Leveraging the Capacity of Human Capital in a Product Development Organization

by

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Abstract

This research has as fundamental purpose, the generation of strategies for the product development organization in Ford of Mexico; the goal is to increase the capability of the workforce for the development of future work streams. In this thesis, a network model for organizational architectures referred as organizational design structure matrix is used to identify the main interactions among the project teams; this interaction pattern is compared to product interfaces captured in a product DSM model. A case study from Ford Motor Company is utilized; the development is narrowed to the analysis of the front end system of a new CD platform vehicle during the main stages of the product development process.

To set up a context for this thesis, I elaborate the product development process from Ford and describe the main design challenges from the case study. In this thesis, I also explain the role that communication plays in an organization due to team geographic location and categories within the organization. DSM concepts and methods are explained to converge further in the application of the product development organization case study.

I start the research with the creation of the product DSM for the front end system team through data collection, and interviews with the core engineering group at the company; surrogate data from current production CD vehicles was analyzed. I survey the Ford front end system team to understand the frequency and level of interaction among component teams during the development of the project. Technical maturity level of each team member is collected as well. Additional data from the program management team is acquired to cross reference project team performance with organizational communication. I compare the data set collected with the product architecture DSM to determine mismatches in the organization interactions. In addition, a series of clustering analyses are also compared to improve the team design structure matrix; these results allow us to convey strategies and recommendations to Ford of Mexico organization, to ultimately enhance the product development organization capabilities.
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<td>Three-dimensional</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
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<td>CAD</td>
<td>Computer Aided Design</td>
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Chapter 1 – Introduction

“The journey of a thousand miles begins with one step”

Lao Tzu

Workforce capability within the car manufactures is an important characteristic to successfully deliver new vehicle designs given the growing market in the auto-industry. The automotive original equipment manufacturers (OEM) have faced more aggressive challenges to meet not only customer demands but also new requirements worldwide. More efficient vehicles to improve fuel economy, reliability, safety and price, for example, are the top four factors that consumers have consistently stated they focus on when it comes to making their final decision about which vehicle to buy, (Environmental Protection Agency, 2010).

Appealing designs, improvement in craftsmanship execution and technology breakthroughs to keep competitiveness are also major factors to succeed. For example, based on Motor Trend magazine evaluation the 2010MY Ford Fusion was awarded as car of the year due to the impressive bandwidth as a model range (Stone, 2009). Another recognition by the Autoweek magazine, 2013MY Ford Fusion was awarded as the Best in Show at 2012 NAIAS. Ford group design vice president J. Mays commented, “the Fusion delivers bold styling that projects a more luxurious message than we expect for its broad, family-car mission. The Fusion is built for the 99 percent; chock full of 1 percent panache and punch” (Autoweek, 2012). The previous reasons have pushed OEMs to enhance design methods and human capital maturity models in order to become more competitive with the objective in mind of increasing market share.

For practical purposes, this thesis is narrowed to Ford Motor Company (FoMoCo) in the product development group. Ford in the USA has demonstrated a high maturity in the organization given the large years of experience in car systems design, successful vehicle launches worldwide in the past years and the overcoming of corporate troubles. A good example of the organization leverage was presented in 2008 during the contraction of the auto-industry, when other North American OEMs declined, Ford stood firm. This was not causality; there was a plan developed by Ford in order to keep the company on wheels. This plan incorporated three priorities that
embraced the essential needs for the organization: people – a skill and motivated workforce, products – detail customer knowledge and focus, and productivity – a lean global enterprise (Hoffman, 2012).

Starting from technical to managerial experience in the human capital until the application of internal methodologies, such as failure mode avoidance, engineers have shown that during the development process of a certain project, there are deficiencies to meet deadlines. This behavior has been noted even more in the satellite PD groups such as the Ford of Mexico office, because of the young age of the organization which is the driving force for the development of this thesis. The purpose that I am focusing on with this thesis is the creation of an organizational framework within the product development group at Ford of Mexico. This bridged the product structure relationships with the communication and interaction in the organization through the use of network modeling tools (design structure matrix) and organizational architecture approach.

1.1 Motivation

Thinking about the growing development strategy that Ford of Mexico (FoM) has portrayed, “people” and “process” are two of the main streams that the company has identified as strong connection to satisfy high quality designs in short period of time. This has been demonstrated by the Ford USA product development (PD) structure during the development and launch of more than ten new “top hat” vehicles in the last five years. A “top hat” is defined as the unique exterior upper-body and complete interior designs that share a common vehicle platform; also known as platform derivative product models (Eppinger and Reyes, 2014). For example, the Lincoln MKS shares the same platform of the Ford Taurus but those are different vehicles to the customer’s eyes. A similar example is the Ford Focus and the Ford Escape; these vehicles are derivative models from the C platform.

Focusing on “people” and “process” within the company brings huge opportunities to maximize FoM possibilities to increase “top hat” capabilities in engineering expertise and managerial matters by always having the objective in mind to attract new programs from the USA corporation and transform FoM into a global center of excellence in product design and development.
The product development organization at FoM is a complex system because of the large number of interactions that exist among the different subsystems of the vehicle and the larger amount of tasks that engineers have to complete for each component that they design. Also there is the constant increase in the engineering staff demanded by the management and the diverse capabilities that the workforce shows in a particular project. This organization is compounded by a spectrum of technical knowledge and experience that goes from novice engineers (those that recently finished their professional studies) to leveraged engineers who have developed programs along all the stages of the Ford development process.

Such diversity has brought an interesting effect within the program teams of different projects. For instance, let’s take as a case study the development of a new luxury CD vehicle segment\(^1\) that contains a substantial level of design changes: new engine motorizations, body interior upgrades, rear end updates and complete front end re-design. The result was a fresh car with several reworks during the development process. As part of the front end subsystem development CD project team, I identified that most of the engineers that participated in this program incurred delivery delays, unplanned communication and product interface mismatches. Figure 1-1 shows the typical FMA process at Ford, there is lack of a systematic process/framework that enhances manpower capability; this creates omission while communicating engineering needs. Insufficient information leads to uncontained noise factors which reduce the identification of potential failure modes affecting the overall robustness of the product. Deficiencies in the transfer of technical communication among component teams affect the performance of the project due to reworks in the design and the hard-work effect. The synergy created between the organizational architecture DSM and the FMA process might prevent such failure by improving cross-functional team communication. Component interactions are complemented by the component team structure and team interactions are validated by the product architecture. Information that feeds noise factors, control factors and ideal function will be enriched, failures in the product will be prevented and the program performance will be maximized.

\(^{1}\) A vehicle segment in the OEM world typically defines the size of the car; they are denoted with the following letters starting from the smallest to the largest car: A, B, C, CD and D. For example, subcompact cars like Ford Fiesta are categorized in the B segment, small sedans like Ford Focus are in the C segment.
The summary mentioned above brings the need of contributing with the growth of FoM PD organization with the creation of strategies and/or systematic frameworks in order to enable effective communication and leverage technical knowledge for further “top hat” developments.

1.2 Thesis Objectives and Premises

The development of a new luxury CD platform vehicle at Ford Motor Company was conducted mainly with FoM PD human capital; the main characteristic of this vehicle consisted in the re-design of the front end subsystem, which integrated 35 cross functional teams. The front end subsystem group was established with an unstructured network with deficiencies in the communication process as explained in the section 1.1.

Based on the statement above the objective for this thesis is:

- To identify gaps in communication among cross functional system teams by comparing product interaction and the organization structure of the CD-car project to improve
human capital capabilities in attracting further "top hat" developments to the FoM organization.

Supporting this research proposition with the motivation and objectives mentioned above, I have set up the following premises that will lead the discussion in this thesis:

- Product interfaces are defined with a product architecture DSM; product systems are developed by teams therefore organization DSMs can lead to the development of a project having well organized system team structures.
- Development and implementation of system team structures can improve the performance of a product team and the outcome of a project.
- Structured communication among system team members can enhance personnel capabilities by acquiring experience from cross functional interactions.

1.3 Research Methods and Approaches

I apply the design structure matrix approach and methodologies in this thesis to improve the FoM PD front end system engineering process. For instance, I develop a product design structure matrix for the case study in order to determine cross functional component interactions. I build the interactions based on a front end system boundary diagram from the CD-car vehicle which comes from research done with the help of Ford core engineering. After I conduct interviews within Ford of Mexico cross functional component teams from the CD-car case study to understand the frequency of team interactions and effects of communication presented during the development process of the front end system project. In addition, I survey the same case study group to collect technical maturity data to cross reference communication against experience from the team. Finally, I compare both frameworks to identify gaps in order to portray a strategy for upcoming "top hat" as represented in the short summary below.

![Figure 1-2 Thesis Flow diagram](image-url)
1.4 Thesis Structure

The chapter structure of this thesis is outlined below. Starting from an introduction in chapter 1 premises, objectives and project scope are defined. Brief discussions of the Ford product development system and detail explanation about the organizational case study are delineated in chapter 2. Moving to chapter 3, I describe concepts about communication, design structure matrix (DSM) approach and types of DSMs, with emphasis on organizational DSMs as the main method for this research. In chapter 4, the CD-car case study is modeled using DSMs, analysis of original data set, system team structure and proposed model structures are conducted in order to define strategies for FoM. Finally in chapter 5, I summarize conclusions and recommendations from this research project.

Chapter 2 – Organizational Case Study: CD-Car Project

The research presented in this thesis is limited to the automotive industry; I present a brief description of the product development system at Ford Motor Company in order to bring the CD-car case study for discussion. The scope of this investigation covers the main design phases of the development process given the maturity of the project. I explain the analysis of the front end system as the main feature change for the new CD-car. I also describe the program scalability for this project, high level component decomposition and human capital assigned to the program.

Chapter 3 – Communication in the Organization and Network Modeling Tool

I provide an overview of communication in the organization as soft skill, I explain communication in the company as a function of distance and workplace; categories within FoM are summarized, as well. I cover the design structure matrix (DSM) methods; I briefly describe

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2 The program scalability within the OEMs stands for the amount of design changes contained in a new vehicle development.
the types of DSMs focusing on the organizational DSM in order to establish a baseline of understanding for the application in the CD-car case study.

**Chapter 4 – Analyzing the CD-Car Front End System Case Study**

I model and explain the CD-car case study using organization DSM methodology having as a starting point the analysis of the CD-car front end system component interactions. Here contact and non-contact interfaces are considered. I present original data set from interviews conducted with the project team. A system team structure is portrayed; I develop a proposed model structure through software simulation for comparison with component DSM and original team structure. Understanding of chapter 2 and 3 provides enough foundation for intuitive reorganization of the front end team structure; here clustering team plays the most important role to improve interactions among component team for the success of the project. A brief outline about FoM technical maturity model is explained and cross referenced with frequency of communication among teams. A picture of cross functional communication before and during a milestone is presented as contrast of team efforts to deliver the project on time.

**Chapter 5 – Conclusions and Recommendations**

As final chapter, I recommend to FoM a list of strategies that is needed to leverage the product development workforce skills. Lessons learned are provided as preventive actions for future projects. Ultimately, the utilization at the company of organizational DSM in order to establish right path of communication among cross functional teams.
“I think we are having fun. I think our customers really like our products. And we are always trying to do better”

Steve Jobs

In this chapter, we look at the vehicle segments that lead to the CD-car project, high level decomposition of the vehicle system and component decomposition of the front end subsystem. On the other hand, the scope of this thesis has been limited to the product development process at Ford Motor Company, starting from the concept development to the detail design. The main reason of this constraint is given by the core participation of the engineering group and the program status of the case study. A brief description of the number of changes in the project is enunciated, which eventually brings concepts of the amount of workforce assigned to the program.

