize the robust procedures a sense of empowerment must be created to allow PD to pull the process into their operating habits. The addition of constraints and audits to the system forces PD to remain

[2] Jan Klein, True Change: How Outsiders on the Inside get Things Done in an Organization, San Francisco Joissy-Bass, 2004

reactionary in their application of robust tools as they strive to meet audit requirements instead of delivering quality product. Through the surveys and interviews conducted we have seen it is only through consistent demonstration of the organization valuing the new requirements coupled with the individual experiencing value in actual operation will the robust tools be accepted and the change initiative be fully embrace. In order to root robust processes into the fabric of the PD organization new operating procedures must be created around robust processes that demonstrate value to the organization and allows PD to hold themselves accountable for the quality of their products. Rather than pushing adherence through the use of external audits and punitive measures new methods must be devised that can be used to demonstrate value throughout the organization. So that rather than pushing the change onto Product Development, the change begins to be pulled into the culture. Empowerment and accountability for product performance, not paperwork, will be the key drivers for internalization of robust procedures.

10.2 Product Accountability and Engineering Empowerment

The objective and reason for implementing robust design practices is to provide product engineering the best tools available to deliver high quality products on time, at the required cost with verified performance. Robust tools/processes are the methodology used to deliver product requirements, they are not the deliverable. Any constraint or a requirement added to the system and verified by an external organization detracts from the direct accountability and responsibility of the design organization. The addition of external verification methods drives a reactionary mindset based around being told what is important and prevents product development from creating and pulling needed improvements into the organization. Allowing product development organization to be responsible and accountable for their design will represent a major shift in the culture of a mature firm. Their will be missteps as the product development organization develops new operating procedures to meet the needs of the organization. It will be critical during this time that those responsible for tracking, as well as higher level management holds product development personnel accountable for the end product results and not intermediate deliverables.

By allowing the product development organization to develop their own operating procedures based on robust tools will empower PD to develop additional change initiatives that can further improve the product. In Dr. Klein's book she labels as outsiders-on-the-inside those that

> "are willing to question their own assumptions and those of their organization when faced with a challenge that won't go away or one that they see in the offing."

It is only through the creation of knowledge and empowerment that individuals within the organization will have the confidence and ability to question the operating habits of the organization. In creating a culture of outsiders on the inside – those that bring new ideas into the organization or even from one department to another we can create a culture more open to learning and more acceptant of change requirements of robust tools. As Dr. Klein goes on to demonstrate,

> "These pull initiatives do not have to be large to gain attention... all that is really necessary is that the targeted challenge be important and some urgency to a subset of individuals."

That subset of individuals become the change agents as the culture shifts and generates a critical mass of acceptance of the new culture. In order to create the new operating procedures around robust processes we must first empower the engineering organization by lifting the external requirements which detract from developing the operating procedures which will deliver high quality product.

10.3 Planting the Seeds of a Robust Organization

Working within the current culture to create a new culture focused around robust processes has to be internally driven and based on the recognized needs of the organization. As such, recommending changes to the operating procedures in this context may not be in the best interest of the organization. The generation of awareness of the need, and identification of the shortfalls that have plagued the organization in the past, has been established. Generating new operating procedures to address these shortfalls needs to be accomplished by a team consisting of those empowered to implement change and be held accountable for their deliverables. Generating new, detailed operating procedures here would de-empower the organization from creating its own future.

But, based on review of the current culture and other successful change initiatives and operating procedures, one possible solution that could drive the use of robust tools and verify proper application would be through creating a new culture focused around internal Product Development Assessment Teams (PDAT's). PDAT's would function as an extension and formalization of "Peer Review teams" which are currently used to provide optional design feedback on certain new model programs. PDAT's would be cross-functional teams designated as responsible for reviewing and validating robust processes on program changes for their respective teams. PDAT's would provide the technical validation of robust process usage that is needed by the organization and missing with current external audits, as well as create a learning organization developed around team success and organizational knowledge sharing between cross-functional team members.

