Global Product Development: A Framework for Organizational Diagnosis

by

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ABSTRACT

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The main purpose of this thesis is to present an approach for analyzing product development organizations in a globalizing world. The fragmentation and distribution of several product development activities in the global market have generated a variety of strategies. In addition, an increasing visibility of the influence of cultural diversity in these strategies and an intensified sensitivity to sustainability issues motivate this research. Retaking the questions of which is the best strategy for product development organizations to succeed and, even further, which is the measure of success for these organizations are also part of the motivation behind the research.

The methodology followed for constructing the socio-technical framework presented in this document mainly consisted of gathering, analyzing, and integrating existing literature and frameworks from systems engineering, social, and management studies. Utilizing a macro-framework with three spectra –space, time, and context– the framework allows the decomposition of the product development system into three levels, identifying the key stakeholders and roles within the system. The framework includes four different angles –structural, human resources, political, and symbolic– from which a product development organization can be diagnosed. Also, the knowledge of predictable reflexive human responses is presented as a means for stabilizing an organization. In parallel, the study includes an exploratory approach for finding a robust way of measuring a product development organization. Finally, an intervention strategy is proposed as an outcome of both the research process and the framework presented. An automotive product development organization was selected for testing the applicability of the framework.

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I want to thank all people and organizations that made this enriching learning experience possible for me. Participating in System Design and Management program at MIT has represented an enormous privilege, motivation, and responsibility as a person. I feel honored for having known in person and learnt from the MIT faculty and classmates during this period. I will always be thankful to all people that helped to make this journey so extraordinary.

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Mitsuko and Koji, my sister and brother-in-law,
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My parents, Shigeo and Marbeya,
for their unconditional encouragement for me to achieve my dreams. I will never stop admiring them.

And all my family, friends, and colleagues,
for their support and patience during these years.

MOTIVATION

I was fortunate to meet admirable people who shared similar yearnings of delivering more value to as many people as possible through what we do, product development. With my still relatively short experience in product development arena, I could not resist joining this desire and commitment that implied challenging the *status quo* of an engineering organization as well as of ourselves as individuals. The motivation behind the research work presented in this document is to contribute to the realization of this aim. Specifically, the goal of this research is to acquire the skill set required for analyzing the product development system holistically, exploring the complexity of it, and build on simplicity as a challenge.

I realized that this document should represent a journey, not a destination, for gaining a better understanding of the role of product development organizations in its environment and for facilitating the capitalization of experience and learning within an organization. Hopefully, this research will serve as inspiration for my colleagues and friends to create new ideas and strategies for improving product development organizations and elevating the value that engineering can deliver to the society.

> "Everyone born in this world has a unique role that only he or she can fulfill. Were this not the case, we would not be here. The universe never acts without cause; everything invariably has a reason for being. Even the weeds people love to loathe serve a purpose. I might add that every cherry blossom has its own personality, a purpose and meaning in life that is unique to it—as do the plum, peach and damson."
>
> Daisaku Ikeda

ACRONYMS

CAD	Computer Aided Design
CFC	Chloro Fluoro Compounds
COCOMO II	Constructive Cost Model II
CPU	Cost Per Unit
EWP	Engineering Work Participation
FPS	Ford Production System
GDP	Gross Domestic Product
HR	Human Resources
IT	Information Technology
MDG	Millennium Development Goals
MIT	Massachusetts Institute of Technology
OD	Organization Development
ODP	Ozone Depletion Potential
OEM	Original Equipment Manufacturer
PD	Product Development
PDEO	Product Development Engineering Organization
PDO	Product Development Organization
PDP	Product Development Process
PRICE-H	System Evaluation and Estimation of Resources –Hardware
PRICE-S	Parametric Review of Information for Costing and Evaluation – Software
PRHR	Predictable Reflexive Human Response
R/1000	Repairs per Thousand
ROI	Return On Investment
RSERFT	Raytheon Systems Engineering Resource Forecasting Tool
SDM	System Design and Management
SEER-H	System Evaluation and Estimation of Resources –Hardware
SEER-SEM	System Evaluation and Estimation of Resources –Software Estimation Model
SSCM	Small Satellite Cost Model
TGW	Things Gone Wrong
TPS	Toyota Production System
UN	United Nations
USCM8	Unmanned Spacecraft Cost Model 8
V&V	Verification and Validation

"Organization makes a system of many appear fewer."

(Maeda, 2006)

Chapter 1

INTRODUCTION

Organizing Ideas

In this chapter, the objective and justification of the research are defined, and the formal problem definition is established. Next, the general structure and information flow of the research is illustrated.

1.1 Objectives

The main objective of this research is to present a framework for diagnosing product development organizations in today's global environment. As part of this objective, the intent is to identify at least one robust directional metric that allows a reasonable representation of the competitiveness of product development organization as an engineering entity. Understanding that the ultimate goal of the analysis is to improve the organizations, proposing an improvement strategy, if not multiple, is also an objective of the research.

1.2 Justification

A variety of challenges and strategic options are surrounding product developers, generating invigorated ambitions of improving product development activity in the world today. This research retakes the questions of which is the best strategy for product development organizations to succeed in today's world and, even further, which is the measure of success for these organizations. This research work contributes to the understanding of the role of product development organizations in today's environment and serves as a "fertile field" for the generation of new strategies that deliver more value to stakeholders, capitalizing the experience and learning gained within an organization.

1.3 Problem Definition and Scope

Many product development organizations have been in a constant need for finding new strategies that allow them to be more competitive in the global market. The problem that this research intends to solve is to identify a framework that helps organizations visualize a position they occupy in the world and the elements that may guide them to the generation new strategies.

The unit of analysis of this research is the product development system seen as an engineering entity. The function of the system is, by definition, to develop products in order to create value. The product development system is embodied in a form of product development organizations, which are groupings of people, utilizing tools and following established processes to create products in order to achieve specific goals. Although the commercial aspects of the product development system are not disregarded in this research, they are incorporated as a contextual element for diagnosing the organizations as engineering entities. Therefore, the approach is to emphasize the value of engineering, which is not necessarily measurable by the profit of the organizations.

The framework identified in this research is the result of the analysis and integration of existing concepts and frameworks available in existing systems engineering, social, and management literature. This document presents one example of the applicability of the framework, even though it is expected to be applicable to similar product development organizations. Finally, the research includes the identification of metrics and strategies. Examining the effectiveness of these metrics and strategies in the field would be a research opportunity for future work.

1.4 Thesis Flow

The process followed to conduct this research is analogous to the structure of this document to some extent. The process followed to perform this study is illustrated in Figure 1-1. The first step was to identify the motivations, objectives and scope of the research (Chapter 1). Then, the initial literature review for building the macro-framework was elaborated (Chapter 2) in order to integrate the elements of the framework proposed. After this step, a series of iterations occurred in order to improve the framework (Chapters 3 and 4). The applicability of the framework was tested and evaluated by analyzing an automotive product development organization (Chapter 5). Interviews with the personnel of the organization and an additional literature review were necessary to make adjustment to the framework. Next, a proposal of directional metrics and intervention strategy was created (Chapter 6). Finally, conclusions and future work were described (Chapter 7).

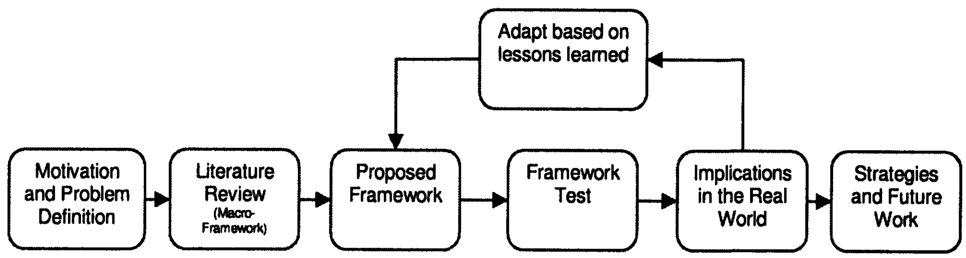

Figure 1-1. Thesis Flow Diagram.

"Simplicity is about subtracting the obvious, and adding the meaningful."

(Maeda, 2006)

Chapter 2

STATE OF THE ART

Building a Macro-Framework

This chapter presents the literature review conducted to elaborate a macro-framework or skeleton that allows the integration of a framework for analyzing product development organizations. Three spectra were identified as the main components of this skeleton: space, time, and context. The elements of this macro-framework include System Engineering models, System Architecture concepts, and studies of product development organizations.

2.1 System Architecture Framework

It is beneficial to treat a product development organization as a system in its own right. This approach allows applying analysis methodologies that lead to a diagnosis of an organization from a holistic perspective, versus circumstantial analyses that can easily lead to conclusions or solutions that are effective only in very unique conditions. A systemic approach focuses on the architectural properties of the systems, allowing the integration of robust solutions and frameworks that have been found to be effective in other systems. The systemic approach provides a means for utilizing principles and tools to analyze product development organizations, while contributing to a better understanding of what a good system design is.

System architecture frameworks provide several benefits in the analysis of product development system. For example, the framework that is being developed by Crawley (2006) incorporates principles, processes and tools that can be applied for structuring and understanding the system in different levels. System architecture frameworks allow the establishment of a common language for discussing and thinking on systems –where "system" can be a product, organization, people, processes, or any combination of this– and the role that each element plays in them.[1] This common language, in turn, will lead to a critique of existing models and the creation of better systems that deliver what they are intended to deliver.

Systems can have different levels of complexity, which in many cases is determined by the number of interactions that occur within their boundaries. Often, the more complex a system becomes the more ambiguity and uncertainty

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[1] In social systems, for example, the role of individuals and communities are often studied in terms of hierarchies and interactions between the elements.

exist. System architecture concepts permit a better management of this ambiguity and the evolution of complexity in time and space dimensions. One of the most valuable contributions of system architecture framework for this research might be the set of insights that allows building a notion of how to think –rather than what to think– in order to diagnose and improve a product development organization.

2.1.1 *Three Basic Systems Attributes: Form, Function, and Concept*

One of the most important system attributes that system architecture approach focuses on is the definition of the form, function, and concept of the system. The form, normally represented by a noun, is the sum of elements related to physical or informational structure that executes a function. The second attribute, the function, referrers to an activity, operation, or transformation that contributes to performance. The function of a system is normally represented by a verb plus noun, and with a limited syntax. When delivered externally, function is closely related to the value of the system. Finally, the system concept is the attribute that captures the system vision, mapping form to function and involving a principle of operation and an abstraction of form. These three elements, form, function, and concept, constitute the basic embodiment of the architecture.

2.1.2 *Description of a Good System Architecture*

Crawley (2006) provides an approach to discern between a good architecture and a poor architecture by identifying seven key deliverables of the architect. The seven deliverables are: goals, context, functional description of the system, concept, notion of existing tensions, and a defined document or process. An architect is expected to deliver a clear, complete, consistent and attainable –within a certain level of confidence– set of goals that the system is to achieve within a known context. The architect has to define the main attributes of a system – function, form, and concept– and a comprehensive notion of the tensions that are inherent to the operation, implementation, and evolution of the system. These tensions usually relate concepts such as cost, risk, performance, and timing. Finally, the architect should be able to shape all the information contained in the previous six deliverables into some kind of document or process that ensures the ultimate outcome of the architecture is achieved as intended. The seven key deliverables of the architect are presented in Figure 2-1.

7 Deliverables of the Architect

- ❑Concept
- ❑Function
- ❑Form
- ❑Goals
- ❑Context
- ❑Notion of Existing Tensions
- ❑Document or Process

Figure 2-1 Crawley's 7 Deliverables of the Architect

Steve Imrich (2006) would probably add two more deliverables to these: character and magic. Character deals with the memorable qualities that a system has over and beyond its lifecycle –it is a description of how the architecture can transcend over time, while magic is the universal appeal, attraction, and surprise. Having a notion of the characteristics or elements that make an architecture better than others can be a useful reference when evaluating an existing system –e.g. a product development organization– or creating a new one. The key deliverables of the architect presented by Imrich are shown in Figure 2-2.

6 Key Architectural Elements

- Concept
- Content
- Context
- Circuitry
- *Character*
- *Magic*

Figure 2-2 Imrich's 6 Key Architectural Elements

2.2 Product Development System

Product development can be broadly defined as a human activity in which processes and sub-processes are executed with the use of existing tools in order to conceive, design and commercialize a physical or informational asset. Other definitions could include the manipulation and integration of different materials to create a functional artifact. The product development system involves all essential elements required to perform this activity; such as people, processes, products, tools, and goals inherent to the system (Aguirre, 2008). From a socio-technical perspective, a product development organization can be considered as a sub-system of the product development system that contains all essential elements within its boundaries. This set of definitions imply the existence of an organizational structure of people, a set of interests, and common objectives that well combined is expected to create value to the stakeholders. Therefore, product development can be seen as a system where all these elements –product, process, tools, people, and goals– interact with each other to achieve a specific mission.

The complexity of product development systems is determined by the complexity of the product, the type of people interactions, the utilization of tools, and the scope of mission that is intended to be accomplished. Moreover, product development systems can be considered complex by definition because the interactions that occur within it are not only between elements of the same type. That is, there are interactions between people and product, people and tools, tools and product, etc. Literature suggests different ways to analyze and improve product development in specific contexts. Most of the suggestions seem to converge in touching the three aforementioned main spectra: space, time, and context. The first one, the spatial spectrum, focuses on mapping the size of the system and sub-systems and their boundaries. The second spectrum, time, addresses time horizons and sequence of events that take place in/around the product development process. Finally, the contextual spectrum provides the settings of the environment in which the system exists in a specific point in time. The utilization of these three spectra allows approaching system analysis and design holistically and managing the complexity in an organized way.

2.2.1 Spatial Spectrum

Product development systems –and in fact any kind of systems–l can be decomposed and classified in several ways. Analyzing the system by grouping elements with similar structure, size, or type of interactions are only some examples of system decomposition. Another approach to understand product development systems is to analyze a single element of the system first and expand the analysis by identifying properties that are affected by external elements or operations until reaching the boundaries of the system under study. Crawley (2006), for example, describes product development systems by analyzing product attributes first. By starting to identify the product form, function and concept, and then expanding the analysis to describe attributes such as needs, goals, and operands allows encountering the boundary between the product level space and the enterprise level space. During this process, the interactions between the elements of the system such as the product development process, people organization, tools, enterprise identity and goals are properly described. These interactions are illustrated in Figure 2-3.

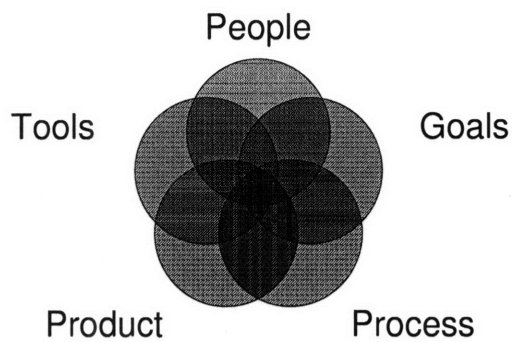


Figure 2-3 Essential Elements of Product Development System

When moving from a product level space to an enterprise level space, the portion of the system that is being visualized becomes larger, as it includes more elements and interactions. The analysis can be expanded further if, for example, we understand the enterprise –or product development organization– as a component of a specific industry, or a larger economic, social or political system. In this way, product development as an entity can be understood as a system in a space spectrum and can be decomposed in several levels.

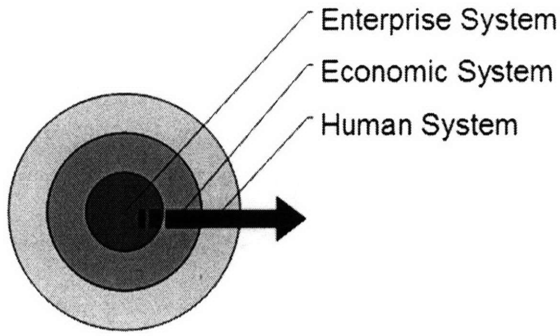


Figure 2-4 System Spatial Analysis Framework

2.2.2 *Temporal Spectrum*

Product Development Organizations, as most systems do, have dynamics properties –which can be physical transformation of materials, design processes, and human activities– that allow transitioning from an initial state to a desired state of the system. In this transition, it is possible to identify sequences, tasks, and product transformations that in turn can be classified. The product development process described by Ulrich and Eppinger (2004) is an example of how a product development system can be examined in the temporal spectrum. As shown in Figure 2-5, Ulrich and Eppinger propose a generic 6-phase process, which includes: Planning, Concept Development, System-Level Design, Detail Design, Testing and Refinement, and Production Ramp-Up.

Generic Product Development Process

Phase 0: Planning
Phase 1: Concept Development
Phase 2: System-Level Design
Phase 3: Detail Design
Phase 4: Testing and Refinement
Phase 5: Production Ramp-Up

Figure 2-5. Ulrich and Eppinger's PDP Model

Valerdi (2004) demonstrated that many product development organizations tend to use a variation of this framework. The general idea is to define the product or project, design the product, validate the design, and launch the final product –see *Appendix A*–. Many product development process frameworks have elements in common and have some similarity with generic problem resolution processes. How we represent temporal factors in product development systems determines not only the ability to perceive the internal operations but also the overall system behavior and evolution pattern over time.[2]

2.2.3 Contextual Spectrum

Systems can respond to different stimuli and behave according to specific conditions. An important portion of the analysis of systems includes the study of the environment in which the system exists. For example, it is necessary to understand organizational issues such as individual and collective behaviors, management styles, and the learning culture under specific stress conditions. Any other social, economical, political, and environmental issues related to the region or the historical period in which the product development organization works become important inputs to the analysis and design of product development

[2] System dynamics tools can be utilized for modeling the changes in product development system behaviors and structures. (Sterman, 2000)

systems. The contextual spectrum, then, can be seen as a specific case of a combination of spatial and temporal elements –both internal and external to the system in question that can make the system to be unique because of the space it is occupying or the moment it is coexisting with other systems.

