Using Datum Flow Chain and Design Structure Matrix to Manage Team Structure and Integration

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Submitted to the System Design and Management Program
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ABSTRACT

Using a functional based Design Structure Matrix (DSM) technique, interfaces between product parameters and organizational boundaries of an automobile front end were examined. Additionally, the Datum Flow Chain (DFC) was used to show how the assembly chain interacts with the key characteristics that need to be delivered. A case study of the front-end design on a current model automobile was used to facilitate the study. An effort was made to "over lay" the DFC and DSM in order to see the interrelationship between the assembly chain and the organizational structure. Finally, since DFC is a new tool to large automotive companies, a portion of the thesis was dedicated to explaining how it should fit into the engineering processes and what future improvements are required.

Both the DSM and the DFC showed the complex nature of the design and integration of the front-end system. The DSM showed the large cross-functional integration effort that must be managed. It also showed the current state of the sub-system design functions. In order to deliver customer key characteristics, the DFC study showed the multiple subsystem and complex supplier chains between the body and the chassis functional groups. The DFC showed that a single supplier controlled a majority of the critical components, which cross the body and chassis functional boundaries. The supplier manufactured the subsystems in two separate divisions. The suggestion has been made that the design team insure that the supplier's two divisions manage these critical subsystems which combined are required for the critical assembly. Additionally, the key characteristics can be delivered only when both the body and chassis functions internal to vehicle manufacturer work together in an integrated fashion. From these three results it is clear that a team or group within the organization has to be in charge of the engineering integration between both the internal and external functional engineering groups.

Finally, the DFC has been suggested to be part of the generic architecture organization. Future work has been suggested to improve the visualization features of the tool and the backend software that drives the DFC analysis.

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Chapter 1. Introduction

Chapter 1.1: Motivation

Many efforts have been made in automobile companies to improve the overall vehicle quality delivered to the customer using robust engineering techniques. This has proven to pay benefits but there still are many issues that arise at the interfacing points between systems, organizations, and/or vendors. In a large automotive company it is easy to lose sight of the interfaces and focus mainly on smaller sub systems. Issues within the interfacing areas tend to be found and addressed later in the development process when it is more costly and time consuming.

When looking at the interfacing areas between functional groups, the organization has to have a plan to manage the design and engineering of these key subsystem-to-subsystem interfaces. The question needs to be answered as to how these interfaces should be managed and between what subsystems. Another question is what the assembly effects are from a geometric standpoint due to the order in which the subassemblies are brought together during final assembly. One effort currently underway by one large auto company is called geometry assurance. This team is trying to focus the product team on holistic system related decisions versus component and sub-system driven decisions.

If one were to look at a holistic approach to a vehicle it might look like the mind map in Figure 1. This thesis will focus mainly on the managing interfaces and system engineering branches. The issue with the current approach is that the components are designed and engineered well but the interface between the subsystems is not formally managed. Currently managing interfaces
and systems engineering is left up to the individuals within the component centric teams to manage. There is little motivation provided for this to happen.

![Mind Map of Holistic Platform Approach to Automotive Architecture](image)

**Figure 1**

Chapter 1.2: Description of the Mind Map

**Form and function maps to customers' latent and known needs**

With the holistic approach, the architect can focus the team on the total vehicle and the total vehicle needs of the customer. Even in the current system automotive companies do a fairly good job of understanding the customer. One way a holistic approach may help is with those latent or unknown needs of the customer. As you look at the whole you will better see ways to
give the customer exciting things that he/she may not know they want. The holistic approach will give the total picture of all of the trade-offs and effects of new features. Additionally, with the multi-derivative approach more time can be spent focusing and responding to the customers' changing needs versus developing new architecture every time.

**Profitability**

There are two areas that will affect profitability with the holistic approach. The first is with reliability. With the holistic approach you not only consider the current product but the potential derivatives and future of the platform. Planning is done so that if future derivatives are desirable they can be done. In this way the platform will evolve from generation to generation versus being all new each time. With this evolution, the product will see increased reliability because you will be taking the known and building on it. In the current way of handling product development, which involves reinventing a lot of the architecture, launch quality issues and an inability to deliver long-term reliability have plagued many automotive companies. The bottom line is that increased reliability will lead to decreased warranty cost and, thus, increased profitability.

The second area where profitability can be impacted with the holistic approach is the cost of derivatives. Again, in the holistic approach, the architect will look at the long-term goals for the architecture. If plans are made up front for derivatives, part, tooling, and assembly considerations can be made to allow for these changes. It may cost more initially but the payback will come with the lower costs associated with the derivatives. Instead of comparable costs for each new product (say 100% for each product) the holistic approach should yield something along the lines of 140% for the first product; then the cost should go down to 40-50%
for each derivative. These savings come from the reuse and flexibility of the architecture. This may drive up essential complexity that the architect must balance.

**Managing Usage, Complexity, and Interfaces**

All three of those areas (usage, complexity, and interfaces) are areas a holistic view will aid in managing and dealing with developing architecture. As mentioned previously architectural usage (stand alone vs. multi product) is an important strategy that can lead to profitability and reliability gains. If the architect doesn't have a strategy for the architecture beyond the initial product, this is short sighted. Required flexibility for future products will be optimized out to gain initial cost savings.

Complexity is another area the holistic approach will aid in managing. The architect will look at the total system effects of decreasing or increasing complexity. Decreasing complexity for a subsystem may be good for that system but it may have an adverse effect on the total structure or architecture. Also, the only way to measure and balance essential complexity with requirements of flexibility is to have a holistic view of the architecture.

The management of interfaces between subsystems is an area the holistic view greatly improves. Many of the major issues automotive companies have with automotive development are at the interfaces between subsystems. This idea has been reinforced by many of the speakers and courses in the SDM program. One of the projects the author has recently been involved with is developing a new organization that will explicitly manage the interfaces. In the past automotive companies have depended on the individual subsystem engineers to manage the interfaces between systems. What ultimately happens is the individual defends his own systems and doesn't consider the effects on the whole architecture.
System Engineering Tools

System engineering tools will help gain a holistic view for not only the architect but for the entire team. There are two tools currently used across most automotive companies. They are the digital buck and dimensional variation analysis. Digital buck is a desktop CAD tool that gives everyone on the team access to all release data. With this a structures engineer can see what the latest chassis information looks like and vice a versa. The dimensional variation analysis looks at the total structure and analytically gives the spread of tolerances for any given point on the structure due to the total system build up. The third tool, datum flow chain, is a tool developed at MIT which looks at the high level critical dimensional relationships and assists the architect in determining if they are obtainable based on the architecture. DFC has been discussed in this thesis.

Decomposition and integration

The final area of the mind map deals with the decomposition and integration of the vehicle. Chapter 1.2 will discuss the current way the vehicle is decomposed and integrated based on a historical prospective. This thesis particularly for the body and chassis activities will show that the historical technique is in need of an update. This thesis will propose a technique that would decompose and integrate so that the number of cross organizational/function boundaries is minimized.