10.4 PDAT Concept

Final development of the PDAT concept will be dependant on the organization which will be utilizing them. Consideration for current workload and responsibility levels will be required. Development of the operating procedures and team structures needs to be tailored to the individual organizations needs and culture. Listed here are building block recommendations that can be used to generate PDAT's for the mature automotive organization studied. For implementation into alternate organizations, an understanding of the individual organizations culture would be required to make the assessment teams successful.

The PDAT concept would be based essentially around validation and learning assessment analysis being conducted by the product development team instead of an external audit organization. The internal assessment team would consist of representatives from various areas of the organization. System level supervisors and engineers from various current and forward model applications would be required to participate in the PDAT structure. In order to create support for the new format, performance objectives of all responsible, plus the managers and executives of those participating on the teams would be based at least partially in participation and support of the new PDAT structure. Generation of robust process documentation for checkpoint review will remain the responsibility of the system group creating the new design option. The PDAT will be generated to understand, improve, and validate the robust process used by the responsible design organization. PDAT's will function similar to the external audit individual except documentation review will be performed on a regular basis prior to the checkpoint review. Passing through the checkpoint will be dependant on sign-off approval of the robust process documentation by the PDAT. Sign-off would signify complete understanding and approval of the process documentation. In order to avoid PDAT performing only cursory approval and understanding robust tool specialists can be utilized to lead the review process. The robust tool specialist could report directly to the executive engineer who is responsible for delivering final product quality. Unfortunately, in the short term the PDAT structure will drive higher workload as the teams work to implement higher quality product. However, as shown through the systems dynamics model in Chapter 8, with higher quality up-front work, future workload will diminish as higher quality product is engineered. Sticking to the PDAT process will create the pull for robust processes as the higher quality of new products is experienced. The key remains creating an empowered organization held accountable to the end deliverable, only then will true performance improvements be experienced.

10.5 Conclusions and Organizational Considerations

Thorough analysis and understanding of the organizational requirements, operating procedures and cultural habits are required for the successful incorporation of new operating procedures. This study has made an attempt to identify and quantify these habits and requirements in order to facilitate the internalization of robust engineering procedures into the product development organization. A recommendation has been made to recreate the product development operating habits around internal, robustness focused product development assessment teams. These PDAT's would function as formalized peer review teams responsible for validating, sharing and learning from alternate departments robust engineering efforts. Incorporation of these new teams will be challenging and present at least an initial strain on the organization. Based on the analysis performed throughout this study, the following key observations need to be considered and addressed as the organization designs new operating procedures around the PDAT structure:

1. **Training** – while the organizations reported level of robust tool understanding is high, requiring and supporting additional training in the use and application of the tools would drive the recognition of value placed on their usage by management.
2. **Engineering Stability** – Position stability and retained knowledge is key to proper application and usage of robust tools. Continuous rotation of engineering personnel degrades the overall technical expertise of the organization and hampers development of high quality products.
3. **Empowerment** – Current culture is based on policing and tracking performance of other areas creating a reactionary workforce. In order to allow development of value of new initiatives, each organization needs to be given the opportunity to develop internal operating procedures and internal checks and balances that will ensure delivery of high quality end product and not diversionary intermediate steps.
4. **External Accountability** – Each level of the organization from the executive level on down to the engineer must be held accountable by the company for delivering the performance of the end product, not the intermediate steps
5. **Internal Accountability** – Product development must create the operating procedures to demonstrate the ability to design robust products and hold itself accountable for deliverables which will verify system performance.
6. **Metrics** – Performance metrics must be created through all levels of the organization that align the organizations requirements to the use and successful application and validation of robust tools.
7. **Lessons Learned** – Creation of robust documentation and verification test data is valuable to both current engineers and future engineers and problem solvers. An easy to access website similar to the 6-sigma data base should be created to organize and maintain the valuable robust engineering documentation.
8. **Robustness Specialists** – The complexity of the tools will require specialists to assist in the application and validation of the process. In order to provide the opportunity for an unbiased assessment of the progress these specialists should report to the executive responsible for the overall quality of the product. The executive will hold the systems and components manager responsible for delivering robust on time product.
9. **Current Model Gateways** – To reduce continuous problem regeneration in current model applications additional robust design requirements are needed

for current model applications. Gateways appear to be an effective method currently employed in forward model programs that could be scaled down and utilized for current model changes.