2.3 Product Development Metrics

Metrics are a system of parameters that ideally reflect a quantified perception of the high level outcomes of the system in terms of the benefit that it yields to the stakeholders, cost and timing issues, uncertainty, robustness, and safety –if humans are involved–. Metrics are the basis of many –if not all– architectural decisions such as the definition of goals, prioritization of intended system performance, and the balancing of existing trade-offs. In order words, metrics combined with a target value can define a system goal. Prioritization of performance determines the levels of importance between primary functions and secondary functions of a system, by having a 'weight' variable assigned to each performance metric.

2.3.1 Influence of Metrics in Product Development

In product development, metrics are principally used for defining a system and for tracking the progress. First, during the definition of a system, architectural decisions are usually made by comparing quantitative metric between two or more options. The challenge in this type of use is that identifying the appropriate metrics is not always –and rarely is– a trivial task for engineering system design. The ideal state or ideal performance of a system is difficult to be defined and represented in numbers because it comes from a subjective 'desire' or voice of the customer that usually does not specify a quantitative reference. Additionally, in complex systems, the compatibility or traceability between the ideal state of the highest level system and the performance and interactions between the sub-systems and components are difficult to assess. The challenge is to identify metrics that most closely represent the value that is delivered, while understanding the limitations of the metrics identified for envisioning future system improvements.

The second use of metrics is for tracking the progress of a system, in terms of either the development process or the outcome over time. Discrepancies between the target and the actual state measured may lead to subsequent decisions such as adding or subtracting resources, and adjusting timing or cost assumptions. The challenges and risks associated with this type of use are related to the non-linear nature of the systems. That is, there is an apparent tendency in the behavior of the system where viewed under a limited time horizon it can generate erroneous – linear interpretation of the actual nature of the system. When the system behavior seems to move away from the expected behavior, people tend to make hurried decisions in order to correct that behavior; however, many times these kinds of limited and hurried decisions makes things worse. Therefore, metrics have an important role not only in the initial definition of the system architecture, but also in the evolution of it over time.

From a system architecture perspective, metrics are a critical component of system goals. Crawley (2006) describes a useful goal as the sum of a metric and a target value. From the goals one should be able to spot what the product is – form– what its intent is, and what it does –process–. Metrics linked to intent are more likely to assure value delivery, and this can be achieved when metrics focus on one or two highest level goal(s) of the system. Traditionally, metrics have been based on the amount of benefit obtained due a certain level of performance – benefit per performance–. Some current practices indicate that metrics are more useful when are based on benefit, performance, and cost –schedule and risk can be assessed later. Ideally, however, it would be expected to have all these attributes –benefit, performance, schedule, cost and risk– associated and integrated into the same assessment and reflected clearly in the metrics.

2.3.2 *Pitfalls and Opportunities*

The use of metrics is a task that carries certain levels of uncertainty. This is because many times what it is supposed to be measured and made manageable are some subjective perceptions or abstract concepts. For example, the concept of "value" in general can be subjective to the eyes of individual perceptions. Each individual can be looking for a specific benefit –different from others, associated with that value. Additionally, metrics are often lagging indicators. In other words, even if the value of a system could be reasonably well represented by metrics, it may require some time to obtain a picture of the actual state measured in a specific point in time. For instance, if we wanted to measure the value of a product development project, one way to do it might be to represent that value in terms of the profitability of the product. However, profitability is unknown until the product is finished and commercialized. Then, the value of the project becomes difficult to know during the development period. The uncertainty incorporated into this kind of metrics plus the effect of time delays can lead to a misinterpretation of the real system structure and behavior.

An important question to ask is how to obtain the major benefit possible from using metrics. One of the most mentioned approach in the literature that address this question suggests that the incorporation of sustainability factors can make an important difference in the magnitude of benefits that a system can provide. The idea is that even when metrics can be quite limited in terms of time or scope within the system, or include a certain level of uncertainty –for example, due to time delays mentioned above– if the metrics are aligned with what it is understood as sustainable development, then it is more likely that the system will perform successfully. The incorporation of sustainable factors into the definition and use of metrics may imply the utilization of proximate measures that are trajectory measures toward value (Crawley, 2006)[3], rather than absolute and

[3] System Architecture Lecture

punctual numbers. Therefore, selecting and using metrics can have a strong weight on architecture definition and analysis, and on the management of its performance once it is implemented.

2.3.3 Metrics Utilized in Product Development Systems

There is not a single set of metrics utilized by all existing product development systems. A list some of the metrics that are most commonly used was developed by Crow (2001) –see *Appendix B*–. In this list metrics are classified in 12 categories: Requirements and Specifications, Electrical Design, Mechanical Design, Software Engineering, Product Assurance, Parts Procurement, Enterprise, Portfolio and Pipeline, Organization/Team, Program Management, Product, and Technology.

There could be alternate approaches to classify metrics, but what most of the approaches would conclude is that metrics that are being commonly used in product development systems are located in several layers within the system and many of them are focused only on one single portion of the whole system. This fact suggests that because some metrics correspond to different territories than others, there is a risk of having disconnection between metrics within an organization, extremely complex interactions between them and contradicting metrics as well. The notion that each metric responds to a specific need that does not affect the others generates various challenges for dealing with product development decisions. This is one manifestation of the source of the trade-offs that product development systems experience.

Accurately and precisely measuring things in product development systems is not for free. Identifying the most suitable measurement system takes time and effort. Gathering data and analyze it requires investing on an efficient IT infrastructure and the corresponding training to implement almost any measurement program. However, quantifying the cost of a measurement system is not the most difficult part. A more challenging task is to know which measurement system will yield the biggest benefit for the organization. Investigations done in software development have documented data that quantify the benefits of different measurements utilized by different organizations (Broadman and Johnson, 1996). Other studies have documented the various metrics utilized by several firms, showing that two different firms adopting different measurements can have similar positive results (Collins, 2001). Therefore, decision makers in product development organizations face the challenge of deciding which measurement programs to invest in and on what additional actions need to be taken in order to use the metrics properly, allowing for the best estimate possible on the expected benefit.

Chapters 4, 5, and 6 provide a set of metrics that are adequate for diagnosing a product development organization. These are organized in a framework that helps identify their complementary properties.

Align all components of your system towards consistent goals.

Chapter 3

PRODUCT DEVELOPMENT SYSTEM FRAMEWORK

Integrating Frameworks for Understanding Today's Product Development Organizations

The objective of this chapter is to present a framework for analyzing product development organizations, utilizing the macro-framework of the three spectra – space, time, and context– explained in Chapter 2. The framework identifies three levels for decomposing the product development system, the key stakeholders and roles within the system, and four different angles –structural, human resources, political, symbolic– from which a product development organization can be described. Temporal considerations, such as product development process and problem-solving process are also treated in this chapter. Finally, globalization, cultural studies and global challenges are presented as the main contextual components of this framework.

3.1 Spatial Elements in Product Development

3.1.1 Multi-Level Decomposition Model

An essential component in the spatial analysis of a product development system is to identify the boundaries between the different levels of the system; that is, the different ways of decomposing and grouping the elements into sub-systems. There are at least two benefits that can be obtained by decomposing the system into several levels. First, decomposition facilitates the identification of focus points that are of greater interest for the study of a system. Second, it helps to identify how an element of the system interacts with other elements and its influence to the other levels of the system, facilitating the identification of the value that it delivers to the whole system.

For the purpose of this research, three levels of decomposition have been set in order to analyze product development organizations. The three levels are: the enterprise level, the regional level and global level. Figure 3-1 illustrates these three proposed levels to analyze a product development organization as a system.

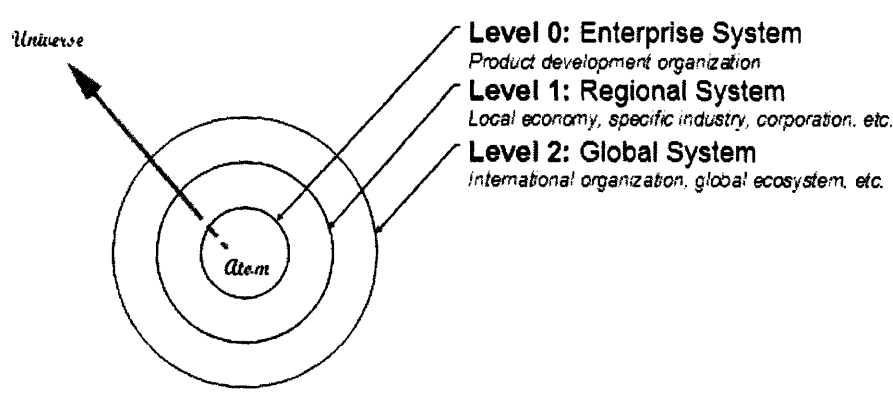


Figure 3-1. System Decomposition Model.

The hierarchy of the levels is based on the physical size of the system. Hypothetically, the lowest level would correspond to an atom, whereas the highest level would correspond to the universe itself. The three proposed levels are located in intermediate points within this hierarchic system, where the systems of higher levels include the lower ones. In this case, enterprise level, regional level, and global level correspond to the lower, middle, and higher levels, respectively.

The enterprise level is the lowest level within this model. It would correspond, for example, to a product development business unit, which mainly includes the engineering team and the supporting functions such as purchasing, marketing, finance, IT, etc. At this level, a product development organization can be studied in terms of the main tasks that it accomplishes and how people, processes, and tools are integrated in order to develop products that deliver the highest possible value to the customers.

The intermediate level between the enterprise level and global level is the regional level. This level can be a corporation, a specific industry, an economic sector, or government in which the product development business unit exists. At this level, it can be seen how the interactions that occur between the different entities that are under a common jurisdiction –e.g. same geographic zone, market, economic sector, government, and culture– have influence on the definition and compliance of the local regulations and norms, as well as specific market requirements. The main emphasis when looking at this level is on observing how the product development activity addresses specific markets and/or regional needs and how it contributes to the well-being of the communities in a specific jurisdiction.

Finally, the highest level of the model is the global system level. This includes international organizations involved in international socio-political phenomena, economy, natural phenomena, and in general, all human activity that takes place globally. The main center of attention in this level is the way in which the different groups of people are affected by and attempt to solve global challenges. In a more general sense, this level can help to visualize how the scientific knowledge and technology are leveraged in order to solve the problems that affect human being as a whole.

Consequently, expanding the panorama of what product development is and its role under the different levels of decomposition enables a macro view of the situation. The practice of product development responds to local market needs and regional conditions and, ideally, solves problems of global nature at the same time. Using this three-level decomposition model allows the analysis of a product development organization from a holistic point of view.

3.1.2 Four-Player Organizational Model

Product development is easily seen as an autonomous product creation "machine", where human factors represent a secondary issue that has to be addressed only by the Human Resources Department or by managers for the product development process to take place. In fact, in highly technical environments, human factors are commonly seen as "noise" for the product development process. However, product development organizations are indeed groupings of people interacting, learning, and transforming the environment; that is, they are social systems as well. Therefore, when analyzing product development systems, it is necessary to look at product development organizations in a socio-technical context.

Studies made on social systems can help to identify behaviors and structures that are common in many organizations. The four-player model, developed by Sales (2006), allows identifying predictable human behaviors that can be expected to occur under predictable conditions when social interactions take place. For the purpose of this research, this model is expected to help in identifying those conditions and human behaviors that have already been found in other social systems and incorporate this knowledge into the analysis of product development systems.

Sales identifies four main roles that constitute any social system. The four roles are called: Tops, Middles, Bottoms, and Environmental Players. Each of these actors has different responsibilities and faces a unique set of challenges. Each of these *players* also experience particular stresses that, under predictable conditions, contributes to the generation of predictable reflexive responses. The four-player model can be used to identify those predictable reflexive responses that affect the stability of the whole system in order to design strategies that can minimize them.

Four Players

- ❑ ***Tops*** have overall responsibility for the system.
- ❑ ***Middles*** stand between Tops and Bottoms.
- ❑ ***Bottoms*** do the specific work.
- ❑ ***Environmental Players*** are the beneficiaries.

Figure 3-2. Four-Player Model

The first type of actors in an organization is called the Tops. They have the overall responsibility of the system. For a company, for example, top management could be considered the Tops of the system. For Tops, being overloaded at work is a common condition, and it is a common reason for being stressed. Also, since each Top has a unique function, the emotional distance with other individuals is always at risk of increasing. The high degree of responsibility that usually characterizes the Tops, plus the emotional distance to other members of the system, generates a counter-intuitive yet very common behavior on them: to absorb even more responsibilities and workload. This reflexive response of Tops deserves attention, since the reinforcing loop formed by their natural stress condition, the incremental workload, emotional distance with others, and absorption of additional responsibilities contributes to the destabilization of the system, as illustrated in Figure 3-3.

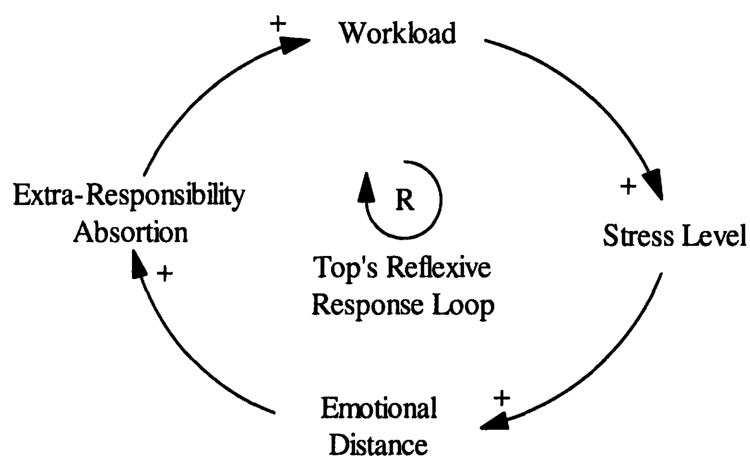


Figure 3-3 Top's Reflexive Response Reinforcing Loop

The third type of players, called the Middles, exist between the Tops and the Bottoms and usually carry out tasks of support or moderation between these two positions. Middles are usually in a constant stress condition, trying to understand, communicate and satisfy Tops' and Bottoms' needs at the same time. Being intermediary between the Tops and the Bottoms, Middles tend to lose independence of thought and action.

A second type of players is called the Bottoms. Bottoms are those who execute the specific tasks for the organization. Normally, they are concentrated on the day-to-day work rather than on mid-term and long-term planning activities. The stress that Bottoms commonly experience comes from a feeling of being ignored by the rest of "the system", and specifically by the Tops and the Middles. In some companies it is common that the employees express their dissatisfaction by complaining that management does not recognize their work or does not pay attention to what is happening on "the field". Often, the stress experienced by Bottoms leads them to blame others when a failure or mistake is found in the system. This reflexive response of Bottoms can generate unnecessary conflicts, diminishing the real capacity of the system to achieve its goal.

Finally, the Environmental Players are all those who depend on the system or are affected by it directly or indirectly. Environmental Players can be internal or external to an organization and are normally seen as the customers or beneficiaries of the system. These customers or beneficiaries are linked to the system by the fact that the satisfaction of their needs depends on what the organization delivers to them. Typically, the visibility that Environmental Players have with regard to the system is limited to the output of it, thus their judgment is normally based only on what the system gives to them, and whether it satisfies their needs or not. Thus, the kind of stress that is common to the Environmental Players is that they feel neglected by the system when their need have not been completely satisfied. The reflexive response to this situation is to stand back from the system and hold it responsible for the unsuccessful and unpleasant experience. Although this form of response is sometimes unavoidable, it is not necessarily the most effective way to solve or improve the situation for the parties involved.

It is important to mention that one person can play all four roles at the same time, depending on how the system is delimited. The reflexive responses of each player can damage the organization's stability, and therefore its success. Some of the measures that can be considered to balance the effects of these behaviors are presented in Chapter 6. The negative consequences of not taking care of the human factor in a social system can range from small misunderstandings at the operational level to big conflicts at higher levels that can potentially lead to disastrous results. A summary of Sale's concepts is shown in Figure 3-4.

PLAYER	ROLE	CONDITION	PREDICTABLE REFLEXIVE RESPONSE	EMOTIONAL DISTANCE	LEADERSHIP
Tops	Have overall responsibility for the system	Overloaded	Suck responsibility up to themselves and away from others	Tend to be separated from each other by specialization of function	Create responsibility throughout a system
Bottoms	Do the specific work	Disregarded	Blame others and hold "them" responsible	When bottoms disagree, their relations can quickly turn ugly	Be responsible for themselves and the system
Middles	Stand between tops and bottoms	Crunched	"Slide" and lose independence of though and action	Are more emotionally distant from each other than the other sets of organizational actors	Maintain their independence of though and action
Environmental Players	Depend on the system to do what it does for them	Neglected	Stand back from the delivery system and hold "it" responsible for what they are not getting that they feel they should	Depends on conflicting interests and other tensions	Make the system's delivery systems work for them

Figure 3-4 Sale's Four-Player Organizational Model

3.1.3 Four-Frame Organizational Model

The four-frame organizational model, developed by Bolman and Deal (2003), offers a framework to explore organizations from different perspectives. These perspectives are represented by the structural frame, human resources frame, political frame and symbolic frame. Studying organizations with this model allows finding strategic tendencies that define some strengths and weaknesses of the each organization under study, as well as intervention opportunities for improvement. The model suggests to be a valuable because it addresses a reasonably wide range of complexity involved in social systems –based on scientific knowledge and historical experience– but without ignoring the real necessity of managing information digestible enough for the generation of strategies for organizational transformation. Figure 3-5 present the four frames and the image of the organization associated to each of them. Figure 3-6, Figure 3-7, and Figure 3-8 present a summary of the model in more detail.

