INSTITUTO TECNOLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

CAMPUS MONTERREY

DIVISION DE INGENIERIA Y ARQUITECTURA

PROGRAMA DE GRADUADOS EN INGENIERIA

TECNOLÓGICO DE MONTERREY®

REFERENCE MODEL AND METHODOLOGY TO CONFIGURE/RECONFIGURE INTEGRATED PRODUCT, PROCESS AND FACILITY DEVELOPMENT PROCESSES

TESIS

PRESENTADA COMO REQUISITO PARCIAL PARA OBTENER EL GRADO ACADEMICO DE:

MAESTRO EN CIENCIAS

ESPECIALIDAD EN SISTEMAS DE MANUFACTURA

JOAQUIN ACA SANCHEZ

FEBRERO, 2004

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Los miembros del Comité de Tesis recomendamos que la presente Tesis del Ing. Joaquín Aca Sánchez sea aceptada como requisito parcial para obtener el grado académico de Maestro en Ciencias con especialidad en:

SISTEMAS DE MANUFACTURA

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Febrero de 2004

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Al Dr. Arturo Molina Gutiérrez

Por su invaluable apoyo, enseñanzas y experiencia que me transmitió durante este periodo de tiempo

Al Dr. Ciro Rodríguez y al Dr. Horacio Ahuet

Por aceptar participar en mi comité de tesis y contribuir con sus valiosos comentarios a la culminación de la misma

Summary

Emerging economies, social and political transitions, and new ways of doing business are changing the world dramatically, these trends suggest that competitive advantages in the new global economy will belong to enterprises capable of develop high customized products. Manufacturing Industry play a leading role in regional development of Mexican Industry, however, the absence of formal programs for New Product Development place Mexican Industry at a competitive disadvantage with respect to other countries. In order to compete, Mexican Companies require adapting structured process to improve their practices in New Product Development. This research thesis proposes the methodological use of a Reference Model that allows the companies to create a Particular Model to set-up successful Integrated Product, Process and Facility Development Processes, independent of the industrial sector of a company, but focusing on specific issues of the company like market opportunities, technological constraints and declared goals. The Reference Model is structured in three dimensions: Processes, Stages and Activities. Processes are a description of the potential cases to be developed: Product Development, Process Development and/or Facility Development. Stages are a set of activities performed to achieve a partial result in a specific Process; this reference model has four types of stages: Conceptualization, Basic Development, Advanced Development and Launching. Activities are specific tasks that must be executed in order to complete a Stage; there are three types of Activities: Analysis, Synthesis and Evaluation. Particular Model is defined as the structured combination of Processes, Stages and Activities, capable to develop the desired product or product family allowing exchange information from one Process to other depending on the information available and the goal of the project. In order the company configures its Process, three activities must be achieved: (1) Project Definition; (2) Activity Sequence Identification; and (2) Activity Mapping in the Company. To demonstrate the use of the Reference Model the derived Methodology was employed in a metalworking company to create its Particular Model and define a New Product Development Program to introduce automotive products. The principal results obtained on this research thesis were: (1) A Reference Model for Integrated Product Process and Facility Development was developed; (2) A Methodology was developed to configure processes for product development; and (3) A case study was developed to demonstrate how to use the Reference Model and Systematic approach can be used to develop New Products. Some conclusions obtained from this research thesis were: (1) Benefits from Reference Model uses are configuration of processes for specific product development in short periods of time and increase of the feasibility of product modification; (2) In order to exploit fully configurability of the proposed systematic approach, Case Development is required to generate an Activities Library that allows reuse knowledge in future Process Configuration; and (3) Processes Configuration requires a steep learning curve, but its systematic structure makes it feasible to be automated and in long term a reduction in configuration time is presented.

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1 Introduction

1.1 Background

Emerging economies, social and political transitions, and new ways of doing business are changing the world dramatically, these trends suggest that competitive advantages in the new global economy will belong to enterprises capable of develop high customized products. Manufacturing Industry play a leading role in regional development of Mexican Industry, however, the absence of formal programs for New Product Development place Mexican Industry at a competitive disadvantage with respect to other countries. In order to compete, Mexican Companies require adopting structured process to improve their practices in New Product Development. On this research thesis a systematic approach is proposed in order to configure Processes for successful Integrated Product, Process and Facility Development, independent of the industrial sector of a company, but focusing on specific issues of the company like market opportunities, technological constraints and declared goals

1.2 Research justification

In general, industrial sector in emergent countries have been established first with activities of low complexity, evolving gradually to activities of high complexity. Typically companies start doing just manufacturing operations. After that, those companies domain manufacture and begin an interaction with its customer or partner in order to make design suggestions to the product in order to improve the manufacturability of the product. Finally, those companies combine depth knowledge of manufacturing with an understanding of product functionality in order to develop new products and processes. Nowadays this evolution is being experimented in Mexican Industry where a Manufacturing Industry has been established and the evolution towards the design activities already has begun; however, it is necessary that Mexican Companies adopt solid methods to develop products, process and facilities.