2.1 Vehicle Segment

Nowadays, different OEMs, regulators and vernaculars have classified vehicles in different segments due to the car size. Ford has denoted five main segments for its portfolio to satisfy customer demands: A, B, C, CD and D. Figure 2-1 lists some of the main products categorized in the different vehicle segments at Ford. Such segmentation represents a strategic division to cover diverse markets, from North America to Asia and from conventional to luxury.
The customer demand has created in Ford the need to expand the vehicle segmentation in an efficient way; this means that the automaker is creating new vehicle projects. However, they are keeping the same foundation form, referred to as platforms, for multiple vehicles.

A platform in the auto-industry is a common under-body system\(^3\) that is shared in a vehicle segment by different upper-body architectures. Platforms are not visible to the customer but they create high value to the final product. In most times, a vehicle platform is slightly modified in order to accommodate unique components for a certain program; in other cases, modular system approaches are used to allow scalability and attribute uniqueness for specific customer needs. A schematic of the OEM platform is described in *Figure 2-2*. A platform is mainly comprised of powertrain, lower body structure, chassis and electrical systems.

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\(^3\) A vehicle architecture is decomposed in two main subsystems:

- **a)** Under-body. It contains components designed in the lower portion of the vehicle such as chassis, cooling lines, exhaust pipes and floor. This is typically known as the vehicle platform.
- **b)** Upper-body. It contains the upper portion of the vehicle, most of the time visible to the customer for example, doors, hood, windshield, interiors, etc. In Ford this is known as “top hat”.

---
A good example of platform application is the Lincoln MKZ 2013MY; it was developed utilizing the platform from the Ford Fusion 2013MY. There were minor changes in the platform due to component incorporation, such as a new reinforcement for the gas strut attachment. This helped to carefully integrate the platform with the new upper-body; both cars correspond to the middle size sedan segment.

![Platform Framework](image)

**Figure 2-2 Platform Framework**

Platforms allow vehicles to be designed in an easier way than if the vehicle were developed from scratch. Having common platforms across different vehicles allows cost sharing and avoids much re-development of new components (Ulrich and Eppinger, 2012).

### 2.2 Automotive System Decomposition

The previous example has shown two different vehicles with the same platform, both of them in the CD segment. The case study applied to this thesis corresponds to the new generation of the premium CD vehicle segment for the North American market. The number of design changes, system architecture and staff allocation to the project will be explained shortly. First, let's analyze the high level decomposition from the vehicle system shown in *Figure 2-3*. 
To create a context, the decomposition of the vehicle system represented above was done based upon the geographic zones of the vehicle that the function lead team at Ford has generated. These are called operational subsystems which provide a concentrated area for block leaders to manage. There are four major operational subsystems that integrate the automobile as follows:

1. **Front End.** In this subsystem, there is a diverse group of components: hood, fenders, grill opening reinforcement or fascia. A detail list of the front end subsystem for the case study will be explained in an upcoming section.

2. **Mid-Upper-body.** Typically this section is the middle upper portion of the car; it is integrated by components such as front and rear doors, body side and roof among others.

3. **Under-body.** This is the lower section of the vehicle; it is the foundation where the upper-body subsystems are mounted. Here, the subsystem is compounded by powertrain, chassis, electrical, lower body structure, etc.

4. **Rear End.** In the back of the car, this subsystem incorporates components such as tail lamps, back light, decklid or rear bumper.

The primary subsystem for the CD-car case study is the front end portion of the automobile. The rationale behind this case study lies in the number of component teams that integrate the design. In addition, as part of the design team of the CD-car project, I had the opportunity to identify gaps in the development process and communication among team members. There was a sense of incidental interactions, inconsistencies in communication and missing important interactions which all emerged during the program flow among different component teams.
A total of 35 component teams were analyzed from the front end subsystem, the type of relationships identified were spatial (contact and non-contact) and information sharing based on three main sources of information:

2.2.1 Product Architecture of the Front End System

Since the analysis of the case study has been narrowed down to the front end subsystem; now we can utilize the word system to denote the front end. The geographic front end system of the vehicle integrates multiple components that add high value to the final product. Usually customers take as a first impression the “face” of the vehicle, determined by the style, geometries and lines of the exterior-visible parts, regularly known in the OEMs as class A surface.

A good execution of the front end system greatly depends on the interaction strategy specified by the program teams; this strategy is defined according to the product architecture of the front end system. The product architecture established for the CD-car project consists in the integration of body structure, front end module and exterior ornamentation, see Figure 2-4. At this point, the product architecture has been decomposed at the highest level. The granularity of the system for the case study has been limited to the second level, given the large number of components that integrate each subsystem. Table 2-1 shows the complete list of components incorporated in the physical product architecture of the front end system for the CD-car case study.
2.2.2 Subsystem Boundary Diagram

Exterior-visible parts and hidden components are intrinsically related; the packaging design is limited by the class A geometries. From this surface, hidden components are designed and constrained by OEM requirements and attributes; however, interfaces are built based on the boundary diagram of the system.

A boundary diagram represents the main relationships of a set of components or subsystems that integrate a system. Figure 2-5 shows the key interactions among the front end system components and stakeholders that are related to them. There are two types of interactions considered for the analysis: a) spatial which includes contact and non-contact interfaces and b) information sharing.

Within the boundary (blue dashed line), the vehicle structure is represented with a combination of contact and non-contact interfaces, both are spatial interactions. Outside the boundary there are important relationships with other program teams that have to be considered, as well. The type of interaction for these relationships is known as information sharing.
Body exterior components interact among themselves to meet different requirements, such as craftsmanship. An example of craftsmanship is the gap distance between the front leading edge of the hood and the upper edge of the fascia; this is a spatial non-contact interaction. A strong non-contact interaction exists in order to ensure that the component interface allows a function or prevents miss function. For the previous example, the right amount of gap between hood and fascia prevents a hard contact while the hood is being slammed.

Furthermore, spatial contact interactions are presented in the system with the same purpose of the non-contact relationships, allowing the systems to function. In this case, class A and/or hidden components are always in touch for attaching, fastening, sealing or supporting among others. For example, the grill is fastened to the bolster and the overslam bumper is supporting the hood weight.

An example of information sharing interaction occurs when there is a transfer of information among program teams. For example, there are constant iterations between design studio and class A components (hood, fender, fascia, engine cover, etc.). To achieve the desired vehicle execution, the design studio has to change the design of the class A surface components, these changes have to be communicated to the proper component teams.

In chapter 4, there will be a description of the product DSM and the main relationships for the product DSM case study. Interactions were taken from the original front end system boundary diagram described previously. Although the information is the same, the data is changed from a structural view to an architectural representation.
Figure 2.3: CD-car Front End System Boundaries
2.2.3 Product Module Team

The third source of information utilized to determine the number of component teams is the product module team at Ford. The product module team (PMT) is the denotation for the subsystem team groups. These groups are integrated by function, whose function is to deliver forward model programs at functional cost, timing and quality targets (Ford Speak, Internal Ford Network, 2014).

At Ford, a global team structure is decomposed in seven main PMT groups: body exterior, body interior, chassis, powertrain, electrical, hybrid technology and vehicle personalization. All these groups speak among themselves as an organized structure. Each group is decomposed in several subsystems; however, they do not communicate as organizational architecture. Given the nature of the design changes of the CD-car project, I selected the PMT body exterior team as the main system for analysis. This PMT has also seven subsystems, three of them have been taken as case study. A decompositional view of the global PMT structure is represented in Figure 2-6.
2.3 Project Size

In Ford, the scalability of a program describes the content change level in the product, generic timing and development cadence of the vehicle. Typically, product changes are reflected in the three domains of the automobile: upper-body, under-body and powertrain. The change levels are measured with a descendant scale from #6 to #1, where #6 means all new and #1 indicates no change or carry over components as shown in Figure 2-7.

For the CD-car project, the program team has specified the scalability of the product as a middle cycle action design with a nomenclature of 433. This means that there is a moderate upper-body style with predominant changes at the front end of the car. The under-body suspension has partial changes and the powertrain is being tuned to achieve emission efficiency.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Upper body (UP)</th>
<th>Under body (UN)</th>
<th>Power train (PT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>All new</td>
<td>All new</td>
<td>All new</td>
</tr>
<tr>
<td>5</td>
<td>Major change</td>
<td>Major change</td>
<td>Major change</td>
</tr>
<tr>
<td>4</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>3</td>
<td>Partially Moderate</td>
<td>Partially Moderate</td>
<td>Partially Moderate</td>
</tr>
<tr>
<td>2</td>
<td>Minor</td>
<td>Minor</td>
<td>Minor almost carry over</td>
</tr>
<tr>
<td>1</td>
<td>Badge work</td>
<td>No change / carry over</td>
<td>No change / carry over</td>
</tr>
</tbody>
</table>

*Figure 2-7 Program Scalability Framework

*Modified from FoMoCo

---

4 A Middle Cycle Action design is launched at the middle of the life cycle of a vehicle program. This is a refreshing model that drives the design of an all new top hat vehicle.
2.4 Product Development Process

Product development process is a series of steps which tasks are developed under a certain methodology; the process leads the design of a new product in order to commercialize it in the market.

The perception of market opportunity drives the design, production, sale and delivery of products (Ulrich and Eppinger, 2012). Competition, market change, product life cycles and technology advancement are elements that push PD organizations to develop products more efficiently and more frequently (Unger and Eppinger, 2011). Other bibliographies have described the transformation of information as the main characteristic of product development, along different stages of the PDP workflow (Aguirre, 2008).

Transformation of information occurs during the exchange of data among different organizations. For example: marketing, finance, purchasing, manufacturing and quality. The interactions of these groups provide input to the main PDP activity; at the same time the PDP generates outcomes for the other entities that participate in the process. The success of the product design highly depends on the level of communication from different organizations, which ultimately will produce the maximum market penetration of the product.

Nowadays, there are different product development processes utilized by companies in function of their needs. For example, the spiral process incorporates planned tasks with feedback loops, which allow the PD team to go back in the process for issue resolution or detail design. The spiral process also incorporates flexibility in designs and reviews among stages in the process, Figure 2-8.

On the other hand, one of the most popular PDPs is the staged process. It is used by companies that iterate a few times; they follow methodic steps and typically stop the design process at the latest stage in order to stabilize the product. This PDPs reduce reworks and design changes. This process is applied to product design in cycles with high quality performance as explained by Unger and Eppinger in their journal Improving Product Development Process Design (2011).
According to Ulrich and Eppinger (2012), the generic product development process is like the process used in a market-pull situation. The company identifies a market opportunity and then uses a proper technology to satisfy market needs. Variants derived from the generic development process exist, as well. Ulrich and Eppinger (2012) have defined the following:

- **Technology-Push Products**: a new technology pushes the product development. After this, the company looks for market opportunities to create a new product.

- **Platform Products**: the platform product is built around a pre-existing technological sub-system. Products built on platforms are simpler to develop compared to technology developed from scratch.

- **Process-Intensive Products**: there is a major restriction from the production process on the product. Product design cannot be separated from the production process design.

- **Customized Products**: a product is developed based on particular requirements of a customer. A company executes a structured design and development process to create a product that meets customer needs.
- **High-Risk Products:** products are developed under large uncertainty where there is high technical or market risk. Here, multiple solutions are developed to ensure one succeeds.

- **Quick-Build Products:** on this variant, products are developed in a very short time taking advantage of rapid prototyping; flexibility in the process is added in order to reiterate through the development phases.

- **Complex Systems:** large-scale products such as automobiles and airplanes are complex systems composed of many interacting subsystems and components. System level design is critical; system is decomposed in subsystem and then in components. A program team is assigned to develop each component. In addition, integration teams are allocated for component integration and testing.