Four Frames

FRAME	IMAGE OF THE ORGANIZATION
1. Structural	Machine
2. Human Resources	Family
3. Political	Jungle
4. Symbolic	Theater

Figure 3-5. Bolman and Deal's Four Frames

The structural frame focuses on rational analysis of roles and responsibilities, as well as the structure and internal functions of an organization. In the context of product development, this frame leads to see the organization as a "machine", which receives the raw material and customer requirements as an input and generates and delivers consumable products as an output to the market. Here the analysis is concentrated in observing the size of this "machine", the elements interacting internally, the sequence and logic of the processes, and the very function of the machine. Intervention opportunities that can be found through this frame look for coherence and alignment between the different internal elements that form the organization so that it can achieve its intended goal.

Nevertheless, product development organizations do not consist only of electromechanical devices, computers, procedures and factories that as a whole generate products or services. They also contain emotions, fears, desires and thoughts; in other words, a product development organization would not exist without human elements, which are the main focus of the human resource frame of the four-player model. Understanding the individuals and work teams that are part of an organization is a critical task that must not be let a side for organizational diagnosis. In large product development organizations, such as big corporations and original equipment manufacturers (OEMs), human factors are generally accepted as an important element for the firm. However, bureaucracy within this kind of company may influence the effectiveness on how these factors are addressed. This is usually not a common issue in smaller organizations, such as startups or work teams that have worked on several projects with the same team members over time. In these conditions, there are not many formal and complex procedures, and the personal interactions are more direct and frequent than in larger firms. In sum, the human resource frame focuses on understanding individuals' needs so that the organization, which is visualized as a "family", can contribute to meet them.

In addition to the structure and the human factor of an organization, political issues have also an important role in the diagnosis of an organization. In the analysis through the political frame, the third of the four-frame model, it is important to recognize that there are internal and external stimuli that generate atmospheres of competition. These atmospheres can be both internal and external to the organization. One example of internal competition could be when the management of an organization announces an attractive project in which many people want to participate, but only a limited number of individuals will be able to do it. People in the organization experience a sense of rivalry, where the prize is to be selected for participating in the project. This sense of competition is also common outside of the organization. For instance, the pressure for obtaining greater presence in the market, brand recognition, and profit margins are the more known ways of competition in which most organizations find themselves involved. As in any competition, the focus is on "winning". Therefore, the political frame focuses on identifying the rules of game governing these competitions, including motivations and conflicting interests.

Finally, the fourth frame, the symbolic frame, addresses another element that influences people's decisions and behaviors besides goals, strategies, procedures, interactions, emotions and sense of competition. This element is the meaning and the faith, which are critical for success as well. The meaning of the existence of an organization or work team and the faith associated with that meaning are the main sources of inspiration and energy that guide individuals and communities to make their decisions. In an engineering organization, it is relatively unusual to take these "soft" elements into account as part of an organizational analysis, since technical aspects gather more people's attention. Nevertheless, these elements indeed define the philosophy, the vision and the core values of the organization.

Frame	Structural	Human resource	Political	Symbolic
Image of Organization	Machine	Family	Jungle	Theater
Disciplinary Roots	Sociology, industrial psychology, economics	Psychology, social psychology	Political science	Social and cultural anthropology
Frame Emphasis	Rationality, formal roles and relationships	The fit between the individual and the organization	Allocation of power and scarce resources	Meaning, purpose, and values
Underlying Assumptions	1. Organizations exist to achieve established goals. 2. Specialization and division of labor increase efficiency and enhance performance. 3. Coordination and control ensure integration of individual and group efforts. 4. Organizations work best when rationality prevails. 5. Structure must align with organizational gals, tasks, technology, and environment. 6. Problems result from structural deficiencies and are remedied by analyzing and restructuring.	1. Organizations exist to serve human needs. 2. People and organizations both need each other. 3. When the fit between individuals and organizations is poor, one or both suffer: each exploits or is exploited. 4. When the fit between individual and organization is good, both benefit.	1. Organizations are coalitions of diverse individuals and interest groups. 2. Differences endure among coalition members: values, beliefs, information, interests, behaviors, and worldviews. 3. All important organizational decisions involve scarce resources: who gets what. 4. Scarce resources and enduring differences make conflict inevitable and power a key asset.	1. What is most important is not what happens but what it means to people. 2. Activity and meaning are loosely coupled: people interpret experiences differently. 3. People create symbols for conflict resolution, predictability, direction, hope. 4. Events and processes may be more important for what they express than what they produce. 5. Culture is the glue that holds organizations together through share values and beliefs.
Action-Logic	Rational Analysis	Attending to people	Winning	Building faith and shared meaning

Figure 3-6 Four-Frame Model (1)

Frame	Structural	Human resource	Political	Symbolic
Path to Organizational Effectiveness	Develop and implement a clear division of labor; create appropriate mechanisms to integrate individual, group, and unit efforts.	Tailor the organization to meet individual needs, train the individual in relevant skills to meet organizational needs.	Bargain, negotiate, build coalitions, set agendas, manage conflict.	Create common vision; devise relevant rituals, ceremonies, and symbols; manage meaning; infuse passion, creativity, and soul.
Potential Issues and Areas to Improve	Rules, regulations, goals, policies, roles, tasks, job designs, job descriptions, technology, environment, chain of command, vertical and horizontal coordinating mechanisms, assessment and reward systems, standard operating procedures, authority spans and structures, spans of control, specialization and division of labor, information systems, formal feedback loops, boundary scanning and management processes	Needs, skills, relationships, norms, perceptions and attitudes, morale, motivation, training and development, interpersonal and group dynamics, supervision, teams, job satisfaction, participation and involvement, informal organization, support, respect for diversity, formal and informal leadership	Key stakeholders, divergent interests, scarce resources, areas of uncertainty, individual and group agendas, sources and bases of power, power distributions, formal and informal resource allocation systems and processes, influence, conflict, competition, politicking, coalitions, formal and informal alliances and networks, interdependence, control of rewards and punishment, informal communication channels	Culture, rituals, ceremonies, stories, myths, symbols, metaphors, meaning, spirituality, values, vision, charisma, passion and commitments
Central Tensions	Differentiation and integration Centralization and decentralization Tight boundaries and openness to the environment Bureaucracy and entrepreneurism	Autonomy and interdependence Employee participation and authority decision making Self-regulation and external controls Meeting individual needs and meeting organizational needs	Authority centered and partisan centered Similarity and diversity Empowerment and control Individual and collective	Innovation and respect for tradition Individuality and shared vision Strong culture and permeable culture Prose and poetry

Figure 3-7 Four-Frame Model (2)

Frame	Structural	Human resource	Political	Symbolic
Focus of Organizational Development	Aligning structure to organizational mission and purpose	Facilitating the fit between individual and organizational needs	Attuning the distribution of power, influence, and alliances to achieve organizational goals	Creating a vision and culture that support organizational goals and individual creativity
Change Agent Role	Analyst, organizational architect	Facilitator, teacher, coach	Political strategist, community organizer, advocate	Dramaturge, artist, poet
Possible Intervention Options	Restructuring infrastructure adjustments, vertical and lateral coordinating mechanisms, technology upgrades, environmental scanning, job design and redesign	Training and education, job and work redesign, hiring practices, job enrichment, workforce development, quality of work life programming, team building, process consultation, survey feedback, fostering participation, expanding of information networks, empowerment, diagnosis of the informal organization, norms, decision making, counseling, coaching.	Charting power relationships, adjusting formal or informal networks, redistributing decision making, managing diversity, altering communication channels, clarifying or forging agendas, developing arenas to surface conflict, building or dismantling coalitions, rethinking formal and informal reward systems, advocacy and education	Vision and values work, culture analysis, framing opportunities, reframing challenge or conflict, creating rituals or ceremonies, using organizational histories and stories, training on how to give voice to the vision and develop charisma, rewarding heroes and heroines, fostering humor and play
Intended Meta-Outcome	Clarity, efficiency	Satisfaction, motivation, productivity, empowerment	Competitive advantage, distributive justice	Passion, spirit, creativity, soul

Figure 3-8 Four-Frame Model (3)

3.2 Temporal Elements in Product Development

There are different existing ways to describe the temporal aspects of product development organizations. The format can vary, depending on the purpose and stakeholders that are involved in the design or use of the models or frameworks. For example, Ulrich and Eppinger (2004) offer a comprehensive description of product development process in 6 phases. Other studies and theories such as Design for Six-Sigma describe the process in more phases. Also, the history and the context of the organizations have generated adaptations of these product development models to facilitate the understanding and execution of product development according to specific necessities. Some examples of these are the Toyota Production System (Liker, 2004) and Ford Production System. The temporal notion of a product development organization is determined, to a certain extent, by the product development process that each organization adopts.

There are at least two important potential benefits of having a product development process model within an organization. First, it facilitates the organization and classification of tasks in a chronological sequence to create a product. The model implies the specific knowledge of the product that will be created and the value that it delivers, the tools that will be used, the people who will participate in the process and, of course, the purpose of creating that specific product. Second, it helps the individuals that comprise the organization to maintain a unified notion of the time during their normal activities; that is, a more abstract understanding of the time as a problem solving process. Taking into account these opportunities can make a difference on the capacity of an organization to evolve and to reach its higher mission.

3.2.1 Product Development as a Sequence of Actions

The Figure 3-9 illustrates the temporal notion that a product development organization can adopt with the purpose of establishing anchoring points in time.

This framework is a way to see product development as a sequence of actions, in which portions of time are assigned to do specific functions. The figure shows four phases: the Definition phase, Design phase, Validation phase, and Launch phase.

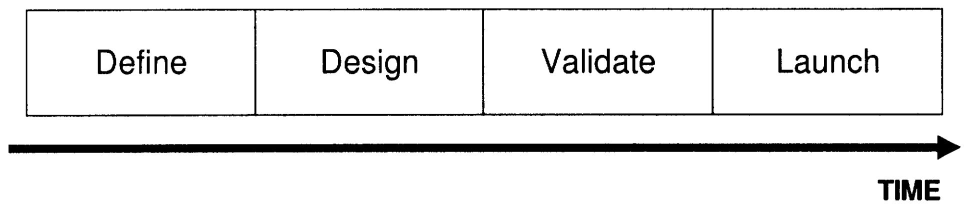


Figure 3-9. Four-Phase Model.

The Definition phase consists of integrating the accumulated knowledge to generate a world view. Based on this model, a mission to accomplish or a problem to solve is set. In the Design phase, the objective is to create the solution will solve the problem established in the Definition phase. In the Validation phase, the goal is to certify that the solution created in the Design phase meets the design expectations; that is to say, to certify that the design will indeed solve the problem if it is implemented. Finally, the Launch phase is the implementation of the solution created and certified in the previous phases and the confirmation of the accomplishment of the mission.

1. *Define* a world view and the mission to fulfill.

2. *Design* the solution.

3. *Validate* the solution with respect to the world view and the defined mission.

4. *Launch* the design into the real world.

From an operational standpoint, the four-phase model described above is related directly to the process for creating products –for which each organization implements its own product development process–. For example, if an organization used the PDP of Ulrich and Eppinger –see Figure 2-5–, the Definition phase could include phases zero and one –planning and development of concept, respectively–. The Design phase could correspond to phases 2 and 3 –design at level system and design to detail, respectively–. The Validation phase could correspond to phase 4 –test and refinement– and, finally, the Launch phase could be the phase 5 –production–.

3.2.2 Simultaneity of Influence on Short-Term and Long-Term Missions

Organizations develop different types of projects with diverse levels of complexity. Generally, the most complex projects require more development time than the projects with less complexity. In addition, it is required to accomplish several smaller projects in order to develop one bigger and more complex project. Figure 3-10 shows an example of this situation.[4] Here, a project is represented in the time line as a series of the four phases: *Define, Design*, *Validate* and *Launch*. Nevertheless, since each of these phases represents in itself a task or a problem to solve, the organization, as part of its problem solving process, must pass through another series of four phases to execute each of these phases. These processes can be explicit in some form of documentation of the project or implicit as part of mental process of the individuals that execute the tasks.

[4] This model can be considered as a simplified adaptation of Boehm's Spiral Model.

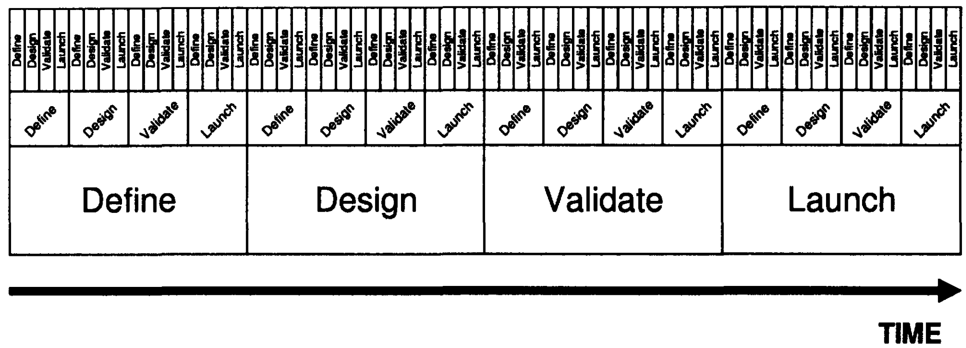


Figure 3-10. Four-Phases-in-One Model

The concept of simultaneity of influence of a task comes from the fact that a specific action contributes progress of all the effective projects at the time of the execution of that action. It is important to mention that for an organization, a project not necessarily means the complete development of a product. A project can be something more specific like designing the tools necessary to develop only a component of the product. Also, a project can be something broader like creating a new market or improving the infrastructure of a region. In these cases, the development of a product can be a complementary part of that greater project. A project in product development could have a scope as large as the organization's mission, or as small as the function of a single employee.

3.2.3 Common Issues in Time Spectrum

Product development organizations usually have several challenges. Some of these include the organization and classification of tasks in a chronological order and the generation of a unified time understanding within the organization. More specifically, organizations have to find the way to define the time that will be allocated to each phase of a project. This depends on the level of complexity of the project and the capacity of the organization to manage this complexity. A second challenge is related to the synchronization of projects. A product development organization can –and usually does– work in different projects simultaneously. These could be different product lines that must be launched into the market at the same time or at different moments, but that require parallel development. The challenge of the synchronization is in accommodating the different projects in a time line in such a way that resources are utilized efficiently –for example, by using common tooling, transferring the knowledge from one project to another, etc.–. Finally, a third challenge is to align all the small projects to the greater project of the organization, that is to say, to its mission. To generate and to maintain a temporal association of each project to the accomplishment of the mega-project –and of each of its intermediate stages– contributes to the coherence between the objectives that have been set for short and long term.

3.3 The Global Nature of Product Development Environment

3.3.1 Globalization as the Main Scenario for Product Development

Today globalization represents an important set of attractive opportunities and an unavoidable combination of challenges and uncertainties. The global economy has opened many doors to several players in the world for participating and contributing actively to specific business arenas. Globalization can be understood as "the changes in the international economy and domestic economies that are moving toward creating one world market" (Berger, 2006) It has become so powerful that it is leading us to make traditional national borders almost disappear and putting the industrial activity as a determinant factor for many decisions in the modern world.

These changes in the international economy, product of a series of political, economic, and technological stimuli that have taken place since the early 1980s, are drastically altering the way in which product development practices are articulated nowadays. Berger (2006) argues that the most important of the changes under way as part of globalization could be the emergence of some of the developing countries as major challengers of the advanced economies. At the same time, the notion of globalization raises several attractions and threats: some people think that it raises their standard of living and some also believe that it is bad for employment and job security. These perceptions –which are not necessarily wrong or right– are some of the components that affect the decision-making in product development systems as well. Therefore, some of the most relevant questions affecting product development systems include: which activities to keep within the own organization limits, which to outsource to other firms, which to keep within the own home countries, and which to locate outside borders. Each product development organization is in the need to answer these questions and implement the corresponding actions in order to be competitive.

The notion of "competitiveness" in product development and how to become a leader in a specific industry or market might be susceptible to several approaches. Many business and engineering studies present different descriptions of competitiveness and propose different sets of best practices to become a leader based on experience in specific areas. However, more recent studies suggest that there is no single right answer for these questions. It is generally agreed that the notion of competitiveness relates to what the organization can do perform better than any other organization; however, "there are different possible ways for firms to do well under the constraint of the great new pressures to adapt rapidly to international markets, [and these pressures] do not dictate a single best strategy for surviving and growing, even for firms in the same industries." (Berger, 2006) Some examples to illustrate this will be presented in Chapter 4.

3.3.2 Cultural Values and Behaviors

Cultural differences affect product development practices and strategies. Nowadays, even the smallest corporations have global customers, partners and operations. These corporations do not only have to deal with professional and corporate culture issues, but with those emerging from the national culture differences as well. This may represent a significant challenge for product development organizations because cultural values and beliefs have a major influence on behavior and the decision-making processes. Also, "as markets globalize the need for standardization in organizational design, systems and procedures increases. [At the same time, managers have] to adapt their organization to the local characteristics of the market, the legislation, the fiscal regime, the socio-political system and cultural system" (Trompenaars and Hampden-Turner, 1998). This is a "global" versus "local" dilemma that most of the organizations are facing today in their different hierarchical levels. Therefore, cultural issues are another factor that has to be taken into account for analyzing organizations and driving product development practices and strategies.

Instead of focusing on the notion that there should be only one best way of solving a problem that applies for everyone, having more knowledge of cultural patterns seems to be more effective for analyzing organizational strategies. This truth is because practices do not come without a meaning for the people that execute them. One single practice may have several meanings for different people, and thus, may yield different results. Similarly, different practices may converge in a similar meaning for people and yield similar results. The evaluation of the results may also differ from culture to culture. Identifying some of the key cultural patterns to explore the diversity of problem-solving approaches helps to find more suitable strategies for an organization in a specific time-space-environment scenario.