In order to compete, Mexican firms require develop New Product Development Programs with a knowledgeable and skilled work force, and flexible management structures that stimulate co-operative initiatives within and among companies. The incorporation of New Product Development concepts to this industry will contribute to enterprise growth and their expected impact and benefits will create a more competitive industry for this region as well as higher-value-added jobs. Therefore research and development in the area is necessary to ensure that Mexico is not placed at a competitive disadvantage with respect to other countries. The challenge is to ensure that a larger number of Mexican manufacturing companies will be able to compete with the best in the world in the 21st century [Molina; 1999a].

1.3 Objectives

The objectives of the present research are:

- Develop a Reference Model for Integrated Product, Process and Facility Development.
- Develop a methodology to configure the Reference Model in order to set-up successful Integrated Product, Process and Facility Development Processes.
- Demonstrate the use of the Reference Model and Methodology through a case of study in Mexican Industry.

1.4 Scope of the Research

Product Life Cycle describe the evolution of the product from its conception to its disposal. The standard product life cycle tends to have six phases, first three phases are oriented to engineering design activities and last three phases are oriented to supply and production issues (Figure 1-1). Following are described briefly six proposed stages:

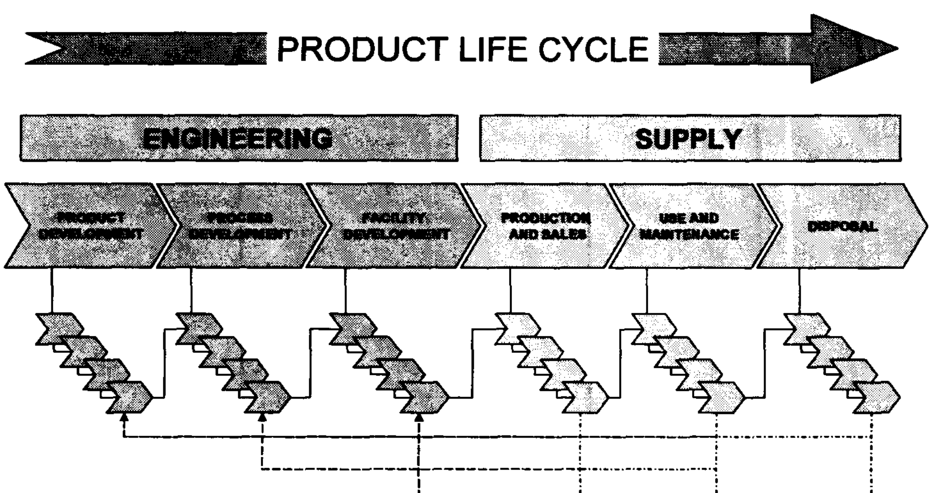


Figure 1-1 Product Life Cycle Phases

- *Product Development* includes collection of market requirements and conceptual and detailed development until meet the customer requirements.

- Process Development is the selection of material and manufacturing process for all individual components of product in development.

- Facility Development is the selection of supplier for standard components, process planning and/or facility design for manufactured components.

- *Production and Sales* includes production manufacturing, supply of raw materials, packaging, shipping and sales.

- *Use and Maintenance*, not directly controlled by the manufacturer but is influenced by how products are designed, manufacturer maintenance, and regulatory requirements instituted by a government.

- *Disposal*, when a product is no longer satisfactory because obsolescence, component degradation or changed business.

The present investigation addresses in a methodology for Integrated Product Development during the first three stages of Product Life Cycle: Product Development, Process Development and Facility Development.

1.5 Thesis Organization

The research presented is organized in six chapters described bellow:

- Chapter 2 – Research fundamentals of this work are introduced. Product Life Cycle is formally defined and three successful research projects in Integrated Product and Process Development (IPPD) are described briefly.

- Chapter 3 – A literature review analysis achieved about recent research projects in IPPD and Collaborative Design concepts.

- Chapter 4 – The reference model for implementation of Integrated Product and Process and Facility Development (IPPFD) is described.