Although there are several variants in the product development process, the generic process phases are well defined. Based on Ulrich and Eppinger (2012) theory they are:

- **Planning:** during this phase product portfolio, timing and product development process are developed. Strategies for product technology are set up to fully fill market needs; production and supply chain strategies are identified, as well.

- **Concept development:** this phase involves customer need identification, benchmark analysis and manufacturing assessment. Economic analysis is also performed.

- **System level design:** product architecture, sub-systems and components are defined in this phase. In addition, product specifications and assembly processes are developed.

- **Detail design:** complete product specifications are established, process and control plans are specified, as well.

- **Testing and refining:** this phase incorporates component and system validation of prototype parts, according to specifications. Part failures are identified; product improvements are implemented in the design.
- **Production ramp-up:** in this phase, the product is released utilizing the design manufacturing process. Tool trials and operator training take place during this phase. Design intent and process are matched to launch final product.

In the automotive field, OEMs typically utilize the staged product development process for automobiles development. The simplified process of the staged framework can be summarized by four main activities: define, design, validate and launch (Lopez, 2014).

Within the four steps previously mentioned, Ford has incorporated major milestones that combine program management waterfalls and design activities, which allow the design in cycle of new products. *Figure 2-9* compares the generic staged process from Unger and Eppinger (2011), simplified process and milestones characterized by Ford.

a) The **Define** phase includes marketing operations. The program collects customer vehicle preferences for approval; then the program begins. In parallel, the design team initiates the development of concept alternatives, few iterations are considered before a vehicle theme is accepted.

b) During the **Design** phase, the program defines high level strategies from different organizations in the PDP, targets and sourcing are determined, as well. The vehicle theme is created and the preliminary system architecture generated; the engineering team starts preliminary feasibility analysis. The program team refines targets and strategies; this allows engineers to deeply analyze the design before it freezes. Manufacturing teams develop the assembly lines for the new product. At the end of this stage, the design, targets and strategies are frozen. Bill of materials is mapped and early prototyping phase starts for validation. Program objectives and economics are approved, as well.

c) In the **Validation** phase, prototypes are available, system and component validation takes place. During testing, preliminary validation and final validation sign-off are completed. At this point the product is ready for launch. Tool trials are prepared for assembly process and validation.
d) The **Launch** phase incorporates assembly line trials to validate product versus tool, system compatibility is evaluated and supplier quality checks are conducted. Production ramp-up starts.

![General Staged Process](image)

**Figure 2-9 Staged PDP Comparison**

*Modified from Unger and Eppinger, 2011*

The CD-Car case study has been limited to the analysis of the second half portion of the definition phase and the complete design phase (red dashed box from *Figure 2-9*) which included four main milestones: design phase 0, design phase 1, design phase 2 and design release. The scope was narrowed to that portion of the development process, because during the early define phase, the engineering team did not have major tasks. Validation and launch steps incorporated a new engineering group called production vehicle team; tasks prior to these stages were done with the original team that was researched for this thesis.
Chapter 3 – Communication in the Organization and Network

Modeling Tool

“I am a great believer that any tool that enhances communication has profound effects in terms of how people can learn from each other, and how they can achieve the kind of freedoms that they are interested in”

Bill Gates

Product development performance is highly defined by the effectiveness of communication in the organization. Technical communication in the development organization is determined by a combination between product architecture and organizational architecture (Sosa, Eppinger and Rowles, 2000).

In this chapter, we start with the definition of communication and types of communication in an organization. These concepts will lead to the communication in technical organizations and the effect of the communication at the work place. The organizational structure and physical space also play an important role in the product development success. For example, flow of communication in the product development organization from two different locations: United States and Mexico. A framework of categories in communication and techniques for increasing communication awareness will be explained.

The relationship between product design and organization management can be modeled utilizing a network modeling tool called design structure matrix. DSM’s definition and process are stated in this section. There are four primary types of DSM described by Eppinger and Browning in the book Design Structure Matrix Methods and Applications (2012): product, process, organization and multidomain; the detail for each one will be defined later. Method for clustering analysis is listed with the explanation of cluster meaning. In the latest portion of this chapter, I will show a couple of examples to illustrate product and process DSMs. In depth discussion for organizational DSMs will be stated in chapter 4 in order to create a baseline of knowledge for application case.
3.1 Communication in the Organization

Communication can be defined as the exchange of information between two or more individuals in order to achieve a desired goal. The communication process can be executed with language, sounds, signals or gestures; this is the code that the communication parties utilize. To enable effective communication the transmitter should be able to provide the message in a proper codification, this will allow the receptor to decode the information and process it for replication to the transmitter. The process is reverted once the information was analyzed, receptor becomes transmitter and vice versa. In addition to the usage of code for communicating, there should be a channel to transmit the information, such as radio waves, paper or data.

In technical organizations, communication of information can be transmitted in multiple ways; for example, face to face interactions, phone calls, video conferences, text messages or emails. The effectiveness of communication is given by two elements: a) frequency of interaction and b) quality of information exchanged. The transfer of information for the development of innovative new products depends on the organization’s knowledge and task to manage knowledge; however the success of the process requires the organization to access, maintain and transfer knowledge among individuals (Allen and Henn, 2007).

The development process of a product typically involves a high number of tasks; these tasks are developed by a determined number of people. When the product becomes more complex, the project requires more workforce which at the same time increases technical communication; similarly, the network in the organization is expanded. The program management should recognize the difficulty by having a larger network of communication; frequency of interactions is reduced and quality of information exchanged is deteriorated. Another challenge in product development organizations is the geographical barriers to communicate within the organization (Morelli and Eppinger, 1993). These barriers have emerged due to the need to expand worldwide the product development organization; that is executed by utilizing low cost resources and strategic locations for designing new products. Global product development operations require cross functional teams divided in several groups segregated over a region (Dean and Susman, 1989). Even with the segregation, communication barriers persist such as language, culture or time difference. For example, in the latest years Ford Motor Company has developed several programs globally, having the product development team in USA, design studio in Germany and
manufacturing operations in China. It is understandable that the combination of different regions
for different product development entities create big challenges in communication. Nevertheless,
“enhancement of communication between engineering groups on the same floor (e.g. doors and
body sides groups) is also a big challenge in communication” as commented by side closures
manager at GM Grant Nelson (2014). Further explanation about this behavior will be discussed
in the Communication at Workplace section.

We have enunciated previously that the performance of a product development organization lies
on how effective is the communication. However, there are barriers in the network that create
high risk on the delivery of communication. Aguirre in his thesis *Designs of Product
Development Systems* (2008) has specified that if the organizational structure is designed
properly then there will be flexible risk capability. This means that there is a clear understanding
about who should communicate with, in terms of frequency and quality. There would be a good
understanding on the level of responsibilities from each group in the product development
process. When every portion of the organizational network matches the responsibility to the role
(Aguirre, 2008) transfer of communication will flow smoothly.

To have a better understanding about knowledge transfer, technical communication in the
product development organizations can be divided; for the purpose of this thesis I will focus on
the type of communications framed by Thomas Allen (1986). He has developed three different
types:

- **Communication for coordination.** Multiple engineering teams communicate in order to
  coordinate the work progress of a project.

- **Communication for information.** Information is transferred in order to keep the
  organization with the latest level of data in a project.

Communication for coordination and information typically are concentrated in the organization
structure. Allen and Henn (2007) explained that structuring organizations determine how
different project teams relate to each other. The interaction of the team is critical to managing
cost, performance and schedule. An example of organizational structures for coordination and
Information in Ford USA is the body closures and the stamping business unit. The body closures team is in charge of leading the design and development of sheet metal components such as hoods, doors or decklids. These components are integrated by large panels, which need feasibility analysis for stamping formability. In parallel, the stamping business unit designs and develops the die tool which comes from the body closure design. The coordination of work progress and transfer of knowledge takes place in the same area of the building (e.g. 2D zone). The array of the organizational structure was laid down having a mirror layout. This means that for each body closures engineer there is a stamping designer. The workplace is divided by manager offices which act as awareness area as shown in Figure 3-1. The communication between engineering and stamping teams flows in two ways; for instance, engineering provides 3D CAD data to the stamping group for analysis. After the data is analyzed, the stamping team gives feedback to engineering for geometry improvement. Stamping also requests engineering material specifications and sheet metal blank size among others.

Figure 3-1 Body Closures and Stamping Unit Layout

- **Communication for inspiration.** This type of communication is cross disciplinary and cross functional occurring spontaneously with the objective of generating creative solutions to issues in a certain project (Allen and Henn, 2007).
The bibliography from Allen and Henn (2007) also discussed the difficulty to find organizational structures designed to manage communication for inspiration. Knowledge creation can be addressed by having common spaces to increase the level of interactions between project teams as exemplified in the Hallmark case.

Common spaces centralizing communication for inspiration can be seen in technology companies. For example, HubSpot is an inbound marketing company whose objective is to increase sales to other companies through software application. This business has implemented several common spaces to increase knowledge creation and data exchange.

Appliances and distinct features were added: the cafeteria is like a “candy shop” full with colors and unique dinner tables; there is a game room with soccer and pool tables, a rock-band area was also combined with the working offices. All these areas function by bringing people together from diverse locations of the building, which enable conversations for problem solving through creative ways.

![Figure 3-2 HubSpot common spaces](https://www.kareer.me/discover/hubspot-inc)

Common spaces are created to stimulate thinking, conversing and creativity; which drive innovation in technical organizations, per Allen and Henn (2007) theory.
3.2 Communication as Function of the Workplace

In a technical organization, there is always the need for creation of new products, processes or methods for new markets. The activity designated for those needs is the innovation. Innovation has several definitions that vary from industries; even the definition has been differentiated by experts in the matter.

For the purpose of this thesis, we can define innovation as the development of new products or services; renewing or changing a process or product, or simply the improvement in the way how things are done. Innovation is a sustainable growth for a business (Lopez, 2014).

Managing the innovation process depends on the organizational structure and physical space (Allen and Henn, 2007); human capital is organized through different forms: hierarchy, project team or function lead teams. On the other hand, workplace configuration depends on how managers set communication channels that facilitates the organization’s knowledge creation.

Organizational structures raise capability and coordinate abilities; they encourage technical specialization, and cross functional communication (Gulati and Eppinger, 1996). These characteristics are influenced by the grouping of people in the organization, represented in organizational charts. Layout of the office and proximity of people working in a project are determinant for the organization as explained by Allen and Henn (2007).

Figure 3-3 Hierarchy and Closed Workplace

Source: Allen and Henn, 2007 The Organization and Architecture of Innovation: Managing the Flow of Technology
In Figure 3-3, there are two different types of organization structures. Organization A) is a hierarchy representation that enables information top-down; the exchange of communication flows from the upper management to the first line workforce. This configuration limits knowledge exchange for creative solutions, coordination between project teams is rarely established given that the transfer of information comes downwards, and not lateral. In contrast, structure B) represents a physical open space, knowledge transfer is exchanged among people in multiple ways; communication is encouraged and there is no restriction from the hierarchy.

Similarly, Ulrich and Eppinger (2012) have explained that a product development organization is the scheme by which individual designers and developers are linked together into groups. Organizations are formed by establishing links among individuals; links may be formal or informal which may include the following according to Ulrich and Eppinger (2012):

- **Reporting Relationships:** these are formal links visualized on organization charts, relationship among hierarchy elements are represented.

- **Financial arrangements:** team members are related when they are part of the same financial group, for example: a particular budget category or profit-and-loss statement.

- **Physical layout:** links between individuals are shown when they are in the same workplace area, facility or site. Links are informal and encounters among people are spontaneous.

In addition, Ulrich and Eppinger (2012) have stated that individuals in a product development organization can be categorized based on the function or the project they are participating in. Figure 3-4 shows various product development organizations.