10. **PDAT Participation** – Initial support and participation on PDAT's will likely meet with resistance as these teams struggle to create value in their actions while satisfying current job requirements. Only through recognition, support and performance metrics based around team participation will these teams initially be successful. Direct management of each level of the organization must contain performance metrics based around support of the new team structure in order to drive the value of contribution.
11. **Current Module Team Structure** – Further analysis will be required to determine how best to integrate the new team structure within current operating team performance. The objective is to minimize the additional work required while providing the best value to the organization.

In conclusion, there is a lot to consider as the organization strives to create an improved organization built around robust product development. Only through first identifying and understanding the current operating culture can new operating procedures be put in place to shift habits to robust methodologies. The organization must be cautious as operating procedures are modified. Close monitoring of performance is required so that adjustments to undesirable habits can be recognized and implemented quickly. As adjustments are identified as required, the corrective actions must be based on elimination of root cause of improper performance and not the symptom that results. By following the outlined actions the organization should be able to develop and implement a new operating culture based on the use of robust process and the delivery of the highest quality most cost effective product.

11 APPENDIX 1: ENGINEERING QUESTIONNAIRES

SUMMARY OF COMMENTS NOT CAPTURED IN SURVEY ANALYSIS

Forward Model ENGINEERING ROBUSTNESS QUESTIONAIRE

1. **What percent of projects you work on fully utilize robust tools?**
   - It is hard to answer this question. Not all work involves problem solving and all the robustness tools. Nor does all problems or issues have a need for all the tools. In general, I would think about 50% of the project utilize robust tools.
   - I currently work on a 2005 fwd model gas program that is utilizing the full robust tool set. We utilized robust tools for the 2004 current model programs driven by the reliability engineer assigned to the Dept. I'd say 100% of all new programs utilize the robust tools since the "clean green" initiative is being tracked by our new Dept. rep.
2. **What are the primary reasons you may not completely follow robust procedures?**
   - Time and available resources. It is always easier and quicker to jump to a conclusion or rely on your past experience and expertise with a particular product to solve a problem. As the problems get more difficult or not as easily explained, you tend to pull in the robustness tools to help solve or resolve issues. The investment in time and resources must be offset by the severity of the problem.
   - Time consuming, problems are very straight forward.
   - Robust tools historically never applied.
   - Some tools may not apply to situation. Time constraints.
   - too much emphasis on paper generation
   - Not being disciplined enough, not required by the management.
   - Familiarity with the technology breeds contempt for dotting all the 'i's and crossing all the 't's in all of the robustness tools. But to be fair, it is this familiarity that enables engineers and management to hone in on the areas of concern without getting bogged done in the robustness paperwork they already know the answer to. More rigorous use of robustness tools is used on newer, less understood, technology and applications and less on "tried and true" designs.
   - Current position does not permit me to use these tools at this time. I did utilize these tools 95% of the time in my previous position as Plant Resident.
   - N/A – pre-program timing allows for full integration of robustness tools. These items are reviewed on a regular basis with program deliverables.

3. **Does management sufficiently encourage and support use of robust tools?**
   - No. We are more reactionary in the use of these tools.
   - No, there's greater tendency to treat it as a document which needs to be filled out rather than as a tool.
   - Yes, but management also recognizes they have limited resources. This often leads to limited use of the tools in areas that are fairly well understood.
   - Depends on management. If time is not limited, it is supported well.