- Chapter 5 – Presents a detailed description of the generic model of Reference Model developed in Chapter 4.
- Chapter 6 – A complete case of study is offered. This chapter show step by step the implementation of methodology proposed in chapter 4.
- Chapter 7 – Reports results and conclusions of this thesis.

Finally at the end the thesis a group of appendixes are included with all documentation derived during the implementation of the methodology and development of case of study.

2 Research Fundamentals

2.1 Product Life Cycle

2.1.1 Life Cycle Design of Products

The increasing competitiveness has forced companies to develop products in shorter times and with less cost. This has impel companies to organize in a different and more efficiently way. An important factor to consider for this issue is the Product Life Cycle, according with [Smith 2000] the product life cycles are getting shorter and demand curves steeper.

Product Life Cycle is an approach that describes the evolution of the product from its conception to its disposal. This description represents all the activities, information and resources needed to manage the product development process [Sanchez 1998].

Each company will have to develop a life-cycle concept for its products. Here it will be necessary to define how subcontractors and suppliers are considered to be a part of the life-cycle concept. The research and development community will have to come up with a generic life-cycle component (Figure 2.1) which individual companies can use to tailor their own specific concept [Alting 1993].

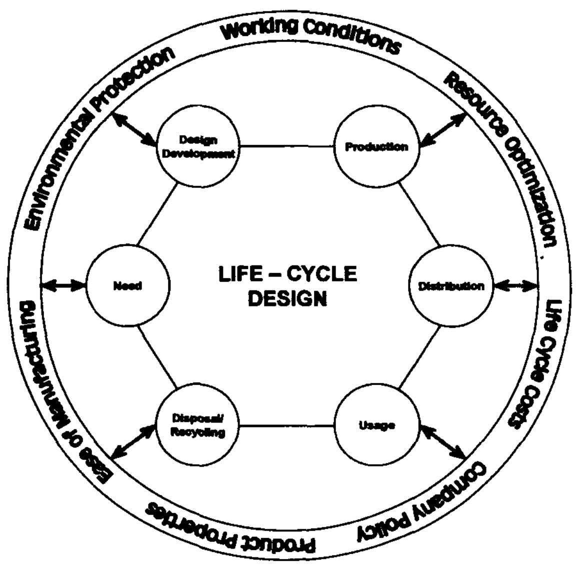


Figure 2-1 The life-cycle concept of product design [Alting 1993].

The phases a product goes through are: Need recognition; Design development; Production, Distribution; Usage; and Disposal / Recycling. The selection of possible solutions is guided by a criteria function. This criteria function must contain elements like: Environmental Protection; Working Conditions; Resource Optimization; Life Cycle Costs; Company Policy; Product Properties; and Ease of Manufacturing

2.1.2 Conventional Stages in Technology Commercialization

Technology commercialization is about performing successfully a range of things, each adding value to the technology as it progress. Five activities constitute the key sub-processes involved in bringing new technologies to market [Jolly 1997]:

- *Imaging,* this is when the prospects for a technical breakthrough get combined with a potentially attractive market opportunity.

- *Incubating* the technology to define its commercializability. The idea needs to be proved in some unequivocal manner, both technological and in terms of the need it is supposed to fulfill.

- *Demonstrating* it contextually in products and /or processes. This is the stage associated with product development.

- *Promoting*, for new technologies the promotional challenge has two dimensions: one has to do with persuading people to adopt it and the other dimension relates the infrastructure that has to be created in order to deliver the technology's full benefit.

- *Sustaining,* the key to realizing value from any new technology is to make sure the products and processes incorporating it enjoy a long presence on the market and that a fair share of the long-term value they generate are appropriated by the technology's initiator.

The five sub-processes described above are not themselves exceptional. In fact, most stage-by-stage descriptions of the innovation process can be mapped onto them, as show in Table 2.1.

Table 2-1 How the segmented view of commercialization corresponds with conventional stages in technological innovation [Jolly 1997]

The Segmented, Value Build-Up View pf Commercialization	Schumpeterian and Traditional 3-Way Classifications	Bright (1970) Stages	Cooper (1986) Seven Stage New Product Game Plan	National Society of Professional Engineers (1990) Engineering Stages	Du Pount (1995)
1. Imaging		1. Scientific suggestion, discovery, recognition, of need or opportunity. 2. Proposal of theory or design concept.	1. Idea generation	1. Concept	1. Idea
2. Incubating	1. Concept development (basic and applied research leading to invention)	3. Laboratory verification of theory or design concept.	2. Preliminary assessment 3. Concept generation (technological)	2. Technical feasibility	2. Scouting
3. Demonstrating	2. Product development	4. Laboratory demonstration of application. *5. Fuel scale or field trial*	4. Development (engineering, design and prototypes) 5. Testing 6. Trial Production and test market	3. Development 4. Commercial validation and production preparation 5. Full-scale production	3. Project 4. Prototype
4. Promoting	3. Market Development	6. Commercial introduction or first operation use	7. Full production and market launch		5. Introduction and commercial
5. Sustaining		7. Widespread adoption as indicated by substantial profits, common usage, significant impact. 8. Proliferation		6. Product support	6. Product support