Chapter 1.3: History of the automotive architecture approach

If you think about how major automotive manufacturers decompose vehicles during the product development process, it seems at first that it is done based on the organization. It has been true the last ten years that vehicles were decomposed based on the organization but as you
look at the organization, it was originally set up based on the decomposition, Body, Chassis, Powertrain, and Manufacturing. History is an important part of the decomposition. As shown in figure #1, the vehicle and the people are the other portions to this integration question.

Prior to the early to mid-80s, almost all American-made vehicles were body on frame. Body on frame is currently the way pickup trucks like the Chevy Silverado is architected. The passenger component (i.e. the body) is a completely separate module from the frame (i.e. chassis system) and the powertrain module. Each of these modules was independent. The chassis, body, and powertrain could be built up independently and redesigned independently. At the time, it made sense to divide the car up into these three areas. The chassis/frame and the powertrain are longer lead items. They were not changing all of the time and interfaced little with the body. As a matter of fact, the body attached to the chassis/frame in about six to eight locations. These were the only interfaces between the chassis/frame and body except, of course, for the gas and brake pedal and the steering wheel. Each component basically had a minimal number of functions. This was great for the automakers. If they wanted to make a change in any of the modules, it had little effect on the others. This had one major flaw. The cars were heavy and not very small and sporty compared to the imports. Additionally, the vehicle dynamics (roll and rigidity) were poor. The solution to this was to go to the unitized body where the body and the frame are integral. The body now acted like the frame and was required to carry many of the loads that previously were carried by the frame. There were many more interfaces between the body, chassis, and powertrain. As the architecture of the car evolved, the organizational decomposition (organizational structure) never seemed to change. Yes, there was the new body and chassis
organization but, in fact, body still did body and chassis still did chassis. Did this make sense with all of the new interfaces?

As the vehicle evolved from a framed body to a unitized body there were many new interfaces. A lot of these new interfaces were body-to-body sub-systems. An example of this would be the structure rail. With the framed body the structural frame rail was a chassis part and the chassis suspension mounted to it. With the advent of the unitized body the rail was integral to the body. So the chassis suspension components (via a sub-frame) mount to the body. These new interfaces didn't result in a new vehicle or team decomposition. Additionally, through all of this, manufacturing has been on its own as an "outsider" to the team. As discussed above, the frame on body decomposition is a fair way of doing business. It gives you the modular approach. With the advent of the unitized body, this may not be the most favorable decomposition. Figure #2 shows how this organization and vehicle decomposition currently is done. Most of the communication is done within the body, chassis, and powertrain organizations with little information flow horizontally. There is little information flow between the organizations until the vehicle is in the prototype phase. By this time there is little leverage to change or improve the architecture. As a matter of fact, by this time it is generally an "us vs. them" issue and what is best for the customer is lost. Additionally, when issues do arise, the options for resolution are limited because of the time constraints. One thing in the last seven years that has helped this issue is the advent of collocated dictated teams. Now the people may sit close to one another and even may start discussions earlier in the process but there is no set process to dictate this is done correctly and there still is an "us vs. them" mentality. You still have body, chassis, and other managers who protect their own turf.
These are the main issues with the current (figure #2) decomposition and organization:

1. Cross organization interfaces have major partisan issues.
2. Teams are not focused on what is best for the customer but what is most cost effective for their team or organization.
3. Since there is no metric or process to manage the interfaces going from one team to the other, issues can be missed or not addressed.
4. Inconsistent management direction (goes back to points #1 and #2 above)
5. Manufacturing has been separated from the product development organization.

Chapter 1.4: The Challenge

The big question is can we prove that there are integration issues and, if we can, are the integration and interfacing issues critical to the delivering of the customer key characteristics?
Most people with any large automotive company will agree that the interfacing issues are critical but with no real process to manage the area. The challenge for this thesis is to show the size of the integration issue and the complexity of the interfacing issues. Once armed with this information, Design Structure Matrix (discussed in chapter 2) and organizational lens analysis can be used to propose an improved approach. Organizational lens analysis states that any organization change has to consider three things, the structure, the political, and the cultural aspects of the current and proposed state of the organization. The way it is taught is that the change agent must look through all three of these lenses while examining and revising any organization.

Chapter 1.5: The Hypothesis

There is one main hypothesis for this project. **There is a complex chain of subsystems which must be managed in order to deliver customer key characteristics. This chain is driven by the cross-functional integration that occurs because of the product architecture and the complexity of the customer requirements.** This hypothesis is supported by the author's experience and prior research done on similar complex structures [1].

Chapter 1.6: Approach for the Study

Two tools developed at MIT will be used to objectively look at the hypothesis. First, Design Structure Matrix (DSM) will be used to look at information requirements. The technique used will be a novel approach. The traditional way to perform a DSM is to interview individuals to try and gain an understanding of the nature of information flow. With the approached used in this thesis the information flow is developed by looking at what design requirements are used to
meet specific functional requirements [2]. This approach will be used to examine the interrelationships between the different design and functional requirements for both Body and Chassis in order to develop the DSM. The DSM will then be clustered using a technique developed by Professor Steven Eppinger [3] to look for the potential integration required between different functional areas.

Secondly, the Datum Flow Chain (DFC) tool [6,7] will be used to take a holistic view of the front-end body system in terms of the geometric constraints and the key characteristics (KC's) that the system has to deliver. DFC can be used to look at the KC's that are jointly related between body and chassis. The DFC can be used to explore whether the KC can be effectively delivered if the body and chassis mating points are designed independently or if the KC is more robust if the body and chassis mating points are designed jointly within a single team. The supplier relationship to the DFC will also be examined to see the impact of the supplier chain on delivering the KC.

Additionally, DFC as a system engineering tool will be discussed. Where in the PD process does it belong and how does the ultimate tool need to perform? Can it be a tool to help deliver a more holistic generic architecture? These are all questions that must be addressed. The following is an outline of the thesis

**Chapter 2:** Development of a DSM based on Functional Requirements

**Chapter 3:** Discussion of DFC, what is it, what is required to do the analysis, what has been done thus far in the auto industry, and where does it fit in?

**Chapter 4:** Development of DFC for comparison to DSM results

**Chapter 5:** Recommendations, conclusions, and next steps.
Chapter 2: Development of a DSM based on Functional Requirements

Chapter 2.1: DSM Background

DSM is a technique that predicts the required information flows in a project and can help identify where coordination and system integration are required. The traditional way to do a DSM is to first define a topic that you are going to study. Then you must create an interviewing process or survey to gather information from the knowledge base within a company. You would then take that information and create the DSM. Once the DSM is created, you can use different algorithms to partition and/or cluster. Partitioning tries to push all of the information below the diagonal in-order to reduce feedback of information and to minimize the number of tasks internal to any necessary feedback loops.

An example of this is given below in figure 3. The order of the parameters is A then B then C. An "x" in the row means information is needed i.e. parameter A requires information from parameter C and etc. An "x" in the column means information is passed onto for a later parameter, i.e. parameter B passes information to parameter C.

