Management Framework of Automotive Full Service Supplier in Computer Aided Engineering (CAE)

by

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Abstract

Outsourcing design & development works to supplier is a new and aggressive trend in the automotive industry. Its purpose are many folds including reducing development & product costs, reducing the complexity of supplier management and increasing shareholder value by reducing fixed asset costs and refocusing the company resource in creating new value. CAE is an important and integral part of design and development process and often overlooked however in the outsourcing strategy due to its small cost. There is a strong tension between two strategies of dealing with CAE outsourcing. The first strategy is keeping all CAE works in house as before and continues to direct supplier on "how" to design its commodity. This strategy could run the risk of a long term lower supplier efficiency and innovation. The second strategy is to delegate to supplier full responsibility of the design and development of its commodity including the use of CAE. This option will often run into operational problems of potential low quality, reworks and delay due to many factors like supplier initial CAE learning curve and the immaturity of the vehicle manufacturer's system engineering target cascading process. There are interfaces in both process and technical that the Vehicle Manufacture (VM) must understand in order to manage.

Computer Aided Engineering (CAE) technology is widely used throughout the Product Development (PD) process. Instead of the traditional "hardware" approach of "build-break-build" to develop the vehicle, the VM rely on CAE to speed up the "build-break-build" process digitally. With its potential to reduce PD time, reduce cost and improve performance, CAE could be a "core competence". In this thesis a useful framework in looking at core competency is used to address the type of CAE outsourcing.

Not all the benefits and pitfalls of outsourcing CAE to supplier are well understood and captured in literature or in practice. At least in one of the big vehicle manufacturers (the focus of this thesis) low understanding of CAE outsourcing process is believed to be the additional reason besides cost for low attention to the area of outsourcing CAE. This thesis takes a closer look at the current practice of CAE outsourcing by using different analysis frames like Engineering-Design-Analysis (EDA), System Engineering in target cascading and System Dynamic loop in the managing project dynamics.

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ACKNOWLEDGMENTS

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GLOSSARY

CAE. Computer Aided Engineering (majority usages from application of finite element method)

Core Commodity. Commodity expertise is exclusive or most efficient or strategically.

Core Competency. Core competency is the collective know-how of an organization that gives it a competitive advantage. This know how is a result of learning that is driven by business strategy and built through a process of continuous improvement and enhancement that may span a decade or longer. (Grady, Successful Software Process Improvement)

Full Service Supplier: Supplier that has full responsibility in design, develop, test, fix-up and manufacturing.

NVH. Noise, Vibration and Harshness.

Productivity. Work accomplished per hour of effort, regardless of completeness or correctness

Quality. Fraction of work just accomplished that is correct and complete, i.e. will not need rework.

Vehicle Manufacturer (VM). Automotive major companies (GM, Ford, Chrysler)

Waste. Anything that does not add value to the final consumer

1 INTRODUCTION

1.1 Introduction

One of the latest areas of product development that a vehicle manufacturer (VM) starts partially outsourcing is CAE (Computer Aided Engineering). Not long ago, suppliers are limited to just the manufacturing of the products according to a set of given design specifications. Now most of them are being asked to take on a full array of additional responsibilities in the development, design & verification process. This so called Full Service Supplier (FSS) strategy is viewed as a new business model to gain further advantages in 3 areas

1. Maximizing the utilization of supplier expertise
2. Achieving greater product development efficiency
3. Creating competitive processes and products

As the suppliers are "forward integration" insisted by the vehicle manufacturers, new players along with their processes and tools are brought in and must be matched up with the existing VM PD structure. The fuzziness nature of the PD "front-end" where information is not in concrete forms creates the complexity of coordination. The complexity in cascading functional targets from vehicle level down to FSS commodity level requires more than a written contract since the current product development process is a highly iterative. While much of literatures have been written to address the outsourcing make and buy decision and about collaborating framework in general, non has addressed a unique situation of outsourcing CAE in automotive industry. Not much practical experiences and lesson learns either exists for management guidance of the issue. Being a subset of general outsourcing, CAE outsourcing has similar issues and benefits that will be fully analyzed later in this paper. What new and interesting is the uniqueness of CAE role in PD process that managing it requires a particular understanding. Where would CAE contributing to the overall goals of PD? What is the CAE value stream and its core competency? What portion then of CAE is outsourced? Where is the management attention should be focused to realize the benefits? This is new paradigm thinking for VM CAE management since many efforts in the past 10 years has been mostly internally focused in trying to improve the effectiveness of CAE. Now there is a new way, better or worse, of conducting the CAE business: by outsourcing a portion of it! The emerging issues of managing FSS CAE should be carefully looked at.

1.2 What are being outsourced?

Examples of typical commodities being outsourced from the ground up of the vehicle includes: tires, wheels, knuckle, spindle, suspension, steering gears, steering shaft, tie-rod, shock, spring, exhaust, frame, bushing, seats, instrument panel, steering column, air bag, interior trims. The two major systems in the vehicles: body and powertrain tend to be the last two commodities being outsourced at most vehicle manufactures. Throughout this thesis steering column is used to illustrate related issues to the outsourcing process that applicable to all other commodities. Where there are exceptions to the steering column example others will be brought in for illustration. When the VM decide to outsource a commodity (steering column) they also outsource the steering column CAE works to the same supplier.

Steering Column System Example:

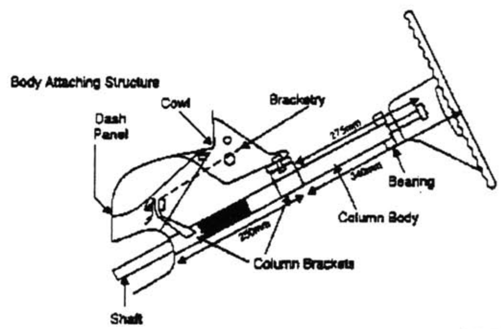


Figure 1: Typical Steering Column System

Figure 1: The steering column system consists of steering wheel, air bag, tilt mechanism, steering shaft, bearings, steering column body, and attached brackets. The bracket is the structure attaching the column to the body through component structures named cowl and dash.

1.3 Vehicle Manufacturer CAE capability:

Presently the vehicle manufacturer has the capability to create a CAE model that simulates the physical shape and behavior of the actual full vehicle. This "Vehicle CAE model" can then be used to make performance assessment of the vehicle targets such as NVH (noise, vibration & harshness), structural durability and crashworthiness. The full vehicle CAE model is constructed by a process of connecting all component CAE models through well-defined interfaces. Such interfaces in typical truck vehicle architecture are: discrete numbers of body mounts that connect the body and frame. Four bolts that connect the steering column to cross car beam structure. Four bolts that connect the seat to the floor, etc ... these component CAE models are the deliverables from the full service suppliers according to the VM given specifications. The FSS use these component CAE models to guide the design and provide the models back to the VM on time and on target to be assembled back into an updated full vehicle CAE model.

1.4 Target Decomposition Process:

Figure 2 below illustrates an "ideal" process of system engineering where vehicle targets are simulated in the full vehicle CAE model as in step 1. The process of "functional decomposition" or target cascade is used to decompose vehicle targets into component targets. In the ideal world again, this decomposition process as just simple as unplugging the CAE vehicle model interfaces and having each component CAE model performance as a component design target. For example, the baseline vehicle NVH CAE model can be modified in several key structural parameters like the stiffness of the column body, supporting brackets, supporting body structures to improve the steering column vertical resonance frequency in the vehicle. After that, the full vehicle CAE model is separated along its interfaces. The steering column system CAE model will be measured for its natural frequency at subsystem and component levels. The component targets of the steering column itself would be determined and given to steering column supplier. The steering wheel component target will be given to steering wheel supplier, the instrument panel and cross car beam target will be given to the appropriate supplier, the body stiffness contribution target is given to the body design (most of the times the body will still belong to VM).

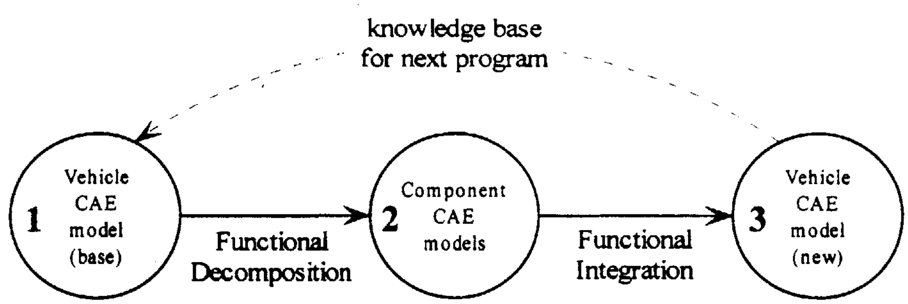


Figure 2: Ideal CAE Process

The second CAE capability is in optimization of the component. In this case, CAE is used to guide the detail design to meet component target in cost, weight and assembly. In the step 2, other requirements are also taken into account simultaneously along with NVH requirements to produce a feasible design. These additional requirements come from packaging space, durability and safety etc... The design is therefore iterative in nature and takes considerable time and effort to find a "feasible solution" to meeting multiple and possible conflicting constraints.

In step 3, all of the new component CAE models after meeting the required targets are assembled back into the full vehicle CAE model. This model is then used to verify if all designs meet the vehicle level targets. It also is used for a variety of applications in the final tuning of vehicle NVH, durability and safety. It is used to determine root cause of problem in vehicle level and finally serving as a good baseline model for future programs.

1.5 The Problem:

Not all vehicle targets can be decomposed into component targets.

Example of that is the performance of the steering column system in crash test. To meet the requirement of occupant chest deflection in a vehicle frontal impact there are many parameters involved like the body and frame crush distance and pattern, the engine movement and intrusion into the body's dash and floor space. The air bag inflator parameters (inflating rate, volume, venting) mounted on the steering column and wheel. The steering column stiffness, the collapsible rate of the steering column in impact and many other factors ... Simply there are too many interactions among all mentioned parameters and more that VM often rely on the engineering experience and incremental change to manage the complexity.

The VM do not use full vehicle CAE to cascade targets.

In the current practice today (Figure 3: Current Target Cascade) as apposed to the ideal state in (Figure 2) the VM will select the target vehicle on the market based on the voice of the customers. (Customer satisfaction index is one indication). The competitor vehicle then becomes an "image" vehicle (step 1a) for the VM to exceed its performance targets. Benchmark test measurements are then conducted on this vehicle in both vehicle and component levels. The example would be selecting the vehicle on the market that have good steering column NVH performance and start the measurement of its natural frequency in the vehicle position. The next step is to disassemble the subsystem of instrument panel and steering column system to measure the steering column natural frequency on rigid fixture (bedplate). Further benchmark is done by disassembling the steering column, wheel and airbag from the instrument panel and testing them in the rigid support ...

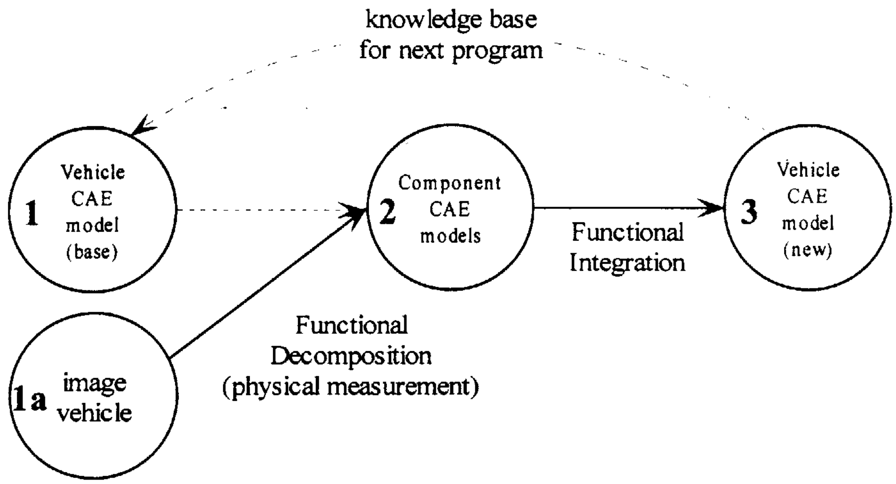


Figure 3: Current Target Cascade

Vehicle CAE model (step 1) plays a supporting role in that it can provide the baseline data for comparison with the image vehicle.

By taking this approach of using physical prototype to target decomposition and the digital CAE baseline vehicle model to drive design toward targets, the VM often runs into these four situations:

	Component Target	Vehicle Target
Case 1:	Not Met	Met
Case 2:	Not Met	Not Met
Case 3:	Met	Met
Case 4:	Met	Not Met

Case 1: this is a very typical situation seen when putting together all component CAE models that not all of them meeting the cascaded targets the full vehicle target could still possibly be met. This is a "pleasant surprise" that demonstrates the immaturity of the above-mentioned current target cascading process. Because of this the VM often rely on the full vehicle CAE model to verify vehicle level target. A typical decision then would be to reduce the asking target for the components. Great pain however is caused to the

suppliers involved. They could have spent great amount of efforts to achieve the component targets that proved to be not so critical for system level performance.

Case 2 / 3 demonstrated the target cascading is appropriate.

Case 4 is an "un-pleasant surprise" and this problem is difficult to deal with. Suppliers are usually not so happy to revise their targets upward and spending more time and money to meet new targets late in the product development process.

The challenge of management step 2 and 3 when commodity is outsourced:

The difficulty in target decomposition and the continuing of selecting the physical test as benchmarks mentioned above creates challenge in managing the commodity outsourcing. Suppliers are now given targets cascaded from different functional attributes (NVH, safety, durability) that may be of conflict of each other and also may in conflict with traditional design targets like package, assembly and cost. The conflict can only be known and resolved after the intensive study and CAE component analysis. Cascaded targets then could be re-negotiated and trade-offs process can be conducted. Target negotiation and trade-offs are harder to do than before if involved commodities belong to different suppliers. The long-term remedy for this problem is to have bigger and bigger supplier so that the single mega supplier could perform the trade-off. The co-location of all suppliers together in one development center is also a solution for fast trade-off process.

1.6 The principle of VM outsourcing strategy:

The principle of outsourcing the component to supplier is that *supplier design engineer will replace the "VM component design engineer"*. In this way the FSS component design engineer has one advantage in that there is a strong tie back into manufacturing. When a design is proposed by him most likely all manufacturing and cost issues already worked out in advance. There are two modes of communication between VM and FSS. To ensure smooth communication with VM PD structure, FSS component engineer is required to be on-board collocated in the VM facility if it is judged that the amount of communication with VM activities is daily. If needed communication is judged only occasional FSS component engineer presentation at the regular meetings at VM will be enough. FSS CAE communication with VM CAE has been in this ladder mode partially because FSS CAE would like to centralize their CAE capability at their home office.

1.7 Summary of FSS skill set expectation:

- Project Management: FSS is expected to be a design leader that owns the design process. FSS should understand the VM product structure in order to interface effectively. FSS is responsible to design to cost target and has capability in project management.