4. **What has been the main driver for the increased usage?**
   - The more familiarity with these tools. The willingness to invest the time and resources to complete the process.
   - More training, and more pressure from management to demonstrate problems using some of these tools.
   - Accepted philosophy of data driven decisions to ensure quality of the product.
   - Reducing warranty costs (6-sigma)
   - Upper management interest in quality improvements and more systematic approach to continuous internal process improvements driven by ISO.
   - Fear of the Clean Green Audit.

Current Model COMPONENTS ENGINEERING ROBUSTNESS QUESTIONAIRE

1. **What percent of projects you work on fully utilize robust tools?**
    - 25% I work on current model and we rarely get "fully" involved in robustness tools, we do most of the above minus the stat methods and P diagrams—maybe black belt involvement will improve that.
    - 25% maximum, but we are getting better. Engineers work in a reactionary mode rather than planning accordingly. Supervisors need to ensure this work is getting done upfront and that engineers are trained to do so. There is a lot of resistance, especially from some of the seasoned engineers.
    - Timing constraints; directing solution rather than answer driven; cost constraints (parts not available, time to order and acquire parts excessive, vehicle availability, discouraged when identified fix costs money that management is unwilling to spend).
    - We use most of the problem solving tool consistently. Clean Green tools are new & paper work intensive.

2. **What are the primary reasons you may not completely follow robust procedures?**
    - Time vs payback. I realize that robustness may not pay back immediately but often you are time constrained and need to get it released—once again, talking about stat methods and P diagrams—we do most the others above (for current model – MCR/Warranty improvement)
    - Timing, priorities, workload constraints, poor planning, poor mid-level management support, mid-level management not understanding what is required or what tools are needed, etc....

3. **Does management sufficiently encourage and support use of robust tools?**
    - Could be pushed more but they make it known that it is helpful
    - Yes, for showcase. No, they don't structure the organization and processes to allow the tools to be used as norm
    - No. Our upper management (Chief Engineer and Director level) seem to be more versed in the application of these tools than mid-management.
    - The management asks the right questions, but is deficient in supporting the cause with manpower, hardware, and facilities. We are on a path to become the next American Motors.

4. **What has been the main driver for the increased usage?**
    - Bringing robustness engineers in to the departments—have been in systems depts for a couple years, we now also have in components (within last month)
    - The use is slowly increasing, but just over the past year. FTEP APEL requirements have helped. Engineers approach the Clean Green documentation required as if they are simply going through the motions of completing it rather than garnering knowledge from the process.
    - Common sense. Engineering is based in science. Tools that help focus the data and logical discriminating investigation is fundamental to our job.
    - Quality indicators in the field & customer satisfaction indicators... robust tools ensure we are designing to the customer requirements, not designing to fix problems.

Mixed model MECH COMPONENTS ENGINEERING ROBUSTNESS QUESTIONAIRE

1. **What percent of projects you work on fully utilize robust tools?**
   - Most. There may be a simple situation without investigation, problem solving, or data generation & analysis that can be completed quickly

2. **What are the primary reasons you may not completely follow robust procedures?**
   - There isn't time and resource to follow Ford's processes. Some, like the interface matrix, don't show me value on the parts that I work on.
   - Not enough time available to go through the each step in detail and to complete the proper documentation for the project. So most of the time it starts out as "6 Sigma project" type direction and is left uncompleted once main resolution of the problem comes in to sight.
   - Not given the time to utilize the tools as intended. If this is a new program the tools are a must for quality and needed to support the various audits. The majority of our work is minor revisions to current designs which the tools are not used.
   - The tools are not required
   - Main reasons we may fall short is cost, test priority and timing. We've got a pretty good base on documentation, (RDM, P-diagrams, Fishbone etc), but A-B-A and tail testing is an issue due to the main reasons listed above.