![Unpartitioned DSM](image)

Unpartitioned DSM
Figure 3

From this we see there is a feedback loop created with all three tasks. Task B may be unnecessarily done multiple times. If we partition the DSM, we will end up with a matrix as shown in figure 4.
Parameter B feeds parameter C once. The parameters A and C are completed in a feedback loop with potential for an iterative process. Clustering will be discussed later in this chapter. Additional information can be found regarding DSM in Steward [3] and Eppinger et al [5].

Chapter 2.2: Functional Based DSM

The approach used to develop the DSM for this study was based on work done by Qi Dong and documented in [2]. The technique was modified but the approach using a functional vs. design matrix in order to generate the DSM was preserved. Dong used Axiomatic Design techniques to create her function vs. design matrix. For this study, current information and the author's knowledge reinforced by area experts was used to generate the functional vs. design matrix. The matrix can be seen in figure 5.

First, a list of key functional requirements was put together. These are high level and encompass a lot of lower level detail. Additionally, a few key attribute requirements were included because of their importance and influence on the final product. This list was developed using existing functional requirement lists within the company. The list is shown on the right hand column of the matrix in figure 5.

Since the focus of the study was mainly on the front-end system, the design parameters were examined for that area. Again there are existing documents for design requirements for both
body and chassis. These requirements are from all different levels of the architectural decomposition. These lists were adjusted in order to get high level groups of design parameters.

Body and chassis experts have reviewed these portions of the functional matrix for accuracy and concurrence. The manufacturing and design portions of the matrix were constructed from the author's prior knowledge and with the help of other experts in these areas. These design parameters can be seen across the top row of the matrix in figure 5.
Once the functional and design information was generated, the author, based on his knowledge, use of design guidelines, and expert assistance created the matrix seen in figure 5. A "1" in a box means that the particular design parameter has an impact on the particular functional requirement. So for example the "1" circled in figure 5 means that material selection of the front structure will impact the functional requirement "meet 5 mph bumper impact". In this case it is clear that the two are related. If a low yield material is selected for rail, bumper, shotgun, or all three components, damage to the front structure may occur and the requirement will not be met. With this information, a DSM can be created.

Chapter 2.3: DSM Creation

The DSM is directly linked to the functional versus design matrix. Each of the 53 design parameters was evaluated relative to the other design parameters. This was done in the following fashion:

1. Compare each of the design parameters individually relative to the other 52 parameters.
2. Are they both required to meet a certain functional requirement?
3. If yes, is the relationship first order (first order means the design parameters directly relate and are at most 1 part/system removed).
4. If yes a "1" is entered in to the DSM at both row-column intersections of that pair of tasks.
5. If no to either question 2 or 3, there is no mark entered into the DSM.
This evaluation, as with the functional matrix, was completed by using the author's knowledge, existing documents, and area experts. The DSM that was created can be seen in figure 6. Here is an example of how the "1" circled in figure 6 was generated. When looking at structural
material selection and attachment point stiffness there are four main functional requirements that tie these two design parameters together.

1. Meet 10-year life requirement- this will require the material selection and the attachment point stiffness to be balanced. If the material is too soft or if the attachment is too weak, you may get a fatigue failure

2. Squeak and rattle- If the material selection is not correct again the joint may experience relative motion which, in turn, will create squeak and rattle.

3. Personal safety- The attachment must be stiff for fatigue issues but the material must be elastic enough to absorb energy during a front impact

4. Margin and Flushness- Similar to 1 and 2 there has to be balance in the stiffness of the base structure material and the attachment stiffness or one will move relative to the other and margin and flushness variation will be unacceptable.

The final note regarding the DSM has to do with its symmetric nature. Symmetry was created because a conservative approach was taken. The assumption was made that information needs were mutual between the design parameters. In further studies this constraint should be removed to further investigate the effects of the non-mutual case. The author's feeling is that it will have little effect on the outcome.

2.4: Clustering results

Once the base DSM was constructed, the analysis of the data was performed. The technique used to do the analysis was similar to the process discussed in [3]. The idea was to cluster the DSM so you push as many "1's" to the diagonal as possible. The remaining off diagonal "1's" were pushed to the right for marks above the diagonal and to the bottom for marks below the
diagonal. Once this is done you will have the activities that can work together as a team without outside intervention clustered close to the diagonal. The remaining off diagonal marks constitute the activities that require integration between the different teams that are clustered closed to the diagonal.

The clustered matrix can be seen in figure 7. There are seven main clusters. The body, chassis, appearance development, manufacturing, and packaging clusters have the high-level design parameters that are required under the current system. This is a good indication that for these functional groups the DSM is accurate. The two clusters from this study that are not as accurate are the clusters that have been named NVH and water management design. The NVH cluster is missing a parameter related to interior noise level (i.e. what noise level is targeted for the interior of the vehicle). Water management is missing a parameter that is related to static sealing. In future work, these areas of the DSM and functional vs. design parameter matrix should be explored further for improvement. Even with these less than accurate areas of the matrix the DSM still gives a clear picture with regards to this study.

The integration area of the matrix showed exactly what was stated in the hypothesis. There is a large and complex integration task that must be undertaken. If this critical integration that is seen in figure 7 is not managed and left to chance, a lot of time late in the product development cycle will be spent addressing this information. Every one of these marks has to be addressed. Some may be addressed by chance. Some may be addressed early in the product development cycle and some later in the process. However, without any management of the integration process the efforts are at a minimum inefficient. A well-known rule of thumb is that the later an issue is surfaced and addressed in the product development cycle, the more costly it becomes.
Clustered DSM
Figure 7

Figure 8 shows this effect. The idea behind managing the integration shown in figure 7 is to push issue resolution to the left side of the graph shown in figure 8.

Cost and desired issue discovery vs. time for a typical product development cycle
Figure 8
Using the functional requirement vs. design parameter matrix a DSM can be constructed and clustered. For this study the clustered DSM as seen in figure 7 shows the integration issue. DFC will know be explored to see if the assembly chain shows the same integration issues.

In order to resolve this issue the integration process has to be part of the structure of the product development process and organization. A proposal for this structure will be discussed in the chapter 5.
Chapter 3: Discussion of DFC

Chapter 3.1: What is DFC?

DFC is a technique developed at MIT by Dr Daniel Whitney [6,7]. The technique is used to look at complex assemblies to determine if a particular system can deliver selected key characteristics (KC) based on the geometry of the architecture. KC's can be customer visible demands like door to fender margins or they can be more tactile demands like steering wheel drafts and pulls. Drafts and pulls occur when the vehicle should be going straight forward and because of wheel alignment issues veers to the right or left. Drafts are more of a gradual motion to the right or left and pulls are more of a severe type (you better hold onto the wheel or you will be in the ditch in a flash). The customer driven KC's are known as "product KC's". KC's can be internal to the OEM, in which case they are called assembly KC's. A particular assembly may have to deliver a certain dimension. This dimension is not critical to the customer but is critical to delivering a product KC. An example of this may be the shotgun (see appendix 1 for the anatomy of the front end structure). The y and z location (see appendix 1 for description of the coordinate system) of a shotgun on the front end of vehicle is of little importance to a customer. The customer will care about the margin and flushness of the hood to fender. So in this case the hood to fender margin and flushness are the product KC and the shotgun location is the assembly KC.