From the arenas that cultural studies have explored, there are at least three major issues that seem to be useful for analyzing organizations. One of them is related to the relationships with people, and it has to do with the different sets of values, beliefs and motives behind people's behaviors when interacting with others. This first category can be analyzed from different dimensions; such as, individualism versus communitarianism, neutral versus emotional, and achievement versus ascription.

The second major issue to be considered is the attitudes to time, that is, the different ways of looking at time. How people look at time affects directly the decision-making process for defining and implementing organizational strategies and may determine some bias toward short-term or long-term perspectives. Finally, the third major issue is the attitude to environment. "Some cultures see the major focus affecting their lives and the origins of vice and virtue as residing within the person. Here, motivations and values are derived from with. Other cultures see the world as more powerful than individuals. These people see nature as something to be feared or emulated." (Trompenaars and Hampden-Turner, 1998)

In sum, addressing the major cultural issues provides valuable information for understanding and managing product development in a globalizing world. Cultural values lead to behavioral tendencies and these, in turn, contribute to the characterization of organizational profiles. The way people tend to relate with other people, how they conceptualize the time horizons and the interpretations they give to the phenomena that occur in their environment constitute an intangible yet influent factor in business practices and management. "The more fundamental differences in culture and their effects may not be directly measurable by objective criteria, but they will certainly play a very important role in the success of an international organization". (Trompenaars and Hampden-Turner, 1998).

3.3.3 Global Issues and Challenges

Many issues and challenges that affect human beings as a whole have a great relevance in the contextual analysis of product development activity. In a globalizing world, socio-political, economic, and other scientific studies have brought afloat issues of different nature that affect not only one economic sector, community or firm, but all those that inhabit this planet. At the same time, it is known that, by definition, the foundation of the existence of engineering as such is to solve problems for the well-being of the humanity. Therefore, these phenomena that repel in the welfare of the human being represent a set of challenges that engineering, including product development, should not overlook.

The increase in world population and the concentration of it in urban zones, for example, has had several consequences worldwide. In these conditions, the efficiency in the use of resources –e.g. water and electricity– has had influence on how to address specific needs; such as communication, transportation, employment, housing, and security issues. The quality of air and water has also become an important concern in these areas with intense human activity. Product development organizations exist in this environment, attending to the needs generated by these conditions. No matter what the political or cultural bias can be generated by these issues, for product development organizations, demographic conditions in the world have effect not only on the establishment of manufacturing and engineering sites, but also on regulations, business strategies, and specific customer needs that end up in the definition of the product that will be developed and commercialized.

Global warming is another challenge that the international community has raised as a critical sustainability subject to be addressed. Industrial activity, buildings, and transportation means are listed as the top offenders, among others, due to the harmful emissions to the atmosphere that these produce. It is here again where the integration of the scientific knowledge and technologies play an essential role for the solution of these problems. It is a matter for engineering communities to incorporate sustainable and economically feasible solutions into business operations, infrastructure and products.

Finally, the subject of health and security has also caught the attention of many international organizations. It is clear that implementation of new scientific and technological solutions has increasingly being desired by society to offer greater levels of security and health to everybody. Hence, the role that engineering organizations plays in this subject is vital.

3.4 Using the Framework for Organizational Diagnosis

3.4.1 Identity Recognition and Analysis

One of the benefits that organizational diagnosis offers is to have the opportunity to explore and to discover the critical characteristics by which the organization under study is defined. These characteristics are determined by the people, processes, tools, and products and the set of goals that comprise the organization and also constitute the identity of it. Additionally, organizational diagnosis allows making a comprehensive analysis of the current state of the organization and identifying those conditions that are acknowledged to move away from an ideal state. Generally, quantitative information is desirable to characterize these conditions. However, this is not always possible or advisable. Sometimes it is valuable to consider some factors that depend on a qualitative evaluation such as cultural studies. Consequently, the diagnosis allows recognizing the identity of the organization and the current conditions that can be modified or reinforced in order to reach a desired state. In other words, the diagnosis can serve as a means for identifying the role of the organization in the world and the value that it is supposed to deliver.

3.4.2 Unification

Organizational diagnosis also facilitates the generation of a common understanding of the reality within the people who are in the organization being studied. People from different layers of the organization can participate and share information related to the state of the organization and how they contribute to it. Then, people can build on the knowledge provided by the original diagnosis and generate a collective yet individually conscious notion that may contribute to better communication practices and teamwork. Thus, the diagnosis helps to generate a harmonization process where individual agendas and expectations are associated to the vision and goals of the organization.

3.4.3 Learning and Evolution

In order to continue existing in a highly complex and dynamic environment, product development organizations are in the necessity to be constantly alert of what happens around them and also what occurs within themselves. One of the key factors for achieving this purpose is the learning capacity that organizations can develop. The final intent of an organizational diagnosis is that people acquire the knowledge and abilities to perceive different signals from the surroundings, identify the key interactions that happen between themselves and the organization, and take actions to improve. In other words, the organization must able to generate its own transformation opportunely in order to continue existing and deliver the intended value to the world. An effective diagnosis would be expected to serve as an enabler for the generation of actionable strategies that allow this organizational transformation.

3.4.4 Utilization of the Framework

The following generic steps can be followed for utilizing the framework presented in this chapter:

1. *Define the system under study.* Identify the key stakeholders of the system and associate them to one system level and role. Identify the temporal and contextual aspects that affect the system.

2. *Identify potential issues*, classifying the issues by system level and by frame.

3. *Design possible solutions* by identifying actions that compensate the predictable reflexive responses of each player.

The first step for initiating the analysis with this framework is to define the product development organization being studied. Then, the critical elements in the space spectrum are identified; that is, the three levels of system decomposition as described in section 3.1.1., and the stakeholders that occupy each level. In this case, the *enterprises level* can be entirely occupied by the organization being studied. Also one of the four roles described in section 3.1.2 – Tops, Bottoms, Middles, and Environmental Players– is associated to each stakeholder in each system level. At the regional level, the organization plays the role of *Middles*, and from a global level perspective, it plays the role of *Bottoms*. The organization can be considered as an *environmental player* for systems that are beyond the scope of the study.

Once the key stakeholders that play each role are identified, the next step is to observe and identify the potential tensions and issues that can be found in the organization from the structural frame, human resources frame, political frame and symbolic frame perspectives, taking into account the temporal and contextual considerations. The nature of the issues varies depending on the system level from which the observation is done, thus classifying the issues by frame and by system level facilitates the analysis.

Finally, the third step is to generate improvement actions for the issues found. Improvement actions or strategies are generated for each role within the organization under study; that is, at least one action is created for each of the four players –Tops, Bottoms, Middles, and Environmental Players– in order to attack one issue. In other words, the improvement actions are oriented to compensate the predictable reflexive responses of each player when facing the issue. Identifying a set of improvement actions for addressing each issue is the ultimate goal for this study.

Assess the level of complexity of your system and adjust the level of the components' autonomy.

Chapter 4

DIRECTIONAL METRICS FOR PRODUCT DEVELOPMENT ORGANIZATIONS

Exploring of the Global Environment

The incorporation of sustainable factors into the definition and use of metrics may imply the utilization of proximate measures that are trajectory measures toward value, rather than absolute and punctual numbers. Data coming from benchmarking and cultural studies are used as examples of external metrics, while cost, time, and scope are considered internal metrics that drive most of decisions in product development organizations. Options of how to manage internal and external metrics are also explored in this chapter. The challenge is to identify metrics that most closely represent the value delivered, while understanding the limitations of these metrics in order to envision future system improvements.

4.1 External References for Product Development Organizations

4.1.1 Benchmarking: Organizations Affecting Other Organizations

Many times, the use of metrics in an organization is affected by other organizations. When product development organizations look at what other organizations are measuring –this happens very often when benchmarking studies are conducted– and perceive that another organization is the best in class in a specific area, they often attempt to adopt the metrics utilized by that best-in-class organization and even imitate the same practices. However, changing metrics through benchmarking can have advantages and disadvantages. Among the advantages: it provides a means to identify who is the best in class in one specific area or activity, and it provides an opportunity for the rest of the organizations to learn something new. The disadvantage comes when an organization impulsively tries to imitate what the best-in-class did without enough thought. While there might be some exceptions, organizations that are affected by other organizations in this way rarely achieve the same results as the best-in-class organization had achieved.

To identify which is the best product development approach in the world is not an easy task. Several studies try to answer this question utilizing different criteria, providing potentially useful information for the organizations.

One study suggests that organizations that have chosen two opposite strategies can lead to equally positive results. For example, in the electronic components and telecommunications industry in the United States, Cisco out-sources all manufacturing, while Intel does almost all manufacturing in-house, and both had a very similar profit/revenue ratio in 2004, 20 percent and 22 percent, respectively. (Hauser, 2001)

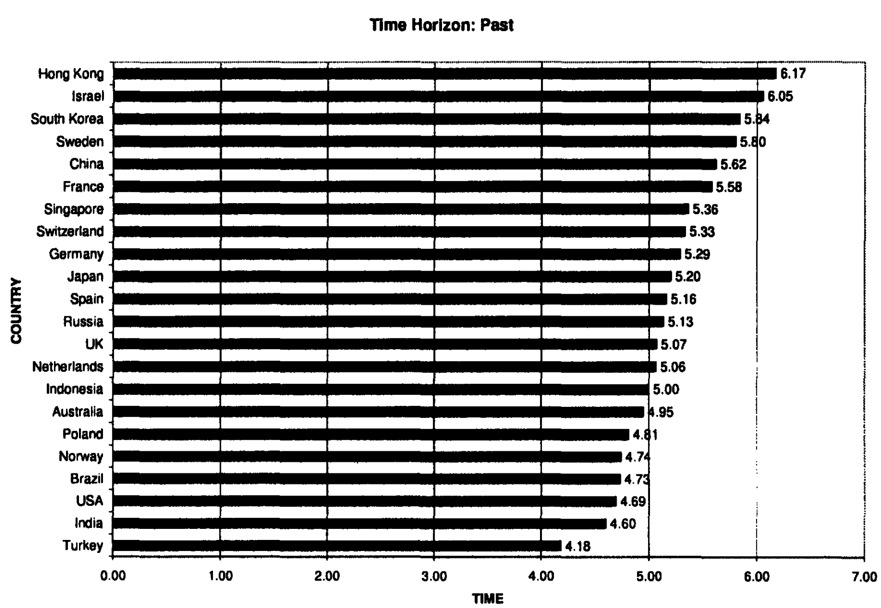
The apparel industry shows another example. The fastest growing European clothing retailer, Zara, which tripled its net profits over a period (1999–2004), makes more than the fifty percent of its products at its home country, Spain. Meanwhile, American Apparel, whose most of its manufacturing takes place in low-cost countries, doubled its workforce in the year after 2004. (Berger, 2006).

At the same time, similar strategies implemented in different places have yielded opposite results. At Dell, for example, personal computers have been the heart of the company that is growing by $6 billion to $7 billion a year, while IBM suffered of significant losses year after year until finally it decided to sell off its personal computer division in 2004. Then, IBM chose to focus on its services business and on the fast-tech segment of electronics, where it has found an important niche market (Berger, 2006).

From the cases described above, two conclusions can be considered. First, there is no one strategy for all organizations to succeed. Second, since each organization has different capabilities to assimilate and execute a strategy, the purpose of benchmarking studies must be defined carefully. Thus, the strategic metrics utilized by some organizations are not necessarily the best for other organizations. It seems to be easier for a company to get started if it can focus on its own particular strong point –this could even be one single stage of the development process of a product and not a whole process– and buy the other services. As an example, because Apple was able to build an iPod using components already being made by many other companies and assemble it using contract manufacturers, it could bring its digital music player to market very rapidly (Berger, 2006).

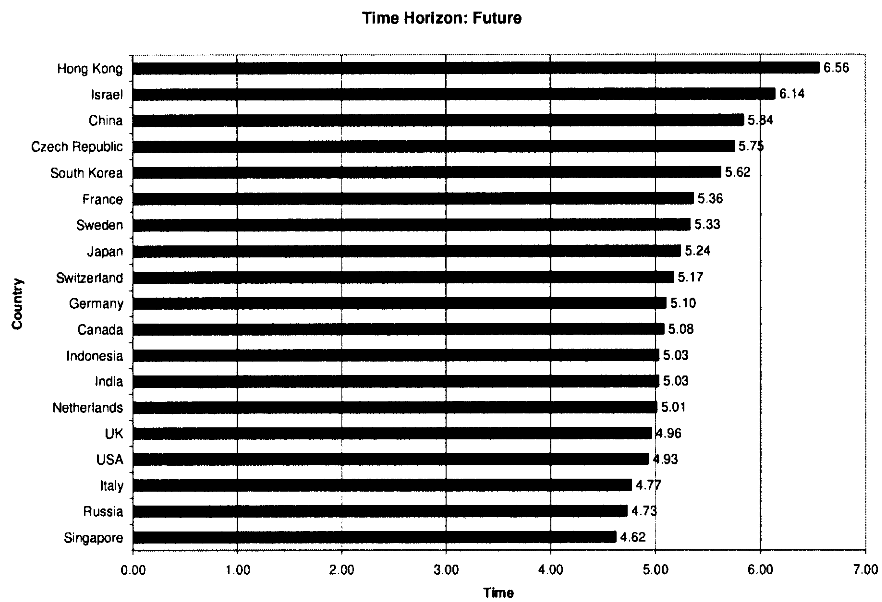
4.1.2 *Cross-Cultural Leadership and Profiles*

Product development organizations are structured and operate in accordance with how they understand time. Kluckhohn and Strodtbeck (1960) identified three types of cultures: present-oriented, past-oriented, and future-oriented. Present-oriented cultures are basically timeless, tend to have no traditions and ignore the future. Past-oriented cultures are usually concerned about keeping and protecting the traditions in the present, while future-oriented cultures tend to look for a more desirable future and ways of realizing it. In an organization, planning activities, strategies, objectives and goals are all future oriented. However, the scope of these orientations is what can make a difference from one organization to another. Trompenaars and Hampden-Turner (1998) show that there are important differences between long-term past orientation, the perceived extension of the present and a long-term view of the future. A selection of scores is presented in Figure 4-1 and Figure 4-2.



0 –seconds, 7 –years

Figure 4-1 Past Time Horizon



0 –seconds, 7 –years

Figure 4-2 Future Time Horizon

Another dimension that determines organizational operations is the uncertainty avoidance, which refers to a "society's discomfort with uncertainty, preferring predictability and stability" (Schneider and Barsoux, 2003). The level of uncertainty avoidance can provide referential information about the level of "aggressiveness" that certain organizations can incorporate in their strategies in relation to others and their willingness to change. Hoftsede (2001) combines this dimension with the power distance, which is the extent to which a society accepts the unequal distribution of power in the organization (Schneider and Barsoux, 2003). Figure 4-3 illustrates the country rankings on each dimension.

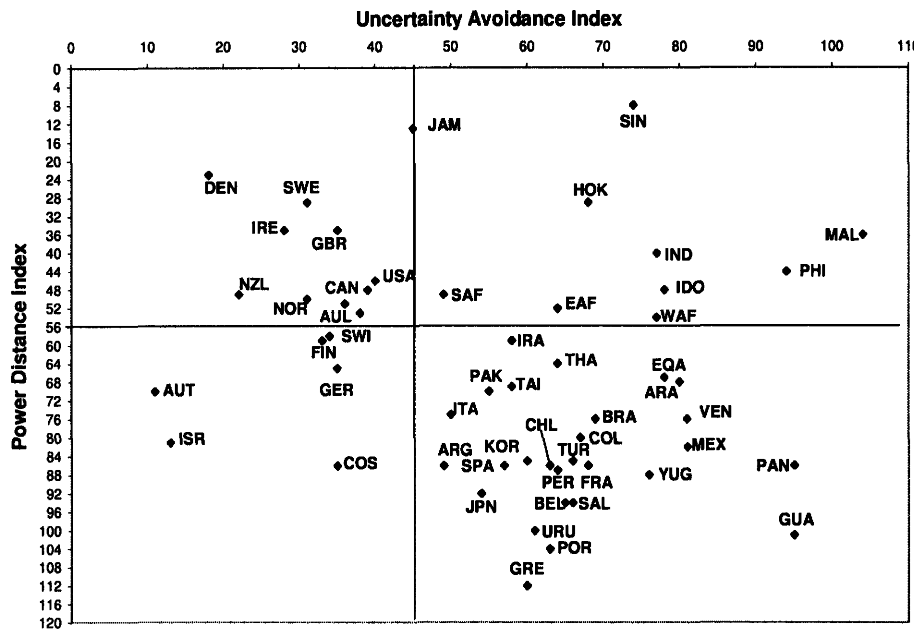


Figure 4-3 Hofstede's Map of Power Distance vs. Uncertainty Avoidance

4.2 Internal Metrics for Product Development Transformation

4.2.1 Scope, Cost, and Time

In product development, many kinds of metrics are used to measure different aspects of the development activity. Some measure the product design characteristics, while others are used to measure the resources that the organizations allocate to each activity. In recent years, some product development organizations emphasize that measuring the product development time is critical to success, since it affects the competitiveness of the organization in the market. With the use of all these metrics product development organizations attempt to become even more efficient, competitive, and successful in achieving their goals.

In system architecture, one thing that seems to be essential for accomplishing a successful project is to visualize the natural trade-off created by three major concepts: scope, cost, and time. Figure 4-4 illustrates this trade-off. First, *scope* refers to the amount of work or the quality expected to be achieved. Product definition, functions, specifications, and performance can also be considered in this category. Second, *cost* includes the physical and economic resources required or invested to accomplish a specific project. Fixed overhead cost and variable cost are examples of this type of metric. Finally, *time* measures the amount of time that the organization takes to accomplish the project. The trade-off occurs because in general organizations want to accomplish more things –scope– with less resources –cost– at a faster rate –time–. How a product development organization solves the trade-off formed by this iron-triangle seems to be determinant of their success.