3. **Does management sufficiently encourage and support use of robust tools?**
   - Yes – verbally (local management), with time and resources – no (corporate management).
   - Yes. I think it's expected on most projects. We also have available training & coaching.
   - Yes, as evidenced by management reviews.

4. **What has been the main driver for the increased usage?**
   - Peer pressure / competitive pressure.
   - The realization that our product & processes aren't as good as our competitors'.
   - Awareness and training have helped. Software packages like REDPRP also help. Management requirement that the tools be used.
   - New initiatives and awareness. The main driver is the focus on Six Sigma. Although most of the tools are not new, the focus and awareness on Six Sigma has brought these tools to life.
   - Managements fear from external audit.

12 APPENDIX 2: SAMPLE INTERVIEW RESULTS

1. Are the projects you review typically new product development following FPDS timing?
    a. If they are new programs, what process (meetings, design reviews, checkpoints) do you use to enforce robust engineering procedures?
        - QPAT meetings – roll in the subsystems on a monthly basis. Training is done through the meetings. Some additional training is still required and is accomplished through workshops where they will pick a particular sub-system and work through that system in the workshop session.
        - Some competitive companies we've worked with, testing is not written procedure based it is experience and personal expert based. Adds to the accountability and pride in the job done. But, relies on training and internship to ensure proper testing performed. Have to ask very pointed questions to get exactly what is done to verify design.
        - Actually follows a jointly develop timing schedule since it is a partnership between two major automotive companies. The quality deliverables are different between each company. We are responsible for meeting the clean green/EQOS requirements for our program. The other company does not use anything like a p-diagram or noise factor management or RDM. They do use boundary diagrams to try to manage interfaces. Our new requirements for EQOS with the threat of clean green audits is driving us to go back and recreate these documents in order to meet Our requirements despite the design essentially already having been completed by The other company. There is some opportunities on a few components to address design issue if they were to arise through the application of Our robust process. For the most part, we are doing the work as a learning experience to try to generate and document our understanding of the function of the transmission.
        - Integrated CPMT between the two companies so can address background of the design and develop understanding to get the ford engineers up to speed on the designs. Trying to let the parts and the design considerations drive the learning.
        - The other company currently does not link noise factors to actual testing
        - Begin to develop DVP&R for the components. Are sharing component level testing where can. Comparing test requirements, loads and cycles. Equal improvements are occurring on both sides as to how and what to test. Can't share duty cycles based on engines used – proprietary information, but in general do evaluate if the loading is acceptable for both applications. # of events they run, etc... Systems testing will be performed separately since it is dependant on the boundaries of the applications – Our engine and vehicles.

b. How are shortfalls in the complete tool usage addressed?
    - Identify gaps and follow-up. Would like to perform reviews month or more before checkpoint
    - Don't review that directly. Due question that the tools are there. Expectation is that the design manager is responsible for usage and enforcement of the tools.
    - Have not really had any yet. Clean Green is a real big motivator. That is not the kind of attention you want focused on your program. EQOS requirements are the way we are expected to be engineering our systems and now with clean green to verify compliance there really is no way around it. There is a great deal of personal drive within the department to make sure we are doing the right thing and to learn as much as we possibly can from this new system, and to just learn in general, but clean green is definitely a big bat aimed for our heads making sure the motivation is unwaivering.

c. Do you run into issues with enforcing tool usage? Why? How do you proceed?
    - Yes, primarily do to understanding of the tools and knowing what is required. Integrating knowledge generated with work already complete by GM is difficult. Going back to suppliers and making them redo paperwork so that it fits into the model or subset of what was identified in the P-diagram is not particularity value added.
    - No, not yet, hope that we wont. We have essentially weekly workshops to help apply and develop the use of the tools. The workshops are a joint ownership between the systems, RIE and components teams, they are essentially working together to meet the checkpoint requirements. Each CPMT team will have 1 day a month, twice per checkpoint to develop the requirements for the next checkpoint. During the 1 day review shortfalls to clean green and EQOS requirements are identified and the engineer is given to the end of the week (Monday reviews, Friday updates required)
    - Usually good about it – accept that there is no way out. Some applications are significantly better than others. Helps to have a generic starting point. Documents that are done after design is done are just created to support clean green audit are obviously worthless, end up having the document, but the paper is worthless