The way DFC looks at the architecture is by examining part interfaces and determining the geometric constraint state of the system. The technique uses the six degrees of freedom (3 rotational and three transitional) to determine if a part is under constrained, over constrained, or properly constrained [8]. Under constraint occurs when there are no product or fixture features
that set and or control a particular degree of freedom (see figure 9). In this case part B is underconstrained in the x direction.

![Diagram of underconstrained example](image)

**DFC of under constrained example**
**Figure 9**

The \( \circ \) in figure 9 represents a part or a fixture. The tail of the arrow indicates what fixture or part is setting the part or fixture at the head of the arrow. So in the figure above the fixture is setting parts A and B. The 6 next to the arrow indicates the fixture is setting all six degrees of freedom of part A. The \( Y, Z, \theta_x, \theta_y, \theta_z \) indicates the degrees of freedom for part B set by the fixture. The double line indicates the key relationship.

Over constraint is when just the opposite occurs. There are multiple product and/or fixture features trying to control a particular degree of freedom (see figure 10). For the case shown in figure 10, the fixture pins in combination with the butt joint between parts A and B cause the assembly to be overconstrained in the x-direction.

![Diagram of over constrained example](image)

**DFC of over constrained example**
**Figure 10**
The theoretically ideal state is for the system to be properly constrained (see figure 11). In this case, the fixture is the only entity giving parts A and B x-direction location.

In most large complex systems proper constraint is impossible. In an automobile improper constraint can cause water management issues, load path issues, and many other functionally degrading conditions. As with other attributes, geometric requirements must be balanced with the other attributes the vehicle has to deliver to the customer.

With this in mind, DFC's virtues are that first it visually communicates the geometric constraint state of the system. Second, it helps direct a product engineer in the early phases of development in terms of how the system interfaces and assembly sequence should flow in order to maximize dimensional accuracy. When an over constraint exists the engineer can use this knowledge to balance the key characteristics in order to make trade-offs between what can and can’t be delivered independently. Additionally, when the overconstraints cause one KC to be dependent on another KC, the team can plan to tune, monitor, and manage the components and subsystems that caused this overconstraint.

DFC does have an assumption that parts are rigid. Caution needs to be taken when looking at highly flexible parts (fascias, fenders, and etc.). This assumption is comparable to the linearity
assumption FEA makes (F=kx). There is currently ongoing work at MIT to understand flexible parts and come up with the best way to deal with them in the DFC analysis.

Chapter 3.2: What is required to do the analysis?

The first thing you need to make DFC useful is the right mindset. This mindset has to be that **geometry is a critical attribute that must be engineered in as much detail as NVH, ride and handling, and etc.** In the end, most of the critical attributes are interdependent.

One incorrect assumption people tend to make is that geometry only affects things like margins and flushness. One of the concepts you learn quickly is even though this technique looks at key characteristics from a geometric standpoint, the geometry raises issues related to ride and handling, NVH, and etc. that traditionally are overlooked. The issue with the large automotive company examined in this thesis was that the organization is not set up to treat geometry as an attribute. Sure there may be a "global dimensional control department" but they don't engineer or insure the geometry of the vehicle architecture to insure the geometry will deliver the KC's. In the proposed organization in chapter 5 this group would be incorporate as a service group similar in nature to the current body cad group or testing group.

The second thing that is required is knowledge of the locating strategy. The user has to know if part A will be fixtured to mate with part B or will features on the parts locate them to one another. If a fixture is used, features of the fixture must be understood. Are the parts going to be pinned in the fixture? If yes, what degrees of freedom will the pin control? Are the parts going to reference net surfaces in the fixture? If yes, what degrees of freedom will the surface control? Each subassembly in the system must be examined in this fashion.
In addition to understanding the locating strategy, knowledge of part-to-part interfaces must be understood. Like parts A and B in figures 9-11 above, will the parts mate with butt joints, lap joints, and etc? Libraries of these mating conditions and locating features can be found in [8].

Once the complete system is described in these terms, what is the locating strategy and what is the part-to-part interface definition? An analysis can be done to examine what the constraint state is and what the best assembly process is. On the other hand, if an assembly process/sequence is already known it can be used in conjunction with the analysis to examine the current state of the system.

Chapter 3.3: What have we done thus far in the auto industry with DFC?

With this information regarding DFC, how do you use it on a more complex system? Following is an example of a study done on two potential roof processes called single stage and two stage. The goal of this study was to see if there was a feasible way to independently control both roof ditches on a car. A roof ditch is the trough created when the roof panel and the bodyside are welded together. Typically a molding is placed in the ditch to cover up the weld locations. Both processes are looked at to see if one or the either can achieve the goal and, if not, can an alternative process be developed?

First, what is two stage and what is single stage framing? A comparison is shown below in figure 12. Single stage framing takes a roof subassembly (headers, bows, and roof welded together) and welds it to the bodyside in a single framing station. Two stage framing welds the
headers and bows to the car body sides in the first framing station and welds the roof to the headers and bows in the second framing station.

Comparison of single vs. two stage framing
Figure 12

Next, what does the DFC look like for these two processes? The DFC shown in figure 13 is for the single stage process. The dashed lines are the constraints set in the roof sub assembly operation. The solid lines are the constraints set in the framing fixture. In figure 13 it is shown that the right and left hand bodyside locations are controlled in framing fixture 1. Because of this the only y dimension free is the distance between the two bodysides. The framing fixture 1 also places the roof in the y direction. With the bodysides being set in the y when the roof is located, only one y degree of freedom is left. Because of this all that can be independently controlled is one of the two ditches between the roof and the bodyside. The other is dependent on the roof y dimension, how well the frame fixture 1 sets the roof, and how well the framing fixture 1 sets the two bodysides in the y direction.
Current Process – Single Stage Framing (constraints)

Figure 13

Figure 14 shows the DFC for the two stage framing process. This process loses any chance of setting the ditches independently in the first framing station. Once the headers and bow are welded in place the overall y-distance between the bodysides is set. There is only one y degree of freedom left which comes from the roof setting process. So again only one of the two ditches can be set independently.

Upon further investigation it becomes clear the two stage process will never be able to independently set both roof ditches. The first framing station by its nature sets the cross car width, thus insureing when the roof is installed in frame station 2 that there is only one y-direction degree of freedom left. This comes from the roof. The roof can only be set in a single y location, thus only allowing one of the ditches to be set independently. The other side is
dependent on the overall stamping quality of the roof and how well the fixture sets the roof in the y direction.