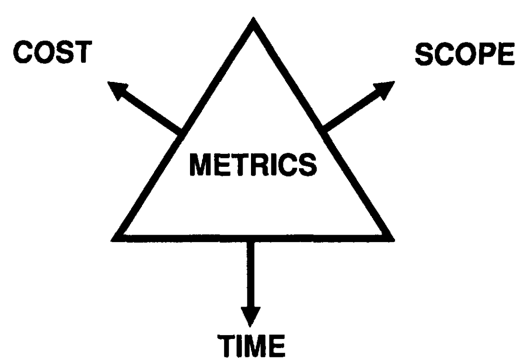


Figure 4-4. Iron Triangle: Cost, Scope, and Time

4.2.2 *Using Metrics with Flexibility*

Product development organizations nowadays seem to be rewarded by the market based on their ability to perform against a set of strategic metrics that involve project scope, time and cost. Hauser (2000) proposes a method to work with these three aspects by adding flexibility to the organizations. The method proposed by Hauser consists of fine-tuning a firm's relative emphasis on one metrics at a time. This method seems to be effective for solving the iron-triangle problem by adding flexibility in product development decision-making process.

The concept of flexibility in the use of metrics resides in having the ability to prioritize *Scope, Cost,* and *Time* so that the total benefit is maximized. Giving a relative emphasis on one metric at a time does not mean that one must be pursued in the exclusion of all other metrics. A very broad analytic description of Hauser's method is as follows. The first step is to identify the *actions* performed by people in the organization. Second, choose metrics that are correlate to profit –or another representation of high-level system goal– are measurable, and are affected by the actions. Third, assess which metrics have more impact on maximizing profit; then, assign a weight to each metric. The result is a set of prioritized metrics associated to specific product development tasks.

Giving relative emphasis on only one major metric at a time –for example, giving more emphasis on reducing development time rather than reducing cost or increasing project scope– has shown some advantages. For example, Xerox is known for having implemented a successful time-to-market process that reduced cycle time by a factor of 2.5. However, in the 1980s Xerox shifted from a single goal of return on investment (ROI) to a focus on customer satisfaction, generating a successful transformation to become a better competitor in the international market (Menezes, 1994). One benefit of this kind of strategy is that people within the organization can work and interact with more focus on the company's priorities, facilitating decision-making at all levels. Also, the organization becomes more sensitive to its environment, enabling it to react faster to an emerging need or change the course to accomplish a more ambitious goal.

4.2.3 Product Features and Organization Features

Nowadays, the most accepted and generalized means for evaluating companies is the profitability of the firm. For evaluating and improving product development activity, however, profit might not be the most beneficial or direct metric to use because there might be internal and external forces –such as changes in market conditions or financial investments in capital– that can affect the profitability of an organization, making it difficult to identify the contribution of product development activity.

For example, some financial incentives that are implemented with the purpose of increasing sales volume of a product might help to increase the profit of the company. However, for an engineering organization, it generates noise because the increase in profits does not necessary reflect that a product has a higher performance or that was developed with less resources or time tan others. Therefore, profit as a means for evaluating organizations, is not the most predictive metric for evaluating product development activity.

Perhaps one step behind the economic value or profit of a product development organization is the value contained in the product development work, which ultimately is reflected in the product created. Thus, one way to measure product development performance could be based on the characteristics or features of the product. This would provide a more realistic reference of what the organization is delivering to the market. If the product indeed solves a specific problem or satisfies a specific need, then it would be possible to obtain a quantitative sense of the value of a product development organization by, for example, calculating *product features per resources allocated* or *product features per development time.*

The approach described above would work well if only one organization was responsible for the whole product development process and product. The reality is that product development is becoming more fragmented, which means that different organizations all over the world are responsible for specific portions of the process of creating a product. This implies that there are more product development organizations that do not have complete control over the finished product that the end customer receives or that do not even deliver a product but a specific engineering service such as testing and validation activities. In this situation, measuring product development only by product feature might still have some limitations.

One approach to compensate this limitation is to incorporate the service aspects of the organization when managing metrics; that is, to consider the *description of the job performed plus the product features affected.* The description of the job performed is a description of one specific portion of the value stream of the end product, and the product features affected are the number of product variants that are affected by the job. This approach offers two potential advantages. First, it helps to align organizations toward the value chain of the end product, allowing stronger focus on customer needs. Second, this approach can be cascaded within an organization to an individual level.

4.3 Global Priorities as Unifier of Internal and External Metrics

Product development organizations are part of other systems. Thus, ideally there should be a means for measuring the contribution of these organizations to the whole system. In other words, there should be a way for the metrics that are internal to each organization to map to those that are utilized for measuring the system at the highest level. The most accepted and available means nowadays are the economic indicators. However, non-economic indicators might also be helpful to visualize the contribution of an engineering organization to the world. In this sense, measuring the system in terms of its capacity to solve specific problems –those that affect the wellbeing of humans– might be a way to improve the alignment of product development organizations toward the goals and objectives of the planet.

For example, one of the global priorities stated by the United Nations[5] is the assurance of environmental sustainability. This issue is described in terms of specific indicators that include: the proportion of land area covered by forest, energy use –kg oil equivalent– per $1 GDP, carbon dioxide emissions, proportion of population with sustainable access to an improved water source, and others. Paying more attention to these kinds of metrics may help to evaluate a product development as an engineering entity in terms of their potential to impact the highest priority issues in the world.

In the next chapter, an example of the applicability of the framework presented in this chapter will be presented.

[5] United Nations Millennium Development Goals.

Make a system that inspires living beings to live with or in it.

Chapter 5

FRAMEWORK TEST

Looking at an Automotive Product Development Organization

The main purpose of this section is to present an example of the applicability of the framework described in Chapter 3. For this example, an automotive product development organization was selected. While this chapter does not provide a complete description of the current state of the organization being studied, it provides an example of how an organization can be analyzed from spatial, temporal and contextual perspectives, using the framework proposed in this document. The information presented in this example was obtained from public and non-public documentation of the company as well as from interviews with management and employees of the organization.

5.1 Reframing the Organization

The product development organization selected for this framework test is an automotive product development engineering organization (PDEO) of a U.S. automaker with facilities located in Mexico. For simplification purposes this organization will be identified in this document as *PDEO*. As many other firms today, this automaker is redefining its strategies for globalizing its product development operations and remaining competitive in the twenty first century. The PDEO is part of this process, which provides a good opportunity for re-thinking the current state of the organization and establishing strategies that help the organization to meet these global business needs.

The PDEO is comprised of about 210 engineers, and has the expectations to grow during the coming years. Traditionally, the product development activity of this PDEO mainly consisted of making adaptations of vehicle designs created in the U.S. and Europe for local markets during the last ten to fifteen years. In recent years, however, the PDEO has had more involvement in the earlier stages of the vehicle development process, even for some vehicles commercialized in markets outside of Mexico. The PDEO, being located in a developing country, has received more attention by the corporation as the globalization of the business has progressed.

5.1.1 Spatial Considerations

The PDEO occupies the enterprise level –level 0– of the system decomposition model described in Chapter 3. As a product development organization, it is structured with a top management layer, formed by directors and senior managers; one or two middle management layers –depending on the area– formed by younger managers and supervisors; and the engineers, who execute and support the design and development activity. As an engineering organization, the PDEO has its own supporting departments, such as: IT, Purchasing, Marketing, and Human Resources, among others as well.

Within the level zero of system decomposition model, it is possible to find the four roles –Tops, Middles, Bottoms, and Environmental Players– described by the four-player model described in Chapter 3. The top management, mainly formed by directors and senior managers, are the *Tops* of the PDEO. They are responsible for the enterprise to function as intended. The engineers and supporting personnel are the *Bottoms* of the organization. They execute specific tasks in order to get the product development work done. Between the top management and engineers, are engineering teams and management teams, whose one of the main functions is to facilitate the communication between the top management and the engineers. They organize the strategic information generated by the top management layer and cascade it to the rest of the organization. Conversely, they also capture the information generated by the engineers –for example, work progress, concerns and proposals– so that the information can be manageable by the directors and senior managers. These engineering teams and management teams are the *Middles* of the PDEO. Finally, specific people and organizations inside or outside of the PDEO such as customers can be considered the *Environmental Players* of this enterprise level system.

The PDEO is one of several product development organizations throughout the world that are part of one larger automaker in the United States. Thus, the PDEO must align its operations with corporate standards and strategies, which may include product concepts and specifications, engineering tools, communication channels and protocols between people, financial and strategic goals, and the product development process itself. Even though the PDEO has a certain degree of autonomy on the definition and execution of some of its internal operations, it always has to assess the impact on the corporation.

The corporation can be considered one element in the level one of the decomposition model, since the PDEO is a component of the multinational corporation. Additionally, the PDEO, located in Mexico, has to comply with local norms and governmental requirements in order to operate. Therefore, the local governmental entities can also be included in the level one of the decomposition model.

PDEO's human resources are mostly comprised of local workforce. It is common that the organization interacts with local recruitment agencies and universities in order to communicate PDEO's needs –e.g. required skill sets and engineers' profiles– and contribute to the productivity of the local workforce. In this sense, recruitment agencies and universities are also level one elements of the decomposition model.

The stakeholders identified in this level one system perform specific roles that can also be classified using the four-player model. The corporation and local government are the *Tops* of the level one system, while the recruitment agencies and universities can represent the *Bottoms*. The PDEO stands as a *Middle* of this system, acting as an intermediary for meeting the needs of government and corporation on one side and the local workforce on the other.

When looking at level 2 of the decomposition model, the elements in level 1 and level zero seem smaller. Level 2 is the global system that includes practically a wide range of activities. The responsibility of integrating these activities so that the system functions as a whole –i.e. the responsibility of the *Tops*– is being absorbed by international institutions and committees, which develop international policies and standards as well as define long-term goals for global advancement. The PDEO becomes now an element –i.e. the *Bottoms*– that executes a specific function, and the local governments and corporations are in-between. The *Environmental Players* are the people who are benefited from the system in one way or other. This is summarized in Figure 5-1.

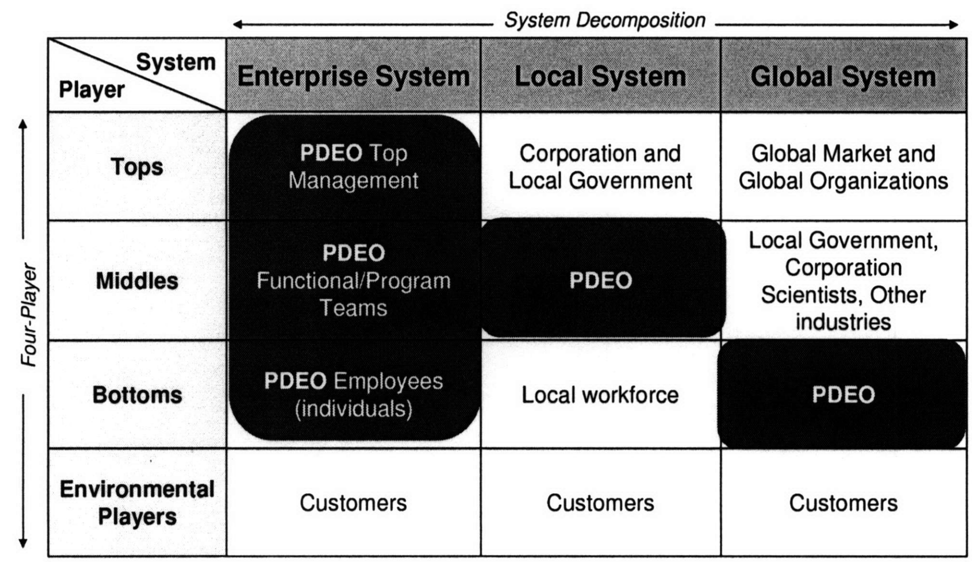


Figure 5-1. Framework Test (Spatial Spectrum)

5.1.2 Temporal Considerations

There are two major temporal considerations that affect the PDEO as an organization. The first component is the product development process. Two years ago, the corporation launched a global product development system with the purpose of improving the existing product development process and unifying the way different business units of the corporation in the world operate, including the PDEO. Among other things, this product development system establishes a set of milestones that span from product definition to launch. There are several milestones during development process that includes the design of the sub-systems and components of the vehicles, as well as the validation of each of them. The process is scalable in time, which means that the duration between the milestones can be adjusted to the level of complexity of the product that is developed.

The product development process allows for the visualization of the four phases –Define, Design, Validate, and Launch– for a product line, as well as the existence of these four faces within each individual phase. For example, for a vehicle to be defined, designed, validated and launched, each sub-system of the vehicle –e.g. powertrain, chassis, electrical, body interior and exterior– must be defined, designed, validated and launched. Moreover, all components of each sub-system must also follow this process in order to produce a reliable and robust sub-system. Therefore, each individual action taken to develop one component directly impacts the development process of the whole product line of the corporation.

The second temporal consideration is the PDEO business plan. One of the most relevant plans for the PDEO is a 5-year business plan that was created for better aligning PDEO operations to the short-term and long-term objectives of the corporation. This plan includes the definition of specific product development strategies, the core competencies that the PDEO will develop in the coming years, as well as the training plan that must be followed to achieve it.

5.1.3 Other Contextual Considerations

As described in previous chapters, the product development activity is fragmenting into several instances and distributed across multiple organizations, including business units and suppliers all over the world. PDEO is not excluded from the effect of this globalization process. For this PDEO in particular, being located in a developing country, has the potential to have a greater influence on the global business than it has had in the past. The PDEO is considered a low-cost product development center, which represents an option for the corporation to move some of the development activities to this organization.

Another contextual consideration is the cultural profile of the organization. It can be said that the PDEO, located in Mexico and comprised mostly of local workers, is immersed in this culture. According to Trompenaars and Hampden-Turner's studies, Mexico would have a relatively longer time orientation –both past and future– than, for example, the United States.[6] The U.S. perspective could be explained as follows: "because (...) individuals cannot do very much about the *distant* future –there are simply too many events that could occur– the USA's idea of the future is short-term, something controllable from the present. (...) Success now causes greater success in the future". (Trompenaars and Hampden-Turner, 1998). In contrast, Mexico seems to be more similar in time orientations to counties like Japan, Germany, and China, where future opportunities for these cultures are perceived to be more connected to the success of the past.

[6] Although the numerical values of the time orientation for Mexico are not shown in the graphs, a case study described by Trompenaars and Hampden-Turner suggests a reasonable compatibility between Spain, France , and Mexico as far as time orientation goes.

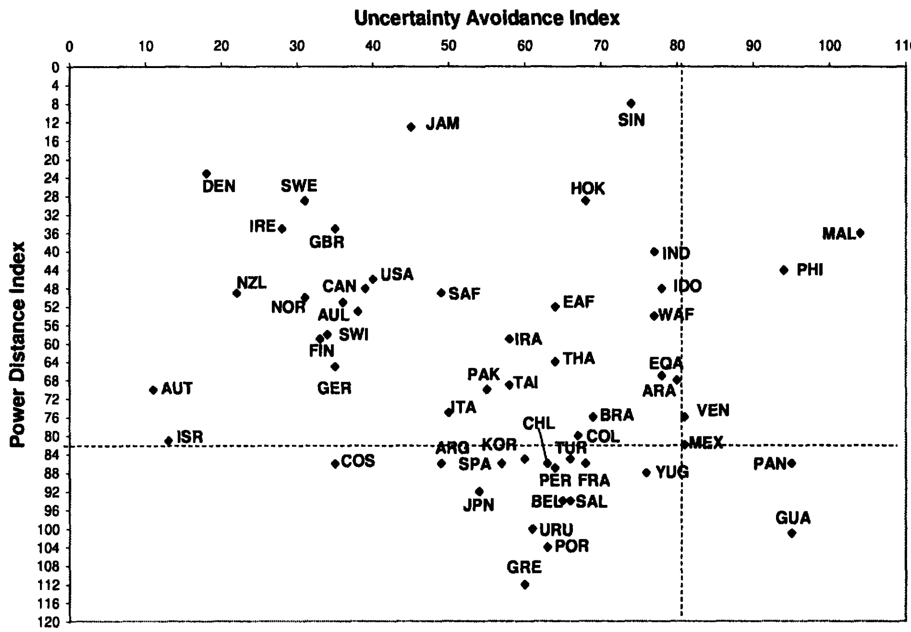


Figure 5-2 Relative Power Distance and Uncertainty Avoidance (Mexico)

Uncertainty avoidance index and power distance index are other factors that distinguish Mexico from some other cultures. For example, the uncertainty avoidance level of Mexico –which is very similar to countries like Turkey, Argentina, and Brazil– is lower than Japan, and much higher than the United States and Germany. Additionally, the power distance level of Mexico –which is similar to Venezuela and India– is higher than all these countries, specially with respect to the United States, Great Britain and Germany. In sum, Mexico has a culture that have relatively high uncertainty avoidance index and high power distance index, along with countries like Japan, Turkey, and many other Latin American countries, which may represent both advantages or disadvantages in certain situations. This analysis may explain one of the best known concerns among the employees of the PDEO with regard to its interaction with the corporation: a preoccupation for the uncertainty generated by the "too variable" future plans and directions that are "passed down" from the corporation, which jeopardize the stability of the current job.

Finally, the third contextual consideration relates to the global agenda of problems to solve by the international community. The agenda includes a long list of global issues with debatable priorities and interpretations, which are not included in the scope of this research. Instead, only one issue has been selected to illustrate the inclusion of this consideration into the analysis of the PDEO as an example.