- Product: FSS is expected to be the expert in customer wants as they apply to the supplier's commodity. FSS conducts competitive benchmarking. FSS must understand how to translate customer wants into effective design solution. They must also have expertise in developing design specification to effectively deliver the functional requirements of the FSS commodity.

- Core Design: FSS is expected to have skills in quality/ reliability, system engineering, prototype build and launch, craftsmanship and analytical capability (CAE).

This principle when applied to the CAE will often cause operational problem. *One FSS CAE analyst could not be assumed to equal to one VM CAE analyst.*

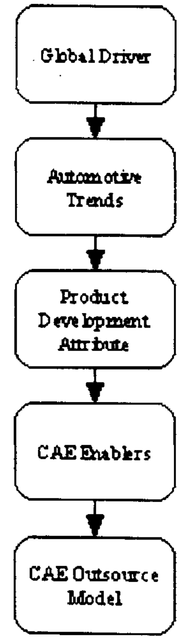
1.8 The Scope & Aim

This thesis will not address the entire problem of automotive outsourcing. It rather focuses on the business of outsourcing CAE. However, there will be considerable business analysis upfront that will demonstrate the benefits of outsourcing the design and development to FSS and thus making the case for outsourcing CAE works to them as well.

The thesis is not advocating for the transferring of CAE works entirely to the FSS and thus "reducing" the CAE workforce. It is not definitely about "downsizing" by getting rid of in-house works and go "contracting". It is about "re-organizing" the boundary of responsibility and expanding the business by applying existing CAE resource somewhere else in the value stream that could be a competitive advantage for the VM. It is about how to manage the supplier component CAE (the target inputs and design optimization) and the integration back into the full vehicle CAE with intended quality and timing. The VM CAE resource should then be redeployed to make the vehicle CAE model more predictable to increase its usefulness more in the target cascading process and in the later verification phase.

1.9 Research Approach

A system engineering approach, requirement flown down, is used as the approach of this research. Starting with the global drivers that force every company to race into new direction for operating their business. The specific trends of the automotive industry are then analyzed in this context. The goals of product development are defined and linked back to the company goals. CAE value stream is defined and matched up in supporting the PD. The outsourcing portion of CAE business is looked at. Three specific frameworks are used for the analysis of FSS CAE process to gain understanding. A CAE outsource framework is proposed along with principles for management guidance. Data, information and knowledge in supporting this thesis are obtained from several sources:



- The author's own working experience
- Interviewing of the CAE managers for their strategic thinking on the subject
- Interviewing with FSS CAE on the subject
- Literature & articles on outsourcing, product development process and general CAE
- Course notes and lectures from the MIT System Design & Management program

2 TRENDS IN THE ECONOMY / AUTOMOTIVE

2.1 Transition to The New Economy

Automotive industry has been known as the flagship of the old industry economy where investors measured its values through quantifiable physical assets owned by the company: lands, manufacturing facilities, raw materials and inventory. In the new information economy of today, values are measured very differently. They are based on human capital, R&D, innovation and networks. Understanding these intangibles is important in the effort of improving company total market value. Existing measures today however are insufficient at expressing the value of the new industry even for the financial measurement. As one senior portfolio manager said "Financial performance tells me what a company has already done, Non-financial performance tells me what it is likely to do." The asset of today economy is knowledge that resides in people, product and organization. The two biggest drivers are the globalization and the accelerated technological growth. Together they create an information age that information is ubiquitously available. The production of information instead of physical things requires different skill sets from the workers. It requires knowledge. It changes the behaviors of the consumers, the investors and the competitions.

2.1.1 Globalization (bigger market)

Throughout history, industry revolution comes as people are connected together. The railroad system that connected American towns together brought local competition into a national scene sparking a new industrial revolution. Similarly, world peace today opens up country borders to physically connect people from all over the world. The national market transforms into a bigger global market. Although international business existed at the time of the Cold War, but political stability of world today gives focus and confidence for developed and developing countries to adapt free trade has made automotive in particular a truly global industry. In short, the bigger market gives the followings:

- *More investors* with higher expectation for their return on investment (ROI) will make capital mobility increases. Automotive industry will have to change business process to compete not only with each other in the same field but with other newly created information industries for investor's capitals. With the historical heavy asset dependent, the VM must transform its business model to re-deploy asset throughout its value chain. Outsourcing to FSS is one of the strategic management tools to accomplish this.

- *More consumers* with higher purchasing power due to the converging of standard living around the world. This puts the consumers in control and poise to change a historical "push" industry to a consumer "pull" industry. It is about time the VM will have to build to order specified from those sophisticated consumer needs.

- *More competitions* with similar access to technology will create even a more competitive environment for survival.

2.1.2 Technology Acceleration (faster market)

If globalization gives a bigger market, accelerated technology growth gives the market a speed! Digitalization creates and transforms information at the speed of light. While the invention of the telephone mechanized the business, the existence of the Internet today brings richer medium of exchanging information that enables business to be anywhere and any time. The new way of doing business like E-Commerce promises to drastically reduce the business friction.

If the automotive industry was a fantastic industry of the last century, it anticipates having an extraordinary potential in this century because it has become global. As Ford CEO Jac Nasser said, "when a new country is formed, first it designs a flag, then a national anthem and then a car company." There are still plenty of countries with enormous number of people ready to enjoy the personal freedom of being on wheel.

2.2 Current Automotive Industry Trend

As more investors are expecting higher and consistent return of their investment, meeting their expectation is a financially competitive advantage. As customers are in command, what a car will do is to support their lifestyles. This creates a potential for the VM to be the providers of "transportation" and other lifestyle services rather than just the facilitators of "vehicle ownership". Customer satisfaction becomes the highest objective of the consumer focus company. And finally, as there are more competitions, the VM must find a way to leverage the economy of scales to further reduce the cost structure. The drive to modularity to achieve platform de-proliferation will enable the VM to do that.

2.2.1 Shareholder Value

The first challenge in automotive industry is increasing "shareholder value". On this, the VM still rely on an economy of scale strategy. To gain incremental volume the VM embrace furiously a strategy of globalization, consolidation and platform de-proliferation [1]. There is however high barrier to entry cost to the emerging market like the required plant co-location that VM must meet to be able to extend their global footing. Organization boundaries are more permeable, roles and responsibility shift in the new product development process. Speed of product development increases fast as new technology (E-commerce) reduces business transaction frictions and brings competition from around the world.

2.2.2 *Customer Satisfaction*

The second challenge to sustain the consumer base is the renew effort towards mastering the consumer satisfaction. Consumer satisfaction is the key determinant of additional product and service sales. Retail environment illustration of this point indicates that a consumer will leave the sore if he or she doesn't find the first product they are looking for with a reasonable amount of time. Conversely, if they do find it, they will not only stay, but will also add further five or six items to their list of purchases. In a similar vein, a satisfied customer can lead to an average of between 9 to 11 referrals. There are two distinctive consumer demands that global VM must satisfy. For the established market, the products are replacement products and will serve to fit the customer's lifestyle. For the emerging market the vehicles remain basic transportation needs and personal freedom. There is a challenge for the new product development processes on the global scale that can meeting both.

2.2.3 *Platform De-proliferation*

Platform architecture is the answer the VM rely on to implement economy of scales. It enables the reduction in cost. It gives the flexibility to tailor to the needs of different consumers markets and the speed to market. Growing trend in the industry is that suppliers will become bigger and will take on the role of a module supplier.

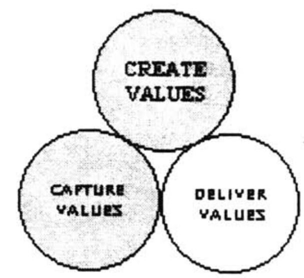


Figure 4: Values

It is useful to think of any business as about providing value to the final customers. There are three components: creating values, capturing values and delivering values to the customers (Figure 4). In the vertical integrated company, all three value components often handled by it. Today, the scarcity of resource and asset force the company to rethink its strategic position in making choices and focus. The observation from today automotive trend is that there is a movement toward the two components of creating values and capturing it. The VM rely more and more on mega supplier to deliver value through their acquired capability.

3 CAE VALUE IN PRODUCT DEVELOPMENT

CAE is "process engineering". It uses information to generate useful information to support design decision. The value of CAE contribution must therefore add to the product development value. It is hard to measure directly in dollar terms how much value CAE could bring into product development just as it is as hard to estimate the value of product development to the overall product life cycle. The VM however needs to appreciate the value of the PD and CAE to be able to use them effectively. One way to do that is to see where they play a role in the process. The PD has the following characteristics:

Indirect Nature of PD Value: Value for PD could be defined as the right information products delivered at the right time, to downstream processes and customers. One useful framework to deal with "information transformation" business like PD and CAE is the use of four broad metrics "Form, Fit, Function and Timeliness" or FFFT [4]. Value within the PD process, which is based on information, is a function of the FFFT.

- Form: Information must be in concrete form, explicitly stored
- Fit: Information must be in a form that is (seamlessly) useful to downstream processes
- Function - Information (design) must satisfy end-user and downstream process needs. Have an acceptable probability of working (risk). Satisfy direct customer requirements for documentation
- Timeliness: Right information, right time

This FFFT framework is useful when analyzing the problem of collaborating with FSS CAE to avoid operational problem. This issue will be addressed later in this thesis.

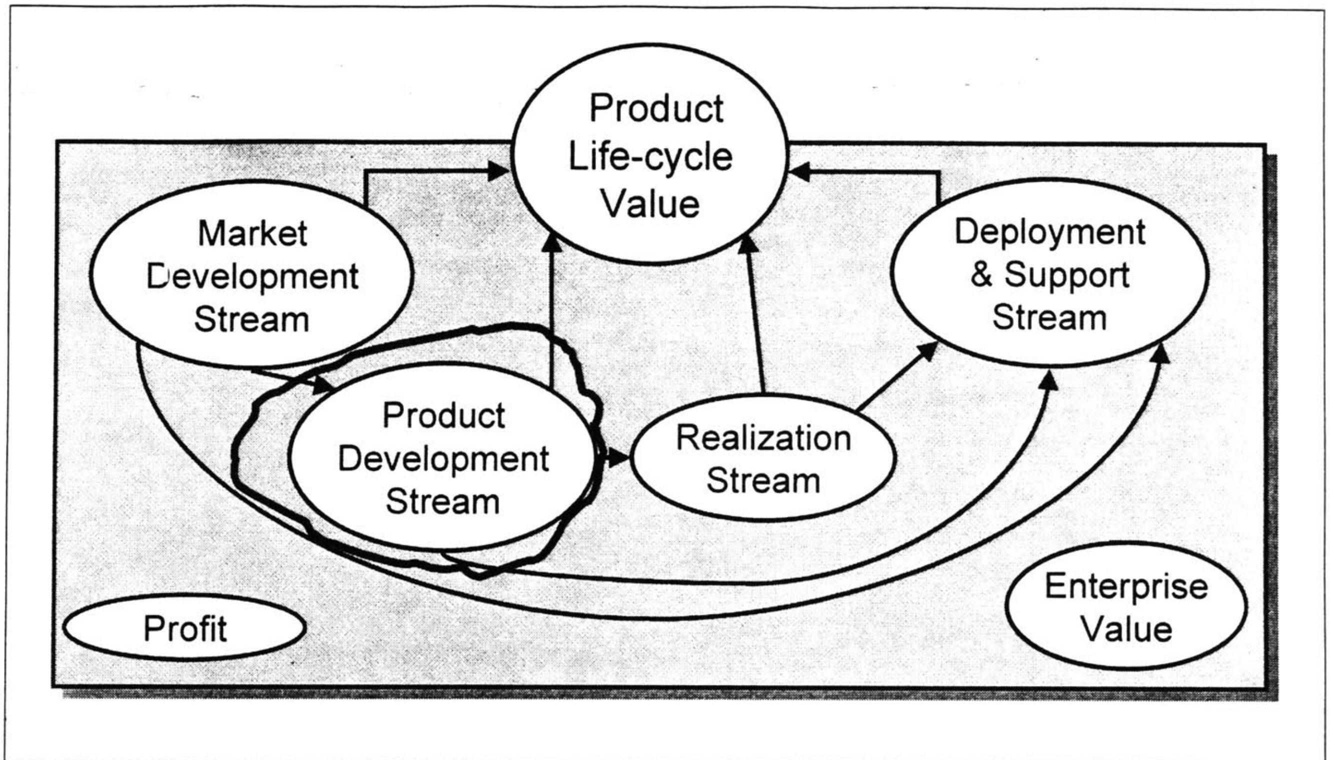


Figure 5: The Big Picture

3.1 Automotive Enterprise Value

The value stream of the automotive industry in the biggest picture could be seen as a series of 4 steps (Figure 5: The Big Picture) Market Development stream, Product Development stream, Realization stream and Deployment and Supports stream. All streams support the product life-cycle value. Today trend shows that there are 2 significant strategic moves occurring in the automotive industry. The first is the shifting of the VM management resource towards the Market Development as VM are transforming the company towards being a more consumer focus. This first driver leads to the second strategic move in the value stream, the suppliers that have been responsible for manufacturing now stepping forward to design and develop all aspects of their products. They also begin to replace the role of the VM in managing other sub-tier downstream. Generally, focusing on the Market Development stream creates value due to its upstream leveraging position.

3.2 Product Development Value

Product development, the focus of this research, also possesses a very high leverage to the product life cycle. It was determined that up to 75% of the manufacturing costs are determined in the development stage. It is however hard to measure exactly the value of it. The product development has the following characteristics:

- PD is imbedded in the product life-cycle value stream, in supplier chain and lean enterprise.

- PD delivers value indirectly. These values must pass through manufacturing, upgrades, before being realized by end user.

3.2.1 Five goals of product development:

Since CAE is a small portion of product development process, the major goals of PD must be clearly understood first before analyzing CAE contribution to the PD process. There are five main goals of PD: increase quality, reduce cost, increase speed, reduce risk and manage knowledge. Each will be analyzed below:

3.2.1.1 Quality

The sophisticated consumers today have unprecedented information and product options to make their purchase decision. Consumer choices are about optimizing for their lifestyle. Thus the product must go beyond meeting expected traditional quality like numbers of things go wrong (TGW).... It must excite consumers. This goal of PD is to support the VM strategy in being closer to consumer to achieve customer satisfaction and loyalty.

CAE is capable of predicting a variety of structural failure modes which if not captured early will show up as things go wrong to the consumers. Beyond quality, CAE is used to exceed structural performance targets of vehicle in the most cost efficient way. This strategy could be used to produce customer delight (exceeding their expectation) and retaining customer's loyalty.

3.2.1.2 Cost

Exceeding the customer expectation in quality and emotional performance with an advantage of a low cost producer is a great challenge but nevertheless a "must" goal of PD. It can ensure value to investors. It is about reducing cost of the final product, the cost of developing the product and cost of supporting it. PD has a tremendous potential to reduce all of these types of cost. Being a matured industry, the automotive "dominant design" has long been established. The competitive advantage for the VM is therefore to compete on the "way" to bring lower cost. E-commerce can serve as a means to take waste out of the system by making supply market transaction more direct. A great way to buffer against economic downturn is capability in reducing cost.