d. Do other priorities hamper your ability to enforce robust engineering processes?
    - Yes, engineer doesn't have the time to apply all tools properly. CFE is the expert that offers opinions on how to apply.
    - No, not yet, as get closer to testing and launch, timing may become an issue. Hopefully with the upfront work we will be able to more quickly address the issues as they arise.
    - No, not yet, we are still in the very early design stages. We are able to fairly well manage our workload and requirements. We have not had any real big panics yet they may drive compromises in the future.
    - Hopefully we are doing our homework up front so there won't be as many surprises down the road, we'll see.

e. How do you capture the knowledge generated during these earlier design stages for possible future issues?
    - Evidence books. Scattered and poor carry-over lessons learned.
    - Evidence Books, Lessons learned forums on Thursdays and weekly technical reviews. Design books are slowly being published and calibration procedures
    - Don't know, think most of the info is being stored in the E-room directories. Developing evidence books that will have paper copies of everything stored within them.

2. For the projects your involved with that are Warranty/Durability improvement actions,
    a. What drives change, how do you select issues?
        - Systems groups drive, can't usually convince other way. Difficult to monitor warranty from a components perspective, most component engineers don't push for change.
    b. Do you run into issues with enforcing tool usage? Why?
        - Yes, difficult people/assumptions about what is occurring. Both with our customers and within section. Don't always see benefit to use of tools when "know" solution.
        - Continual changes in the quality office in terms of what the requirements are, who is going to lead them, which tools we will use, what format we will report out in, constant state of flux makes learning and applying difficult.
3. What are the primary reasons we do not completely follow robust procedures?
    - Confusion over what they are and exactly what should be applied. Inappropriate application. Doesn't always give ability to pick and choose as appropriate.
    - Value, sometimes it is just checking the box with no value.
4. Do you think there is a general resistance to use robust tools? Why?
    - Yes, policy, robustness only used with in the right cost and timing range.
    - Clean Green will make more work to cram into the same time to try and make things green again.
    - If CG doesn't actually stop a program for not following processes than it is not worth the time. The only way to justify the added work – some of it not valid due to the simplicity of some components – is if we show we are serious about robust tools and delay programs based on incomplete process.
    - In the beginning yes definitely, the added requirements and increases in time required. This is gradually being overcome as we begin to see successful projects implemented which have truly resolved the issues – issues that may have been around for years before.
5. Engineering Stability Program –
    - Marginal effect on the use of robust processes. Will help prevent mistakes based on experience with the product and knowledge of function, previous issues and performance requirements. Risk is close mindedness associated with "its how it was done in the past"

- Deploying resources – pay more attention on these issues, programs and dedicate the time and priority to accomplish these. It has the ability to drive the behavior but it will take more time and may mean added workload.

6. 6-sigma
   - Probably one of the best methods for roll-out and addition of the use of robust tools. As people get out of the program and out of training and go back into the organization they have a great impact on the work being performed around them.:
7. APEL's:
   - Not a major influence, Doesn't enforce different behavior, become almost just a basic requirement to get tests passed not sure of true knowledge add
8. Head count reductions:
   - Negative impact – happens about every year so start to manage the work and new programs to carry based on the cutbacks anticipated.
9. MCR actions:
   - Managing so many actions, at some point can't be involved as you'd like to be on all of them. Continual pushing for full understanding but progress tends to be slow and we may march ahead despite not having a full understanding. Gets back to risk management. Usually a workload issue. Tend to manage it based on projects selected to pursue as MCR actions. Allow difficult or risky ones to be easily rejected to mitigate risk based on knowledge of workload capabilities.