There is one possibility of setting the roof ditches independently. This comes about with the single stage process. If framing fixture one doesn't set the upper y-direction of the roof and a "roof setting fixture" is used, independent ditches may be possible. The fixture holding the bodyside would have to be unconstrained, with in 4-5 mm, in the y-direction. The DFC for this proposed process in shown in figure 15. The roof fixture shown in this DFC would be the ONLY feature controlling the y location of both bodysides and the roof. It is critical the framing one fixture doesn't impede the y movement of the roofline of the body side. A sectional view of this DFC can be seen in figure 16.
Proposed Process – Single Stage Framing (constraints)

Proposed dual stage framing DFC
Figure 15

Single stage framing where roof ditch can be set using net blocks

Sectional view of proposed dual stage framing DFC
Figure 16
Figure 17 shows the potential improvements to both the single and dual stage framing process. One keynote is that if the ditch is not the most important cross car KC, then the DFC would have to be reevaluated.

<table>
<thead>
<tr>
<th>Single Stage</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Framing Fixture over-constrains bodyside in y, ( \theta_y )</td>
<td>- Incorporate a secondary fixture, within the main framing fixture, which coordinates the bodyside to the roof. It would set ( y, \theta_y ). This fixture would clamp the roof and bodyside to a net block in the ditch. This fixture would reference from the framing fixture. The framing fixture would only set ( x, \theta_x ), at the top of the bodyside. Additionally the framing fixture would only control the x direction of the roof sub assembly.</td>
<td></td>
</tr>
<tr>
<td>- Framing fixture over-constrains package tray in z, ( \theta_z ) and ( \theta_y )</td>
<td>- Let bodyside set ( z, \theta_z ), of the package tray and let fixture set ( x, \theta_x ). This would mean NO high-low nets in fixtures and compliant (high-low only) clamps.</td>
<td></td>
</tr>
<tr>
<td>- Framing Fixture over-constrains roof sub in y, z, ( \theta_y, \theta_z )</td>
<td>- The roof fixture only sets ( x, y, \theta_x ) of roof. The headers would set the other degrees of freedom. This would mean NO high-low nets in fixtures and compliant (high-low only) clamps.</td>
<td></td>
</tr>
<tr>
<td>- Roof fixture over-constrains roof in y, ( \theta_y )</td>
<td>- With this proposal both the left and right ditch can be set independently with the proposed fixture.</td>
<td></td>
</tr>
<tr>
<td>- Roof ditch cannot be adjusted independently of other KCs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two Stage</th>
<th>Current</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Framing Fixture #1 over-constrains headers, bows, and package tray in z, ( \theta_z ) and ( \theta_y )</td>
<td>- Let bodyside set ( z, \theta_z ), of the headers, bows, and package tray and let fixture set ( x, \theta_x ). This would mean NO high-low nets in fixtures and compliant (high-low only) clamps.</td>
<td></td>
</tr>
<tr>
<td>- Framing Fixture #2 over-constrains roof in z, ( \theta_z ), ( \theta_y ) (Note bodyside and fixture are both trying to set these degrees of freedom).</td>
<td>- Let bodyside set ( z, \theta_z ), of roof (this is done simply by the act of setting the roof on the bodyside) and only use pushers in fixture #2 to center and set fore-aft (( x, \theta_x )) of roof.</td>
<td></td>
</tr>
<tr>
<td>- Roof ditch cannot be adjusted independently of other KCs</td>
<td>- There is no way to independently set both ditch widths.</td>
<td></td>
</tr>
</tbody>
</table>

Proposal for improvements for both the single and dual stage framing

Figure 17

Additionally, geometrically the proposed single stage framing will give you the independent ditch setting capability but there are other issues that have to be considered. As stated above, other attributes have to be balanced. These issues are listed below.

- The proposed secondary fixture with compliance in the y-direction is not within standard fixturing practices.
- This fixture may increase cycle time.
There will be additional maintenance because of the y-direction compliance.

Single Stage is an advantage for the ditch if the proposal given above is followed because you would be able to set two dimensions, the right and left ditch widths. But if other assembly KC's, such as front and rear glass openings and decklid opening requiring the left to right cross car assembly KC, became the top priority either the single or two stage framing process could be used with no clear advantage of one process over the other.

The information from this study was shared with a large automotive company and results verified. Because of the proprietary nature of the other studies that have been done, the data cannot be shared but the areas that were examined had to do with front-end fits. This was done for two independent teams with recommendations coming from both DFC studies. Portions of the recommendations have been used in the product design.

From the studies that have been done, some key lessons have to be learned.

The DFC provides a visual picture of the tolerance chain between parts, which make up key characteristics. As an engineer develops a system and as parts in the system change, the DFC will be a quick visual reference as to whether a particular part has an effect on the geometric integration of the key characteristics. Additionally, the DFC is a clear means to communicate the geometric intentions of the system from one engineer to another.

The DFC also shows overconstraint and underconstraint aspects of the system. Of course, there are many instances when it is desirable to have an overconstraint but it is important the engineer
understands the state of the system. As the system goes to production, careful attention can be paid to the overconstraints to insure the KCs are met. The important point is that DFC gives the engineer an objective evaluation and knowledge about the constraint state versus guessing and hoping everything works out in the end.

Chapter 3.4: Where does DFC fit into a typical automotive organization?

All of the studies, including the work contained in this thesis, that will be discussed in chapter 4 have been done for ad hoc teams. No defined process home has been identified for DFC. If DFC is to be integrated and used in the future as a knowledge repository to pass from one team to the next, there has be a well defined owner. The owner would be the central contact and would be responsible to insure the DFC was kept up to date. There is little doubt anyone would argue with this point. The disagreements would come when discussing who should own this tool. What follows is the author’s opinion as to where this tool should reside and why.

The tool fits well with the team or organization that is responsible for the generic architecture of the vehicle. Any large automotive company with plans for a strong future would have such an organization. This group would be responsible to generate and update the different architectures (front wheel drive car, rear wheel drive car, small truck, large truck, sport utility vehicle, and etc.). Let's call this group the generic architecture organization (GAO). The GAO group would pass the architecture to the program teams. Program teams would trim the architecture to deliver to the customer an end product. GAO would generate the architectures by balancing the list of customer functional and attribute requirements, similar to the DSM list discussed in chapter 2, and the Generic Manufacturing Standards (GMS) in order to create a
robust architecture that meets all of these requirements. Of course, the customer functional and attribute requirements and the GMS are directly correlated to the KC's.

The GAO would also be the group that would insure the architecture could deliver the geometric needs; of course, this is tied to the KC delivery. In order to insure geometric needs are met, DFC would be an excellent tool. Each of the generic architectures would have a DFC and, as improvements for the architecture come along, the DFC can be updated to insure the KC's can be delivered based on the constraint states of the architecture. As overconstraints in the architecture are identified, the DFC would assist in generating a clear plan of what components need to be monitored in process. Remember: if a part is overconstrained, there are multiple features (from mating parts and fixtures) trying to control this component in a particular degree of freedom. This entire system will have to maintain a consistent day to day "nominal" (i.e. low variation and mean shift) or there will be issues created by this overconstraint (i.e. locked in stress, out of position mating parts, and etc.).