2.2 Integrated Product and Process Development (IPPD)

2.2.1 Department of Defense (DoD) IPPD Handbook

IPPD is a management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing, and supportability processes. IPPD facilitates meeting cost, schedule, and performance objectives from product concept though production, including field support [OUSD 1998].

Five key principles described in the DoD IPPD Handbook were essential to the effective implementation of IPPD:

i) Customer Focus: The primary objective of IPPD is to identify and satisfy the customer's needs better, faster, and cheaper. This is accomplished by including the customer in decision making and on multidisciplinary teams throughout the entire development process.

ii) Concurrent Development of Products and Processes: Processes should be developed concurrently with the products they support to ensure that the product design does not drive an unnecessarily costly, complicated, or unworkable process when the product is produced and fielded.

iii) Multidisciplinary Teamwork: Multidisciplinary teamwork is implemented through the use of Integrated Product Teams (IPT). Teams comprise members from technical, cost, manufacturing and support functions and organizations, including customers and suppliers. Team members are empowered to make decisions for their respective organizations as well as keep them informed of the product and process decisions.

iv) Proactive Identification and Management of Risk: Risk management in support of IPPD includes the use of an organized, comprehensive, and iterative approach for identifying and analyzing cost, technical, and schedule risks, and instituting risk-handling options to control critical risk areas.

v) Integrated Information Environment: A seamless information environment is used for requirements identification, planning, resource allocation, execution and program tracking over the product's lifecycle. This ensures that teams have all available information, enhancing team decision-making at all levels.

2.2.2 ProcessIPPD™

ProcessIPPD™ is a methodology ad toolkit for process modeling and analysis in support of IPPD-enabled collaborative product development and complex systems engineering [Madni 1998].

End-users or ProcessIPPD™ are systems engineers and program managers, i.e., non-programmers. The purpose of ProcessIPPD™ is to support these individuals in capturing, verifying, visualizing, analyzing, and streamlining their system engineering or product development processes prior to their implementation and execution. The key aspects of ProcessIPPD™ that set it apart from other process tools are:

i) Process reuse through a Process Asset Library.

ii) Specific focus on systems engineering and IPPD.

iii) Rich set of analysis capabilities that are made possible by a powerful underlying ontology.

iv) Import/export facilities

v) Interoperability with third party simulation tools and workflow engines

vi) Multi-perspective, multi-level process visualization including process maps, activity dependency graphs, data flows, work breakdown structure (i.e. process decomposition hierarchy), and cross-functional process interdependency views.

At the highest level, the IPPD ontology embodies there fundamental concepts:

- An enterprise has a set of resources that it uses to achieve its goals. It is called *enterprise modeling*.
- A process, as part of an enterprise, performs its activities, consumes or utilizes resources or products in the enterprise, and produces other resources or products in accord with the enterprise goals. It is called *process modeling*.

- To achieve its goals, an enterprise has to provide adequate resources and manage their utilization in a timely manner during the operation of the enterprise (i.e. the execution of its process). It is called *process execution and management.*

The IPPD ontology defines four basic objects that are refined into more specific objects to characterize a systems engineering or product development enterprise:

- *Entity* represents any type of artifact within a product development enterprise. The properties of Entity, among others, include simply the name and description of the entity.

- *Enterprise* is a type of *Entity* that represents a collection of *Entities* that are used to achieve a set of Goals. *Enterprise* is the core concept. Everything else is centered around and related to *Enterprise*, which is defined through a set of relations. Thus an enterprise model is a web of other subclasses of *Entity*, such as Goal, Role, Person, Process, and Goods/Material. An enterprise can be decomposed into a hierarchy of other, smaller *Enterprises.*

- *Process* is a subclass of *Entity.* It represents a series of activities. When a process is first created, it is a description o what will be done (i.e. the process model). When a process is executed or performed (i.e. workflow/process instance), it represents a series of real world activities that consume/utilize the allocated entities and, in turn, produce new entities. A *Process*, in addition to having a set of properties, can be decomposed into a hierarchy or other, smaller process (i.e. sub-processes). At the bottommost level in the process decomposition hierarchy is a subclass of *Process*, called *Activity.*

- *Constraints* are restrictions or boundary conditions that govern the execution of a process. A *constraint* may be defined by the states and/or conditions of one or more entities.