CAE is a great tool in cost reduction especially for the minor scale vehicle programs that come after a major one. CAE in this case has the benefit of actual test data for model correlation. Parts that survived a rigorous structural test are candidates for further optimization like down gage or changing materials. CAE analyses are used in A to B comparison to make engineering assessment.

3.2.1.3 Speed

Consumers are getting richer and more flickering in their tastes and choices, identifying the latent needs to satisfy them first before any competitors can is the advantage. This is the goal of Market Development Phase preceding PD phase. However, the speed of the PD is essential to bring the idea about consumer need from concept into concrete form for production. Being first on market gain so much competitive advantages. The major benefits from a fast development process are listed below [2]

- *Increase sale:* Early introduction of product brings benefits from a larger sales life and from a large market share. This supporting the automotive strategic move about "economy of scales".
- *Beat competition to market*
- *Be responsible to changing markets, styles and technologies Maintaining a market leadership position*

CAE can deliver impressive speed to product development. Instead of the traditional process of build-break-build in hardware which is time consuming. CAE can provide a quicker way to understand interactions among different variables.

3.2.1.4 Risk

Risk is a goal of PD that is not obvious to the final consumer. To the VM, however it is major undertaking evidence in the product development process that fills with gateway or stage gate reviews. Each review has risk metric to measure the performance of component and system designs. Managing risk is critical to deliver "consistent" return on investment (ROI) to today demanded investors.

Due to its predictive capability, CAE is constantly used during the product development process by vehicle engineering as an overall indication of program health, to see target gap and feasible road map to get back to target. The role of CAE in management of risk would not change in contracting out a component CAE to FSS.

3.2.1.5 Knowledge

Another product development goal that is not apparent either to the final customers but it is very critical to future success of the VM is knowledge. With knowledge, VM can ensure continuous growth and retains its competitive advantage.

CAE is particular important in this aspect. In CAE engineering data are captured in the form of computer inputs. The vehicle is modeled and loaded to simulate different load conditions. CAE can be used to conduct design of experiments to understand critical factors and their interactions. Knowledge like these can be generated quickly and more reliably.

Figure 6 below depicts a goal cascading process and CAE contribution. The ultimate goal of the vehicle manufacturers is to increase shareholder value over time. This in turns means increasing the return on investment (ROI) consistently. Consistency is important to long term shareholder and it can be achieved by having a process to reduce the risk and increasing knowledge. To increase (ROI), the VM needs to increase revenue, reduce cost and reduce investment. Further cascading down in the diagram in order to increase revenue, the VM need to increase customer delight, quality, delivery and reduce cost. To reduce cost, the VM needs to reduce product cost, development cost and transaction cost in conducting outsourcing. To reduce investment, the VM could reduce investment asset along with transaction cost.

In outsourcing a commodity, the VM are focusing on reducing cost and reducing investment by having the suppliers spending their capital dollars in tooling, design and development. These costs are to be rolled up in variable piece cost. By setting up this way, suppliers will share the risk on market share. The lower the product market share the higher the risk suppliers will not have enough product volume to recover fixed investment. This is an emerging issue in automotive supplier chain management.

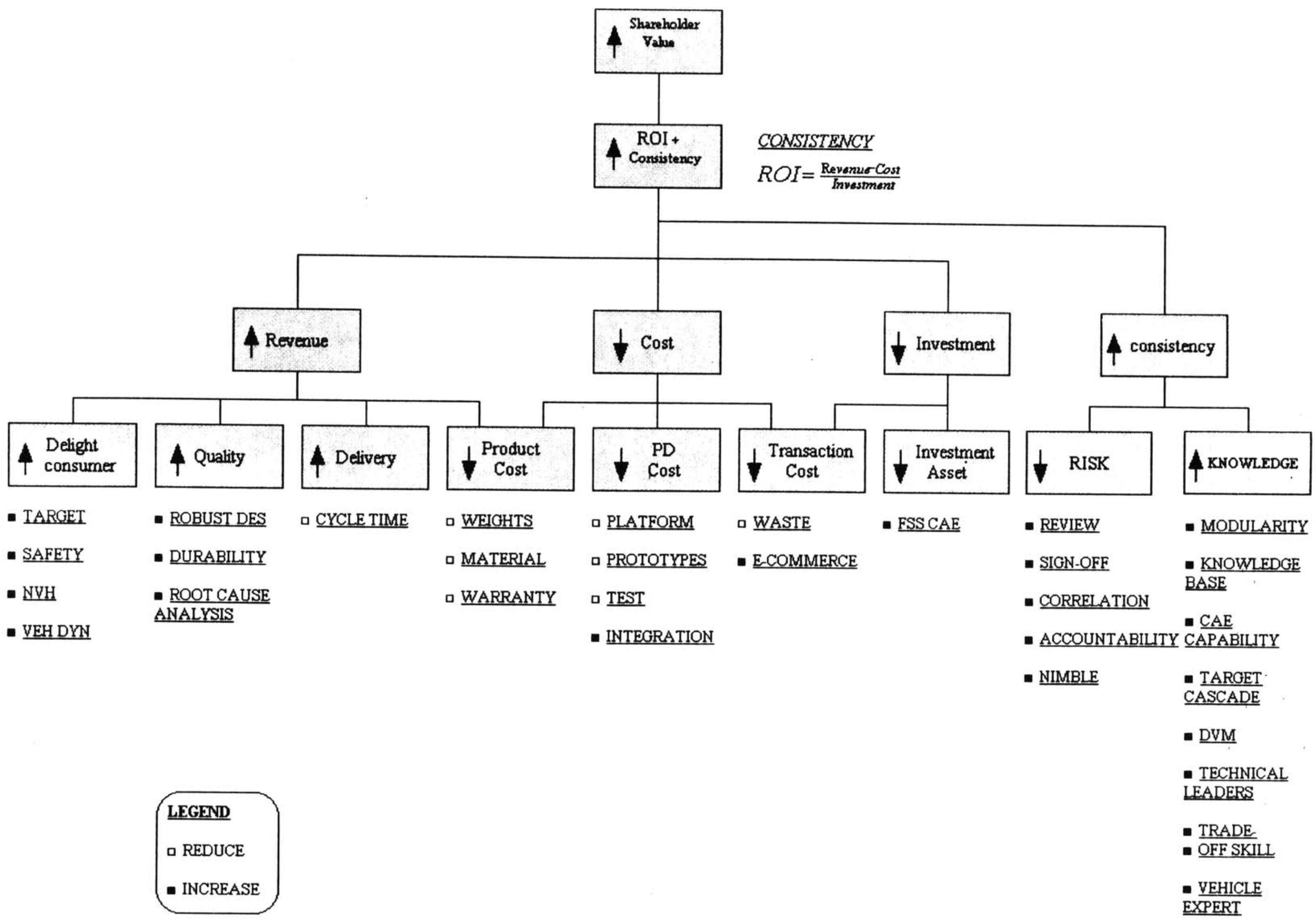


Figure 6: Goal Cascading

3.3 CAE Value

3.3.1 Uniqueness about CAE management

An often-raised question when dealing with CAE outsourcing is "what is unique about CAE that outsourcing it requires special attention?". The followings are review of CAE overall values:

- *Value of CAE is imbedded within the PD* therefore it is hard to measure. CAE transforms information. Management of CAE therefore needs to understand intangible values of CAE and be able to communicate it with upper management in securing investments so that CAE investment will not be viewed as additional cost for the design.

- *CAE value in managing risk and knowledge are not apparent* although CAE supports all five goals of product development: quality, cost, speed, risk and knowledge. These two values however are unique to CAE. Management of CAE therefore needs to understand these two particular intangible values of CAE. For example, the difference between CAD and CAE is that CAE deals with behavior model of the design while CAD deals with the geometry of design. CAE is a living knowledge while CAD is a "frozen knowledge" model.

- *CAE quality verification is a unique challenge*. Unlike CAD model that could be verified through dimensionality study, CAE model bears physical properties and constraints that processed by people upstream (material property, road load, constraints). The potential for modeling error is greater with CAE model. Also for CAE analysis, since it is done upfront to guide CAD designs, no hardware available for correlation. The use of CAE therefore needs special management attention in terms of using appropriate CAE capability and confidence levels to impact design decision effectively.

3.3.2 CAE Value Stream.

Since CAE is used throughout the product development its value could be drawn as in the (Figure 7) below. A more detail breakdown of CAE process is presented here to facilitate the CAE contribution to the total product development. The value stream map can be used then to see if any CAE step can be a candidate for outsourcing.

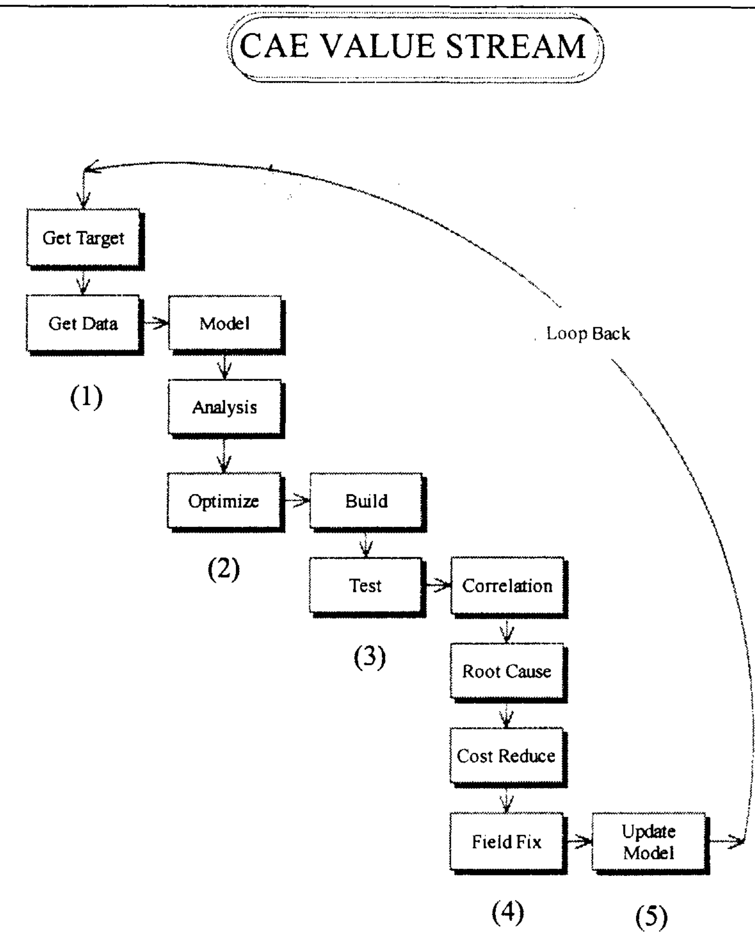


Figure 7: CAE Value Stream

3.3.3 Can CAE be outsourced?

Dr. Daniel Whitney (senior scientist) and Prof. Charles Fine of MIT Center for Technology, Policy, and Industrial Development have proposed in "Is the Make-Buy Decision Process a Core Competence?" a framework for determining the commodities that are candidates for outsourcing (Figure 8). Product decomposability is the criteria for looking at the outsourcing candidates. Best candidate for outsourcing is in the upper right quadrant (decomposable & dependent for capacity).

Target decomposition is a complicated process because of the multi-requirements for the commodity. The traditional rule of thumb only serves well for a traditional vehicle structure. When new structure is demanded rule of thumb (or heuristics) runs into difficulty. One example is in designing the engine rubber mounts, the conventional rubber volume required by the VM is 14 in^3 or larger for it to provide both NVH isolation and remain durable under service load. When package space is limited due to changes in vehicle and powertrain architectures this rubber volume requirement to FSS often does not help the FSS CAE in searching for a feasible design. It is frustrated to FSS to know that competitive vehicle on market can have engine mounts that are far less than 14 in^3 in volume. Without decomposable targets in this case, FSS cannot manage their engine mount development works independently. The target trade-offs thus relies too much on full vehicle hardware testing at VM which is an expensive and time-consuming process to do. The solution is to this using CAE to conduct trade-off using multi-physic simulation. This multi-functional optimization field, although not matured, is a growing field at the VM.

In order to make progress in achieving higher level of target decomposition (but not perfect), VM needs to devote more efforts in developing and fine tuning the multi-physic CAE model (model that can simulate multi-functions simultaneously). FSS with its expertise in component design can provide data and realistic design and manufacturing constraints to make the simulation successful. Much of current VM efforts of using knowledge base computer system to capture information on current target cascading should serve as a means for lesson learns and continuous improvements. Potential targets that are cascaded from different VM disciplines to the same FSS will surface quickly under this knowledge base system. "Decomposability index" of each commodity could possibly then be determined.

There is potential synergy between VM and FSS in this endeavor. Management should then pay a good attention to the collaborating with FSS.

Figure 8: Matrix of Dependency and Outsourcing

	DEPENDENT FOR KNOWLEDGE	DEPENDENT FOR CAPACITY
OUTSOURCED ITEM IS DECOMPOSABLE	A POTENTIAL OUTSOURCING TRAP YOUR PARTNERS COULD SUPLLANT YOU. THEY HAVE AS MUCH OR MORE KNOWLEDGE AND CAN OBTAIN THE SAME ELEMENTS YOU CAN	BEST OUTSOURCING OPPORTUNITY YOU UNDERSTAND IT, YOU CAN PLUG IT INTO YOUR PROCESS OR PRODUCT, AND IT PROBABLY CAN BE OBTAINED FROM SEVERAL SOURCES. IT PROBABLY DOES NOT REPRESENT COMPETITITVE ADVANTAGE IN AND OF ITSELF. BUYING IT MEANS YOU SAVE ATTENTION TO PUT INTO AREAS WHERE YOU HAVE COMPETITIVE ADVANTAGE, SUCH AS INTEGRATING OTHER THINGS
OUTSOURCE ITEM IS INTEGRAL	WORST OUTSOURCING SITUATION YOU DON'T UNDERSTAND WHAT YOU ARE BUYING OR HOW TO INTEGRATE IT. THE RESULT COULD BE FAILURE SINCE YOU WILL SPEND SO MUCH TIME ON REWORK OR RETHINKING	CAN LIVE WITH OUTSOURCING YOU KNOW HOW TO INTEGRATE THE ITEM SO YOU MAY RETAIN COMPETITIVE ADVANTAGE EVEN IF OTHERS HAVE ACCESS TO THE SAME ITEM.

The above matrix will be used in the following CAE outsourcing analysis to determine what CAE step is a candidate and a not candidate of outsourcing.

CAE step outsourcing analysis:

CAE has high potential to impact all 5 goals of product development as described above. The detail CAE Value stream map (Figure 7) could be categorized in 5 steps and potential outsourcing steps are analyzed.

1. Step 1: get target and engineering data. This step should not be outsourced since much of knowledge here is about system engineering. Targets are set based on the integrated requirements from customers, government and corporate goals. The engineering data are from vehicle level like road load, vehicle durability test and evaluation and competitive vehicle benchmarking. The function is not decomposable and knowledge dependent. It is therefore the worst case to outsource.