### 3.2.1 Functional Organization

In terms of organization, an area of responsibility usually involving specialized education, training or experience is known as function. The product development organization incorporates
functions such as marketing, design and manufacturing. In functional organizations, the organizational links are primarily among those who perform similar functions (Ulrich and Eppinger, 2012).

3.2.2 Project Organization

A project is a set of activities in the development process for a particular product which includes tasks such as customer need identification and product concept generations. On this classification, organizational links are primarily among those who work on the same project. This organization would be made up of people from different functions focused on the development of a specific product (Ulrich and Eppinger, 2012).

3.2.3 Matrix Organization

This organization is classified as a combination of function and project; individuals are linked according to the project they work on and their function. Each individual typically has two supervisors: project manager and functional manager (Ulrich and Eppinger, 2012).

There are two variants of the previous classification denoted by (Hayes et al., 1988): heavyweight project organization and lightweight project organization. The first variant contains strong project links. Heavyweight project teams in various industries may be called integrated product teams, design-build teams or product development teams. On the other hand, lightweight project organizations contain weaker project links and strong functional links (Ulrich and Eppinger, 2012).
3.2.4 Examples of Communication in the Organization

Allen and Henn (2007) argue that business organizations can be seen as social organizations which have needs in organizational and spatial levels. These aspects are important because they lay under the area of influence of management (Aguirre, 2008). The way an organization is architected in a business impacts performance in a project team; it has this main elements: managerial structure (Figure 3-4), interaction process, culture and competences.

The location of people at the workplace has an effect. There are two critical characteristics that induce such phenomena: physical location and distance between people. The way these elements are laid in the organizations either promote or deteriorate the interactions in the project teams; communication is affected as well. Most of the time there is a need to set up additional
mechanisms to counter negative impacts. For example, a close workspace can be transformed into an open space; this configuration encourages all types of communication. That can be achieved for example, when manager's offices integrate glass walls which ensure that executives are visible to everybody, as explained by Allen and Henn (2007). Another key element seen in their literature is the common space. This area not only enables creativity among people but also pulls managers out from their offices to create encounters with colleagues and employees.

Previous elements can be seen in the Skoda automotive assembly plant where manager offices are located along the central spine surrounded by the production line. The center of activity is the interaction between managers and workers on the line; physical open spaces allow interaction (Allen and Henn, 2007).

![Figure 3-5 Skoda automotive assembly plant](image)

*Source: Allen and Henn, 2007 The Organization and Architecture of Innovation: Managing the Flow of Technology*

Another example of communication flow as function of distance is the case described by Reyes in the write-up *The Flow of Communication in Space: The Body Exterior Organization Case* (2014), as follows:
The North American PD team includes Ford USA and FoM PD organizations. The FoM body exteriors office is a departmental organization encapsulated in a single floor of a building integrated by a total of 6 floors, *Figure 3-6 a*). This office is located on the third floor of the building with no visibility to other groups; this limits the communication network with the PD organization. The physical location of the body exterior team and the structure of the physical space reduce the probability of a pair of people communicating with each other; this is represented in *Figure 3-6 b*) by Allen and Henn (2007).

![FoM Building and Probability of Communication](image)

**Figure 3-6 a) FoM Building, b) Probability of Communication**

*Source b): Allen and Henn, 2007 The Organization and Architecture of Innovation: Managing the Flow of Technology*

The previous effect in communication within the FoM organization is heavily noticeable; it is unusual to see engineers going from the third to the upper floors to attend face to face meetings with the program teams. Instead they interact by phone, typically because of the minimum level of technical communication that they exchange; in most of the cases the meetings are related to program status or bulletins.

That behavior fits Allen’s framework about the communication medium as a function of distance of low complexity information; telephone is highly used when communication subjects are simple even in short distance as shown in *Figure 3-7*. 
The FoM PD group as part of the North American organization plays an important role in the development of body exterior systems. However, the distance between both offices affects the effectiveness of communication. Although this example may sound obvious, there are deeper issues.

Firstly, there are cultural and personal differences, time zone differences and long distance separations between countries. These characteristics between the work spaces create challenges of getting people to talk with each other and transfer effectively technical knowledge. The natural medium for communication given in this case is the use of media tools such as video conferences, webex and frequently the telephone. Nevertheless, when there is a need to transfer complex information among teams (e.g. CAE analysis at system level) or when important milestones happen during the product development process (e.g. component financial statements), it is necessary to interact face to face with the program teams even when the distance is extended as represented in Figure 3-8.

The FoM PD group has portrayed the strategy of business trips in order to establish face to face communication between sites; most of the engineers in the organization have business trips as part of their assignments to interact face to face with their counterparts in USA. With this
strategy, the team makes sure that the communication flows successfully and the program tasks are complete in form and time.

![High complexity information graph]

Figure 3-8 High complexity information

*Source: Allen and Henn, 2007 The Organization and Architecture of Innovation: Managing the Flow of Technology*

As contrast, the USA PD work physical space is located in a two floor building with a spine that interconnects the different PD teams. However every single team group has semi-open spaces at the center filled with manager offices like the body exterior group, *Figure 3-9.*

![Body Exterior Departmental Organization diagram]

Figure 3-9 Body Exterior Departmental Organization
These spaces act as awareness areas because there is high flow of interaction and communication among team members of the department. For instance, the amount of people that is localized in these areas are smaller groups that have to communicate to each other technical matters or program reviews. In any case, the probability of communication is increased as explained by Allen and Henn (2007) in Figure 3-10.

![Figure 3-10 Departmental Size and communication](image)

Source: Allen and Henn, 2007 The Organization and Architecture of Innovation: Managing the Flow of Technology

The physical configuration of the space and the organizational structure of the human capital allow the process of innovation, as described in a previous section. For example, during face to face technical design review meetings of a certain matter (e.g. corrosion issues in aluminum sheet metal panels) a variety of opinions are exchanged in the group, lessons learned and best practices from different programs are shared as well; this means that the flow and application of ideas take place to solve particular issues.

Another important finding is the fact that people that have worked in a program that is ending sometimes are moved to another section of the office in order to increase interdepartmental communication. These interactions allow transfer of experiences to prevent failure modes in the products.
3.3 Various Frameworks of Communication

We have described that communication is influenced by the workplace and how to overcome constraints in organizations. However, the response that project team members should provide to surpass such constraints is an open question.

3.3.1 Leadership Perspective

A team member can be considered as leader in his own role. For example, he delegates tasks to other project teams; he reconciles groups or simply restores communication breakdowns.

The team member should be responsible for his actions and certainly capable to overcome communication constraints. Saada Saar and Hargrove in their book *Leading with Conviction* (2013) have illustrated that communication is a process that should be captured by leaders. Essentially they do not have to remain silent. Instead they have to over-communicate. If the wider organization is not kept in the loop, naysayers cluster and subcultures start to proliferate (Saada Saar and Hargrove, 2013).

In a leadership environment, over-communicate means to conduct intensive sessions with people at all levels to communicate changes, report on progress, solicit feedback, and enable people to express themselves by sharing their own narratives (Saada Saar and Hargrove, 2013). The previous idea expresses good will but there is no structure identified in order to allow team members to overcome communication restrictions.

3.3.2 FoM Approach

Ford of Mexico has portrayed an idea to overcome those constraints by improving communication capabilities among engineers. *Table 3-1* characterizes four quadrants of communication awareness.

The awareness framework corresponds to the engineer by himself and not among engineers. We first have to understand if engineers know how to communicate: Q1 indicates that engineers think they know how to communicate but they do not know about their poor communication skills; in the second quadrant, engineers are aware that they need improvement in communication skills. in Q3, engineers do not know they are good communicators but they
perform well. Finally, in the fourth quadrant, they know that they communicate well and they know how to execute.

<table>
<thead>
<tr>
<th>Key Talents</th>
<th>“They know that they know”</th>
<th>“They don’t know that they know”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q4</td>
<td>They know how to communicate and they do it well</td>
<td>They were born with the skill and they are solid communicators</td>
</tr>
<tr>
<td>Q3</td>
<td>They think they are solid communicators, but are <strong>UNAWARE</strong> they have a poor skills</td>
<td>They understand their gaps and know how to develop them</td>
</tr>
<tr>
<td>Q2</td>
<td>“They don’t know that they don’t know”</td>
<td>“They know that they don’t know”</td>
</tr>
</tbody>
</table>

### Table 3-1 The know-don’t know quadrant

*Source: Diaz, 2014 Evolved Technical Maturity Model*

Once the communication awareness is identified, FoM applies mechanisms to move to the fourth quadrant. These mechanisms have been consolidated in communication training with specialized firms by exposing engineers’ real talents. However, this action does not guarantee effective communication among project teams. There is no framework yet that interconnects engineering interactions between team members.

### 3.3.3 Lean Design Principle

Womack, Jones and Roos in the book *The Machine that Changed the World* (1990) stated that lean design has established communication as a means to resolve critical design trade-offs.
Confrontation of these trade-offs are faced upfront in early stages of the design process. This leads to the correction of problems before they multiply and ends up with much less total effort and higher quality in the end (Womack, Jones and Roos, 1990). These authors have also compared sequential against simultaneous developments. The first idea indicates that an activity can be done once the previous task was complete. Whereas, simultaneous development involves several tasks done in parallel which results in less costs and less human effort (reworks avoidance). Yet the simultaneous development does not lie in the completion of parallel tasks but the intense communication between project teams during the development of a product (Womack, Jones and Roos, 1990).

Womack, Jones and Roos (1990) have exemplified such communication with the Honda design and cutting dies case. Die designers know the size of the new vehicle and number of panels to order die steel blocks. They also identify the panel design process, and then the panel designer’s final solution is anticipated as well. In parallel, die makers prepare scheduling production at the die cutting shop to achieve flexible cutting machines for product evolution. The result is the production of dies in one year which is half the time needed from other OEMs.

The previous example shows how well Honda has identified critical interactions between two project teams. These interactions are working tasks strongly linked between die designer and die makers; the channel and degree of communication should be established upfront per lean design principle.

Continuing focusing on people interaction for lean development, Womack, Jones and Roos (1990) pointed out that intense communication enhances product development performance. *Table 3-2* provides an outlook of product development performance for different regions of the auto industry in the mid 80’s. It is clearly seen that producers that utilize these methodologies like Japan get the best performance. Another study conducted in an European OEM dedicated its attention to evaluate challenges by the implementing of lean product development such as difficulties in communication, flow of information and knowledge transfer, among others. The summary of the research found that socio-technical dimensions have become more complex and unmanageable. Volume of interaction between teams through the product development process is still a key challenge that auto makers have to address (Saunders, Gao and Shah, 2014).
Multiple researches in lean design and product development have indicated that communication, integration and transfer of knowledge are key characteristics for project success. Lean design incorporates additional elements that improve people capability and performance at the organization; however, there are still complex challenges to overcome like knowledge management and communication transfer.

### 3.3.4 Organization in Product Innovation

The development of new products in technical organizations requires frameworks to properly allocate teams and facilitate cross functional interaction for different projects. Clayton M. Christensen in *The Innovator’s Dilemma* (1997) has framed an organizational structure that mirrors the product architecture of a system represented in *Figure 3-11*. 

---

**Table 3-2 Product Development Performance comparison by regional auto industries**

Source: Womack, Jones and Roos, 1990 *The Machine that Changed the World*
The explanation of the behavior starts in early stages of industry’s history. Technical efforts are focused on architectural innovation; product designs tend to be integral meaning that individual components are integral to other components and projects are managed by integrated teams. However, when a dominant architecture emerges, the application of technological energies tends to improve performance and cost-effectiveness of individual components and subsystems. Once there is a shift from architectural to component innovation, technical groups tend to be organized in firms to focus on component improvements and specialization takes place within specific functions (Christensen, 1997).