One of the global agenda items, established in the Millennium Development Goals (MDG) of the United Nations, is the assurance of environmental sustainability. One of the targets related to this goal is to "integrate the principles of sustainable development into country policies and programs and reverse the loss of environmental resources" (United Nations), and one of the indicators utilized for this target is the carbon dioxide emissions.

According to United Nations, Mexico contributed to roughly 1.7 percent of the world carbon dioxide emissions during the period of 1990 to 2004.[7] This put Mexico in the group of the top fifteen countries that contributed to global carbon dioxide emissions during this period.

Besides the position that Mexico occupies in this arena, PDEO has at least two additional linkages to this portion of the global agenda. First, the PDEO is part of a corporation operated in the United States, the country with the highest levels of carbon dioxide emissions in the world.[8] Second, the PDEO is an entity that

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[7] Mexico increased by nearly 25,000 thousand metric tons of CO_2 from 1990 to 2004, reaching a total of almost 440,000 thousand metric tons of CO_2 in 2004.

[8] United States exceeded the 6,000,000 thousand metric tons of CO2 in 2004, contributing to the 22.3% of the total world carbon dioxide emission in this year.

belongs to the auto industry and transportation sector, which have contributed to the 20-30 percent of the total carbon dioxide emissions in the world in 2007. (European Federation for Transport and Environment, 2007). Therefore, it is clear that PDEO may have a certain contribution to the solution of this global issue.

5.2 Organizational Metrics

5.2.1 Balanced Scorecard

The PDEO uses a balanced scorecard (Kaplan and Norton, 1996) as the main tool for defining, and monitoring the goals set for each year. The balance scorecard utilized by the PDEO contains more than 30 items, including product line quality targets, such as Repairs per thousand (R/1000) and Things Gone Wrong (TGWs), cost reduction targets, process control targets, employee satisfaction targets, and others.[9] The balanced scorecard has also been used as a tool to define the employees' annual objectives, by identifying the contribution of each employee to the achievement of PDEO's targets.

Most of the metrics in the balanced scorecard utilized by PDEO can be classified either as *scope* or *cost* from the iron triangle described in Chapter 4.[10] Apparently, 70 percent of the items listed in the balanced scorecard related to *scope*: such as, achieving specific quality targets or accomplishing specific tasks measured in percentage completion of task. Additionally, 20 percent of the items could be related to cost; such as complying with variable and fixed cost targets. The remaining 10% of the items have some association with time; however, even

[9] Reference: PDEO's balanced scorecards corresponding to 2005-2007.

[10] The iron triangle is formed by three components: cost, time, and scope of any project.

though the items in this category had a "meet to timing plan" statement, there was not any explicit target related to reduce development time.

Based on the description above, the PDEO's balanced scorecard reflected a higher focus on measuring the execution of tasks more than on costs or development time. Although it was unclear whether this prioritization of targets was a deliberate decision made by the top management, it reflects some realities of the PDEO. One interpretation of this inclination towards the *scope* axis could be that, being in a low-cost country, PDEO is "by nature" competitive in the cost axis of the triangle, and only few metrics are seen as necessary for controlling this aspect. PDEO is also a relatively small organization compared to the corporation in the United States.[11] This fact allows PDEO to operate with more flexibility and agility, thus being "faster" has not been a natural need for PDEO so far. Besides, the total development time of the products is mostly defined by the corporation, and PDEO's contribution to it might be limited in some extent.

5.2.2 Product Design Information

The design of the vehicles is characterized by a large number and many types of metrics. Some of the metrics describe the physical characteristics of the product; such as: dimensions, weight, rigidity, color, etc. Other metrics are used to characterize the performance of the product; such as: fuel economy, electrical and electronic functions, safety performance, etc. All these product design metrics are stored in the product specifications, two-dimensional drawings, and three-dimensional CAD files. The use of these metrics is as complex as the product itself. Cascading the vehicle level targets into sub-system level and component level targets and then validating each is one of the core activities in product development.

[11] PDEO is about 3 percent of the size of the corporation in the U.S.

5.2.3 *Process Control System*

There is a corporate monitoring system that the PDEO utilizes for measuring the progress of its product development activity. Based on the corporate product development process, this tool indicates the engineering tasks and deliverables that must be accomplished in order to guarantee a robust product development process and comply with the corporate targets. Each engineering team is responsible for executing the tasks established in the corporate product development process and using this system to report the progress based on a *green-yellow-red* assessment. The general definition of these assessments is as follows: green means that the activity is on track to achieve metric objective; *yellow* indicates that the activity is not achieving the target, but there is and agreed plan to achieve it; and *red* means that the activity is not achieving the target and there is no recovery plan yet. Ideally, the system helps to notify any abnormality in the process or risk of not accomplishing a specific deliverable, so that the organization can support the required corrective action.

5.2.4 *Quality Control Systems*

The PDEO also counts with a corporate quality control system, which basically measures the quality of the products. The quality of the vehicles is measured using the warranty data and customer reviews on the product. Some of the metrics include the number of repairs per volume produced (R/1000) and TGWs, which serve as measures of defect rates. The cost of quality is measured using metrics like *cost per unit* repaired (CPU). The system has been useful for the PDEO in the identification and improvement of the quality of the vehicles that it develops.

It is important to note that this system has been effective for improving the product designs only in mid and long term. Because the quality data comes from the vehicles already in the field –when the development activity of that vehicle is already done– the effect of the improvement actions can only be seen after several months when the next production or development cycle takes place. Therefore, the response of the product development organization from the measurement this quality control system comes with delay.

5.2.5 Business Plan

The PDEO has a five-year business plan that includes PDEO's vision, at least 4 objectives, a description of the current state of each objective, the proposed strategies, and an implementation timing plan. Compared to the balanced scorecard, which is more focused on measuring the execution of product development activities in a year, this business plan focuses on measuring the strategic aspects of the business with a longer time horizon.

5.3 Main Observations

Through the utilization of the framework it was possible to find several potential challenges or improvement areas for PDEO. The four-frame model and the three system levels –of the system decomposition model– were utilized to classify the observations.

First, from the *structural frame* perspective, at the enterprise level –level 0– it was found that although a general description of the scope of work of the PDEO had been created, the description did not suggest a direct formulation of individuals' job descriptions within the organization. A potential misalignment between PDEO's work description and individuals' work descriptions can affect the effectiveness for PDEO to achieve its mission. At regional level –level 1– the PDEO's scope of work has not been fully integrated and implemented as part of the global operations, to a great extent because PDEO is still in a re-definition phase of its operations for facing the new business challenges. Finally, at global level –level 2– PDEO is receiving some amount of pressure from different sources to reduce the carbon dioxide emissions of the vehicles that it produces, due to its contribution to the environmental sustainability issues.

Second, from the *human resources* perspective at the enterprise level, it was found that individual work plans and career plans are still under development, creating confusion and preoccupation about the future in some of the employees. At the regional level, there were cases where new required training programs for the engineers to comply with the new organizational scope of work were not fully identified. In some other cases, the required relationships with specific areas of the corporation had not been established yet. Finally, at the global level there was some level of uncertainty regarding the idea about having selected the right core competency to develop as an organization mainly because it has not yet proved.

The third perspective is the political frame. The employee satisfaction index obtained by internal surveys at PDEO has historically gotten one of the highest scores within the corporation, even though, there are still some conservative perceptions regarding the performance review process and reward system reflected in recent surveys. Another challenge that the PDEO needs to face within this frame is that while the corporation is looking for more efficiency in the utilization of resources; such as headcount and infrastructure, the local country –Mexico– is expecting PDEO to grow and generate more jobs. Finally, the globalization of the business –the decentralization of some product development activities from the corporation– has generated tensions regarding the "who gets what?" aspect of the business. If this issue is not addressed properly, the clarity on governance and decision-making for solving issues that involve several sites in different countries might be affected.

From the symbolic point of view, there are some other potential challenges that the PDEO might be facing. First, the organizational culture that has prevailed within PDEO for a decade or more might have been softened by the incorporation of a high number of new employees into PDEO in the recent years.[12] This situation is not necessarily a problem, but rather an opportunity for PDEO to redefine its organizational culture. Second, due to de recent corporate strategies, the interaction between PDEO and the corporation has been increasing among all layers of the organization. Although this is generally seen as an attractive scenario by many, the potential generation of misunderstandings due to differences between Mexican and American cultures is still an important consideration. Taking this scenario further to the entire world business, where the interaction between diverse countries is almost a given, makes more evident the potential challenge for the organization to manage the global operations in a multicultural arena. A summary of the observations made is presented in Figure 5-3.

[12] The number of engineers in PDEO increased almost 250 percent from 2004 to 2007.

	OBSERVATIONS		
System Level	**Level 0**	**Level 1**	**Level 2**
Structural	Although a general description of the scope of work of the organization the link between of it to the job description of each engineer is not clear.	PDEO's scope of work is not fully integrated into the global operations.	PDEO is required to reduce the CO2 emissions of the vehicles that it produces, inspite of the technological, political and commercial implications.
Human resource	Individual work plans and career plans are still under development.	the new scope of work of the organization to meet global business needs affect the scope of work of the individuals, requiring new training and relationships.	the idea of having selected the right core competency for being competitive in the global business is ambiguous (not proved yet)
Political	Although the employee internal satisfaction surveys yield a relatively acceptable result, there are still some conservative perceptions regarding the performance review process and reward system.	The corporation looks for improving the efficiency in the use of resources, while local country requires PDEO to generate more jobs.	The globalization process of the business (the decentralization of some product development activities from the corporation) has generated some tensions about "who gets what" portion of the business, affecting the clarity on governance and decision-making in issues that involves sites in different countries.
Symbolic	The incorporation of a high number of new employees, the organizational culture within PDEO is not very clear	The interaction between PDEO and the corporation (Mexico and USA) is increasing in all layers of the organizations, generating risk of cultural conflicts.	The interaction between organizations in different countries represents a challenge for the global operations to succeed.

Figure 5-3 Framework Test (Observations)

Whatever you do, create value.

Chapter 6

INTERVENTION STRATEGIES

Identifying Improvement Actions for the Organization

The real value of the organizational diagnosis is in its projection towards the elaboration of actionable strategies for improving the organization. This chapter presents the recommended intervention strategy and metrics that are expected to contribute to this improvement.

6.1 Moving Toward an Intervention Strategy

The research done for developing the previous chapters has provided hints for visualizing an intervention strategy that helps a product development organization to contribute to the creation of an improved product development system. First, there is a variety of strategies that have yield equally successful economic results for several product development organizations. Second, the success of a system can be determined by the capacity of the system to contribute to the achievement of the higher level system goals. Third, one stakeholder can play different roles, depending on the system level in which it is observed. Finally, the fragmentation of the product development activity in the world suggests the importance of knowing what portion of the product development value structure each organization will own.

The intervention strategy proposed in this chapter has an implicit assumption that the existing metrics, such as profit and product quality and process control metrics, have an important role in the management of product development organizations. Profit is still one of the major references for measuring the value of product development organizations as business entities. Also, product quality and process control metrics have shown to be useful for providing feedback for evaluating levels of excellence in some specific plan executions and helping the generation of specific improvement solutions over time. The strategy presented in this document is expected to be able to complement some aspects of existing strategies adopted by the organizations.

The intervention strategy proposed has five main components:

1. Create the *job description* of the organization.
2. Identify the *product features* that are visible to the end customer and that can be quantified and measured by the organization.
3. Maximize the *engineering work participation* of the organization by increasing the number of product features influenced by the engineering work.
4. Use efficiency metrics in terms of the engineering work participation as *decision variables*.
5. Incorporate measures for minimizing the negative *predictable reflexive human responses* into the specific improvement actions.

6.1.1 Job Description

Create the job description of the organization. This has to reflect the core competency that the organization owns and for which it will be distinguished in the world and represent the value that it delivers to the world. The scope of work is expressed as a portion of the value stream of the products that the end customers receive. Having a better understanding of the different profiles and tendencies that exist in the world, such as those described in cultural studies, may help to identify the core competencies that the organization would more naturally adopt. Also, understanding the global agenda of problems to solve –such as environmental sustainability– and the metrics utilized for describing these problems may help to evaluate the scope and influence of the engineering activity that is being done by the organization. While creating the job description, individuals must answer the question of what to do in-house and what to outsource, focusing on the higher-level goals and the end customer needs.

6.1.2 Product Features

Identify the product features that are visible to the end customer and that can be quantified and measured by the organization. The value of the engineering work –or at least part of it– is materialized in the product that is created and delivered to the end customers. Thus, the value imprinted in the product is a reasonable reference for assessing the value of the organization. The most viable way to have this reference is by characterizing the product features that are relevant for achieving higher-level system goals and satisfying end customer needs. The characterization is highly dependant on the product. For example, while a firm that creates video games could be characterizing the product by the game themes, apparel designers could be characterizing the product by the design variants.

The precision and scale of the characterization can also vary. For example, a product development organization in the automotive industry can characterize the product in several ways. Figure 6-1 illustrates an example of the different levels of precision can be found when characterizing a product called a "vehicle". At a very high level, vehicles can be characterized by their size, "cars" and "trucks". However, they can also be characterized by vehicle line, which has more granularity than the other characterization because there can be more than one vehicle line with in the "cars" or "trucks" categories. Moreover, there can be different models for one vehicle line, and different catalogs for one model.

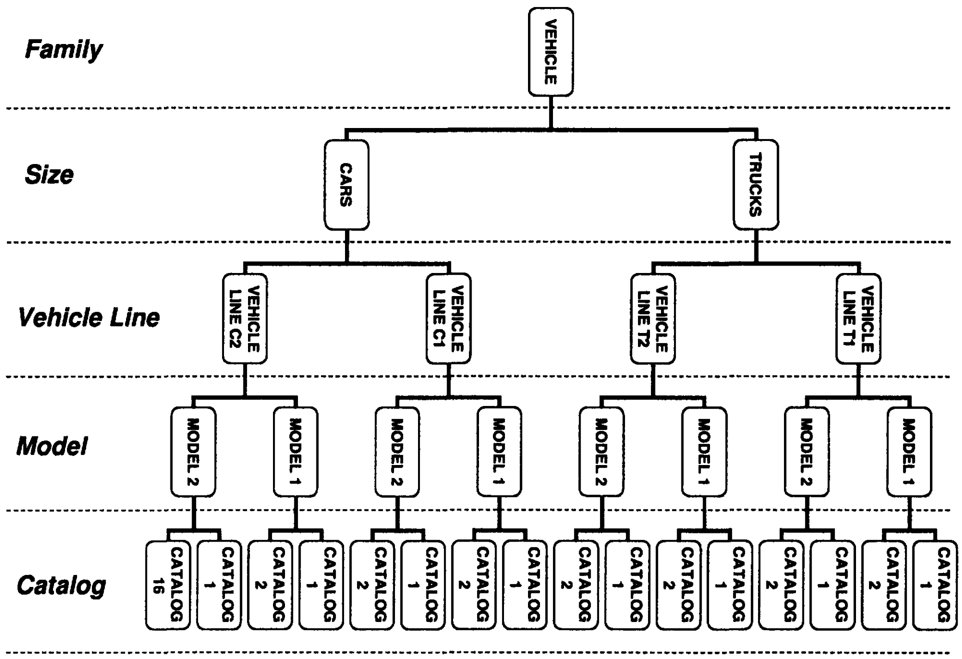

Figure 6-1. Characterizations of Product Features
(Vehicle)

Furthermore, the characterization does not have to limit to a single product family, nor even a product of the same industry. How to characterize product features depends on the vision and preferences of each organization and its ability to manage the complexity of this information.

6.1.3 Engineering Work Participation (EWP)

Maximize the engineering work participation of the organization by increasing the number of product features influenced by the engineering work. This strategy can also be interpreted as maximizing the impact of the value that it creates through the job performed by the organization. The engineering work participation (EWP) is defined by the number of product features on which the organization has participation via its job, divided by the total number of product features possible. The universe of product features is determined by customer needs. It is assumed that for an additional customer need identified, there is at least one opportunity space for a product feature to exist. In the practice, the total of product features possible is defined by the organization, and it could be within, for example, a market sector, an industry, a corporation, etc.

$$EWP = \frac{product\ features\ under\ \inf luence}{total\ product\ features\ possible}$$

Engineering work participation equal to one would mean that the organization has gained the full ownership of a specific portion of the product value stream; that is to say, the organization's core competency has reached the maximum level of impact possible on the relevant product.

The method for characterizing the product features may vary. One approach to facilitate this task is to create a *product feature code*. The product feature code contains the information of the critical characteristics of the product features, and usually depends on the topology of the product. For example, Figure 6-1 can be utilized for creating the product feature code illustrated in Figure 6-2.

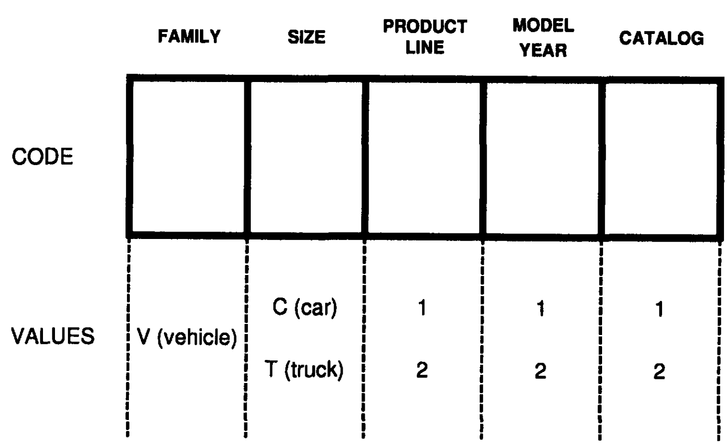

Figure 6-2 Product Feature Code (Example)

In the example mentioned above, the product feature is characterized by a description of the product family, size, product line, model year, and catalog. For the product feature code shown in Figure 6-2, the total features possible is 16, since this is the maximum number of code variants that can be generated. For example, if the organization decided that the differentiation by product line is not relevant to the end customer, then this block could be eliminated and the total product features possible would become 8.