2.2.3 The Total View Approach

A framework is proposed for integrated product development called *The Total View Approach* [Loureiro and Leaney 1998]. The total view approach is based on the assumption that the result of the product development effort is not only the product itself but also its life cycle processes and some of their performing organizations, as illustrated in Figure 2-2.

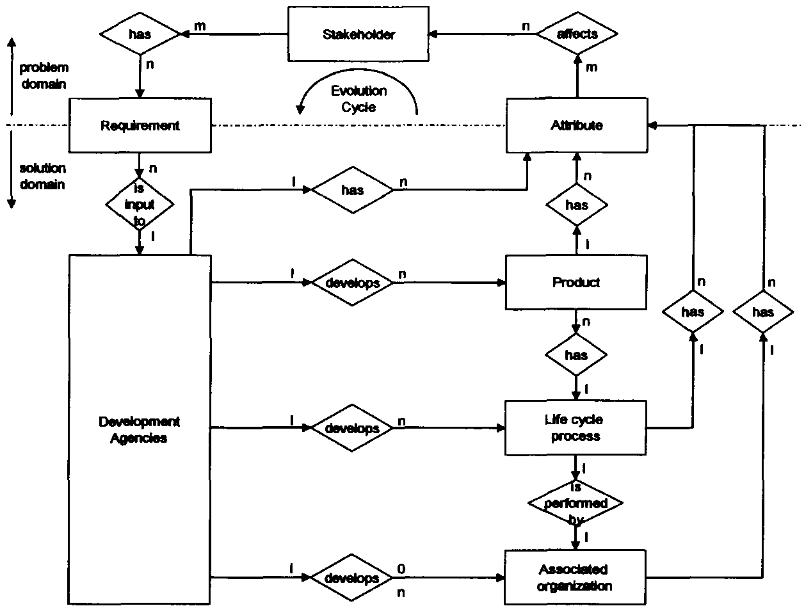


Figure 2-2 The proposed integrated development model for the total view approach

The Total View Approach is a structured analysis framework that enlarges the scope of the system under development to contain not only the product, but also its life cycle processes and some of their performing organizations. The total view approach then mirrors the systems engineering process to analyze the whole-integrated system. The mainstream of the systems engineering process, according to modern standards (e.g. Mil- Std-499B, IEEE-Std-1220-19949, and EIA- 63210), consists basically of the requirements analysis, functional analysis and synthesis. The total view approach performs the requirements analysis, functional analysis and physical analysis sub-processes. The physical analysis models the physical architecture of the system resulting from the synthesis process. The approach is applied recursively to all levels of the product breakdown structure and can then be represented by the pyramid section illustrated in Figure 2-3.

Integration takes place in the following ways:

- Linking stakeholders and development agencies through a common shared central project database. This includes the relationship between customer and supplier or between prime and subcontractor.

- Linking requirements to the elements of the functional architecture and these to the elements of the physical architecture

- Linking product elements, process elements and organization elements within their respective models
- Linking product, process and organization elements between their respective models
- Linking product, process and organization elements by identifying the interactions among their attributes.

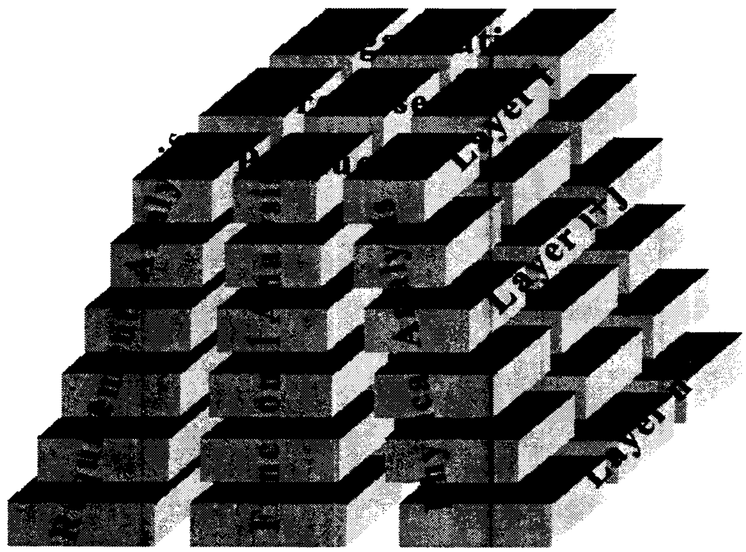


Figure 2-3 A representation of the total view approach

A tool that implements all the basic capabilities listed above and the required expansions for hardware, process and people systems analysis is Cradle (hereafter referred to as "the SEE"). It is a commercial software tool, developed by 3SL. It is defined as a systems and software engineering environment that provides through life support from requirements capture to system implementation with supporting configuration management, project control, and document generation capabilities [14].