2. Step 2: model, analysis and optimize. This step is fairly modularized given target and data inputs. Instead of the VM CAE who will perform the CAE component works, FSS CAE is responsible for it. Although the target is not fully decomposable, it could be outsourced with care. As mentioned before, there are lots of trade-offs of the design and CAE analyses occurring at this stage to meet target requirements from different functional attributes, it is often a tedious and time consuming process. Outsourcing it will free up CAE resource for other purpose. This falls under lower right hand quadrant in Figure 8. The integration is still the same whether VM or FSS CAE conduct this step 2.

3. Step 3: supporting hardware build and test. In this step CAE full vehicle model is used to guide the build of vehicle prototypes for objective and subjective evaluation. This step should not be outsourced since again it is at vehicle level that naturally should remain with the VM.

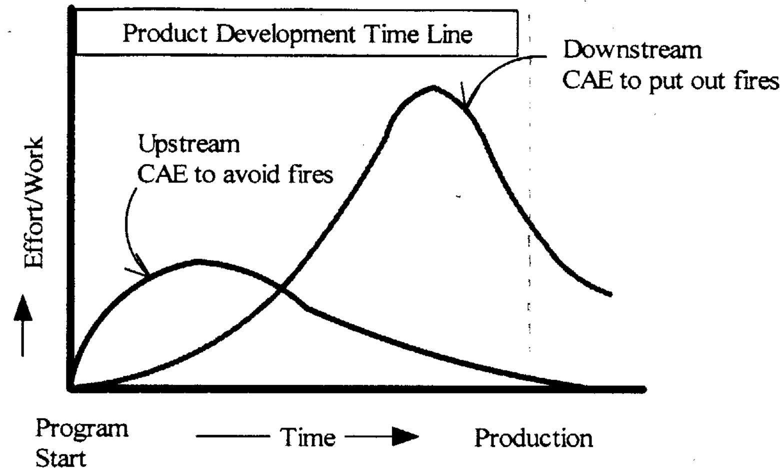


Figure 9: Upfront CAE

4. Step 4: conduct correlation, root cause, cost reduction and field fix. This post "hardware" step is typically a busy time for VM CAE to resolve problems. If the upfront CAE of step 2 is not done properly, huge amount of works in step 4 will exist (Figure 9) [3].

5. Step 5: update model and loop back to step 1. This step is usually overlooked since it is at the end of the program and serves no further purpose for that particular program. However, it is invaluable for the new programs that will use it as a baseline model. The deviation between information in CAD and CAE model could be significant at this stage and may affecting the accuracy of the analysis on the future baseline program. The VM could "off-shore" the modeling of full vehicle CAE model to a modeling company oversea to save cost.

3.3.4 Barriers to CAE effectiveness

Being potential wonderful tool like this, CAE does not come without any shortcoming. As the matter of fact, the implementation of CAE in the established automotive organization that used to be comfortable with the hardware world has been a good challenge. Understanding these challenges are prerequisite to gain insight on how to manage CAE itself and in the scenario that it is outsourced to FSS CAE. CAE in the large VM often is centralized to leverage the knowledge and capacity therefore it is managed separately from other department (CAD, Engineering). The followings are weakness of VM CAE

1. *CAE modeling time is a bottleneck*. This is aggravated by the interoperability problem between CAD and CAE. Briefly this is the problem that CAD deliverables information does not 'fit' into the usage of downstream CAE. This is often due to different organizations that manage CAD and manage CAE. Outsourcing to FSS, CAE modeling is usually taken care by the same organization. There is a strong incentive for FSS to make the process works smoothly to minimize cost and delays.

2. *CAE acceptance is inconsistent*. In the past, VM CAE has been not able to fully integrate into the PD process. This is due to organization issues similar to the issue of CAD/CAE organization mentioned above. The inconsistent acceptance of CAE recommendation also stemmed from the fact that CAE quality is also inconsistent. The complexity of CAE model size sometimes hinders the rework discovery process. The author therefore proposes a quality modeling check process as a remedy for problem (see page 63).

3. *CAE is not implemented upfront enough.* Too much of "throw over the walls" engineering still occurring between CAD and CAE. A consistent theme of organization problem is seen again here. Enablers that tie CAD / CAE together, in the form of integrated CAE/CAD package, are beginning to emerge that could help bridging the culture gap between designers and analysts. Upfront CAE values (problem prevention) are harder to be realized than at downstream stage where there are problems and CAE can be a solution.

4. *CAE capability coverage is not complete*. There are still a variety of vehicle phenomena that CAE vehicle system model does not address. The limit is due to technology and human resource. Therefore, it is much harder to affect the design with partial solution. This creates difficulties if decomposing the system target to component target.

4 CAE OUTSOURCING

4.1 About Outsourcing

Outsourcing is not just a management fad:

Unlike "instant coffee" management tools of "down sizing" and "re-engineering" that are applied in a way not relevant to the company problem. Outsourcing is a long-term strategic management tool that requires cares in make/buy decision, determining of core competency and the management of the collaboration process. The following views are appropriate and applicable to the automotive product development organization.

4.1.1 Outsourcing is "re-organization"

Outsourcing is the shifting boundaries of organizations

The shifting occurs to take advantage of "specialization" among partners. In outsourcing, organization is "re-drawn" not reduced. The internal staff becomes external staff and the focus is on the growth of business instead of maintaining it.

4.1.2 Outsourcing is about "specialization"

Specialization is nothing more than the division of works among the specialists. The VM in this case is the specialist in integration instead of being a generalist coordinating the tasks. Specialization benefits derived based on the principle of "relative effectiveness". For example, even though the company can do both two activities A and B better than anybody else, it still should outsource the lesser value task B to use the time and resource for producing a more value task A. Before the "re-drawn" boundary of the organization occurs one needs to know how to determine "core competency" for long term development as a competitive advantages and which activities will be farmed out. Since outsourcing is about re-organization to ensure its success, all traditional good principle of management needs to apply: setting goals, monitoring performance, take corrective actions and creative environment for growth are still applicable to outsourcing however, the form and format for doing that have changed.

4.1.3 Outsourcing is a "strategic" management tool

Outsourcing is nothing more and nothing less than a management tool. It is used to achieve specific management objectives. There is no right and wrong, but there is right and wrong within the context of what the organization is trying to accomplish. Outsourcing is management and not "abdication" and therefore requires proactive management. The management style however is very different from the style of managing internal organization.

1. It is also important to distinguish between outsourcing and contracting. In outsourcing the company gives up the control of the "how" and focuses only on the "what" of deliverable. Thus it demands a new style of management and new skill sets. Dr. Michael Useem of Wharton refers to as leading laterally as opposed to managing down.

4.2 Outsourcing Strategy

4.2.1 FSS process – the drive towards modularity

There is a drive to give suppliers even more responsibility in the automotive industry.

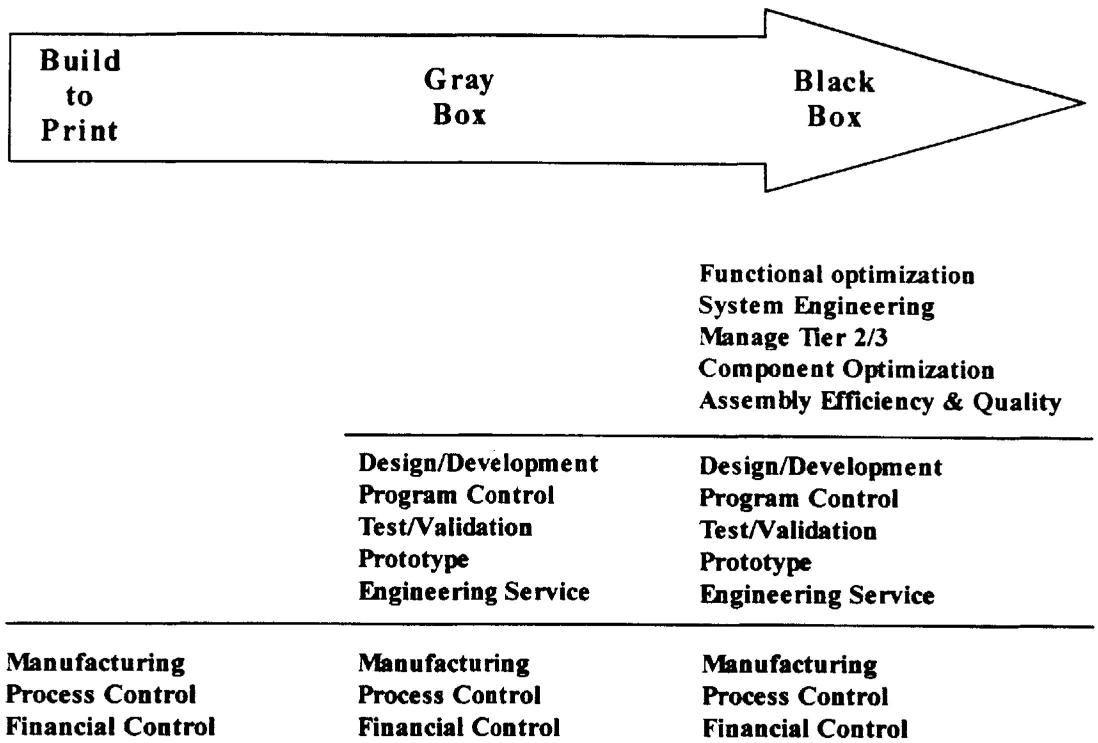


Figure 10: Supplier Hierarchy

Figure 10: Full Service Suppliers today have "Gray Box" responsibility. They are however encouraged to become "module suppliers" that will have "Black Box" responsibility. A typical FSS selection process begins with FSS "self assessing" their capability according to provided guidance. If FSS capability is not there to meet all requirements, FSS usually have the option to submit the "self-development" plan to get the capability. The VM then review the status of the FSS application. If the application is not accepted the FSS will conduct further self-development and resubmit the application again.

The observation of this process is that there are plenty of rooms for the FSS to qualify for the FSS status. This FSS recognition process however heavily depends on the supplier "self-assessment". This perhaps is driven by a higher level strategic outsourcing which will select 3 to 4 competitive FSS with the same commodity to get different outsource contracts for different vehicle programs. The strategy here is to keep FSS competing with each other to manage risk and reducing cost.

4.2.2 CAE FSS process

VM CAE usually has no inputs into the selection process of FSS. They are informed by the VM engineering of the selected FSS suppliers and start the writing statement of work process to detail the CAE requirements. An unstructured collaboration process begins and the results usually are surprises.

4.3 FSS CAE capability

4.3.1 Classification

The FSS CAE capability could be classified as of 3 levels:

1. *No capability*: These FSS rely on independent CAE consultant companies for CAE services. It is done mostly to comply with the request from the VM CAE. Their commodity tends to be small like engine mount, engine mount bracket, knuckles ... The result is that FSS does not engage FEA into the development process. It usually is done at the end for confirmation. The quality of those services varies from vendor to vendor. Since there is no direct contact between the VM CAE and consultant CAE, most of the deliverables do not meet the form, fit, function and time requirements (FFFT). The results are many surprises and reworks.

2. *Developing capability*: These FSS have FEA group in house and have scale due to their size of commodity and they are working for multiple VM. Such commodities are truck frame, instrument panel, seats ... they tend however to centralize the internal CAE group to leverage the expertise and productivity among CAE analysts. They are in a growing pain period that develops standard procedure and CAE structure. This FSS CAE growing period is similar to the long period that most VM CAE have gone through in the past. Yet there is little attention on a strategic level for CAE cooperation among the VM CAE and FSS CAE groups. CAE analysts are sitting with their peers while engineers and designers are together and located at the customer site. There is again problem with this arrangement because CAE requirements from the VM are still relative new to them.

3. *Developed capability*: These FSS have experiences in FEA and FEA has been part of the business for sometimes. They are mega suppliers that have volume and a verity of products. In some cases they are pioneering the re-engineering process of "up-front analysis" one step further than even the VM CAE.

4.3.2 Outsourcing Benefits

Outsourcing a portion of CAE to FSS provides the following immediate benefits

1. *CAE modeling time*. Historically, CAE component modeling has been a bottleneck in the CAE process. It is a laborious and time consuming job that hardly appropriate for the level of skills that typical CAE analysts at the VM who possess Ph.D. and M.S. level in engineering. Hence, by outsourcing this CAE modeling the VM CAE can better utilize its workforce skill and at the same time increasing their job satisfaction. Re-organization in the form of outsourcing in this case can solve a persistent problem of maintaining accountability in quality model within the VM CAE internal organization. Now there is an exclusive entity, the FSS CAE that is accountable for the modeling work. The challenge is to give clear specification for model quality and a quick and easier way for quality verification (see 6.1.1).

2. *Better product*: It is easier for people in the same organization like the FSS to have incentive to work together. The VM CAE does not have to push them for the developing of the product design. The challenge here is to have FSS CAE realizing the dual responsibility of supporting also the VM CAE in the quest for vehicle system model and analysis.

3. *Forcing the VM CAE to be more explicit about the CAE requirements*. This task would not be accomplished easily and seriously in the exclusive VM CAE organization. The reason is that they can work in the "interactive" mode and see the need to write down requirement as something of non-value added. There is a great potential of leveraging FSS CAE for their inputs into the writing of the requirements since FSS is also responsible for testing. The process of CAE correlation by FSS could help modifying the writing of CAE requirements.

4.3.3 Outsourcing Costs:

Besides the obvious cost could be attributed due to outsourcing, many other un-anticipated often hidden transaction costs associated with the project

1. *Assessment cost*: there is time spent to prepare, visit and conducting assessment suppliers. This effort is perhaps the biggest discouragement for VM CAE to get involved and thus rather leave this work for the engineering community, which does not have good CAE knowledge. The danger for VM CAE not involving in this phase is that there will be lots of surprise down the road.

2. *Writing requirement (statement of work)*: there is elaborate time spent to prepare and review the document with FSS and other internal group. There is also a natural tendency for FSS to accept

whatever written in SOW to make good impression about FSS capability in hope that it could develop these skills quickly. The different types of organization also make the gathering of specification a bit challenging. For example, if the VM CAE is organized according to functions with different groups in charge of their separate requirement documents it could take sometime to gather and sort out the conflict. More important and often ignored is that there is a risk associated with giving out standard and method that have been developed in house with years of investment. It is arguably that they are non-competitors and working as our extended enterprise. Nevertheless, almost all suppliers are working for all automotive competitors as part of their business strategy.

3. <u>*Collaborating*</u>: the cost of shadow engineering is likely evident as the VM cannot let go completely all CAE related to FSS. This is so for several reasons. For years, no design and analysis works are given to FSS; a learning curve and resource issue therefore exists in setting up and finding qualified CAE analysts to work for. Secondly, VM are still responsible to the final consumers as they continue to build trust through brand management. There is a high degree of interactions of different functions affecting the design. Some functions are currently only effective at vehicle evaluation such as safety, vehicle dynamics.