There is another tool used industry-wide that can assist in evaluating the geometric state of the system. The tool is called Variation Simulation Analysis (VSA). The VSA tool (as the name indicates) looks at the variation of each individual part and simulates the effect on the overall system. This tool is excellent as long as the parts are properly constrained; if they aren't, and the analyst doesn't recognize the overconstraint, then the data generated will be suspect. DFC is an excellent complement to VSA. DFC can be done prior to a VSA to look at the system and insure the KC delivery and the VSA can be used to verify the "chains" required to deliver the KC's are robust to variation, particularly when it comes to overconstraint. Figure 18 shows how these
tools would work together in order to deliver a geometrically robust generic architecture. Remember the DFC will be a technique to identify constraint in the KC chains so it can be managed through the life of the architecture and VSA is used to insure the KC chains are robust to variation. Nominally a chain may not be overconstrained but if variation is included overconstraint may occur.

The flow chart in figure 18 is the strawman of how DFC can be incorporated into the GAO. Of course, the GAO has to be in place for this to work. In figure 18 if the DFC or the VSA shows an unacceptable condition for constraint and/or variation joint design, part geometry, and/or assembly sequence may be changed to address the issue. If there is no GAO, the DFC will have a hard time finding a home.
Chapter 4: Development of DFC for comparison to DSM results

In order to examine the hypothesis (there is a complex chain of subsystems which must be managed in order to deliver customer key characteristics. This chain is driven by the cross-functional integration that occurs because of the product architecture and the complexity of the customer requirements.), a DSM has been used to look at the information requirements. Now DFC will be used to look at the issue from a system/geometric prospective. The chains will be looked at from the critical key characteristics in order to prove or disprove the hypothesis on the findings from the DSM.

Chapter 4.1: What are the KC's for this study?

As with any DFC, the first thing that needs to be defined are the KC's. Since this study mainly focuses on the front end sub system, in order to examine the chassis and body interactions the product and assembly KC's will be focused in this area.

Product/Assembly KC (order does not imply ranking)
1. Ride feel
2. Alignment
3. Windshield to hood
4. Windshield to wipers
5. Wipers to hood
6. Door to Fender
7. Hood to fender
8. Hood to fascia
9. Headlamp to fender
10. Headlamp to hood
11. Headlamp to fascia/grille
12. Powerpack to dash (note powerpack is sub-assembled with a fixture to Subframe)
13. Power pack to hood and FEM/Rad
For this study the focus was on KC's 1 and 2. Particularly for KC's 1 and 2 there are associated assembly KC's (subframe to body hi-lo, fore-aft, and in-out). KC's 1 and 2 were picked because of the interaction between body and chassis. Note: you most likely could add additional KC's to this group but listing all of them was not the goal. The goal was to give a high level example and insure the critical KC's between body and chassis were covered.

KC 1 covers issues that occur if ride height is not correct or if drifting and pulling occurs. Also included in this KC, but not discussed in this thesis, are issues related to braking. KC 2 is self-explanatory; geometric issues are known to cause alignment issues. The disappointing thing is there is little focus on this piece of the development of a steering system until late in the development process. It is well known there are associated customer concerns with both of these KC deliverables.

Chapter 4.2: Development of the DFC

With the KC's defined the DFC can be developed. For this project the DFC was developed for a current model product. The first step is to look at the assembly process to insure the constraints added by the assembly fixtures are represented in the DFC. As each assembly step is modeled in the DFC, part features (mating conditions) are modeled and supplier information for each part is added. Suppliers are listed as SA to SG with each one being an independent supplier.

Figure 19 shows assembly # 1. It includes the rail inner sub assembly and the dash sub assembly. The rail inner sub assembly is purchased from supplier SA. The dash sub assembly is
assembled at the final assembly plant. Assembly #1, when complete, consists of the left and right hand rail inner sub assemblies welded to the dash sub assembly.

Assembly #1: Rail inner and dash subassembly
Figure 19

Assembly #2: Rail outer subassembly, cowl, and assembly #1
Figure 20
Figure 20 shows assembly 2. It includes the rail outer sub assembly, the cowl, and assembly #1. The rail outer is a sub assembly also purchased from supplier SA. Its DFC is shown in figure 20. The cowl is purchased from SB. Assembly #2, when complete, has the rail outer welded to the rail inner and the cowl. Additionally, the cowl is welded to the dash sub assembly. In both figures 19 and 20 the overconstraint is required to manage load, minimize water leaks, and etc.

![Diagram of assembly processes]

Assembly #3: Center and rear pan and assembly #2
Assembly #4: Side sill and assembly #3

Figure 21

Figure 21 shows assembly 3 and assembly 4. Assembly 3 is the marriage of the front structure to the center and rear floor pans. The suppliers of the major components in these subassemblies are suppliers SA for the rear pan and supplier SB for the center pan. These are critical sub assemblies for the total vehicle but are not critical to the DFC analysis being done in this study. The center pan is welded to the dash and the rear pan is welded to the center pan in this process step. Assembly 4 is where the side sill is welded to the side of assembly number 3. It welds
primarily in the XZ plane to the cowl side, center and rear pans. It welds in the YZ plane to the rail outer. This component is critical to the bottom of the bodyside position in the y-direction.

Assembly #5: Left and right hand Bodyside Subassemblies and assembly #4
Assembly #6: Left and right hand shot gun, roof and assembly #5

Figure 22

Figure 22 shows assemblies 5 and 6. Assembly 5 brings the bodyside sub assemblies to the front structure and underbody. Included in this sub assembly are the roof headers and bows. The major portions of the bodyside sub assembly are purchased from suppliers SA and SB. The sub assembly is constructed at the assembly plant. The bodyside is welded to the underbody and front structure. Assembly 6 welds the roof to the bodyside and headers and the shot gun inners to the front structure and the front edge of the bodyside. The roof is purchased from supplier SB and the shotguns from supplier SD. When complete, the shot gun inner plays a critical role in setting the shot gun outer which, in turn, is critical in setting the fender, hood, and lamp fits. The
bodyside plays a critical role in the door fits, which includes margin, flushness, sealing, and latching.

Assembly 7 (as seen in figure 23) shows the shot gun outer being set to assembly 6. Supplier SD supplies the shotgun outer. The component from assembly 6 the shotgun outer mates to is the shot gun inner. The inner gives the outer high-low location. As mentioned above, these two components will have a large impact on the fit of the fender, hood, and lamps. Assembly 7 represents the completed body in white less the closure panels.

Assembly 8 (as seen in figure 23) shows the front and rear door assembly processes. The supplier of the doors is SB. In reality the rear, then the front door, is assembled in two consecutive stations but for clarity in the DFC, they are shown in one step. The sub assembly process of the doors is shown in figure 24. There is the hinge setting process that is done at the assembly plant and the hemming process that is done at supplier SB. In the hemming process the
inner is set relative to the outer in all directions. In this process, the outer is master. When the hinges (purchased from supplier SG) are set, the inner gives the hinges their location.

Depending on the process when the door is set to the body, the inner or the outer will be used for setting. Looking at the chain it is clear this will give differing results depending on which is used and if the KC you are looking at depends on the outer (margin and flushness) or the inner (seal gap and efforts).