The SEE uses the concept of a central project database that can be accessed through Local Area Network (LAN) or Wide Area Network (WAN). The SEE can, for example, integrate the customer into the project team by either providing the customer with on-line access into the project's central database or providing the customer with a copy of the database and a read-only copy of the SEE used to create it. Also, in order to integrate prime and subcontractor, each subcontractor can be provided with a separate project group within the overall project organizational structure. The access rights of this group would then be designed such that it has access to all reference information for the work that it is to perform and can populate the database with its deliverables.

The SEE is composed of the following modules, as illustrated in Figure 2-4. The characteristics of each of these modules relevant for the development of the total view approach are:

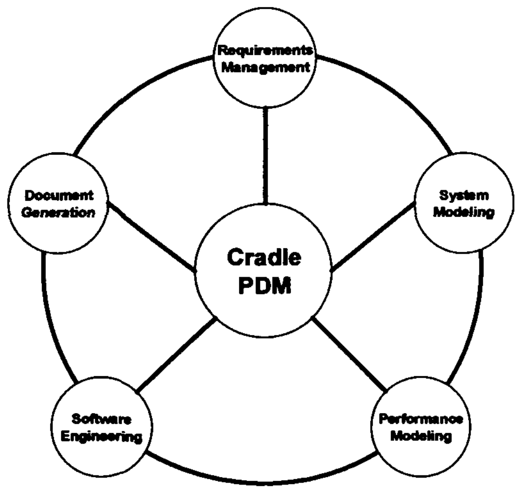


Figure 2-4 Cradle Modules

- *Product Data Management (PDM)*: This module includes configuration management, cross reference, text and graphics reporters, workgroup management, project database, system notes. The configuration management system (CMS) provides mechanisms for: flexible project structures, formal review and approval, baselines, version control, formal change, audit. The CMS contains knowledge of the relationships between individual items of information.

- *Requirements management*: Deals with stakeholder or internally; generated source documents; assesses impact of source document changes; versions source document when changes occur; edits, names and numbers requirements; supports requirements hierarchies; captures requirements from source documents; navigates through requirements using many different search definitions, enabling the user to check for duplication of requirements, no compatibility; cross reference requirements to other items in the project; and other items in the project database.

- *System Modeling*: The SEE separates the system modeling into an essential model and an implementation model, following Yourdon's terminology. The essential model models what the system is supposed to do, its functions and the implementation model models how the system is implemented to accomplish those functions, its architecture. Cradle supports the following modeling notations: extended Yourdon notation, Function Block Diagrams (FBD), Behavior Diagrams (BD), Use Case Model and OMT.

- *Performance Modeling*; The SEE works essentially at the pre-specification stage. However it provides a performance modeling capability. Performance modeling allows any part of a design to be assessed in terms of the characteristics that it needs in order to be viable when built. The performance modeling functionality provided is based on instrument symbols on state models with performance data expressed as sets of Performance Parameters (PPs).

- *Document generation*: This module allows arbitrarily complex documents to be defined and generated from any or all information in a project database. A clear distinction is made between the information reported in a document and the structure of the document.

- *Software engineering*: This module supports code generation and reverse engineering (given the code, a structure chart diagram is generated).

3 Literature Review

The objectives of this Literature Review are

i) Evaluate different research projects in IPPD in order to determine their scope through the initial stages of the Product Life Cycle.

ii) Evaluate different research projects on Collaborative Product Development in order to evaluate their level of collaboration through Product Life Cycle.

3.1 Scope of IPPD research projects

The objective of this evaluation is to determine the scope of different research projects related with IPPD concepts through initial stages of Product Life Cycle. In order to achieve this evaluation a Product Life Cycle map is proposed in Figure 3-1. The PLC map features are next:

- *Processes* are possible cases to be developed during engineering projects: Product Development, Process Development and Facility Development.

- *Stages* are indicators of evolution level for processes: Conceptualization, Basic Development, Advanced Development and Launching.

- *Tollgates* are specific result obtained at the end of every stage for a given process, e.g. Product Idea is the result from Product Development process at Conceptualization stage.