4. <u>*Verification*</u>: since VM retain the final verification task, much of reworks and thus costs are incurred at this stage, as FSS CAE often under time pressure could possibly deliver unfinished CAE product to VM.

4.4 Issues in Outsourcing CAE

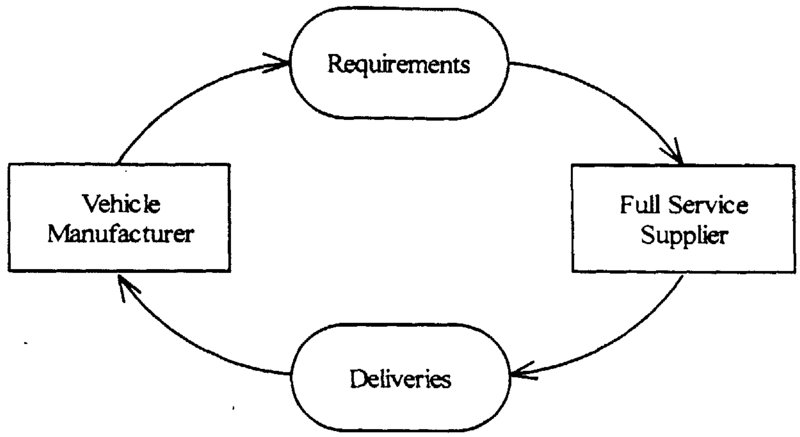
4.4.1 Reworks

(Figure 11) below shows "Future State" depicting an ideal world of FSS management, the VM will write requirements, passing them along to FSS. Full Service Suppliers then performs the works and deliver result back to the VM. The VM verify that they meet the requirement and ending the loop. There is no reworks, obsolete works, non-quality works.

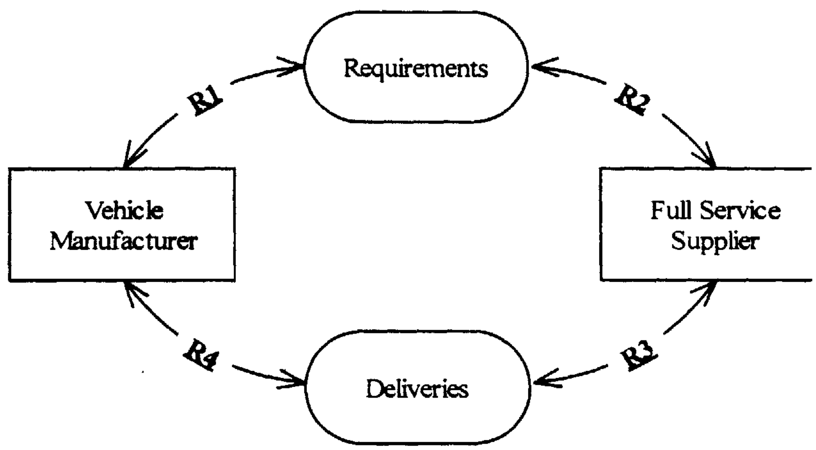
The Current State: however, to be realistic, VM often alter requirements due to unforeseen circumstances such as government regulation changes or due to the lack of a full ability to cascade down targets. The requirements when written down could be possibly mis-interpreted by the FSS a few times due to the unfamiliarity with VM product development system, example of this is that a seat supplier could interpret seat natural frequency with a rigid boundary condition, while what the VM want is a flexible boundary condition having the seat mounted on the floor. FSS can take more than one time to deliver the results due to reworks. Example of this could be that FSS CAE do not have enough and updated information or there is defection to the execution of their CAE works. The deliverables could be rejected due to VM verification process. Example of this could be that VM and FSS CAE are using two different CAE commercial programs that give two different results.

Not much information is accumulated as of how many times the reworks are observed. If the situation is out of control, the VM CAE usually conduct shadow engineering, start checking the model and results from FSS every time.

FUTURE STATE



CURRENT STATE



REWORKS in CURRENT STATE

R1: # times to specify requirement right
R2: # times to interpret requirements right
R3: # times to adjust deliveries right
R4: # times to verify deliveries right

Figure 11: Numbers of reworks

4.4.2 Potential Wastes created

The more players, the more mishaps could occur in the collaborating process. One can view this collaborating effort with FSS as an optimization of flow [4]. Similarly as in the Lean manufacturing process – the 7 waste principles have been studied and reapplied to product development. It could be used to apply in CAE outsource management process.

Analysis of Flow using the 7 Waste (Info)

Figure 12: shows the 7 potential wastes in dealing with information transformation. Since there are more players in the product development, this potential of wastes should be guarded.

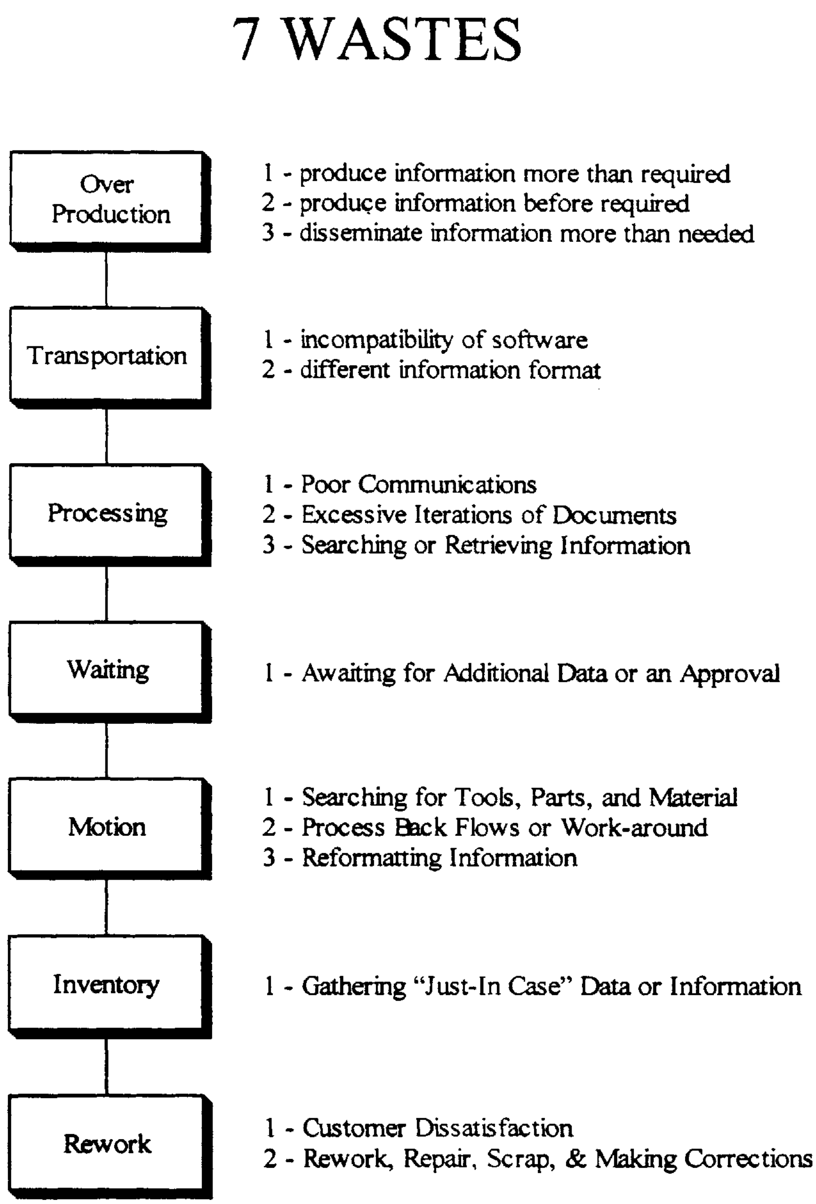


Figure 12: Potential Wastes in CAE

1. **Over-production:** VM may request more than necessary information thus creating larger amount of "work to be done". VM also can request to have more capability (hardware, software, and human-ware) just in case there is occasional need to use it. And this is not lean. The solution is to have a written standard procedure in helping to facilitate the communication and make sure that no two requirements are in conflict and redundant of each other.

2. **Transportation:** here the challenge is greatest since information CAE model does travel from one entity to another. Some of potential problems are information is incompatible and software is incompatible. Communication could be not frequent enough and some other security issues in exchanging information and tools.

3. **Processing:** Excessive customized processing - reformat for management review and data exchange.

4. **Motion:** Lack of direct access (high speed super computing usage) and the format is not appropriate. Too much "re-format" from one result to another.

5. **Waiting:** late deliver of information make the subsequent full vehicle CAE works useless. The delivering of information could be too early, enabling the full vehicle model to go on but the contents are obsolete due to late change in design. This leads to required reworks.

6. **Inventory:** Too much information generated creates a challenge in data management. Storing and retrieving with confidence. The amount of obsolete CAE model can cause more harm than good. Verification method needs to be immediate, otherwise discovering reworks will be a nightmare. Importantly, there should be a process for containment and retrofitting CAE models contains "defects" that are discovered late in the analysis production stage.

7. **Reworks:** Haste to produce information in the desirable time could lead to a CAE model is not quality. At the same time due to time pressure, no much time allowed for the "recovery" process, running out of time for review, test and verification. This problem is escalated in the culture that doesn't accept "nothing to show for" at the milestone review.

5 FSS CAE OUTSOURCING MODEL

5.1 Analysis

Before proposing a reasonable framework to work with FSS CAE, it is important to know the three forces that govern the CAE outsourcing process. They are the "EDA" concept, the CAE system engineering and the general project dynamics effect.

5.1.1 EDA Concept

EDA stands for Engineer, Designer and Analyst. The traditional roles of these three individuals according D.H. Brown Associates [5] as follow:

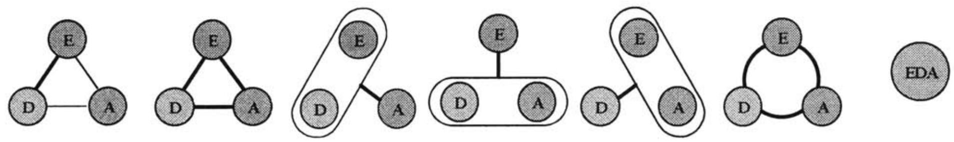
Figure 13: Traditional Roles of EDA

Engineer	Designer	Analyst (CAE)
Overall design concept	Design documentation	Evaluate designs
Schedule management	Packaging study	Solve design problem
Customer contact	Manufacturing assessment	Correlate to test
Supplier management		Calibrate computer model

Figure 13: One characteristic of this traditional EDA role is that the CAE analyst is not kept in the design loop. CAE analyst is kept off aside to solve a particular problem. Most of the works focus on improving the CAE confidence (correlation to test / calibrate the computer model). The workflows of three individuals EDA are very different with CAE analyst's workflow is of the longest. The consequence is that CAE effectiveness is low because most of what CAE recommendations are based not on the latest design and information from designer and engineer.

There are many different possible arrangements of EDA as below:

Engineer / Designer / Analyst Arrangement



Types	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Name	A=sideshow	EDA interface	Design Engineer	Design Analyst	Engineer Analyst	EDA integrated	Super Engineer
Characteristics	E/D interface with each other. A is isolated from E/D. A acts on aside as consultant on needed basic	E/D/A interface, more likely to be collocated but remains on different organization	One engineer does both engineering and designing (ED). A interface with (ED)	One engineer does both designing and analysis(DA). E interfaces with D	One engineer does both engineering and analysis (EA). D interfaces with (EA)	E/D/A are integrated. more likely under one management	Super engineer does all (EDA)

Figure 14: Different Ways of EDA Interaction

Analyst isolated: (Figure 14.a) CAE is isolated from the both the engineer and designer. Generally this is a bad process in which CAE is just a "side-show" very ineffective to influence the design on its own. The CAE recommendation is usually presented late and by that time most of CAD works have been finished. Design changes become costly to implement. This is however a typical characteristic of a young CAE organization. At its initial stage it tends to focus on developing internal CAE capability and less on integration with design. In addition, the role of the product engineer may incorrectly defined as a "release" engineer with focusing on development enough design (CAD) information so that the part can be manufactured. The best way to avoid this situation is to redefine the role of product engineer as releasing the design only when it is "right", this requires extensive usage of simulation driven design process (CAE) and leading to a more "integrated" EDA cycle.

1. **Analysts involve:** (Figure 14.b) shows that analyst interfacing with both engineer and designer. There are two distinct possible workflows.

    a. **CAD leads CAE:** Typically CAD will give CAE the initial design then wait for CAE to come back with the analysis assessment on that particular design before proceeding to the next. The process repeats until CAE finally confirms the design meets functional requirements. By always lagging behind CAD, CAE serves only as an assessment tool of the specific design in time. This process is highly iterative and time consuming.

b. **CAE leads CAD:** This is an appropriate way for "form follows function" design. A higher level of CAE skill and capability are needed to make it work. To precede CAD, CAE needs to do model without the reliance on detail CAD and still able to produce CAD specific recommendation. There are currently several strategies in the industry today

2. **Dual Roles:** (Figure 14.c-e) shows different combinations of two individual functions into one. These types of arrangements are seen at supplier companies. Among those the type (d) is a new trend with CAD system starts handling the preliminary CAE works. At those companies the analysis work is re-categorized into 3 different levels:

   i. **First Pass Analyses:** are those analyses that simple enough for designer to handle while designing. The tool from Ansys " Design Space" facilitates the process by allowing designer to perform basic "what if" questions. Such process filters out bad ideas early before they get through to CAE analyst who will perform the second level analysis – more complex and time consuming. Loading and boundary conditions in first pass analysis are simple and directional only. The CAE analysts help the initial set up.

   ii. **Sophisticated analyses:** are performed by the experience CAE analysts who will use advance FEA solvers to solve assembly problems and complex loading. At this stage, the design will be "tuned" instead of throwing back to CAD.

   iii. **The new problems:** are handle by the third level of CAE analysts, the expert group that set up new methods to increase CAE capability.

Due to its large size of workforce VM have had problem in integrating the three disciplines EDA together. The VM however can set up a process for EDA engineers to interface among each other (14.b). Unlike VM, FSS are smaller size and could be able to combine 3 roles into 2 (14.c-e). This reduces the number of communication links among them. Arrangement 14.f where all EDA are put under one organization (integrated) is also seen on some of the smaller FSS. The last option of "super EDA" engineer (14.g) simply is not practical due to the large amount of works required from each individual.

If the engineers and the designers are from FSS as in the full service supplier process, the analyst should be with FSS as well to keep the EDA cycle as close as possible.

The potential problem is that in this arrangement assumption that one CAE analyst from FSS will be equal to one CAE analyst from the VM is not really true. In the short run this is not the case because VM have a lot more CAE experience than of the FSS. There is needed shadow engineering to make FSS CAE "smarter" in getting through the initial learning curve. Therefore, outsourcing CAE requires VM management to pay attention to the collaboration process and willing to kick in some resource for initial transition. "Spot contracting" simply would not work.

The long-term benefits of letting FSS performing the CAE analysis are:

- Better communication among EDA cycle since all of them are from the same company they will have a strong incentive to work together to satisfy their immediate customer (VM) and actively compete with other suppliers under the free market driver.