Once the doors are in place, the next components to be assembled are the fender then the hood (see figure 25). SE supplies the fender and SB supplies the hood. As mentioned above, the fender location is set relative to the body through fixture 9. Fixture 9 references the shotgun and the door. This is why the shotgun and the door outer locations as mentioned above are so critical. The z location of the fender is set directly from the shotgun outer. The hood in a similar
fashion is set relative to a fixture that, in turn, gets its location from the shotgun outer and the fender. The height of the hood is set in the back by the hinges (see figure 26) and in the front from bumpers that are adjustable in the z-direction. Both the hood and fender, like the doors, are bolt on components.

Now that the front-end closures are complete, the vehicle goes through several other processes that have no known impact to this study. This includes rear end closures, paint, interior trim and
chassis. The next process step of interest is the lamps and front end module (FEM). The FEM will include attachments for the lamps. This portion of the DFC can be seen in figure 27.

Other Assembly goes on not affecting this study

![Diagram](image)

Assembly # 11: FEM, lamp, and assembly 10

Figure 27

Like the doors, this DFC really represents several process steps but for clarity it is shown together. First, the FEM is brought to the car. It receives its location from a fixture that in turn gets its location from the shotgun outer and the rail inner. The second process is for the lamps to be installed. In figure 27 the fender is shown separate from the assembly 10 (which it is part of) because of the critical role it plays in the lamp set. The lamp is set in all six directions from the fender on the outboard side. The FEM also gives the lamp 5 of the six degrees of freedom on the inboard side. The only degree of freedom the FEM doesn't give the lamp is the y-direction. Of course the rotational degrees are constrained by a combination of the inboard and outboard locators. At first glance this may look like over constraint but it is not. The lamp is a long part and is somewhat flexible. By locating the inboard and outboard portions of the lamp the effects of the flexibility are reduced.
The final portion of this DFC is the subframe assembly (see appendix 1 for a pictorial of the chassis system). This subassembly consists of the subframe structure, the lower control arm and the shock/spring assembly. There are other components to this sub assembly but they don’t play a critical role in this analysis. Figure 28 shows this DFC from both the assembly and sub assembly process.

Assembly # 12: subframe assembly and assembly 11
Figure 28

With the complete DFC in place the KC chains can now be examined to address delivery potential.
Chapter 4.3: Develop KC chains

Now that the DFC is in place we can look at the chains that are required to deliver KC's 1 and 2. Remember that what we will show are the associated assembly KC's which are required to deliver product KC's 1 and 2. Three assembly KC's were examined. They are the high-low, fore-aft, and side-to-side KC for the body relative to the chassis systems.

The first one examined is the high-low assembly KC. Looking back at assembly one and two, it is clear that the body portion of this KC is driven by the attachments on the rail inner (the front and rear subframe reinforcement). These are the locations where the chassis subframe attaches to the body indicated by the "Mates" area in figure 29 below. Also in assembly two the spring and shock assembly (the chassis side) attaches to the shock tower. This chain can be seen in figure 29.

---

High Low Assembly KC Chains
Figure 29
This KC is a relative dimension. If one attachment is out of plane relative to the other attachments and/or if the shock tower height relative to the front and rear subframe reinforcements is off, then this KC may not be delivered. On the chassis side this out of plane condition causes the shock and spring assembly to be extended and/or compressed relative to the ground depending on the condition. If this KC is not delivered, a drifting and pulling issue will arise.

The second KC examined is the fore aft KC. The body portions of the chains for this KC are similar to the high-low KC except that the fore aft KC has to do with the fore aft relative positions of the shock tower and front and rear subframe reinforcements. For the chassis portion it is the side view angle of the shock and spring assembly relative to the wheel and ground that is affected by this KC delivery. If this KC is not delivered a drifting and pulling issue will arise.

Figure 30 shows the chains for this KC.
The final KC that was explored was the side-to-side assembly KC. This KC is different from the prior two chains. The chains for the body portion of the KC pass through the dash panel. The dash has the effect of sizing the cross car dimension. This is the reason for the path of this chain. The cross car KC affects only the lower control arm of the chassis system. If this KC is not delivered, the control arm angle in the x-y plane will be off, thus causing an alignment issue.

Figure 30 shows the chains for these KC's.

![Diagram](image)

**Side-to-Side Assembly KC Chains**

*Figure 31*

The KC discussed above comes from the rotation of the subframe. If the side-to-side KC were to exhibit translation there would be what is called toe in and toe out. This KC was not explored in this thesis because of the lack of data as to what customer KC it affects but its chain would look similar to figures 29-31.
These are complex chains that pass through several components, extending across at least two major organizational boundaries, and across at least one major supplier. If the geometric chains are not managed, it is clear the KC delivery will be affected. The effect may be positive or negative but the key is that the engineer knows that a change or particular design feature has an effect on the KC chains. Not knowing is like driving with blinders on. The proposed solution to the complexity, supplier interaction, and future state DFC will be discussed in Chapter 5.
Chapter 5: Conclusions

Chapter 5.1: DFC and DSM findings

The DSM and DFC both show the complex integration that must occur to deliver the body and chassis total system. First, looking at figure 7, there is a large portion cluster of both body and chassis task which can be done within their respective organizations but, as the DSM shows, there is just as large a number of tasks that require cross functional integration/design. The DSM supports the hypothesis. There is a lot of cross-functional integration mainly due to the number of functional/customer driven requirements. As shown in figure 2 the clusters of the DSM are managed well but the integration is at best left to individuals to manage with no structure or organizational authority to make it happen.

A similar conclusion can be drawn from the DFC. The three KC's chains shown in figures 29-31 definitely are complex, crossing two major organizational boundaries (body-chassis-manufacturing). Body engineering designs the rails and the shock tower structures, chassis designs the subframe and suspension, manufacturing assembles the subsystems and a set of suppliers makes the parts and subassemblies. Stiffness targets and other issues are shared but little attention is paid to whether the geometry and constraints of the system are such that the product KC's can be delivered. Added to the complexity is the fact that there are several suppliers involved in delivering this system.

Looking at both the DSM and the DFC, here are the suggestions that can be taken from this thesis:
I. Organize team based on the architectural decompositions vs. historical paradigms.

Below is the proposed structure based on the DSM results, DFC results and experience of the author.

The organizational decomposition proposed above in figure 32 is unconventional to many large automotive companies and breaks many of the current organizational chimneys. The team would be two groups: a front end and an underbody team. This group would have chassis, body structure, certain powertrain sub systems, climate control, and manufacturing all represented on the team. There would be a front end and underbody team leader. The team leaders would report to a single boss who, in turn, would be responsible to deliver the front end and underbody
total systems including manufacturing. The 3-team will have two team leaders, one for body shell and trim (including trunk) and the other for closures (including decklid and sealing) and trim. The 2-team will have a single team leader responsible for all exterior trim, fascias and lamps. This group ultimately may be absorbed by the other groups, most likely team 3, but for now it is stand-alone. There will be one electrical leader and this team (4) will interface with all the other teams. This is an organization within most large automotive companies that really does work well with cross-organizational interfaces. The final team (5) will have two team leaders: one for transmission and one for powertrain. In each of the groups 2-5, as was the case in team (1), the team leaders will report to a single person responsible for that module. Each of the five module leaders will report to a single chief program engineer.