Each one of the research projects evaluated was mapped in Figure 3-1 in order to identify which areas Processes and stages are supported by these projects. Results from this evaluation are show in Table 3-1 and discussed in the last section of this chapter.

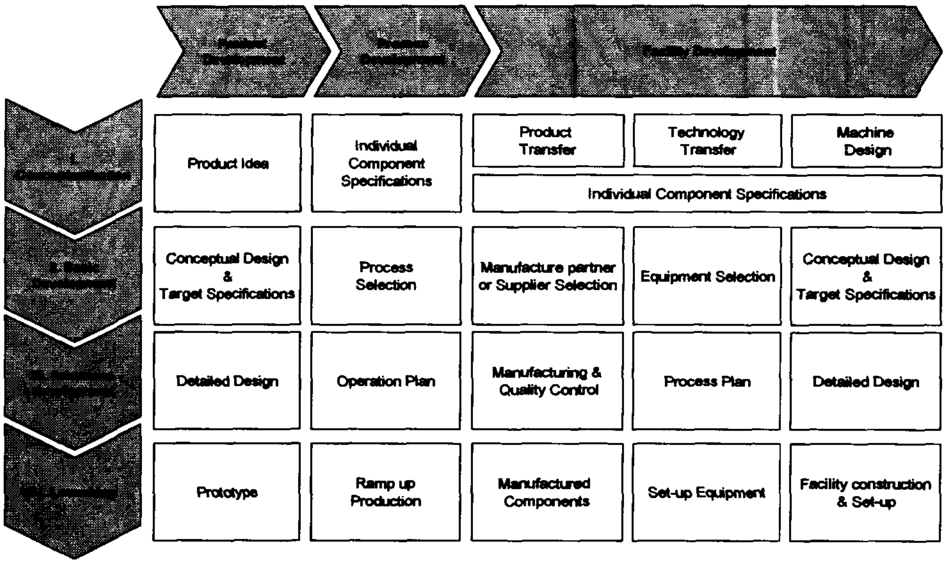


Figure 3-1 Proposed map for engineering stages of Product Life Cycle (PLC)

Table 3-1 Scope of research projects during initial stages of Product Life Cycle (Continue)

	Product Development				Process Development				Facility Development											
									Product Transfer				Technology Transfer				Machine Design			
	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥
Cunha et. al. 2003							X								X			X	X	
Kusar et. al. 2003	X				X				X				X				X			
Lee et. al. 2003			X		X			X			X	X			X	X			X	X
Mendoza et. al. 2003	X	X	X														X	X	X	
Molina and Bell 2003			X				X								X				X	
Mervyn et. al. 2003			X								X	X			X	X				X
Smith et. al. 2003		X	X			X									X					
Yan & Zhou 2003	X				X			X	X				X			X	X			X
Cabrera et. al. 2002							X											X	X	
Lau et. al. 2002							X								X					
Lin & Chen 2002		X	X			X														
Mejia et. al. 2002										X	X									
Ragatz et. al. 2002			X						X	X		X								
Renton et. al. 2002				X				X				X			X					X
Singh 2002			X		X	X	X						X	X						
Wei et. al. 2002				X			X				X	X				X			X	X

Table 3-1 Scope of research projects during initial stages of Product Life Cycle (Continue)

	Product Development				Process Development				Facility Development											
									Product Transfer				Technology Transfer				Facility Design			
	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥	–	=	≡	≥
Molina et. al. 2001										X	X									
Ratchev & Hirani 2001			X				X										X	X	X	
Song et. al. 2001			X			X	X				X	X			X	X			X	X
Wu 2001														X	X	X				
Govil & Magrab 2000		X	X			X	X								X					
Shah et. al. 2000		X																X		
Stone & Wood 2000		X																X		
Charles et. al. 1999													X	X	X					
De Lit et. al. 1999			X												X				X	
Dorador & Young 1999			X	X			X	X							X	X				X
Esawi & Ashby 1998		X	X		X	X									X					
Fisher 1998	X				X				X				X				X			
Gindyand & Ratchev 1998						X							X	X	X					
Swink et. al. 1996	X	X			X	X			X	X			X	X			X	X		
Dong 1994			X											X	X					

3.2 Collaboration levels of Supporting Services for IPPD

The objective of this evaluation is to determine collaboration level of different research projects on development of Supporting Services for Collaborative Product Development during initial stages of Product Life Cycle.

Computer based information systems have been introduced to support Integrated Product Development. In order to evaluate the research project a classification of the supporting services can be as follows:

- *Functional*, systems that support engineers in specific task: CAD, CAM, CAE and Rapid Prototyping (Kochan 1995).