Moreover, Christensen (1997) exemplifies the previous analysis with an OEM firm in charge of designing steering gear; the team will be organized in groups that mirror the components of the steering gear system: steering column group, rack-and-pinion gear group, tie rod group, power steering pump group, etc.

![Product Architecture and Organizational Structure](image)

**Figure 3-11 The Organizational Structure Mirrors the Established Product’s Architecture**

*Source: Christensen, 1997 The Innovator’s Dilemma*

The way components work together is defined by the product architecture. It has been found that the pattern of interaction and communication between individual and teams of the organization
mirror the structure of component interfaces within the product architecture, organizational structure and working patterns serve a company when innovation is modular (Christensen, 1997). In addition, Sosa, Eppinger and Rowles (2000) have also questioned how the product architecture and the system level of the development organization map into each other. This is due to the similarity of design interfaces of a product and team interactions, *Figure 3-12.*

![Figure 3-12 Design interfaces and team interaction similarity](image_url)

*Source: Sosa, Eppinger and Rowles, 2000 Understanding the Effects of Product Architecture on Technical Communication in Product Development Organizations*

From the previous example, component teams know that they have to interact based on component interfaces. These are integrative systems whose components are physically distributed throughout the product resulting in components sharing interfaces (Sosa, Eppinger and Rowles, 2003). In contrast, groups that rarely interact are those whose components have no interface or very minimal relationships; these are modular systems which do not share design interfaces that belong to other systems (Sosa, Eppinger and Rowles, 2000).
3.4 Approach and Design Structure Matrix Methods

Reflecting about the complexity of an automobile system, typically a vehicle is made up of more than 10,000 components with multiple interfaces; this product is categorized as complex system. So, how do you organize people to design, build and put all system pieces together?

In order to frame the answer of previous question, we have to conceptualize the meaning of product architecture and further understand the approach taken by Scholars that have studied similar complex systems. The same approach will be used in this thesis to explain the CD-car case study.

- “Product or system Architecture is defined as the embodiment of concept, and the allocation of physical/informational function to elements of form, and definition of relationships among the elements and with the surrounding context” (Crawley, 2013).
- Ulrich and Eppinger (2012) have simplified the definition as the arrangements of functional elements into physical blocks.

In a journal article related to the research of a large commercial aircraft engine design, Sosa, Eppinger and Rowles (2004) have described a novel approach to compare the architecture of a product with the development organization which designs engine components. According to these authors the method consists of three different steps:

They started by A) comprehending how to capture the product architecture, which allows visualization of the landscape of component interactions in the system. B) Capturing the development of the organization helps to identify the design team responsible for developing the project’s components. This is achieved by surveying project members to capture frequency and importance of interactions among them. C) Finally, they compare the product architecture with the development organization to answer the following key questions:

How accurately can we predict communication coordination by analyzing the coupling of product architecture and the structure of the development organization?

Why do some design interfaces between components not correspond to technical interactions between teams that design them?
Why do design teams that develop independent components still engage in technical interactions?

Firstly, to capture the product architecture, we have to understand the different part dependencies presented in the system. The design interaction between physical components integrates five types of design dependencies (Pimmler and Eppinger, 1994):

- **Spatial**, this dependency specifies the need of physical adjacency for alignment, orientation, serviceability, assembly, weight, etc. For example, in vehicles, hood to a-pillar shall maintain a hood swing clearance to ensure the closing and opening of the closure subsystem.

- **Structural**, dependency indicates existence of functional requirement for transferring design loads, forces or containment. Utilizing the hood subsystem as an example, hinges should withstand load transferred from the hood weight and kinematic moments when hood is in motion.

- **Energy**, functional requirements related to transferring heat energy, vibration energy, electrical energy or noise. For example, the hood insulator attached to the hood subsystem is designed to prevent heat transfer from the engine to the sheet metal. In addition, the insulator provides a seal to the holes added into the hood inner panel.

- **Material**, dependency indicates a functional requirement related to transferring oil, water, air or fuel. For example, hood washer nozzles depend on water to deliver the function; nozzles conduct pressurized water to spray it to the windshield.

- **Information**, dependency indicates functional requirement related to transferring signals or control. An example can be seen in the hood latch assembly; the mechanism transmits a signal to the close/open sensor which depends on the presence of the striker rod.

Once interfaces are identified, critical dependency is captured for the functionality of the component analyzed. Pimmler and Eppinger (1994) also have proposed five point levels to measure the level of criticality as represented in Table 3-3:
<table>
<thead>
<tr>
<th>Level of design dependency criticality</th>
<th>Description</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required</td>
<td>Dependency is necessary for functionality</td>
<td>+2</td>
</tr>
<tr>
<td>Desired</td>
<td>Dependency is beneficial, but not absolutely necessary for functionality</td>
<td>+1</td>
</tr>
<tr>
<td>Indifferent</td>
<td>Dependency does not affect functionality</td>
<td>0</td>
</tr>
<tr>
<td>Undesired</td>
<td>Dependency causes negative effects, but does not prevent functionality</td>
<td>-1</td>
</tr>
<tr>
<td>Detrimental</td>
<td>Dependency must be prevented to achieve functionality</td>
<td>-2</td>
</tr>
</tbody>
</table>

Table 3-3 Design Dependency Criticality

Source: Sosa, Eppinger and Rowles, 2003 Identifying Modular and Integrative Systems and Their Impact on Design Team Interactions

After the design dependency and criticality are defined, the data is integrated in a square design interface matrix (Sosa, Eppinger and Rowles, 2000) known as design structure matrix. Eventually an independent arrangement will be created for the development organization, and lastly both matrices will be examined for conclusion and recommendation.

The research approach has been set up for this thesis so far; DSM meanings are characteristics that have yet to be defined for the application of the organizational case study in this thesis.

3.4.1 Design Structure Matrix Definition

Nowadays multiple Scholars have defined the DSM as a tool that allows the identification of interfaces in complex systems:

1. “A design structure matrix (DSM) is a two-dimensional matrix representation of the structural or functional relationships of objects, variables, tasks or teams” (de Weck and Lyneis, 2011).

2. “The design structure matrix (DSM) is a simple tool to perform both the analysis and the management of complex systems. It enables the user to model, visualize, and analyze the dependencies among the entities of any system and derive suggestions for the improvement or synthesis of a system” (Home DSMweb.org, 2014).
3. “The DSM is a modeling tool used to represent the elements comprising a system and their interactions; thereby highlighting the system’s architecture” (Eppinger and Browning, 2012).

The DSM is a square matrix \((N^2)\) which graphically represents a system architecture. This network modeling method maps the interaction of a set of \(N\) elements in a system (Eppinger and Browning, 2012), see Figure 3-13.

The DSM can be applied in multiple fields, always when a complex system exists. Eppinger and Browning in the book *Design Structure Matrix Methods and Applications* (2012) describe the product architecture DSM for NASA’s Mars Pathfinder project, organizational DSM for GM’s engine development, process architecture DSM for Real State development, etc.

![Figure 3-13 Basic DSM example](Modified from Eppinger and Browning, 2012)

The DSM application for different types of architectures has demonstrated the following advantages according to Eppinger and Browning (2012):
• **Conciseness**, large complex systems are compacted in the DSM.

• **Visualization**, element relationships are highlighted; DSMs provide a view of interactions in a product, process and organization architectures.

• **Intuitive Understanding**, hierarchy and complexity are identifiable.

• **Analysis**, component interactions of a system are visualized; it allows the use of the system information on different analytical tools.

• **Flexibility**, the DSM tool has the ability of being modified; new features can be added in order to maximize potential.

In addition to the approach given to compare the architectures of the front end system and the development organization for this thesis’s case study, it is necessary to know the five step DSM approach to architectural modeling and analysis developed by Eppinger and Browning (2012):

- **Decompose**, the system is breaking down into a certain hierarchy level for analysis.

- **Identify**, component relationship is established.

- **Analyze**, components are re-accommodated for structural and pattern analysis.

- **Display**, system is represented in the DSM to visualize key behaviors.

- **Improve**, after DSM is analyzed, system enhancement takes place.

### 3.4.2 Types of DSM

In previous sections, we have mentioned that DSMs are applied to product, process and organization architectures. According to Eppinger and Browning (2012), these architectures correspond to the main type of DSM models. In addition, there is a fourth classification that integrates the previous domains in a single matrix called multi-domain DSM.
The four types of DSMs are classified in three categories: static architecture, temporal flow and multidomain (Eppinger and Browning, 2012). Figure 3-14 shows a decompositional view of the DSM models; the three main categories are listed. Static architecture covers elements that exist simultaneously; here product architecture and organizational architecture DSMs are included. Temporal flow represents systems that are impacted by time; here the main activity takes place in the process architecture DSM. The multi-domain category incorporates more than one type of DSM in the same matrix.

During the development of the case study in this thesis, a new proposal DSM type emerged. It has been called Multi-dimensional Embedded Matrix (MDEM). Multi-dimensional DSMs include more than one type of DSM, and they are represented in a single DSM matrix denoted as...
Multidomain Design Matrix (MDM). However, they are placed in different areas of the matrix space. In addition clusters are made separately. The MDM in Figure 3-15 contains product, organization and process DSMs overlaid in a single matrix.

![Figure 3-15 Multidomain MDM](image)

*Source: Eppinger and Browning, 2012 Design Structure Matrix Methods and Applications*

### 3.4.2.1 Multi-dimensional Embedded Matrix (MDEM)

A Multi-dimensional Embedded Matrix represents more than one type of DSM overlaid in a single matrix, which compares (for the CD-car case study) the product and organizational architectures similar to the alignment matrix explained by Sosa, Eppinger and Rowles (2007). However, the MDEM in Figure 3-16 shows the re-arranged organizational structure based upon the optimization of the product architecture. This means that the clustering analyses to get new organizational architecture DSMs were done having both product and original team structure in a single DSM at the same time; improvement of product architecture DSM configured the
organizational architecture DSM. In other words, the original organizational architecture DSM and the proposed organizational architecture DSMs for this thesis were embedded in the product architecture of the system. The embedded information allows the organization to be restructured according to the product.

![Multi-dimensional Embedded Matrix](image)

**Figure 3-16 Multi-dimensional Embedded Matrix**

The scope of this thesis did not allow the generations of additional algorithms to replicate the embedded DSMs. Clustering analyses were done utilizing commercial software but embedded iterations were done by hand. Further explanation of multi-dimensional embedded matrix will be described in chapter 4.

### 3.4.3 DSM Process Generation

In order to illustrate how a product architecture DSM is generated, Eppinger and Browning (2012) have provided different elements to consider while creating these types of DSMs:
• **Boundaries**, selection of components within a boundary are incorporated into the DSM in order to define the scope of the system.

• **Interaction types**, different kinds of component dependencies are considered: spatial, structure, energy, material and information (Pimmler and Eppinger, 1994).

• **Interaction strengths**, certain weight is added for each interaction; it may include numerical values or symbols that reveal a degree of component strength relationship.

• **Symmetry**, typically component interaction occurs in two ways: having a spatial dependency, component X interacts with component Y and vice versa. One way interaction may happen: hood close/open sensor needs a signal from the latch system to work, whereas the latch mechanism does not.

• **Granularity**, refers to the level of model component decomposition. Manageable DSMs are typically compounded between 20 and 50 elements. The model can be enriched with additional components based on the purpose of the DSM.

• **Identifying iterations**, achieved by utilizing system documentation or specifications. However, it is recommended to establish a dialog with subject matter experts to populate interactions into the model.