- FSS is free to experiment component innovation. Take steering column system commodity for example, there are multiple design inventions that provide design parameters to achieve NVH stiffness and safety performance characteristic simultaneously. (Delphi's collapsible steering column main housing that provides stiffness for NVH. It is constructed with an outer steel tube jacket over inner stationary steel tube jacket. Sandwiched between the jackets are metal ball bearings. In an impact, the steering column collapses, the outer jacket slides over the inner one. Ball bearings mark groves on the jackets to dissipate energy from crash).

5.1.2 System Engineering Concept

The VM is responsible for the target cascading from full vehicle level down to commodity level for FSS. Regardless if the outsourcing occurs or not, decomposition of target is a necessary condition though my not be sufficient to effectively improve work efficiency at the component levels. Take steering column system example, while a majority of NVH targets could be cascaded, safety target may not be able to. The concept design of the steering column system then has to have "tuning" capability so that design can be changed late in the design cycle.

Among many ways to cascade NVH targets, NVH modal separation chart is a way to cascade targets. An example below will illustrate how to cascade NVH target to each supplier.

There are two main sources of NVH vibration excitations into the vehicle that can affect the steering column vibration (Figure 15). The first is from the powertrain excitation. Engine idle (hot & cold) excitation frequencies are monitored. For some truck vehicle programs that have multiple powertrain options, the excitation spectrum is very dense and makes the modal separation effort more difficult.

The second source of excitation comes from the resonance of other systems. Suspension hop and tramp frequencies, body front-end torsion and bending modes ... in design the steering column, one wish to avoid these frequencies all together.

Benchmark data from "image" vehicle is used to determine the range of frequency target for the steering column in vehicle position and on subsystem rigid bedplate. All frequencies at vehicle level are mapped into the following Modal Separation chart (Figure 17).

After selecting the reasonable target for steering column system in vehicle position (30 -35 Hz) for example, a target cascading process is conducted.

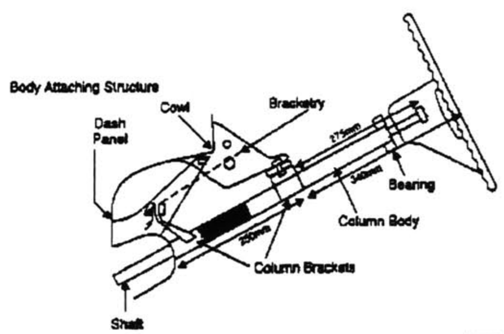


Figure 15: Steering Column

There are two approaches to achieve the target:

1. Based on benchmark. An actual vehicle that has successfully achieved the desired steering column natural frequency range of interest 30 – 35 Hz for example, is decomposed into system, subsystem and components levels. The stiffness of each subsystem is measured and set as target.

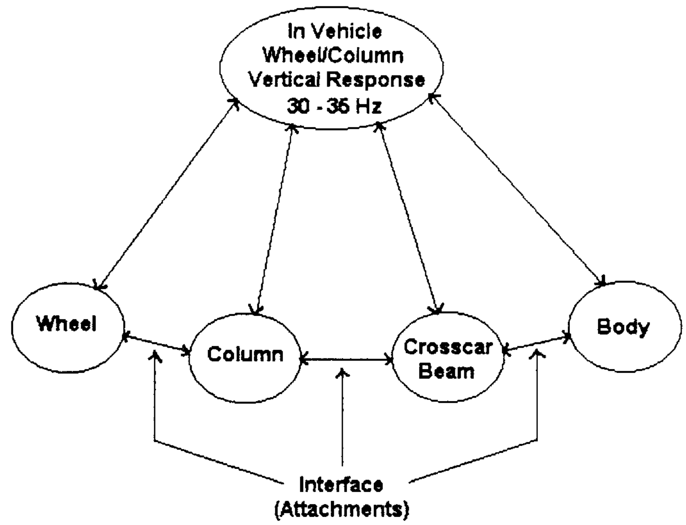


Figure 16: Wheel/Column Vertical Response

(Figure 16) shows the components and interfaces among them that contribute to the total stiffness of steering column in the vehicle.

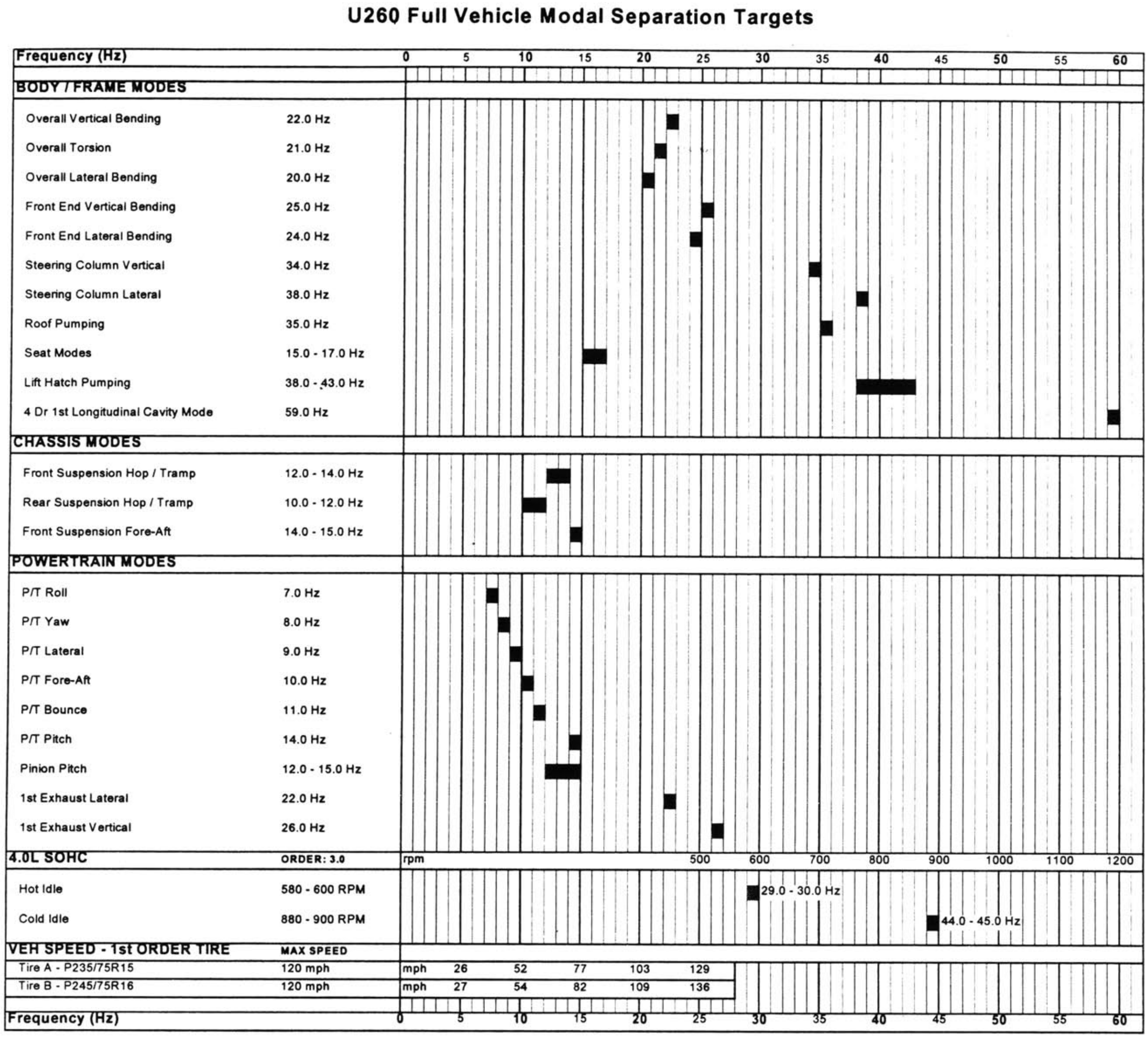


Figure 17: Vehicle Model Separation Target

	Vertical Frequency Target (Hz)	Lateral Frequency Target (Hz)		Verification Method	Key Parameters
Wheel Assembly	>70	> 80		(Bedplate)	Armature/Rim Stiffness Airbag/Controls Mass of Assembly (including cover)
Wheel & Column	> 45	> VERT	> 48 TILT WHEEL > 43 TILT COLUMN	(Bedplate)	Overhang Length Tilt/Telescope Mechanisms Mass of Wheel Assembly
Wheel, Column and Beam	> 38	> VERT	> 40 TILT WHEEL > 36 TILT COLUMN	(Bedplate)	Attachment of Column Mass of Wheel and Column
Wheel, Column, Beam in BIP	> 33 - 36	> VERT	> 35 TILT WHEEL > 33 TILT COLUMN	(Bedplate)	Attachment of Beam Compliance of Body Mass of Wheel, Column and Beam
In Vehicle	> 30 - 35	> VERT	> 35 TILT WHEEL > 30 TILT COLUMN	(In Vehicle)	Mass of Instrument Panel and Components

Figure 18: Cascaded Frequency Target

Except for the vehicle, which is designed by the VM, the other parts: wheel, steering column, cross car beam and in some cases body could be designed by the outsourcing suppliers. As illustrated above that one level performance affecting the performance of the system above it.

Mathematically, one can think of diagram in (Figure 16) as having 4 springs in series, the equivalent stiffness of "steering column system" in vehicle (Keq) could be expressed as:

$$\frac{1}{Keq} = \frac{1}{Kwheel} + \frac{1}{Kcol} + \frac{1}{Kbeam} + \frac{1}{Kbody}$$

2. Using CAE model: the equation of equivalent stiffness above tells the story that in order to achieve a desirable Keq, there are more than one way to cascade down the stiffness target to component levels. Two considerations are needed to determine early is the relative cost in achieving each component target and how realistic the component target is. One would want to avoid writing requirement that costly and infeasible to achieve. The approach (1) described above based on experience and thus these two concerns were somewhat addressed. However, for the entire new vehicle architecture that approach may not be practical. CAE vehicle model can be used to simulate the both target ranges and estimated the mount structure (thus cost)

needed more to achieve the ultimate target.

It is important to note that managing the interface in this situation is very important. This is an area that when having everything integrated with the VM it would give benefit because the functional target and cost trade-off could be done more interactively. With the FSS arrangement, targets need to be cascaded upfront so that negotiation for target and cost trade-off among the multiple suppliers will be at a minimal.

It is vital for FSS to understand the current immaturity of target cascading process. FSS should expect the revising of component targets to support vehicle target level. Participation of FSS in the upfront process will bring FSS expertise and experience in improving the target process.

Even though the component CAE works are handled better with VM due to its closeness with vehicle CAE works, outsourcing the tedious and time consuming component CAE works to FSS will release resource for VM to focus on system engineering of improving the CAE target cascading process.

5.1.3 Project Dynamics Concept

Outsourcing is a project dynamics that has feedback loops. James M. Lyneis of Pugh-Roberts Associate presented this feedback dynamic loop of project management at MIT System Design and Management lecture. This framework is useful to give management an overall picture of the outsourcing project. What source of controls the VM will give up entirely and what sources of critical parameters affecting the typical reworks that VM need to keep track and manage. The entire system dynamics model could be simulated to predict the percentage works really done and staffing requirements. This thesis will use the qualitative results of this system dynamics model to underscore the importance of "quality" control in the dynamic loop.

In outsourcing (verse contracting), VM give up the control of resource management: the selection of staff, hiring, employee skill development, managing of employee morals, work schedule, work quality, productivity rates ... These aspects although are not core business of the VM can have impact into the quality of the products.

There are two essential parties in this model. The VM assumes the role of the owner that specifies the amount of "work to be done". VM provide finance and will own the benefits of the project. The other end is FSS that receive finance to provide resources to deliver and execute the projects. In theory, decomposition of VM requirements and using traditional work break down structure could ideally quantify the amount works to be done. The FSS then can base on those concise specifications will staff, manage productivity and complete the project on time (Figure 20). In practice however there is a consistent pattern that this is not true.

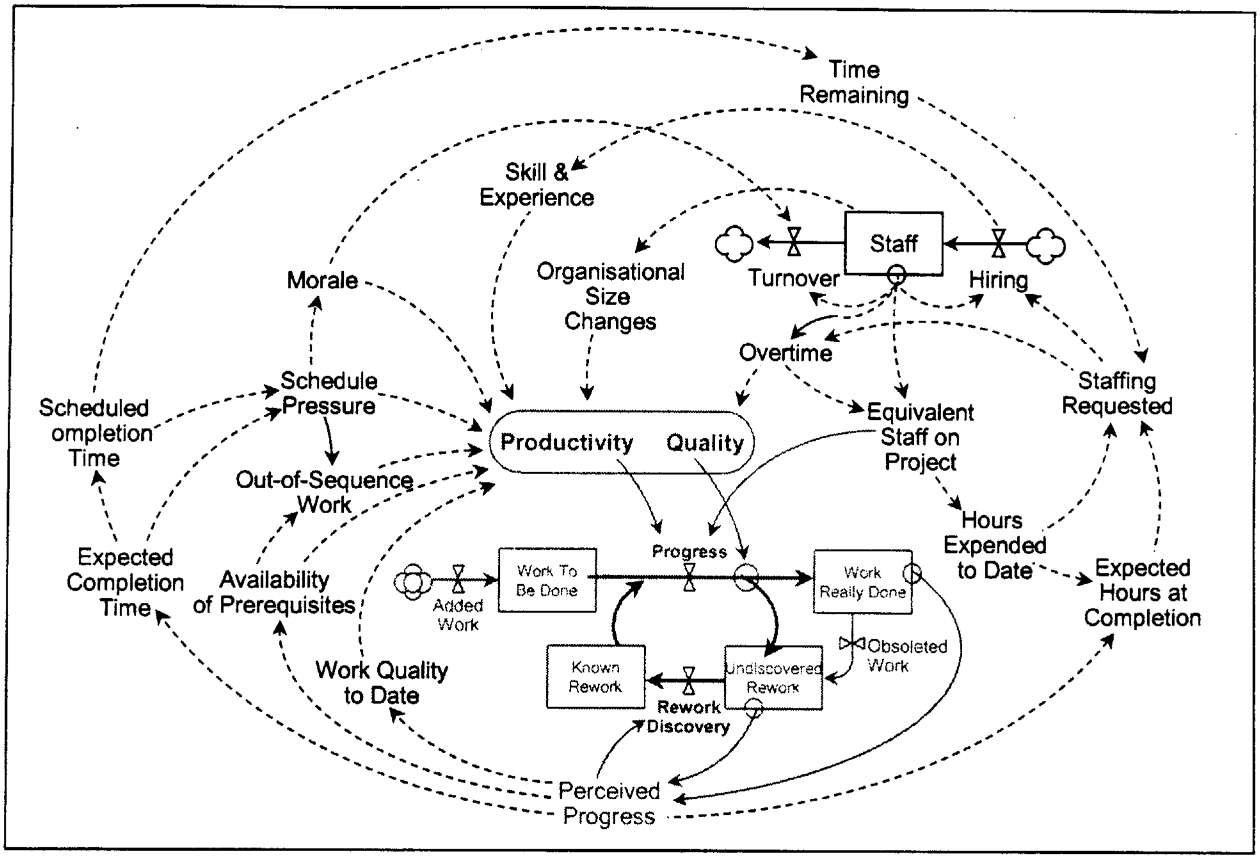


Figure 19: System Dynamic Project

(James M. Lyneis – Pugh-Roberts Associate 1999)