6.1.4 Decision Variables

Use efficiency metrics in terms of the engineering work participation as decision variables. In order to measure work efficiencies, cost, time and scope metrics can be used as denominators of the engineering work participation. For example, *EWP per cost unit* measures the efficiency in economic resources utilization for maximizing EWP. *EWP per time unit* indicates the speed of the organization for gaining the full ownership of a specific job. Indirectly, *EWP per time unit* may also be related to the capacity of the organization to work on a number of product features at the same time. Finally, *EWP per scope unit* can indicate the level of participation that can be achieved by a specific portion of the organization, which can be a tool, process, product, or person. For example, it can be used for defining the amount of work that the organization can hold in order to maintain an acceptable EWP improvement pace.

These efficiency metrics can be used as decision variables for implementing improvement actions that maximize the level of participation. Although these three can be monitored and stimulated at the same time in the organization, prioritization of these variables and their flexibility to change priorities according to the organization's needs may help to maintain the nimbleness of the organization. Hence, the task is to optimize these three efficiencies so that the EWP can be maximized. The importance of using these metrics as decision variables instead of using *Scope, Cost,* and *Time* alone lies in the fact that there is a natural pressure put on the organization to maximize *Scope* and minimize *Cost* and *Time*. This pressure normally comes from the environment, making the trade-off difficult to control. Incorporating EWP in these variables provides a means for compensating the external uncontrolled pressures by setting an engineering direction to the solution of these tensions.

6.1.5 Predictable Reflexive Human Responses

Incorporate measures for minimizing the negative predictable reflexive human responses into the specific improvement actions. When designing improvement actions for a specific purpose, incorporating measures for minimizing the negative reflexive human responses into these actions contributes to the stability of the organization when they are implemented. An example of how the knowledge of predictable reflexive human responses can be incorporated into specific actions is presented in Figure 6-3. The main idea is that for each concern found in the organization, a general improvement action is created. Then, the contribution that each of the four players have on the action is identified. The objective is that each player contributes to the solution of the problems, minimizing the reflexive responses.

System Level		Level 0: Enterprise	Level 1: Region	Level 2: Global
Concern		The link between the scope of work of PDEO and the job description of each engineer is not clear.	PDEO's scope of work is not fully implemented in the global operations.	The vehicles that PDEO develops have CO2 emissions, contributing to the environmental deterioration
Improvement Action		Align the job description of the organization and the job descriptions of the engineers.	Increase the participation of PDEO in the global operations.	Contribute to the reduction of CO2 emissions of the vehicles.
Actions for Minimizing Predictable Reflexive Human Responses	**Tops** *Create responsibility through the organization by…*	defining a clear description of the scope of work of the organization and cascading it through the organization	generating a cascadeable target to increase the participation of the organization, given a specific work description	including the contribution of the organization to the solution of global issues into the description of work of the organization
	Middles *Maintain their independence of thought and action by…*	evaluating and integrating the different job descriptions	interacting with the counterparts in the corporation and creating participation opportunities	integrating the solutions and facilitating the implementation
	Bottoms *Be responsible for themselves and the system by...*	developing one's own job description based on the organization's scope of work	eliminating waste in the own job activity in order to be able to participate more in the international projects	creating specific controllable solutions that contribute to the improvement of C02 emissions
	Environmental Players *Make the system's delivery work for them by…*	participating in the communication of concerns and needs as required		

Figure 6-3. Improvement Actions Minimizing PRHRs. (Structural Issues)

6.2 Putting the Strategy in System Perspective

6.2.1 *Control System Analogy*

In order to visualize the expected effect of the strategy proposed in this chapter, it is helpful to make an analogy. Figure 6-4 shows a negative feedback loop control system diagram. In this diagram, *G* and *H* are two systems that perform specific processes, transforming reference input signals into reference output signals. The variables *x*, *y*, and *e* are the representation of the different types of signals. *G* is the main system, whose objective is to convert the input *x* into a desired output *y*. However, in the presence of noise, *G* can generate an output that differs from the desired output *y*. The function of *H*, then, is to sense the output of *G* and generate a compensation signal *e*. This signal, combined to input *x*, stimulates *G* so that the output approximates to the desired value of *y*.

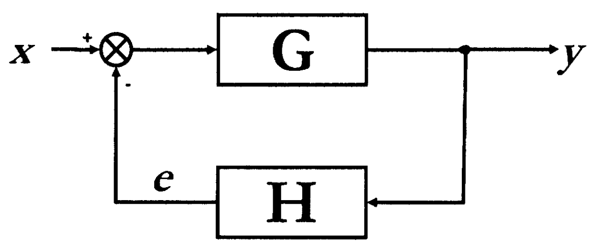

Figure 6-4 Negative Feedback Control System Diagram

The analogy starts when *G* is visualized as a system that takes information about customer needs as input (*x*) and generates a signal that indicates the customer satisfaction level (*y*). If customer needs are satisfied then the reputation of *G* is good, and *G* is perceived as a successful system. The contrary occurs if customer needs are not satisfied.

H is another system whose main function is to assist *G* to generate the desired output signal (*y*), a "good reputation" signal. *H* senses the actual output delivered by *G* in order to generate a compensation signal (*e*) that stimulates *G* to improve its output. The success of *H* lies in its capacity to both accurately sense *y* and deliver an effective compensation signal *e*. If *H* does not perform these two things well, its main function is not accomplished and it can be seen as an unsuccessful system. Additionally, if there is more than one system like *H* connected in parallel –say H_1, H_2, H_3, ..., H_N–, the relative contribution of each *H* to *G* will tend to zero. Therefore, each *H* will have to deliver a clearer compensation signal (*e*) in order to be perceived as a successful system.

Product development system (*G*), as a grouping of several product development organizations, receives information about customer needs in order to satisfy them through the creation of products. It can be said that the success of one product development organization (H) lies on its capacity to assist the whole system to deliver the intended value. A product development organization can be said to be successful if it detects discrepancies between the intended value delivery and the actual output of the system; generates an effective engineering solution (*e*); and maximizes the impact of this solution into the system. The strategy proposed in this chapter is expected to provide a means for a product development organization to operate in the way described above. Therefore, the strategy facilitates the evaluation of the performance of the organization in terms of its contribution to the value delivery of the whole system.

6.2.2 Refining the Strategy

Figure 6-5 is a graphic representation of the strategy proposed in this chapter. This illustration helps to create a mental model for visualizing the expected effects of the strategy on the product development organization as described above. The expected outcome of the strategy is to have a notion of the level of successfulness of a product development organization. This notion comes from the customer satisfaction level that is ultimately reflected in the *reputation* of the organization as an engineering entity.

The input signal for a product development organization is the actual value delivered by the whole product development system. The output of the organization is the engineering work that will solve the flaws in the value delivery of the system. The contribution of the engineering work delivered by the organization is measured by the EWP. If the engineering work participation of the organization increases, the representativeness of the organization within the higher-level system increases, and so does it its contribution to the whole value delivery results. In other words, the magnitude of success –or failure– of the product development organization can be considered as being directly proportional to the EWP. Figure 6-5 shows the input and output of the organization as an H system.

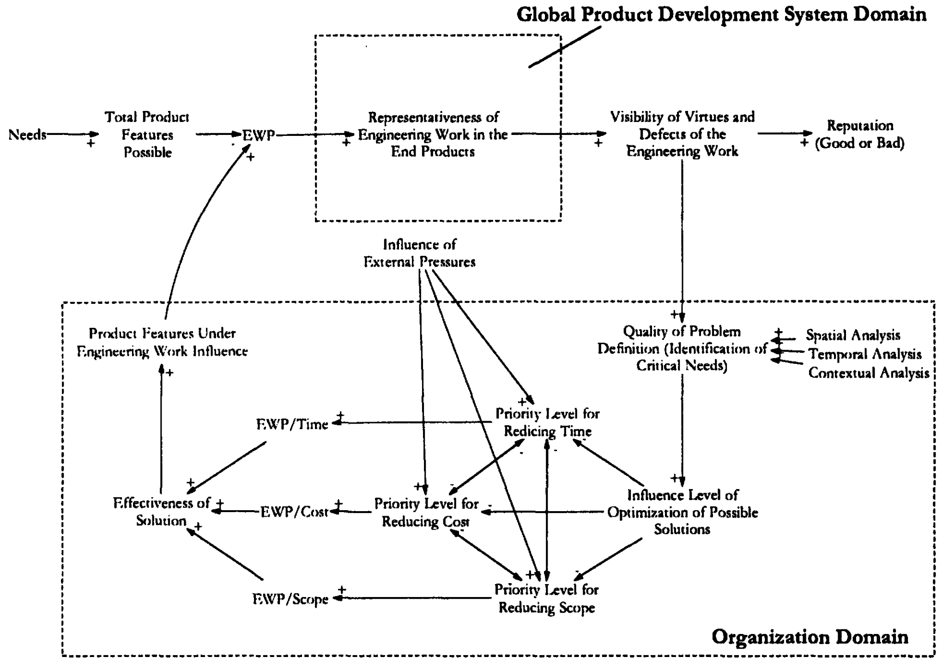

Figure 6-5 Intervention Strategy Diagram

There are three main qualities that enable a product organization to assess its success. The first skill that a product development organization must have is a capacity to sense the value delivery of the whole product development system and detect errors in it. This implies that the organization must have a fixation to observe the actual situation and understand higher-level system goals. The second skill is the capacity of the organization to solve problems. The ability of the organization to optimize its resources for generating robust engineering solutions to specific problems is necessary for having flexibility and direction in the decision-making process. Finally, the third skill of a product development organization is the ability to maximize the impact of the solution it delivers to the system. This ability is critical for two reasons. First, the organization will contribute to improve the efficiency of value delivery of the system; and second, the organization will build its own reputation throughout the system. These three qualities that the organization must have are presented in Figure 6-6.

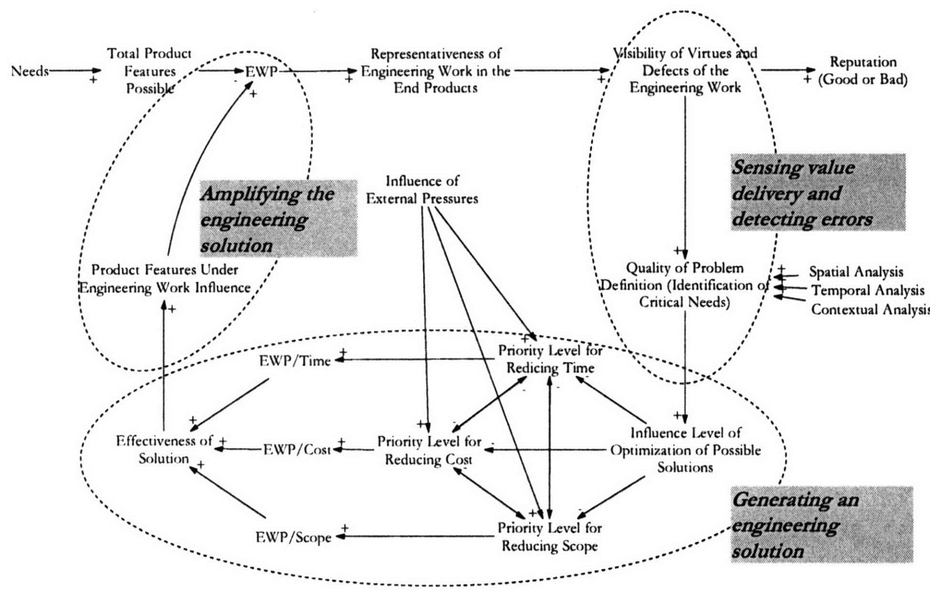

Figure 6-6 Three Required Qualities for an Engineering Organization

Finally, the strategy can be seen as a problem-solving process as illustrated in Figure 6-7.

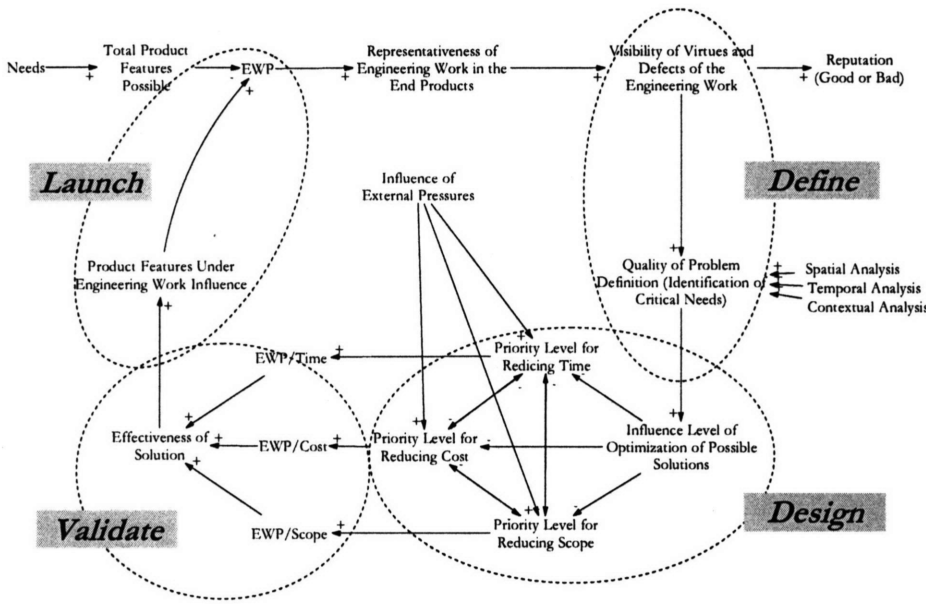

Figure 6-7 Intervention Strategy in Four Phases

Therefore, the strategy can be described in terms of the four-phase model as follows:

1. Define the critical defect in the value delivery of product development.

2. Design the possible solutions to the problem, generating options for optimizing *Scope, Cost,* and *Time.*

3. Validate the solutions, certifying solutions and the expected maximum EWP.

4. Launch the solution, making impact on as many of product features as possible.

Visualizing the strategy as a problem-solving process facilitates the adoption of the strategy within a wider range of organizational environments. This approach is also expected to help the generation of sub-strategies or projects that will potentially generate a momentum for amplifying the efforts of the strategy.

6.2.3 Scope of the Strategy

The strategy proposed in this chapter should not be seen as a substitute of all already existing strategies. The strategy is oriented to detect errors in the value delivery of the product development system by maximizing the impact of the solutions generated by the organizations and facilitating the definition of improvement areas. Additionally, this strategy facilitates the solution of the natural tensions formed between Scope, Cost, and Time by identifying EWP as a variable for which these three variables can be optimized. Given a value proposition of the organization, the EWP associates the engineering effort performed that is imprinted in the products, and the contribution of this effort to the whole value stream. In this way, the strategy includes a means for evaluating the value delivered by the organization.

The underlying argument in this strategy is that in order to know whether an organization is successful or not, it is necessary that the organization has the ability to detect errors in the value delivery of the product development system, generate its best possible solution, and maximize the impact of the solution on the whole system. If the value delivery is successful, then the organization will be prized by the whole system for its contribution to this improvement. Otherwise, the organization would be judged for its inability to understand the critical customer needs, to solve problems, to have presence within the system, or a combination of these reasons. If this condition continues, the organization would eventually disappear from the map of the system.

In the short term, organizations are expected to focus on identifying their strengths, taking advantage of these strengths to solve already known problems and maximize the influence of the organization in the whole system. Some risk-takers may challenge themselves to solve more complex problems or to find unexplored solution spaces. At the same time, in a long-term view, organizations will be building a learning culture by looking for other type of defects in the value delivery system and developing new skills and knowledge in order to evolve.

Envision a system architecture that can evolve along with nature.

Chapter 7

CONCLUSIONS

Summarizing, Evaluating, and Reflecting

In this final chapter, a summary of the research work is presented, as well as the future work and reflection on some system architecture principles.

7.1 Summary

7.1.1 Definition of the Macro-Framework

Product development is a system that be considered complex because it includes many types of interacting components; for example, people, processes, products, tools, and goals. Product development organizations are elements of this system.

There are three generic categories that can be utilized for analyzing a system: space, time, and context. *Space* focuses mainly on system size, structure, and interactions. *Time* focuses on internal processes of the system, including product development cycle and other problem-solving processes. The visualization of the relationship between short-term and long-term solutions affects system evolution. *Context* examines exogenous variables affecting the system being studied. These three categories form the macro-framework this research.

Metrics are a critical component of system goals. Metrics linked to system intent are more likely to assure value delivery, and this can be achieved when metrics focus on one or two high-level goal(s).

7.1.2 Design of the Organizational Diagnosis Framework

Three different models were integrated to address spatial aspects of product development organizations: the system decomposition model, the four-player model, and the four-frame model. The *system decomposition model* focuses on identifying system size, boundaries, and paths of interaction and influence. The *four-player model* focuses on identifying people's roles within a system and their common reflexive responses that affect the stability of the system. The four players are: Tops, Bottoms, Middles, and Environmental Players. Countermeasures to these reflexive contribute to the robustness of the system. Finally, the *four-frame model* focuses on identifying tensions, potential improvement areas, and solution approaches from four different perspectives: structural, human resources, political, and symbolic.

To analyze the temporal aspects of product development, a four-phase model was presented. This four-phase process provides a way to link the product development process adopted by an organization to a generic problem solving process model, which can be cascaded to an individual level. The four phases are: Define Design, Validate, and Launch. Completing one phase of the four-phase model is in itself one problem to solve; thus, another set of four phases within one "longer" phase can be visualized. Therefore, one single action has simultaneous influence on short-term and long-term projects.