At the same time, these authors have summarized in *Table 3-4* criteria for successful DSM:

```
|| Models have a clear purpose ||

|| Models use the appropriate amount of detail for the intended purpose ||

|| Modelers have access to enough knowledge or experience of the system ||

|| DSM is a living model, it can be improved with latest knowledge ||

|| DSMs results in the emergence of otherwise latent knowledge ||
```

*Table 3-4 Criteria for Successful DSMs*

*Source: Eppinger and Browning, 2012 Design Structure Matrix Methods and Applications*
3.4.4 Product Architecture DSM Application

A simple example is given by the analysis of the product architecture of a generic hybrid car system. *Figure 3-17* shows a decompositional view of the hybrid car. It has been decomposed to the second level in order to keep 13 main subsystems for analysis.

The known interactions between components are represented in the boundary diagram from *Figure 3-18*; the interactions represented in this illustration are spatial kind, which means that the product links indicate physical adjacency between components. For example, the electric water pump is plugged by the low voltage harness; both components are assembled together to deliver a specific function.

Moreover, the map of the hybrid components incorporates external subsystems that are strictly related to the architecture study; the type of dependencies is spatial as well.
The previous boundary diagram represents the high level interactions of the system; it was built utilizing interface specifications from the hybrid system team at Ford. Furthermore, the data collection was enriched through interviews with technical experts at the organization.

The hybrid system of a car is represented in the DSM model from Figure 3-19. The subsystem is constituted by 24 components. Interactions are represented in a square matrix of 24 x 24.

The concept of operations in the matrix is related to the electrical process of the hybrid system function as shown in Figure 3-17. It is supported by the electrical interaction clusters from the partitioned DSM. The process starts with the ignition of the system; the electrical power is distributed through high/low voltage harnesses in order to feed the control unit for monitoring of speed and subsequently activation or deactivation of the gasoline engine. When the gasoline
engine is working, the transmission/transaxle transforms the mechanical energy into electrical power in order to charge the battery pack. At the same time, and during breaking, the kinetic energy is converted into electrical power to charge the battery pack.

On the other hand, when the gasoline engine is deactivated, the battery pack supplies power through the high/low voltage harnesses in order to activate the transaxle (electric motor) for vehicle motion. In parallel, the electrical power is converted from DC to AC in order to enable electric pumps to cool the battery pack. Gas depressurization is generated during the breaking process by pressurizing water to cool gasoline engine (Shefali, Chaudhary, Reyes and Cuata, 2013).

![Figure 3-19 Hybrid System DSM model](image)

Source: Shefali, Chaudhary, Reyes and Cuata, 2013 System Architecture, Opportunity Set #5

### 3.4.5 Clustering Analysis

The purpose of clustering DSM is the allocation of N component to M clusters in order to minimize the number and strength of interactions outside the cluster and minimize the size of cluster through the utilization of diverse objective functions (Eppinger and Browning, 2012). Although I am not mentioning additional information related to clustering objective functions
due to project scope; here are main considerations for clustering analysis per Eppinger and Browning (2012) theory:

- **Number of clusters**, there is no restriction for the number of clusters in the DSM; however, it is recommended to develop different solutions for comparison analysis.

- **Clusters size**, single component cluster is allowed; however, cluster max component should be constrained to define a particular size.

- **Overlapping clusters**, according to the purpose of the clustering DSM, cross membership in the clusters is allowed.

- **Interaction types**, according to the component dependency, clustering may result in different number of clusters due to the dependency level.

- **Integrating elements**, refers to those components in the DSM model that stayed out of the clusters; they typically have interactions with different components. The integrative components serve as collective functions.

- **Manual clustering**, accommodation of matrix columns and rows can be done manually; it is useful for sensitive analysis around solutions proposed by clustering algorithms.

- **Multiple clustering solutions**, recommended to generate different cluster solutions for interpretation and analysis to accept an optimal result.

The DSM has been partitioned and represented in *Figure 3-20*. Notice that three main clusters emerged: electrical, steering and supporting systems. The clusters re-assemble the way automotive companies break down the vehicle system by commodities such as electrical, body exterior, chassis, powertrain, etc. Since all the system analysis was not made for the entire vehicle system but just for the hybrid system of a car, the clusters created by the DSM seem logical. Specific component groups with strong interactions were identified. In the first cluster the wiring, engine, transaxle, radiator and other electrical components were grouped. A second cluster for steering components was created. A third cluster contains most of the support systems.
such as the body white components, HVAC subsystem and brakes (Shefali, Chaudhary, Reyes and Cuata, 2013).

Figure 3-20 Clustered Hybrid System DSM model

Source: Shefali, Chaudhary, Reyes and Cuata, 2013 System Architecture, Opportunity Set #5
Chapter 4 – Analyzing the CD-Car Front End System Case Study

“Coming together is a beginning; keeping together is progress; working together is success”

Henry Ford

As a preamble for this section, it is necessary to reflect upon the complexity of the automobile frond end system. It integrates more than 30 subsystems that deliver various functions. For example, lighting, front crash absorption, cooling, engine protection and vehicle appearance. The answer will be provided by analyzing the organizational architecture DSM models from the CD-car case study portrayed in chapter 2. The results of the analysis will dictate the optimal people cluster interaction within the organization and the flow of communication between project teams. These characteristics will impact in a positive way the effectiveness of the development for future systems similar to the one analyzed in this thesis.

4.1 Organizational Architecture DSM Model

4.1.1 Organizational DSM Definitions

We begin with the definition of important concepts for organizational architecture DSMs:

1. **Organization** – “a network of people with a common purpose such as business unit or a project developing, producing, selling or supporting a product” (Eppinger and Browning, 2012).

2. **Organization Architecture** – “structure of the organization. It groups people into teams, departments or any other organizational unit” (Eppinger and Browning, 2012).

3. **Organizational Architecture DSM** – “mapping of network of interactions among the people within the organization” (Eppinger and Browning, 2012).
4. **Interactions** – “relationship among different units in the organization. It is focused on information flow iterations: formal or informal, peer to peer communication such as email, face to face discussion, group meetings, etc. Other interactions are relationships of authority, responsibility, accountability, contractual obligations, etc.” (Eppinger and Browning, 2012).

5. **Cluster** – “a larger organizational such as department, team, or group of teams suggested by analyzing the organization architecture DSM” (Eppinger and Browning, 2012).

6. **Integrative Mechanisms** – “type of work coordination and communication facilitated across organizational units” (Eppinger and Browning, 2012).

Sosa, Eppinger and Rowles in the paper *Are Your Engineers Talking to One Another When They Should?* (2007) have explained how DSM helps managers to identify failures in communication and deficiencies while unplanned technical communication occurs between project teams.

They start the analysis of previous condition by identifying component interfaces in a design interface matrix of the system under development. This model represents the component dependencies required to achieve specific functions. Then technical interaction teams are recorded in a team interaction matrix, expected interactions are included. This matrix shows that specific information/communication is required between teams. Both matrices are overlaid in order to create a new model named as alignment matrix. The new matrix in *Figure 4-1* it can be seen that there is coincidence in some team interfaces compared to design interactions. On the other hand, there are also mismatches in the alignment matrix. These are characterized in two types: a) unattended interface, this occurs when the interaction is identified in the design but not followed by the team; b) unidentified interface, team interaction takes place but it is not highlighted in the design interactions.

Previous mismatches occur due to product and organizational factors: organizational boundaries, lack of interface criticality, use of indirect communication channels, indirectly transfer of communication, carryover interfaces and use of interface standardizations (Sosa, Eppinger and Rowles, 2007).
Similarly to the product architecture DSM, Eppinger and Browning (2012) explains that the organizational architecture DSM compiles different elements to consider when designing the network model; these stipulations are applied to the CD-car front end system case study as follows:

- **Granularity**, refers to the level of decomposition of the organization typically done at team or individual levels. For the CD-car case study, the organization has been decomposed to the individual level; this means that each component in the boundary diagram from Figure 2-5 is designed by a single engineer in the project team.

- **Data Collection**, the case study compiles the frequency of communication between engineers of the project team. For instance, the organization interaction has been denoted with a dot; the presence of a dot indicates that an interaction exists whereas a blank space indicates no interaction between component teams.
• **Symmetry**, in most of the organization interactions, the flow of communications was bi-directional; however, the data collected represents that in some of the component teams the information flow occurs in one way and at different frequencies.

• **Accuracy**, interactions in the DSM should typically represent communication both ways with similar frequencies. That did not happen in some interactions of the CD-car project; for this kind of cases; miscommunication reasons were discussed with component teams. As an example, the fender engineer used to manage daily meetings and daily email notifications with the gap hider engineer in order to define the attachment strategy of the plastic part to the sheet metal. However, the gap hider engineer attended just weekly meetings; emails were replied to weekly most of the time.

• **Representing Interactions**, when there is an interaction between component teams, frequency has been established with three measurements: daily (large size dot), weekly (medium size dot) and monthly (small size dot). In addition, the product architecture of the front end system has dependencies of adjacency; they are represented with yellow color for non-contact interfaces and red color for contact interfaces (or high level dependency). No color nor dot means that there is no interface between components, see *Figure 4-2.*

![Figure 4-2 Frequency of communication and product dependency nomenclature](image)

• **Dynamics**, the CD-car project represents a static view of the organization. The interviews conducted with the project engineers were allocated for the three main stages in the product development process at Ford. Afterwards, the average of frequency was calculated to build the organization architecture DSM models.
4.1.2 Application Case: CD-Car Front End System

The node link diagram shown in Figure 4-3 represents a communication network that the CD-car front end system team established during the development of the project; the arrows represent the direction of flow of communication, the arrow weight is meaningless for this example. It is clearly seen from the figure that there is a complex system of communication among this organization. However, neither the structure of the organization nor the organizational units are visible. Both set the flow of information to effectively develop the front end system of the vehicle.

Figure 4-3 CD-car project team communication network

The lack of understanding on how engineers should interact in the structure of the organization of the case study resulted in deficiencies on the design. For example, during the design phase 1 (Figure 2-9) some component teams such as gap hider, splash shield and hood seal were not
incorporated into the project team. The consequence was a delay in the delivery of the preliminary front end system architecture.

The application of the organizational architecture DSM for the CD-car study was intended to satisfy the following areas of opportunity: identify gaps in communication among cross functional system teams, enhance the product development process by adding organizational DSM analysis into the failure mode avoidance framework, and ultimately to improve human capital capabilities in attracting further “top hat” developments to the FoM organization.

4.1.3 Data Collection Process

In chapter 2, the decomposition level of the CD-car front end system was explained. It is integrated by 28 main components, see Table 2-1 for complete list of components. The type of dependency identified in the system was spatial: contact and non-contact interfaces. These interfaces were then mapped in a boundary diagram, external interfaces were also incorporated as shown in Figure 2-5 in order to end with 35 elements for analysis.

The information that is contained in the boundary diagram was translated into the product architecture DSM displayed in Figure 4-4. The boundary diagram and product DSM were built using the generic system design specification from the three main subsystems of the front end system referred in chapter 2 (body structure, front end module and exterior ornamentation). In addition, critical interactions were discussed with subject matter technical experts within Ford. The result was a product DSM with four clusters which incorporated most of the strong interactions (contact interfaces) in the system.

Similarly, the organizational architecture DSM was built through data collected from the project team members. To achieve data collection, The interview template tool developed by the MIT Research DSM Team (1999) was used for DSM data collection (Home DSMweb.org, 2014) shown in Appendix A.

All the team components were listed based on the front end boundary diagram. Focusing on information as interaction type, interviews were conducted with each component engineer in order to identify the frequency of exchanging technical knowledge during the development of the
project, strength of the interaction and expected transfer of information from different component engineers. Once all the data was filled out into the Interview tool for DSM data collection, the generation of a communication data set DSM shown in Figure 4-5 was the baseline for the analysis of the organization structure.