Traditional "Static" View:

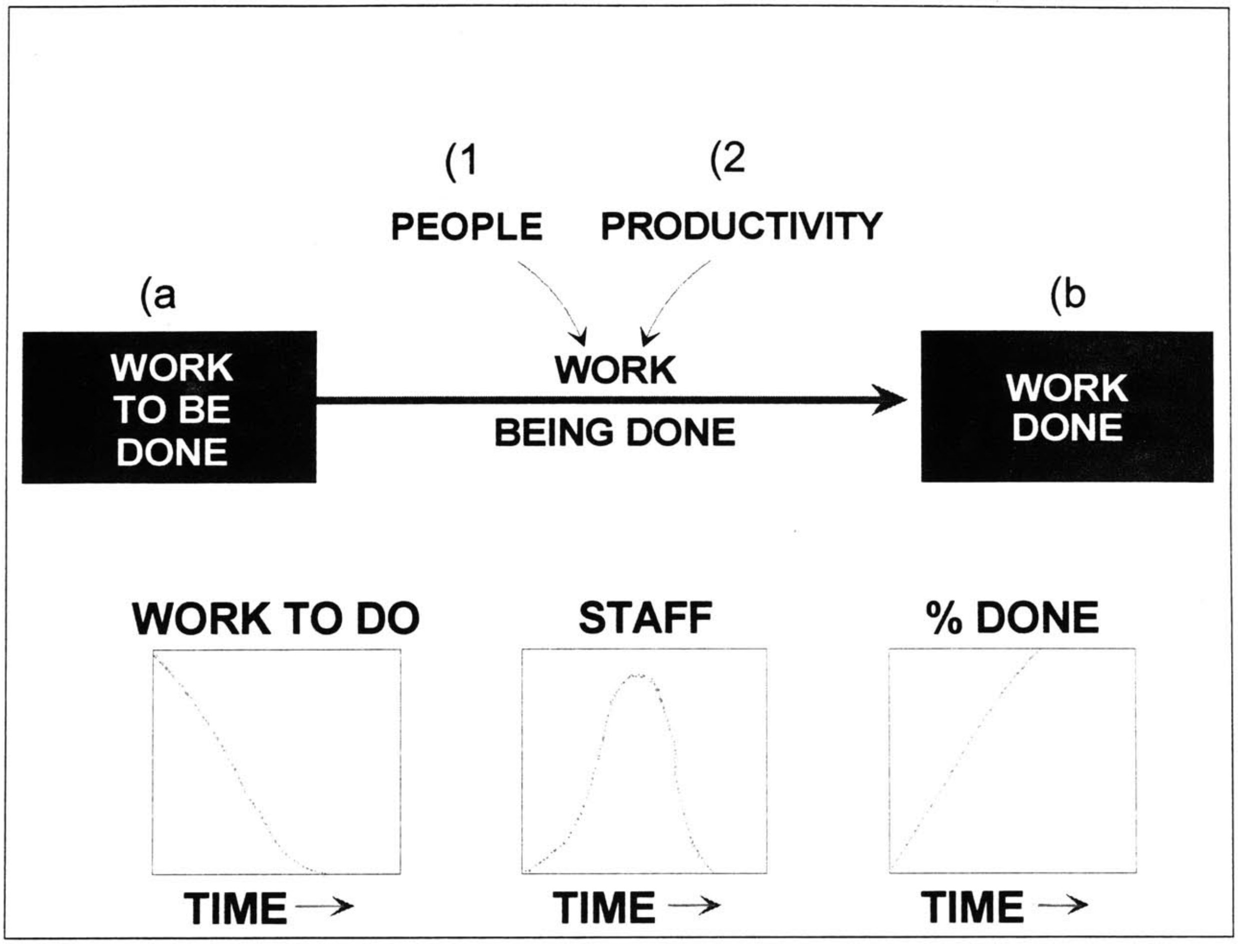


Figure 20: Project "Static" View

Project is more dynamics especially for a long product development cycle of 2-4 years in automotive. During this period of time changes occurs in requirements from government regulation, customer requirements, corporate strategy and the advent of technology. All of these have a major implication to the amount of work to be done. Despite best intention and clear product development process to layout the best plan, new things often surface and could cause stress in VM and FSS "trusting relationship". This could take the form of schedule restriction on program milestone, higher demand on FSS progress reports, introduction of changes in targets and scopes. This causes works out of sequence and can result in a sharp increase in the number of errors being introduced to the system. As new errors start being detected in areas, which were thought to be stable, staff progressively loses trust in the current system's requirements.

Project Dynamics View:

In below (**Figure 21**) a dynamics view of the project is used to take into account effect of quality that causes reworks and delay and even mistrust.

Dynamic Project Model:

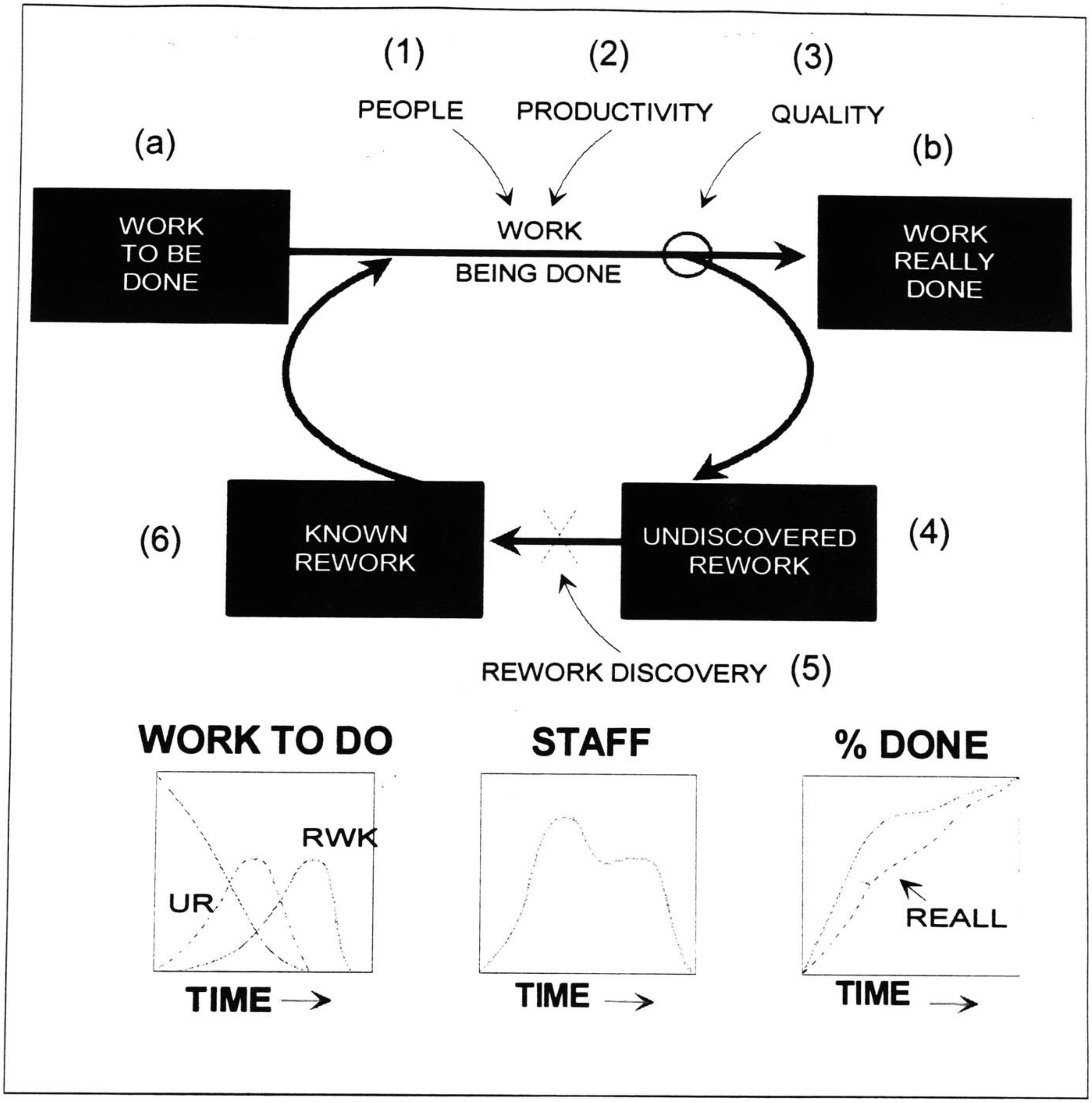


Figure 21: Project "Dynamics" View

(UR: Undiscovered Reworks – RWK: Reworks)

In this model several new steps are accounted for:

(3) Quality is introduced as in the real world. This quality level can be modeled as a constant representing the percentage of quality works (.70 for 70%). FSS reputation and record could provide confidence data in this assessment.

(4) Undiscovered Reworks: this amount is a product of potential work rate and quality. Too high of a potential work rate could be a bad thing if quality is low.

(5) Discovering rework: the time delay for VM or FSS to realize that there is a quality problem. This usually is due to verification at the time of handoff. A systematic approach to discover rework immediately is important for the flow of work from one entity to another. Just like the JIT system invented by Toyota that one of its chief benefit is in the ability to discover rework as soon as it occurs thus preventing the problem for other downstream.

(6) Known rework: this sometimes overwhelms the FSS and pressures them to be out of sequence in the workflow balance. VM can be a place to absorb that to lessen the impact downstream. Also as a way to improve lesson, process ... many cases the reworks could be created by the unclear definition of work to be done. If the VM not to assume this role, then in the assessment phase, FSS must have resource to handle the rework.

The results of reworks show up throughout the product development process in terms of revisions (Figure 22).

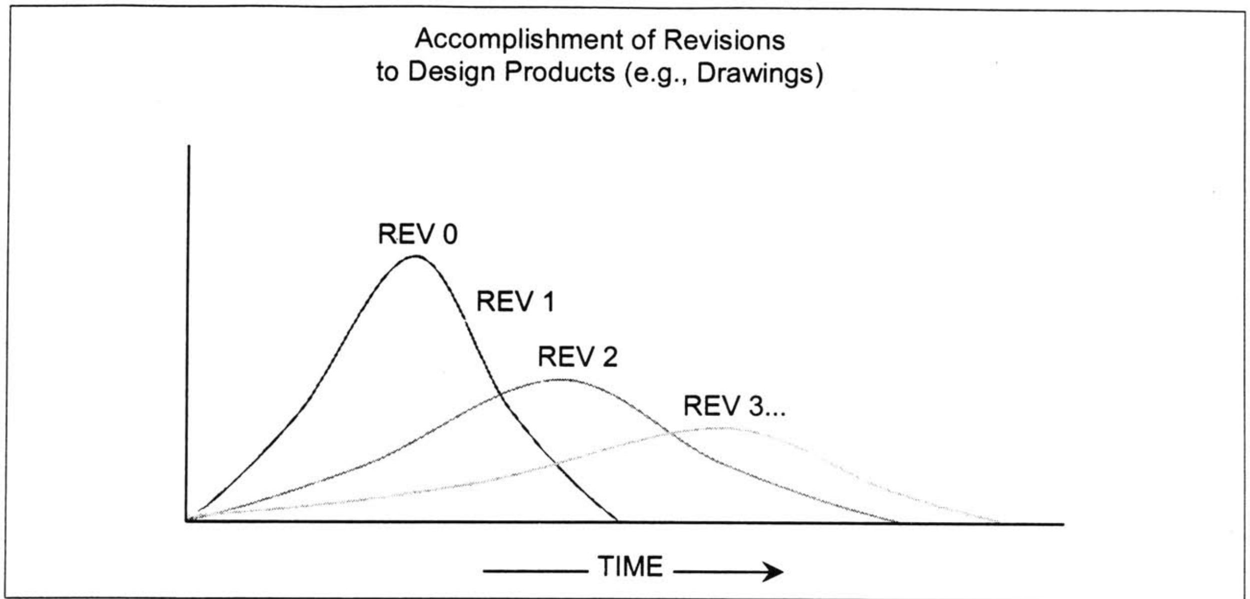


Figure 22: Product Revision Phases

The results of a feedback dynamic loop with quality less than 100% and reworks not necessarily discovered 100% causing revision in the works. The analogy to this is the different build of vehicle prototype phases. In each phase a certain amount of rework is discovered and implemented into the next phase.

The point to be made in this project dynamics is that quality of the CAE model and analysis need to be controlled by both FSS and VM so that the undiscovered reworks can be minimized. The goal is to have zero revision in the work.

5.2 FSS CAE Framework

(Figure 23) below represents the essential framework proposed for the VM to manage FSS CAE outsourcing process.

Requirements that come from multiple stakeholders like customers, corporate and governments create works. FSS should be a partner in determine the "work rate" so that the amount "works to be done" are of value and realistic to FSS.

5.2.1 The FSS CAE Framework

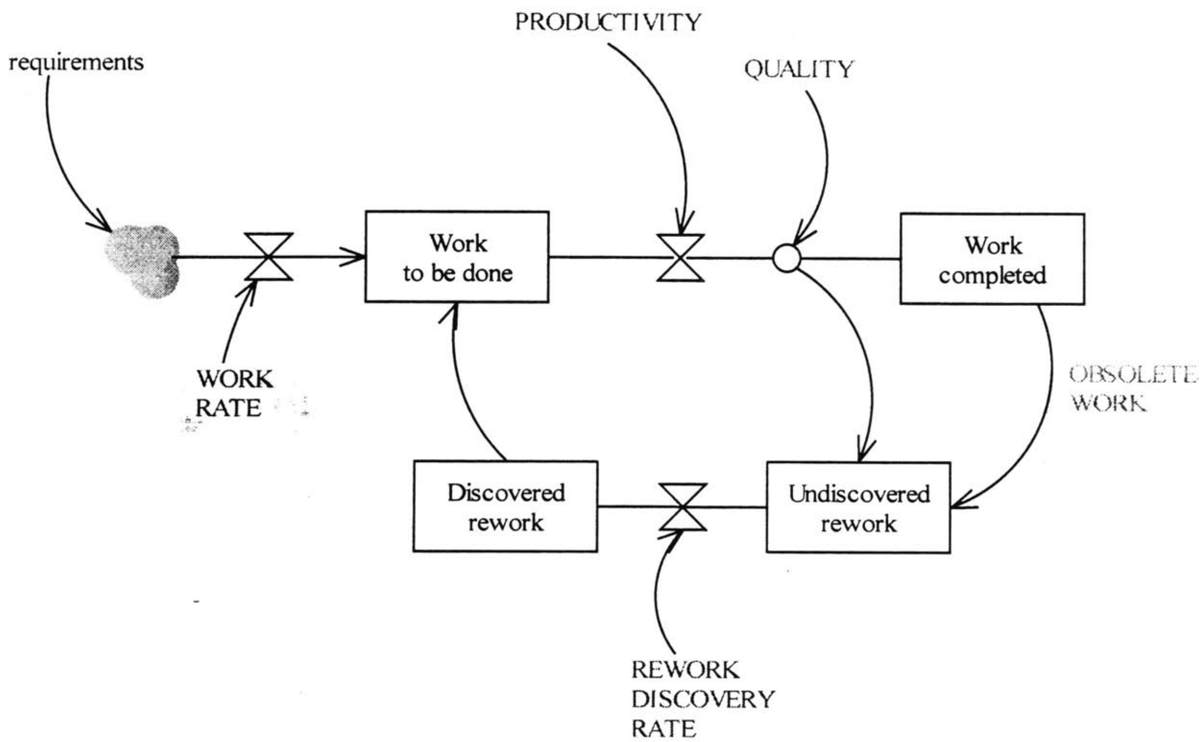


Figure 23: FSS CAE Framework

The objective from both VM and FSS is to minimize the feedback loop.