Three main aspects are considered for contextual analysis: globalization, cultural values, and global issues. *Globalization* is seen as the main source of influence that drives the generation of new business models and strategies for many firms, including product development organizations. Fragmentation in product development activity is generating a critical problem for organizations to solve: to define what to keep in-house and what to outsource. *Cultural values* may affect the perception of how product development organizations should operate, thus they affect planning scope, strategies, goals, and objectives. Cultural studies can provide insights for identifying the competencies that a specific organization would more likely adopt. Finally, *global issues* –such as environmental sustainability– can serve as a guide to align the product development mission with other levels of the ecosystem.

7.1.3 Exploration of Directional Metrics

External metrics and indicators, such as economic indicators and global statistics, can help product development organizations set reference points and know where they stand in the world. Benchmarking also provides referential information, and it is more effective when used for identifying one's own strengths or unique ways to deliver value rather than for replicating the same strategies implemented by others. Indicators utilized for describing the critical global issues may serve as nodes that link internal and external metrics for an engineering organization and unify the understanding of value of engineering within the organization.

Internal metrics vary from organization to organization and from product to product; however, scope, cost, and time seem to be the essence of most of the metrics utilized by organizations. Classifying the metrics in these three categories helps to identify the relative orientation of a specific product development organization toward each of these three categories. Additionally, flexibility is critical when working with metrics. Prioritizing each category of metrics consciously may help to identify and eliminate contradicting strategies within the organization.

In the market as it is known today, profit is a predominant measure of the value of any product development organization as a business unit, thus this measure is required for surviving and growing. However, it is not necessarily the most practical way to measure and elevate the value as an engineering organization. Engineering work participation (EWP) can potentially contribute to this task.

7.1.4 The Intervention Strategy

The intervention strategy proposed includes five main concepts: job description, product features, engineering work participation, decision variables, and predictable reflexive human responses.

Creating a clear *job description* is critical for answering the question of which problems to solve in-house and which solutions to buy.

Identifying and characterizing the *product features* helps to focus on what is relevant to the end customer.

Engineering work participation (EWP) is defined by the number of product features on which the organization has participation via its job, divided by the total number of product features possible. EWP is expected to be directly proportional to the magnitude of success –or failure– of the product development organization.

The use of EWP efficiency metrics as *decision variables* provides a means for setting an engineering direction for solving the *Scope-Cost-Time* trade-offs.

Incorporating measures for minimizing the negative *predictable reflexive human responses* into the specific improvement actions contributes to the stability of the organization.

There are three main qualities that product organizations must have: the ability to detect errors in the value delivery of the whole product development system; the ability to solve problems; and the ability to maximize the impact of the solution that it delivers to the system.

The strategy can be described in terms of the four-phase model as a problem-solving process: (1) Define the defect in the value delivery of product development; (2) Design the possible solutions to the problem, optimizing *Scope, Cost,* and *Time* for maximizing the engineering work participation; (3) Validate the solutions and the expected EWP; and (4) Launch the solution, making impact on as many product features as possible.

7.2 Prevailing Issues and Inspiration for Future Work

7.2.1 Prevailing Issues

Given that no single strategy that has guaranteed the success of all product development organizations has been found, the question of which strategy organizations should follow will still remain. Research for improving the way to measure product development is to be encouraged as a means to understand the real value of product development and engineering activity in the world. The perception of value is still evolving, and globalization in the economy might help to generate more unified conceptions of what product development organizations must deliver and how to measure it.

Also, cross-industry studies on product development organizations and benchmarking will generate a temptation for some organizations to imitate other organizations' strategies, metrics, and practices in the future. These actions might generate false expectations of success for some organizations. Cross-industry studies that create a value stream maps for the whole system –the globe– are more likely to help organizations to find better opportunities for success.

7.2.2 Future Work

For example, one particular study that could potentially contribute to evaluate benefits of using engineering work participation (EWP) as a metric for product development organizations is to investigate the correlation between EWP and profit change over time.

The framework presented in this document is applicable to several system levels and several time horizons. For future studies, it is expected that this framework will help to analyze and evaluate teams and projects within an organization. An example of how this framework could be used is to scale down the framework for analyzing one specific functional team rather than the whole organization. This usage could help to evaluate new strategies that could potentially increase the EWP of the team and the organization, providing evidences of the alignment between functional teams' activities and goals and organizational function and goals.

Investigating new ways of analyzing organizations from different perspectives will always be beneficial, especially if the investigations incorporate the always changing contextual information and critical needs that characterize the system to be studied. Other future application work could include the development of flexible design methods oriented to optimize scope, cost and time that maximize the EWP of an organization. Additionally, identifying decision-making processes that facilitates the validation of both the engineering solution and the EWP would be an interesting area to explore. Finally, validating the strategy proposed in this document by implementing it in a real application scenario would yield valuable information for further analysis.

7.3 Reflections

7.3.1 Retaking the Problem

What are product development organizations competing for? Which is the measure of success? There is a predominant notion that product development organizations are competing for obtaining more profits. While it is true that profit is a very important measure of success of an engineering organization in the business arena, it is also true that the main engineering is about identifying and solving problems, which not necessarily means to make money. The quality of a product development organization is in its ability to detect problems, solve the problems, and make the largest impact possible of the engineering solutions created. Therefore, product development organizations are competing for being the best problem detectors, the best problem solvers, and the best contributors to the society.

What are the major global issues that product development organizations must take into account? There is a large list of problems that have been identified by the international community. The categorization of the problems may vary, and the prioritization of the severity of the problems is debatable. However, taking into account the technologies that are immersed already in people's life and the several kinds of impact that they have had, environmental sustainability, safety and health, and peacekeeping should certainly be in the top priorities of problems to solve.

How can an improvement plan be elaborated from the diagnosis utilizing the existing set of skills and knowledge? Broadly, diagnosis means recognizing abnormalities in the subject that is being studied. When people complain about something that is happening in the organization, or when they are just unhappy at work there is an inherent perception of a defect. It is not uncommon to perceive problems in our environment; however, sometimes it takes a little more effort to define the problem well and move to an action that solves it. Ultimately, a diagnosis should lead to an improvement action. In organizations, understanding the predictable reflexive human responses to specific stress conditions is a way of facilitating the task of defining a problem in a way that the detector of the problem can move towards the creation of the solution rather than worsening the problem. What ignites a good improvement plan is a good problem definition, and then, an effective initial reaction to it.

An effective organizational diagnosis has at least three characteristics. First, the diagnosis must have a clear motivation or purpose. Second, the diagnosis must take into account as many variables as possible, and third, must flow to the creation of improvement actions.

Organizations can generate a learning momentum by visualizing themselves as contributors of a larger system. This approach smooths the progress of focusing on higher-level system goals and customer needs, identifying the most critical errors of that system. In a way, this approach promotes that the organizations and the people within it, experiment the different roles –Tops, Middles, Bottoms, and Environmental Players– and make their best contributions in each role they play. Also, learning comes from feedback or a reaction to what the organization does. In this sense, striving to make a higher impact on the system is a tool for obtaining a greater feedback, and hence, a greater opportunity to learn from their own decisions. Finally, flexibility in the prioritization of each category for defining strategies seems to contribute to the robustness and evolution of organizations.

A product development organization needs to have a strong sense of commitment to solve problems in order to maintain dynamism in the elements that comprise it. However, for an organization to learn and evolve, it is also necessary to create robust solutions. Solving the same recurrent problems will eventually reflect the lack of learning.

Is there any key metrics that allow a realistic representation of product development organization profile and competitiveness? This thesis identified *scope* of work, *cost* and development *time* as the three main variables that can characterize a product development organization. However, what distinguishes one organization from others is the way each organization solves the iron-triangle formed by these variables, since it represents the strategic orientation of the organizations. Additionally, the thesis proposed another key metric for engineering organizations: the engineering work participation (EWP), which is expected to provide a practical reference for assessing the competitiveness of an organization.

The three categories of metrics –scope, cost and time– provides a mean for classifying the existing metrics in an organization. This categorization simplifies the analysis of metrics and facilitates the generation of focused strategies and objectives, by prioritization and flexibility. Although the organizations still have to ask the question of which specific metrics they must use, the implicit question of what is the value that each organization delivers to the environment appears to be more critical. Knowing the answer to this question will yield a better approximation to answer the first question

7.3.2 Consistency

"Trying to achieve inconsistent objectives can lead to disaster" (Lyneis, 2006). Systems are part of larger systems. When creating something, the components and subcomponents that comprise it must be conceived to be part of a common system identity and to perform towards a common goal, avoiding unnecessary internal conflicts. For a system to succeed, each component must follow consistent objectives with the rest of the components so that the system can achieve its intended function. In complex systems, it is common to find conflicting interactions that determine the whole system performance. The system architect is responsible for identifying these interactions –trade-offs– and creating the high level system architecture identity –form, function, concept, goal, context, process, and tensions– in order to adjust the performance of the components toward a prioritized interaction mode.

Product development will have a common and more transparent meaning as the short and long term missions –temporal vision– are harmonized along the several micro and macro levels of the system –spatial vision–. In other words, as an engineering activity, product development organizations will have to look for a greater alignment to the solution of those problems that are affecting humanity the most. The global economy, the interactions between different cultures, and global issues –e.g. environmental, safety and health, etc.– will make the responsibility and need of engineering more evident.

7.3.3 Autonomy

Autonomy seems to have an important role in vitalizing large and complex systems. This is commonly translated as "people ownership" of specific tasks or responsibilities. Instead of centralizing all decisions making in one single person – or a small group of people), it is more efficient and beneficial for an organization that each person takes the responsibility –and freedom– to make the decisions that affect people directly. In the context of product development activity, this principle might be applicable as well. Fragmentation in the product development value chain nowadays is occurring because organizations, both small companies and large corporations, are looking for a genuine strength that distinguishes them from the other organizations and let others do the rest. Individuals involved in product development could potentially look for their own talent and develop it in order to maximize the impact of this talent on the system.

7.3.4 Evolution

As the universe is complex and dynamic, we should foresee the potential evolution that the system will experience. Product development systems are part of larger systems. When conceiving a new product, organization, process, or tool, we are creating a different way of arranging a small portion of the universe. Also, interactions between any elements involved in product development can modify the behavior of others, affecting the whole system. Because all systems are interconnected, the environment around product development activity must be taken into account carefully. This environment includes other organizations, stakeholders, cultural values, and needs, which can all change over time. All product development systems must be flexible enough and be "ready" to evolve.

Product development organizations, as dynamic and evolutionary systems, must learn from their internal architecture as well as from the outside world. An organization focused on learning will find those qualities that make it unique and that represent the maximum value that it can deliver. An organization focused on learning understands the simultaneity of influence on the existing short and long term objectives. Therefore, the value of learning comes from challenging the current state of robustness of the system, to eliminate those elements that give limited value and maximize the value that a system can provide. Product development will continue undergoing transformations of a different nature. The organizations that prevail will be those that are able to adapt their structures, processes, and even their goals to deliver higher levels of value in a changing environment.

7.3.5 *Intangibles and Perceptions*

Good systems are attractive. Some people understand product development as a science, while others understand it as an art. In any case, there should be some kind of attraction behind it. It could be a motivation to create something that represents a huge contribution to the world or simply an important personal challenge. There should be some kind of attractiveness for creating value or seeing benefit from it. A good product development system could potentially be one that can be perceived as both science and art as the same time, where the attractiveness is rooted in a conscious and unconscious perception of value.

Thackara (2006) says that "the more fancy tech you pack into a product, the harder it becomes to impress people with its benefits". When we design an innovative product, it is essential to know what does "innovative" mean for the different stakeholders. For example, a car with air conditioning system was a great innovation some decades ago. In those days having such a car represented a "luxury" and was very attractive to people. Now, the air conditioning system is almost a "given". Nowadays, incorporating this system into a car does not represent a significant innovation for the customers –not incorporating it, however, can have negative effects. Kano's model offers similar insights–. Similarly, engineering must be in constant search for higher value to deliver in order to succeed. This implies to visualize the goals of higher-level systems and transform it to help the whole system to become more robust.

Finally, Engineering, Science, Arts, and all human activities must be oriented towards the wellbeing of humanity. Only those systems –technology, firms, products, etc.– that make evident the benefit for human beings will be accepted as "good" systems.

Appendix

APPENDIX A: DIFFERENT FORMATS OF PRODUCT DEVELOPMENT PROCESS

COCOMO II	Inception		Elaboration		Construction			Transition			
PRICE-S	Concept	System Requirements	Software Requirements	Pre-Design	Detailed Design	Code/Unit Test	I & T	Hardware & Software Interfaces		Field Test	
SEER-SEM	System Concept	Requirement Design	Software Requirement Analysis	Pre-Design	Detail Design	Code & Unit Test	I & T	Program Test		OT&E	Operation Support
PRICE-H	Initial Concept	Design		Production						Operation	Disposal
RSERFT	Management Plan	System Design	System Analysis	Specs & Interfaces	Status & Reviews	Test Plans	Test & Delivery	AI & T	V & V	Support	
SEER-H	Development			Production						Operations	Support
SSCM	Inception			Development						Launch	Orbital Opperation Support
USCM8	Inception			Development						Launch	Orbital Opperation Support

Source: Valerdi (2004)

Appendix B: List Of Common Product Development Metrics

Requirements & Specifications
Number of customer needs identified
Number of discrete requirements identified (overall system and by subsystem)
Number of requirements/specification changes (cumulative or per unit of time)
Requirements creep (new requirements / total number of requirements)
Requirements change rate (requirements changes accepted / total number of requirements)
Percent of requirement deficiencies at qualification testing
Number of to-be-determined (requirements / total requirements)
Verification percentage (number of requirements verified / total number of requirements)

Electrical Design
Number of design review changes / total terminations or connections
Number of post-design release changes / total terminations or connections
Percent fault coverage or number of faults detectable / total number of possible faults
Percent fault isolation
Percent hand assembled parts
Transistors or gates designed per engineering man-month
Number of prototype iterations
First silicon success rate

Mechanical Design
Number of in-process design changes / number of parts
Number of design review deficiencies / number of parts
Number of drafting errors / number of sheets or # of print changes / total print features
Drawing growth (unplanned drawings / total planned drawings)
Producibility rating or assembly efficiency
Number of prototype iterations
Percent of parts modeled in solids

Software Engineering
Manhours per 1,000 software lines of code (KSLOC)
Manhours per function point
Software problem reports (SPR's) before release per 1,000 software lines of code (KSLOC)
SPR's after release per KSLOC
Design review errors per KSLOC
Code review errors per KSLOC
Number of software defects per week
SPR fix response time

Product Assurance
Actual MTBF / predicted MTBF
Percent of build-to-packages released without errors
Percent of testable requirements
Process capability (Cp or Cpk)
Product yield
Field failure rate
Design review cycle time

Open action items
System availability
Percent of parts with no engineering change orders

Parts Procurement
Number of suppliers
Parts per supplier (number of parts / number of suppliers)
% of standard or preferred parts
% of certified suppliers
Percent of suppliers engaged in collaborative design

Enterprise
Breakeven time or time-to-profitability
Development cycle time trend (normalized to program complexity)
Current year percent of revenue from products developed in the last "X" years (where "X" is typically the normal development cycle time or the average product life cycle period)
Percent of products capturing 50% or more of the market
Percent of R&D expense as a percent of revenue
Average engineering change cycle time
Proposal win rate
Total patents filed/pending/awarded per year
R&D headcount and percent increase/decrease in R&D headcount

Portfolio and Pipeline
Number of approved projects ongoing
Development work-in-progress (the non-recurring, cumulative investment in approved development projects including internal labor and overhead and external development expenditures and capital investment, e.g., tooling, prototypes, etc.)
Development turnover (annual sales divided by annual average development work-in-progress)
Pipeline throughput rate
New products completed/released to production last 12 months
Cancelled projects and/or wasted spending last 12 months
Percent R&D resources/investment devoted to new products (versus total of new products plus sustaining and administrative)
Portfolio balance by project/development type (percent of each type of project: new platform/new market, new product, product upgrade, etc.)
Percent of projects approved at each gate review
Number of ideas/proposed products in the pipeline or the investigation stage (prior to formal approval)

Organization/Team
Balanced team scorecard
Percent project personnel receiving team building/team launch training/facilitation
Average training hours per person per year or % of payroll cost for training annually
IPT/PDT turnover rate or average IPT/PDT turnover rate
Percent core team members physically collocated
Staffing ratios (ratio of each discipline's headcount on project to number of design engineers)

Program Management
Actual staffing (hours or headcount) vs. plan
Personnel turnover rate
% of milestone dates met

Schedule performance
Personnel ratios
Cost performance
Milestone or task completion vs. plan
On-schedule task start rate
Phase cycle time vs. plan
Time-to-market or time-to-volume

Product
Unit production cost / target cost
Labor hours or labor hours / target labor hours
Material cost or material cost / target material cost
Product performance or product performance / target product performance or technical performance measures (e.g., power output, mileage, weight, power consumption, mileage, range, payload, sensitivity, noise, CPU frequency, etc.)
Mean time between failures (MTBF)
Mean time to repair (MTTR)
System availability
Number of parts or number of parts / number of parts for last generation product
Defects per million opportunities or per unit
Production yield
Field failure rates or failure rates per unit of time or hours of operation
Engineering changes after release by time period
Design/build/test iterations
Production ramp-up time (example)
Product ship date vs. announced ship date or planned ship date
Product general availability (GA) date vs. announced GA date or planned GA date
% of parts or part characteristics analyzed/simulated
Net present value of cash outflows for development and commercialization and the inflows from sales
Breakeven time (see above)
Expected commercial value (This equals the net present value of product cash flows multiplied by the probability of commercial success minus the commercialization cost. This is multiplied by the probability of technical success minus the development costs)
Percent of parts that can be recycled
Percent of parts used in multiple products
Average number of components per product

Technology
Percent team members with full access to product data and product models
CAD workstation ratio (CAD workstations / number of team members)
Analysis/simulation intensity (analysis/simulation runs per model)

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