### 4.1.4 Product and Organizational Architecture Models

The product DSM in *Figure 4-4* represents the design interaction of three main subsystems from the front end system with spatial dependencies. For example, in the cluster called body structures, the fender system has a dependency of contact with the body side (fender is attached to the body side). This condition was designed in order to keep the fender in a unique position on the vehicle. Although there may be additional geometric features in the fender to allow alignment to surrounding components (e.g. door) and meet fit and finish requirements; that detail of design to keep this thesis within scope is not mentioned.

The product DSM signifies as baseline for comparison against the organizational DSM. Following Sosa, Eppinger and Rowles (2007) approach, the purpose of the product DSM is to identify first technical interfaces between components, and subsequently identification of mismatches between design and team interactions.

On the other hand, the communication data set DSM in *Figure 4-5* represents the communication flow of 339 interactions that exists in the project team. It also shows how frequently the component teams interact with each other. For example, the bolster and the grill opening reinforcement engineers used to interact daily; their interaction is represented with a large dot. Also noted is that the flow of communication between those component teams was reciprocal due to the interface symmetry shown in the row data DSM.
At this point the data illustrated in the preliminary DSM does not provide additional information in terms of the structure of the organization nor mismatches against the product architecture. Therefore, the next step for the analysis of the case study is to re-accommodate interfaces of each component team in order to match the actual front end system team structure utilized during the development of the CD-car project.
The organizational DSM illustrated in Figure 4-6 contains the original front end system team structure that developed the CD-car project. The teams were grouped according to the PMT 1000 of this program. Here transfer of technical communication flows from the team in row $i$ to the team in column $j$; note that for the development of this thesis the DSM convention was used with inputs in rows (IR) and outputs in columns. The structure of the team is a departmental organization integrated by four clusters: sheet metal hood, body exterior ornamentation, sheet metal fender and front end module (FEM).
The product DSM and the original team structure DSM have been overlaid to generate a new DSM called alignment matrix shown in Figure 4-8. In that matrix, there are interfaces that the original team structure matched to the product architecture. They have been highlighted in purple with the I symbol. It can be seen that many interfaces matched; however, there are mismatches in the matrix, as well. For instance, the mismatches were differentiated in two types:

a) **Unattended interface.** Highlighted in red with the X symbol, here the original team structure did not transfer information with other team components whereas the product architecture indicated that an interface exists. For example, the splash shield engineer did not establish any communication to the fender engineer. The transfer of information
occurred in one direction, from the fender to the splash shield. On the product architecture, this interface indicated two directional dependencies. So, why the splash shield engineer did not contact the other component engineer? According to Sosa, Eppinger and Rowles (2007), mismatches occur due to product and organizational factors such as carry over interface which is the case of the previous example.

Based on the accuracy caveat considered for organizational architecture DSM, during interviews with the front end system engineers, the splash shield engineer was asked why he did not create any dialog with the fender engineer. He responded with the statement that the splash shield to fender interface was a carryover condition. On the other hand, the same question was made to the fender engineer. He answered indicating that the fender design was changing in geometry to meet functional requirements (e.g. dings and dents) and materials specification. The latest change would affect the thickness of the sheet metal and consequently the interface with the splash shield. New attachment points may be required or simply, the push pin to attach the shield to the fender may change to overcome the variation of sheet metal thickness.

b) **Unidentified interface.** These are highlighted in navy blue color with the 0 symbol. The interface means that a team interaction exists from the organizational architecture. Nevertheless, the product DSM does not indicate such conditions. For example, flow of communication took place between fascia and GOR interface; the reason lies in the fact that the product architecture is a standardized tool. For this example, a new attachment strategy from the fascia to the GOR was implemented; this induced unplanned communication. Another reason of unplanned communication lies in the fact that the CD-car project team was not enough experienced (average of experience 6.2 years) to understand to whom they should exchange information.
CD-Car Project Alignment Matrix

Figure 4-7 CD-car project Alignment Matrix

4.1.5 Results and Proposed System Team Structures

In addition to the alignment matrix presented in the previous section, additional data was incorporated to the matrix in order to get a better diagnostic of communication interfaces from the CD-car project team. In Figure 4-9, the frequency level of communication was added from the original team structure matrix (daily, weekly or monthly). In a separate column, communication instruments were added for three main channels: email, phone/webex and face to face interaction. Also the component team location within the Ford PD organization was integrated. Finally, the technical maturity data was gathered from project engineers; it was combined with the previous information to assess the impact in the structure of the organization by having different expertise from different component engineers of the front end system.
1. **Communication Frequency.** In a previous section, many of the organizational interfaces matched the product architecture of the front end system; those interactions with high level of frequency (daily and weekly) match the dependencies of contact from the product architecture. However, there are many other unattended and unidentified interfaces that were generated from the organizational architecture. The model incorporates 11 unattended interfaces located in the main component team cluster and 53 in the program integration cluster; in Table 4-1 a summary of alignment matrix counts has been provided for more detail. Another characteristic noticed is that most of the unplanned communication interactions have a monthly frequency. Lastly, a total of 94 interactions including matched interfaces and unidentified interfaces to the product architecture were left out of the cluster teams. These gaps in communication will be enhanced by a series of clustering analyses of the overlaid product and organizational matrices.

![Table 4-1 Count of Design and Organization Interfaces](Modified from Sosa, Eppinger and Rowles, 2004)

2. **Instrument for Communication.** The main instruments used by the component engineers were: email, phone/webex and face to face interaction. The data collected from the component engineers suggests that the transfer of information in the CD-car project was conducted through email at 52.8% utilization on a daily basis, through phone/webex
at 28.6% utilization on a weekly basis and through physical interaction only at 18.5% utilization on a monthly basis.

3. **Front End Team Location.** In terms of the workplace, the clusters are located in two different regions in North America (USA and Mexico), segregated in three different buildings within the PD office. Ford USA is the region where most of the component engineers were located, 54.2%. FoM captured about 45.7% of the team. The map in *Figure 4-7* shows how the front end system component teams are spread along different regions and locations. For those clusters located in the FoM building, the component teams are distributed in different building floors. The arrangement of the team structure makes more difficult the transfer of technical communication due to the distance (Allen and Henn, 2007). However, there are remote communication tools such as email and phone/webex to overcome this constraint; in other cases the FoM management has allowed cross regional travel in order to personally interface with peers and improve the transfer of technical communication. This is a challenge driven by the design of global products and the decentralization of the product development organization as strategy to optimize resources in the company.

![Figure 4-8 Front End System team location map](image-url)
4. **Technical Maturity Data.** The degree of expertise from each component engineer was surveyed, and years of experience within Ford, as well. The engineer experience has been divided into four different levels from the least to the most experienced:

   a. **Build,** the engineer is learning company’s processes, performs basics routine tasks but needs help with more complex situation, contributes with supervision or under direction of others. Average component engineers in the CD-car project have reached 96% of the total build level.

   b. **Apply,** engineers increase in technical ability, handle complex tasks independently, work independently and deliver targeted results, engage team in order to get things done and implement recommendations. Component engineers in the CD-car project are at 90% of the apply scale.

   c. **Leverage,** complex work in a wide variety of situations including novel and unique are performed by engineers; engineers contribute to cross organizations, engage stakeholders across the organization and enterprise to get input and buy-in, contribute to the development of standards and implement standards. The team in the CD-car project is at 75% of expertise.

   d. **Master,** engineers serve as functional mentor in the competency area, perform the most complex work, develop and implement innovative solutions and interventions to address complex, novel and unique situations; stimulate new technical and functional perspectives through ideas and knowledge. Engineers are prepared to develop standards and models for competency area, research and analyze internal and external trends. Finally, they influence the organization assessing external trends and the organizational implications. The CD-car team is prepared at 42% of this competence.
Finally, the data indicates that 32% of the project team members have an experience level of build, 30% of the group is located at apply degree; 25% is at leverage level whereas only 14% have achieved the master level of experience.

The utilization of partitioning algorithms especially clustering analyses helped us to rearrange the interaction network from the original front end team structure matrix in Figure 4-6. The purpose of clustering analysis is to reduce the 94 interactions outside the four main clusters.

In the following section, four different system team structure proposals are provided, which represent the evolution and refinement of the optimal organizational architecture for the front end system team. Component teams are compressed in the new structure of the clusters; high level frequency of interfaces is now contained in the clusters so the sizes of the new structure teams are larger.
4.1.5.1  System Team Structure – Proposal 1

The 94 interactions left out of the clusters from the original front end system team structure typically appear when the program approaches a milestone of the product development process; unidentified interactions are increased. In most of the cases this occurs because component engineers do not communicate needs or requirements effectively. When the problem arises, the program integration team works reactively to satisfy deliverables requested during those milestones. Through partitioning algorithms, the interaction data from the original team structure has been simplified in Figure 4-10. Four new system teams and a program integration team were created. In the new matrix, the number and strength of interaction are incorporated into the new clusters; the interactions left out were reduced to 72. An important condition that characterizes
this solution is the clusters overlap; it represents cross membership in the system teams. Nonetheless, there are still opportunities to integrate interfaces in more robust clusters. For example, in the upper right portion of the DSM there are several interactions with high frequency; this indicates a lot of overlaid between cluster 1 and 3 so this alternative is not optimal (Eppinger and Reyes, 2014).

4.1.5.2 System Team Structure – Proposal 2

The second simulation obtained to optimize the structure of the organization is represented in Figure 4-11. The clustering analysis generated three system teams with the same program integration team. The size of the clusters is equilibrated meaning that there is a balance in the project team. Cluster overlap is present like the previous DSM indicating that the system team 2
should also be working close to system team 1 and 3. This proposal reduced the number of outside components to 65; most of the matched interactions to the product architecture are incorporated in the clusters.

4.1.5.3 System Team Structure – Proposal 3

Utilizing the proposal with 3 clusters from the previous figure, notice that the hood engineer is interacting with most of the other component teams; nevertheless it has not been classified in the program integration team. Taking the essence of the program integration team but applied to the component teams, in Figure 4-12 the incorporation of a component integration team is led by the hood subsystem. Odd as this might sound this has been specified by the body exterior management group at Ford USA that some vehicle subsystems should act as integrator due to the large number of component interaction.

Figure 4-12 Front End System Team Structure – Proposal 3 (3 clusters and Component Integration)
As a final point, the fourth organizational architecture DSM proposed to improve capabilities and communication in the front end system team is represented in Figure 4-13. This is the multidimensional embedded matrix described earlier in chapter 3. Product DSM and organizational DSM were partitioned together. The original structure team was set up in function of the product design with the objective in mind of minimizing the number of clusters and incorporating most of the interactions in the clusters. The results of this simulation were two system teams and one program integration team. The first system team called non-class A component team now incorporates elements from the sheet metal fender and body exterior ornamentation clusters from the original team structure such as fender, hinges, wipers or shotgun bracket. While the second system team named as class-A component team includes parts from the sheet metal hood and front end module clusters; for example, hood, headlamp, grill or fascia.
The reorganization of the team shown in this matrix left only 8 component interactions out of the cluster teams (including unattended interactions); the improvement in capturing outside interactions into clusters was 91%. This means that 91% of technical communication transmission will be taken into account. The mismatched (unidentified and unattended) interfaces have been added to the DSM in Figure 4-13, they were marked by hand. Unplanned communication is now captured in the team structure. Another finding is that both system teams overlap; a dense group of component teams like the fender and hood locked the strict relationship that exists between the two clusters.

Note that the new system teams are much larger. Although the larger teams captured most of the uncontained interactions, large size groups create difficulties for organization and potential delays in the program. Here the tradeoff is to have: a) smaller and manageable system teams leaving important interactions outside the clusters or b) large system teams difficult to manage but capturing most of the interactions during the development of the project. The decision might be taken based on the program needs. For example, there are organizations that require a lot of detail while developing a product; close transfer of technical communication among the whole project team may be needed in order to guarantee the success of the product. On the other hand, there are organizations that rely on the ability to quickly release a product; time is a limitation that they may overcome by handling small project teams.