- FSS need to participate upfront with VM to understand and influence the "work rate" so that amount of work to be done is realistic. Also, FSS would be able to anticipate the works for their resource management.

- VM need to have a way to have confidence in FSS productivity and quality as these two parameters affecting the amount of "work complete". If productivity is low, the amount of work complete might be not in time and results in obsolete works.

- VM and FSS should work closely to reduce amount of "reworks" and make the rework discovery rate as quick as possible.

The following roles and responsibilities are proposed for the collaboration between FSS CAE and VM CAE.

Tasks	VM	FSS	COMMENTS
Setup Requirements	L	S	FSS participate to provide information about downstream capability in meeting requirements
Added Work Rate	L	S	FSS participate to agree on the value added tasks and plan for its completion based on their capability
Productivity (increase)	S	L	VM participate to have assurance about the rate of productivity so that work could be completed on time.
Quality (increase)	S	L	VM participate to provide quality criteria and
Rework Discovery Rate (increase)	S	L	VM participate to provide quality-checking tool that common with VM.
Obsolete Work Rate (reduce)	S	L	VM participate to assist FSS in minimizing the obsolete works by providing program info. And timing.
L= Lead, S= Support			

5.2.2 Communication

The VM CAE and FSS CAE should have essentially 2 types of communications on going.

The first communication is a constant updating from FSS CAE on status of the works so that VM CAE can feel confidence and able to make corrective actions to help FSS CAE back on track to deliver on time. This communication process is essential to building trust relationship.

The second communication is that FSS CAE need to check frequently with VM for the status of change in requirements as quickly as possible. If not this could be a big potential for creating obsolete works and other unnecessary reworks that could delay the projects.

6 CAE Model Criteria

6.1.1 Model quality criteria

As seen from the dynamic project diagram analysis that having quality is critical for FSS CAE to affect the component design and for the VM CAE to build quality into their vehicle model. Therefore quality model should be a management focus. This has not been an easy task even for the internal CAE organization in the past due to the complexity of the FEA model. The problem will be getting worse as more and more details are put into the model to get more accurate analysis results due to the computing cost continuously goes down.

6.1.1.1 Complexity of FEA model:

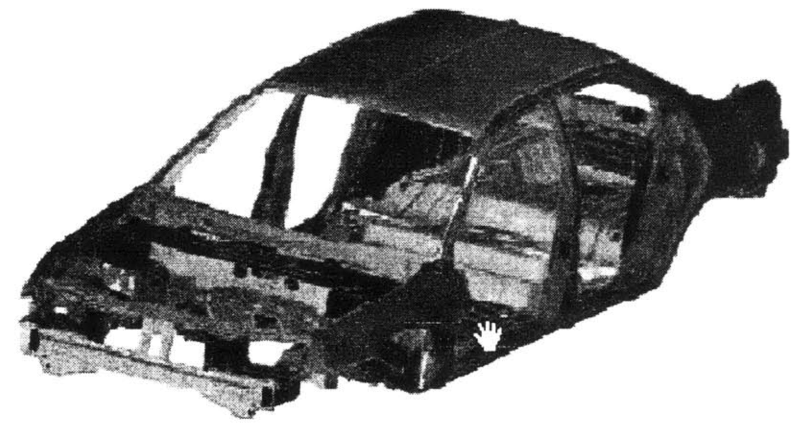


Figure 24: CAE model of Automotive Body

To understand the complexity of the big FEA model, lets look at a typical passenger sedan body CAE model (Figure 24). It has about 100 structural components, 300,000 of nodes and elements, thousand of spot welds, a multitude of material properties and all put together manually by analysts working in a crunched time of today PD process. When putting other components like seats, instrument panels, steering columns, doors, hood, glass ... the complexity could go up 2 times of that easily. At the full vehicle model level, where other systems like powertrain, chassis are incorporated in the complexity could go to the roof... without a systematic way to checkout the model content and quality, the CAE analyst will never have full confidence at the analysis results. There is much progress from commercial FEA vendors to help with the model checking but non has gone extensively to automate all the checking of all failure modes. This is because only the CAE users in VM CAE organization typically ranges from 800 – 1000 analysts can have a critical mass to know all failure modes. The author here proposes a framework using the concept of FMEA to tackle the quality problems based on the following principles:

1. ***Treat FEA model as a real physical product*** that needs thorough verification of all possible failure modes specially the human errors in building up the model. There is an incredible amount of energy in the product development to make sure product "hardware" intent functions are verified at the component, system and full vehicle levels. The same level of intensity should be given to the "software" CAE model verification. It is arguable that the software model verification is even more critical because of its usage to predict performance and changes the design.

2. ***Verify FEA model using an automated and visual method*** to arm any single CAE analyst with the ability to go through the complexity of the model and "visually" give him a sense of model quality. This increases his confidence in his analysis recommendation. Also, the automated program can help FSS CAE to be able to verify their models and more importantly demonstrate quality back to VM CAE at the model hand-off time. If both partners use the same verification method and can be viewed quickly it builds trust and accountability in the relationship. Traditionally, the model checking process relies on the given long list of criteria that requires manual checking sometimes with the help of several tools. Analysts who need to use the model quickly usually skip this checking process all together due to the lack of time and the lack of a feasible accountability system.

3. ***Make CAE FMEA a systematic and continuous improvement method*** to ensure knowledge is captured and incorporated into the checking tool. As a way for continuous improvement, hundred of CAE analysts can instantly report any new failure modes via the intranet system. The database can be used to work with chosen FEA vendor to customize the checking tool. Previous "defected" CAE models should be contained, recalled and retrofitted. Previous analysis recommendation based on "defected" models can be revised or reversed. This suggested process of "recall" is important since CAE recommendation is used to make multi-million dollars decision most of the time without hardware verification. This quality system when demonstrated to the design and release engineers in PD will also gain confidence in them about CAE quality process.

Figure 25: FMEA frame for CAE Model Quality below show a table of things that should be checked before the model is used for analysis. The current process at the VM is that this checking process is often skipped due to time constraints and tedious manual checking process. To demonstrate the model quality it could take

two or three days. When this automatic process is implemented it could be done in about an hour with minimum efforts.

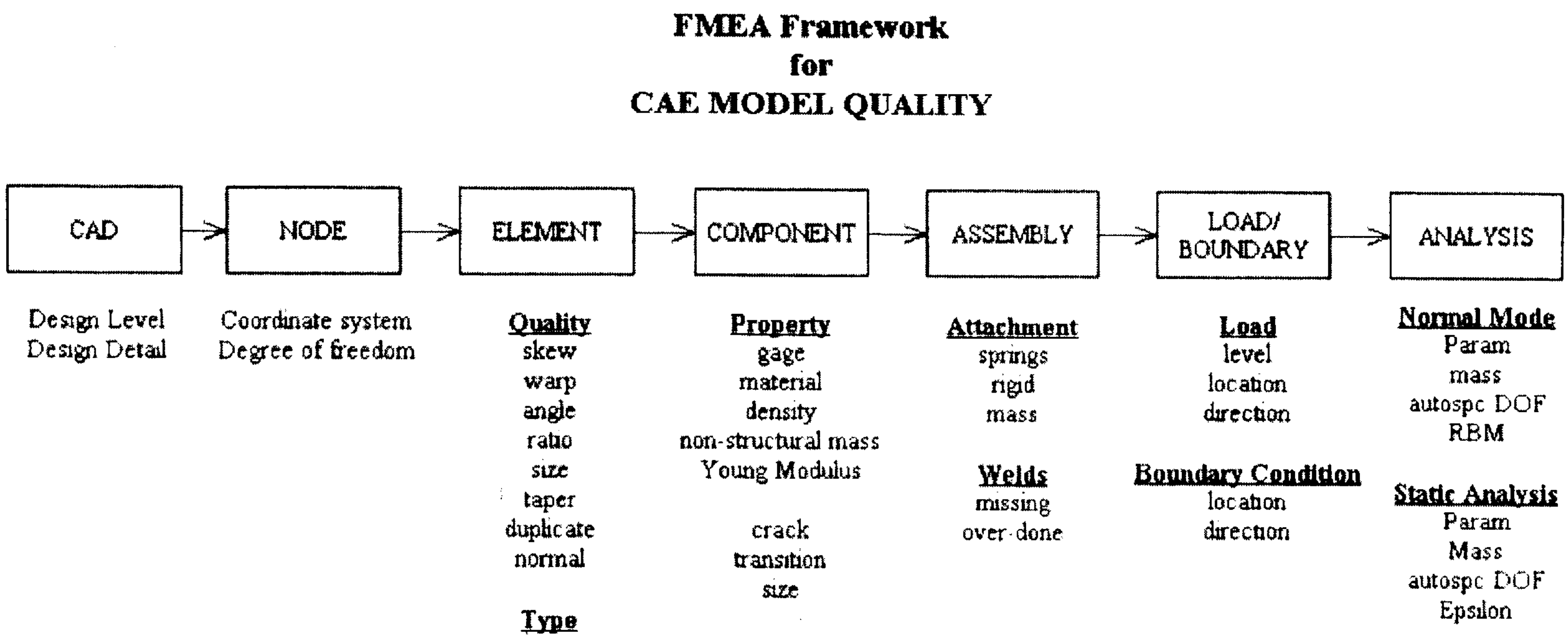


Figure 25: FMEA frame for CAE Model Quality

7 SYNTHESIS

7.1 FSS CAE Principles

The guiding principles for dealing with CAE FSS are proposed as follows:

7.1.1 VM CAE is ultimately responsible for all CAE works.

This will make VM CAE pursuing management instead of abdicating the oversight of FSS CAE process. This includes the involvement of VM CAE right from the beginning of FSS selection, FSS capability assessment, writing target agreement, monitor FSS CAE performance through the form of regular CAE reviews to minimize risk and surprise and to offer helps to FSS CAE for reaching capability gap. Specially, VM CAE should work closely enough to input the performance score for FSS CAE at the end of the program. Target agreement and statement of works must not be treated as a "spot contract". It should be a relationship contract that serves as a framework for further regular collaboration.

7.1.2 Consider Upstream Requirements & Downstream Capability

Part of managing the FSS is to involve FSS CAE capability to support upstream VM CAE requirements. The results would be a more realistic work plan to complete the required works. Collaboration between VM CAE and FSS CAE is continuous with clear roles / responsibilities as proposed.

7.1.3 Focus on CAE Model Quality Verification

CAE models are the common threads between the VM CAE and FSS CAE and therefore they should be thoroughly examined. Customized comprehensive and quick verification tool and not laborious process of checklist should be focused by internal VM CAE to improve both internal VM CAE and FSS CAE model quality. Treat CAE model as if it is a real physical product that needs to be assured of high quality. All CAE failure modes should be captured. Inputs from FSS CAE must be utilized to continue improving the verification tool.

7.1.4 Encourage FSS CAE in pursuing Upfront Analysis

Top managements of both VM and FSS must be committed to the use of CAE and this commitment must be highly visible. The value of CAE must be seen as a "strategic weapon". This means shifting the view from CAE as a "cost of doing business" to that of "strategic weapon" by which both companies should invest and leverage to drive business success. In this area, VM CAE has had lots of experience and should consciously use the experience to influence FSS CAE management for strategic investment on CAE.

7.1.5 Optimization incentive

It is most often that CAE cost is smaller than CAD that they are lumped together in target agreement negotiation between VM and FSS. This practice should be avoided to help VM CAE judge FSS CAE performance verse cost. Since FSS CAE is optimizing their commodity for functional and cost, they tend to give cost a priority to protect their profit margin. Material cost reduction (MCR) will be harder to achieve if there is no incentive. The author here proposes an "optimization incentive" like the following.

After receiving the FSS CAE model that has met the functional targets, the VM CAE at its option can pursue its own optimization for material cost reduction. If there is material saving, the VM CAE will reduce the material cost from the agreed piece cost in supplier contract. The performance rating of this supplier is also recorded for future evaluation.

7.1.6 Organize in assisting FSS process

It helps if the VM CAE organization is matching to that of the FSS CAE organization. By nature, FSS will handle their commodity that has multiple attribute characteristics (durability, NVH, safety). If VM CAE is organized according to commodity (frame, suspension, knuckle) instead of according to attributes (durability, NVH, safety) it will simplify the interfacing process tremendously. There will be constancy in interfacing of people, process and tools and the coordination will be more transparent regardless if a commodity is outsourced or not.

7.1.7 Knowledge Base CAE:

VM CAE should leverage CAE best practice from several FSS CAE in different vehicle programs. FSS tends to work for multiple VM and therefore they absorb different practice from different VM. VM CAE should focus on the upstream cascading target. This is core competency that not easily duplicated either by competitor or suppliers.

7.2 Conclusion

In a big picture view, the world economy drives automotive industry which in turns drives a new set of product development process. Within PD, CAE possesses an important upstream position and thus has inherent high leverage power. Its value however is imbedded within the PD process along with other disciplines (CAD, Prototype, Testing). The PD value is in turns imbedded within the life cycle therefore CAE values are hard to measure directly. Much effort in the past has tried to quantify to some extent the degree of CAE benefit and cost ratio in an attempt to convince management about CAE value to encourage long term CAE investment. The second fold of seeking financial value of CAE is to see where the big impact CAE can make. Much of what VM CAE organization has gone through in the past could be shared with FSS CAE in helping them to see the value of CAE in the PD process.

This thesis hopes to raise a conscious awareness for VM management in outsourcing CAE to FSS. It is the right thing to do only if VM intend to shift CAE resource to focus on developing further full vehicle CAE capability. The component CAE when outsourced must be managed. This requires an active participation of VM CAE and FSS CAE upfront with defined roles and responsibility. VM should realize the short term responsibility to assist FSS in catching up with the CAE process at VM. The CAE model quality checking could be used to facilitate the collaboration process between the two. This will reduce the reworks often exist in the CAE outsourcing process.

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