The reason for this decomposition is that when the vehicle is integrated, the number of external (outside the team) interfaces is at a minimum and a majority of the interfaces will be within the team. By doing this, the most critical cross-organizational interfaces are within a single team and a lot of the KC particularly between chassis and body would be held by a single team (team 1). The other issue is partisanship to a functional group. In the proposed decomposition, the issue of us vs. them will not exist. If you look at figures 29-31 under the current organization you would pass the KC through two major organizations, body and chassis. Under the proposed organization the KC would be managed within team 1. There is a potential for the groups (teams 1-5) to have this issue but it will be greatly reduced by grouping by interfaces vs. by functional knowledge. There still will be interfacing issues but they will be in limited areas across single functional groups. The only cross functional, non-team interfaces will be between powertrain and team (1), as well as wiring and all of the teams but, as stated above, wiring has worked well at managing these interfaces. The team 3 to team1 interface and the
team2 to teams 3 and 1 are within the body functional organization currently and should be managed in a similar fashion as they are currently. This decomposition greatly reduces the extreme numbers of cross-functional, cross-organizational interfaces. This decomposition is driven to manage the interfaces and force the organizational structure to follow what is best for the vehicle and not vice-a-versa. Additionally, it is intended to reduce the number of cross organization or what has been referred to as the "us vs. them" issue as much as possible. The other main outcome of this analysis is that the teams need to be “mixed” and you cannot just focus on body structures, chassis, or powertrain. The final accomplishment is that manufacturing is directly integrated into the team vs. stand-alone.

The balance between customer knowledge (the customer does not like drifts and pulls or alignment issue) and functional knowledge (best way to design a body joint i.e. subframe to rail) is an issue with both the current organization (figure 2) and the proposed structure (figure 32). People tend to work for a long time (5-10 years) on either a product team or within a functional knowledge organization. What happens is people tend to lose the balance. The one additional proposal is to cycle people between these two organizations. This must be a mandate from upper management that is shared with all people of the organization. If this balance is not achieved, the organization will tend to oscillate between the two, which will cause long-term efficiency issues. People will understand the customer really well but not the product or vice-a-versa. This is a tough thing for any organization but is an issue that must be addressed with a corporate-wide strategy.
II. Supplier integration

Another major highlight of the DFC in Chapter 4 was the supplier interaction. If you examine figures 29-31, Supplier SA is responsible to deliver the rail inner sub assembly (body component), the rail outer sub assembly (body component), and the sub frame structural component (chassis component). These are almost all of the major components that are responsible in delivering the three critical assembly KC's. From this, a suggestion has been made and is being looked at to have SA coordinate and monitor these key areas of the system. By this it is meant that they will check not only components, which is currently done, but check the complete front-end system including the subframe. This is a shift in thinking even for the supplier. These components are made in two completely different locations within two different divisions of the supplier. This is a case where the integration of body and chassis by a supplier can insure the entire system is delivered, not just the components.

Chapter 5.2: Future State of DFC

DSM is a tool that is well established. There are conferences and much research going on to use the tool in its current state and also to expand the usefulness of the tool. DFC on the other hand is a new tool to large automotive companies. There is currently student software and libraries for the fixture to product and component-to-component interfaces [7,8]. The proposed process and strawman are shown in figure 18. Portions of this process have been used on several of the pilot DFC projects. The KC identification and study of the architecture and assembly process with the DFC have proven successful. Chapter three also talks about the advantages to using the tool. The one thing that has not been discussed thus far is the "user friendliness" of the tool. Currently
the DFC's shown in chapters 3 and 4 are mainly done by hand. **There is one major step that needs to happen with DFC. It needs to be integrated, in much the same way as other tools like VSA, FEA, and CAD, into more mainstream visualization tools.** VSA tools and other assembly type tools currently are available to show the components coming together. This type of tool should be able to be modified to show the sequence of the DFC chains. The user would still have to digitally create the chain similar to what is shown in chapter 4 but this would be converted and would show actual parts to the user when complete. One example of how it may look is shown in figures 33-35 below. The key addition to the current tools is that it has to visually show the user what degrees of freedom are constrained. The example used is the hood setting from figure 25 in chapter 4.

---

**Figure 33**

Fixature 10 description and setting to fender
Fixture Surface controls Hood \( Y \) and \( \theta_2 \)

Pin on fixture goes to hood (LHS 4-way hole and RHS 2-way slot) to control \( X \) and \( \theta_1 \)

Symmetric hand fixture one per side

Note: Not shown hinges at rear and bumpers at front which control \( z, \theta_k \) and \( \theta_y \)

Fixture 10 to the hood

Figure 34

Comparison of visual vs. current DFC technique

Figure 35

The example shown above may be constructed as follows:

1) User inputs the DFC digitally the way it is shown in figures 19-28. Including mating conditions and related constraints.

2) With the complete DFC user would define the KC's similar to figures 29-31.
3) Next link the \( \bullet \) to the parts and fixtures through an existing CAD tool.

4) At this point intelligent systems or experienced tooling designer or revised tooling logic from GAO would be used to create the figures shown above.

The one tool missing is for step 1. There currently is student software to create the DFC but it is not commercially available. Once it is then this proposal should be fairly simple to implement.

This type of visualization should also be done for the KC chains. An example for the 3 KC's chains from chapter 4 is shown in figures 36-38

![Fore-Aft KC chain for subframe to body](image)

**Figure 36**
High-Low KC chain for subframe to body
Figure 37

This condition causes a ride height variation

Side to Side KC Subframe to Body

This condition causes an alignment issue
Side-to-Side KC chain for subframe to body
Figure 38
In figures 36-38 the KC chain is traced through the digital parts. Comparing this with figures 29-31, it is clear that the more component visualization tools DFC can leverage, the better. The KC visualize would require further intelligence in the software to develop the paths from one side of the KC to the other. But again with a little development work this issue is not insurmountable.

If DFC is added to the arsenal of visualization tools, it can become more widely used and accepted and become an everyday engineering tool.

Chapter 5.3: Future Work

The two main areas of future work have to do with the DSM and DFC. First, the function DSM should be expanded to lower levels of the architectural decompositions. This should be done to further the in depth knowledge it provides and insure that as more detail is added, the finds are still solid. Additionally, with more detailed work, the assumption driving the symmetric DSM would be removed.

The second area of future work has to do with the DFC. First the visualization portion of the tool needs to be developed if the tool is become mainstream. This would include further development of the MIT student DFC as the backend to the visualization tool. Secondly, the flexible part investigation needs to be completed. There are several KC's that extend across flexible components such as fenders, fascias, and etc. that challenge the assumption that all parts in the analysis are rigid.
Appendix 1 – Anatomy of Front End Structure

THREE DIMENSIONAL REFERENCE SYSTEM
(METRICATION)

Hood

Fender

Shock Tower

Shot Gun

Rail

Dash

Radiator support
Bibliography