Having previous results in the MDEM, the proposal is to consider this matrix as the optimal team structure framework for the front end system. As recommendation, additional clustering analyses for the non-class A and class-A component teams are encouraged; future developments of front end systems should be able to easily implement this framework; unplanned communication will be transformed into planned tasks according to the program needs.

*Figure 4-14* represents the evolution of the improvement in the number of component teams outside the clusters for each DSM proposal. The original team structure had 94 interfaces outside clusters; the first partitioning improved the condition to 72, second organizational proposal left 65, the third moved to 46. Finally, the fourth simulation reorganized the organization into two clusters with 8 interactions outside the system teams.
Figure 4-14 Multiple Clustering Solution Summary
Chapter 5 – Conclusions and Recommendations

“I think that is the single best piece of advice: constantly think about how you could be doing things better and questioning yourself”

Elon Musk

5.1 Summary of Results and Conclusions

The effectiveness to succeed in the development of the front end System CD-Car project highly depends on the organizational architecture defined by the program team. Although the original organization team structure for the case study integrated four main subsystem teams, the arrangement was not the optimal; 94 cross functional interactions were not integrated in the clusters. The data suggests that unplanned interactions at different levels of frequency may occur along the development of the CD-car project.

Another characteristic for successful projects are frequency and quality of technical communication in the organization. Various critical dependencies from the product architecture were expected at high frequency, daily and weekly at the most, in organizational team structure. However, 32 product design interactions that matched component team interactions at high levels of frequency were not considered as critical by the PMT group.

The effect of workplace communication has also played an important role in the quality of communication. Team distribution among the two different PD offices was balanced; however, such team segregation brought the use of erroneous channels of communication. For instance, the spreading of CD-car project team members was half in USA and half in Mexico; the transfer of technical knowledge was expected to be performed at least by phone/webex given the complexity of information. Nevertheless, the distance was a major factor to reduce the probability of interactive communication by using email. The high use of email has generated unplanned interactions that were not considered in the product architecture of the front end system. There were 45 unidentified interactions located out of the cluster teams and 18 additional within the clusters. Once again emphasis must be put on the idea that during the development of
the CD-car project, the team communication was established via email approximately 53% on daily basis.

On the other hand, low level of technical maturity from some of the front end system component engineers reduced the number of interactions in the project stated from the product architecture DSM. There were 11 unattended interactions that were critical for the success of the project. The summary of data indicates that about two thirds of the CD-car project team are in the build and apply maturity level; it is expected that an immature organization incurs incapability problems during the development of a technical project.

Additionally, technical expertise for the development of the front end system impacted the frequency in communication; the data illustrated in the alignment matrix suggests that component engineers with working experience of no more than 6 years have communicated at a frequency level of weekly and monthly for most of the component interfaces along the development of the project.

The DSM is an effective network modeling tool that provides a clear picture of the relationships that exist in complex systems. Organizational architecture DSM has important parameters that help us to enhance the organization structure of a project. In the CD-car case study, the clustering analysis brought four team structure proposals; the target of the partitioning simulations was to incorporate most of the interaction external to the clusters into the actual clusters or new clusters. In addition high frequency dependencies were expected to be inside these clusters. The result was a new front end system team structure that can be taken as framework for future development of the same vehicle system.

The framework consists of an organizational architecture DSM that incorporates two main system team clusters; a third cluster is included to capture the program integration. The system team clusters combines critical product design interfaces, frequency of communication interactions, unattended interfaces and unidentified interfaces. The latest feature may be aggregated as complement to the product architecture of the front end system. Unattended interface can be highlighted as critical interfaces with weekly or daily frequency, according to the expectation of the program team. The program integration team works in a more robust manner given that unattended and unidentified interactions were found as well.
Based on the results found with the analysis conducted on the CD-car case study in this thesis, the conclusions according the thesis objectives and premises will be described as follow:

- The identification of gaps in communication among cross functional system teams was certified by comparing the product architecture DSM and the original organizational architecture DSM of the CD-Car project. The result was an alignment matrix that was complemented later with component engineer’s expertise data, physical location of project team, communication channels and frequency level of communication.

- The improvement of human capital capabilities in attracting further “top hat” developments to the FoM organization may not be visualized at this point. However, the application of organizational DSMs brings to the workforce the benefit capabilities enhancement by avoiding mismatched interfaces while exchanging technical information with other project teams.

- Product interfaces are defined with a product architecture DSM; product systems are developed by teams; therefore, organization DSMs can lead to the development of a project having well organized system team structures. The development of a project can be performed without an organizational DSM; however, the degree of success during the development of a project is highly influenced by the optimal organizational team structure. This organization architecture is achieved by utilizing DSMs. The front end system framework has been portrayed in this thesis with a leveraged alignment matrix DSM and a multi-dimensional embedded matrix which bring major benefits to the company: identification of project clusters, mismatches in communication, team communication frequency, channels to transfer information, project integration interfaces, enhancement of innovation process and the overall improvement in the project development.

- Development and implementation of system team structures can improve the performance of a product team and the outcome of a project. Most of the component engineer’s interactions are accommodated in system team clusters, including mismatched
interfaces; this means that if a project team follows the new structure, there will be no new unplanned interactions. In addition, the project team location has been aggregated to the leveraged alignment matrix; there is a correlation in communication efficiencies having the previous variable. The incorporation of the workplace parameters derives the communication channel which highlights component teams’ communication that the program should pay more attention for the success of the project.

- Structured communication among system team members can enhance personnel capabilities by acquiring experience from cross functional interactions. There was not an explicit outcome for this premise; nonetheless, the expectation is that regular communication between project engineers will expand experience to certain team members. The more communication, the more practice from the engineer on the product that is being designed.

5.2 General Recommendations

5.2.1 Recommendations for FoM to Leverage the Capability of Human Capital

- Workplace has an effect on people’s communication. When a project team is distributed in the same facility of the PD organization, the transfer of technical and complex information has to be established with personal contact (face to face). This is a prevention mode to avoid miscommunication while developing a project.

  - Less “e-mail engineering”, more personal contacts/meetings to solve and discuss issues, more face to face meetings to update everyone on expectations/deadlines, meetings minimize the need for chasing down e-mail status updates.
  - Personal contact builds relationships; building relationships facilitates transfer of knowledge in the organization.
  - If you want documentation/record, publish brief minutes on agreements/next steps after meetings.
- Minimize wait on others, walk to the engineer cubicle to discuss.

- It is important to have most of the project teams in the same location in order to prevent excessive communication via email while transferring technical knowledge; it is highly recommended the use of virtual communication tools such as phone or webex when distance is a barrier in communication. Closely manage cross regional business travel when physical interaction is the priority.

- Engineer’s technical maturity level affects the degree of communication in the organization. In theory, the more experience, the more communication; high experienced engineers (leverage level) know that they have to communicate with the team at certain frequencies; whereas if the engineer is a novice (build or apply level), he won’t know the component teams he should interact with or the frequency level of communication while developing a project.

- During the early stages of the product development process, component engineers should be provided with a guideline to develop a preliminary organizational DSM. This will enable a set-up of proper communication channels in order to avoid lack of communication, miscommunication and unexpected communication. The recommendation should be very useful for build and apply level engineers in the FoM organization.

- The framework developed for the front end system should be utilized as a generic tool for:

  a. Organization team structure diagnosis: it applies when the original team structure was set up by the program management team; when deficiencies in communication occur, there is a need to rearrange the organization to improve the performance of the project.

  b. Organization team structure definition: the defining phase of the product development process, the program management team should initiate the development of the organization structure alternative. This framework
incorporated both the alignment matrix with interaction and project team indicators (leveraged alignment matrix) and the optimal front end system team structure (MDEM).

- Incorporate organizational architecture DSM into the failure mode avoidance process at Ford; this is the missing link to integrate a robust development process of a complex system within the company. The organizational DSM will enhance the flow of information in component interfaces, additional noise factors may be contained in the original development. Failure modes will be capture due to efficient interaction among component teams.

- The findings and framework were presented to the Ford USA engineering management; they agreed that the organizational DSM models might add value to the company. DSMs are useful to improve transfer of information within the organization; the framework should fit within the Ford’s processes to optimize communication during the development of a project. Mark Garascia (Body Core Engineering Supervisor at Ford USA) mentioned: “I think this is a nice model, the last week we were talking about communication issues, inefficiencies that occur in projects and proposals to overcome these problems, but how to implement this type of model in Ford? It is a difficult one”. According to Ford’s management, understanding the organizational DSM is relatively easy; however, incorporation in Ford is challenging. For instance, the management team is interested to highlight the proposal in some forums such as Core Manager’s Decision Forum or Director’s EMM meetings in the body group. On the other hand, processes and standards development takes too much time. The proposal is to take a particular project to get a different arrangement of a team. To start up, the implementation should be done in a small application, small programs like an MCA or even smaller Ford organizations to apply DSM structures. The management agreed that a pilot should be run in smaller groups such as Ford of Mexico. Replication of the analysis from this thesis in order to prove the concept for incorporation in a larger scale.

- Although this information may be incorporated in the frameworks mentioned previously, it is highly recommended to redefine the minimum level of communication frequency
while exchanging information given the criticality of the relationship from the product architecture, and program needs.

- Incorporate unidentified interfaces as complements to the front end system product architecture. New component architectures or system innovation may be incorporated; the team should be ready to avoid unexpected communication within the project team.

- As a result from the DSM proposal 3 and according to statements from the body exterior management, the recommendation to the FoM organization is the incorporation of a liaison engineer per commodity group in order to act as component engineer integrator. It will allow him to be part of all team interactions in order to prevent miscommunication, facilitate and promote communication, capture missing links and avoid delays on deliverables.

- Lastly, in terms of workforce expertise, effective cross functional interactions enable technical knowledge capacity. Inversely, more mature technical level (e.g. leverage) enables better communication and interaction among team members of a project. This has been correlated in the leveraged alignment matrix. Experience is acquired by practicing the same task multiple times; it also can be achieved by interacting with subject matter experts or while solving complex issues that leave important lessons learned. The recommendation for FoM is to leverage build and apply engineers over in the Ford assembly plants for a determined period of time. The idea is to link the product design with the assembly process, operations, design for manufacturing and issue resolution. All together to maximize the experience of engineers in preparations for the development of complex products in the organization.

### 5.2.2 Recommendations for Future Research

As a final note, the analysis of the front end system CD-car case study was done for the detail design phase of the product development process. The project is still ongoing. It is highly recommended to continue applying the organizational architecture DSM in the subsequent
phases of the product development process: prototyping, testing and launching in order to ensure the success of the project or to leave a precedent about organization behavior during the second half of the product development process.

Additionally, the utilization of this thesis and application of organizational DSMs for other vehicle subsystems may contribute to the improvement of communication in the organization. Replicability of this research on similar or different vehicle subsystems may create awareness to the company for product development improvement, and human capital capabilities enhancement.

To finalize, MDEM models were prepared with a combination between manual clustering analysis and commercial software tools for partitioning simulation. Due to time and scope of this thesis, the development of new algorithms for clustering in multiple domains at the same time was omitted. Therefore, for future research it is recommended to explore this modeling stream.
6 – Bibliography


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**Appendix A.**

Source: Home DSMweb.org / Interview template for DSM data collection (C) 1999 MIT DSM Research Team

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**Scale:**
1 = Not necessary and no interaction
2 = Necessary and critical interaction
3 = Critical in terms of necessary, but does not prevent functionality
4 = Must be preserved to achieve functionality

**Note:**
- DSM = Diagnostic and Statistical Manual
- DSM Research Team
- Home DSMweb.org

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*Appendix A.*
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