- *Methodological*, standardized best practices: QFD (Revelle 1998), FMEA (Palady 1995) and DFM/DFA (Boothroyd and Alting 1992).

- *Coordination*, systems to support sequencing of activities and flow of information. For example: workflow (Choi et. al 2002) and project management (Barclay and Dann 2000).

- *Collaboration*, systems to foster cooperation among engineer i.e. CSCW - Computer Supported Cooperative Working (Woodcock and Scrivener 1999).

- *Information and Knowledge management*, product information management systems to enable the exchange of product and manufacturing information (Hanneghan et al. 2000).

Collaboration levels of each one of the research projects were analyzed in order to identify the use and description level of the supporting services systems defined above. The evaluation parameters are defined as follow:

Symbol	Level	Description
●	High	Included and described completely
■	Medium	Included and described briefly
▲	Low	Included, but not described
	Null	Not included

Results from this evaluation are show in Table 3-2 and discussed in the last section of this chapter.

Table 3-2 Collaboration levels of Supporting Services for IPPD

	Functional	Methodological	Coordination	Collaboration	Information/ Knowledge Management
Simpson et. al. 2003	●			■	
Deek et. al. 2003		▲	●	●	▲
Reiter 2003				●	■
Shang et. al. 2003				●	
Noel and Brissaud 2003	●		●	●	
Ahn et al. 2002	●			▲	
Bidarra et. al. 2002	●			●	■
Chen et al. 2002				■	●
Choi et al. 2002				▲	●
Jiang et. al. 2002	●			■	
Li et al. 2002				●	
Soares 2002	●			▲	
Ye 2002		■	▲	●	
Gerhard et. al. 2001	●			■	
Wang et. al. 2001	●	▲	●	●	
Al-Ashaab et. al. 2001	●			▲	■
Domazet et al. 2000				●	●
Zaychik et al. 2000				●	●
Gupta et al. 1998	●			■	
Harrison et al. 1996				●	●
Toye et al. 1993	●		●	●	●

3.3 Literature Review Discussion

The literature and current practice indicate that there have been significant changes made in terms of the manufacturing paradigm shift from traditional manufacturing to a world of agile manufacturing, which is able to respond quickly to customer's demands [Newman et. al. 200]. In general, a long product design cycle diminishes the competitiveness of products due to the relatively shortened product lifecycles in the global marketing [Lau et. al. 2002]. This subject is a subject of many research projects in Integrated Product and Process Development (IPPD), Concurrent Engineering (CE) and Collaborative Product Development, from the previous evaluation, important issues are:

- Research projects evaluated in Table 3-1 propose methods and tools to support IPPD, however, the integration level of this methods and tools is restricted to: exchange of information between stages in one Process or exchange of information among Processes for specific stages.

- Several IPPD methods and tools has been reviewed, however, is evident the absence of a methodology able to integrate IPPD methods and tools through all Processes and stages of Product Life Cycle. Actually these methods and tools are treated as two isolated environments that exchange information among specific stages.

- In Supporting Services for Collaborative Product Development none of the research projects evaluated describes completely the use of the five supporting services defined for , most of the collaborative projects explode fully the use of the collaboration service and just one other of the supporting services defined. In addition, the absent of proved methods which support the engineering activities between customers - engineers, design team, design and manufacturing engineers.

4 Reference Model and Methodology for Reconfigurable Integrated Product, Process and Facility Development (IPPFD)

In this chapter a systematic approach is proposed on how activities can be selected and configured from a Reference Model for a successful product development system, independent of the industrial sector of a company, but dependent on its problems, market, constraints and declared goals. For an effective application of methods and tools in product development, a comprehensive framework is needed, which supports the selection, coordination, and assessment according to domain – and company – specific needs and constraints [Negele et. al. 1998].

This chapter is divided in three sections, in the first section a Reference Model and their elements is described, in second section a systematic approach for Methodologies Configuration is defined and finally in third section the methodology is described in detail.

4.1 Reference Model Integrated Product, Process and Facility Development (IPPFD).

In the present section a Reference Model for Integrated Product, Process and Facility Development (IPPDM) and their elements are described. The proposed Reference Model is described through three axes (Figure 4-1):

- *Processes* are a description of the possible set of future events. In this reference model there are three types of Processes: Product Development, Process Development and Facility Development.

- *Stages* are a set of activities performed to achieve a partial result in a specific Process. This reference model has four types of Stages: Conceptualization, Basic Development, Advanced Development and Launching.

- *Activities* are specific tasks that must be executed in order to complete a Stage. There are three types of Activities: Analysis, Synthesis and Evaluation.

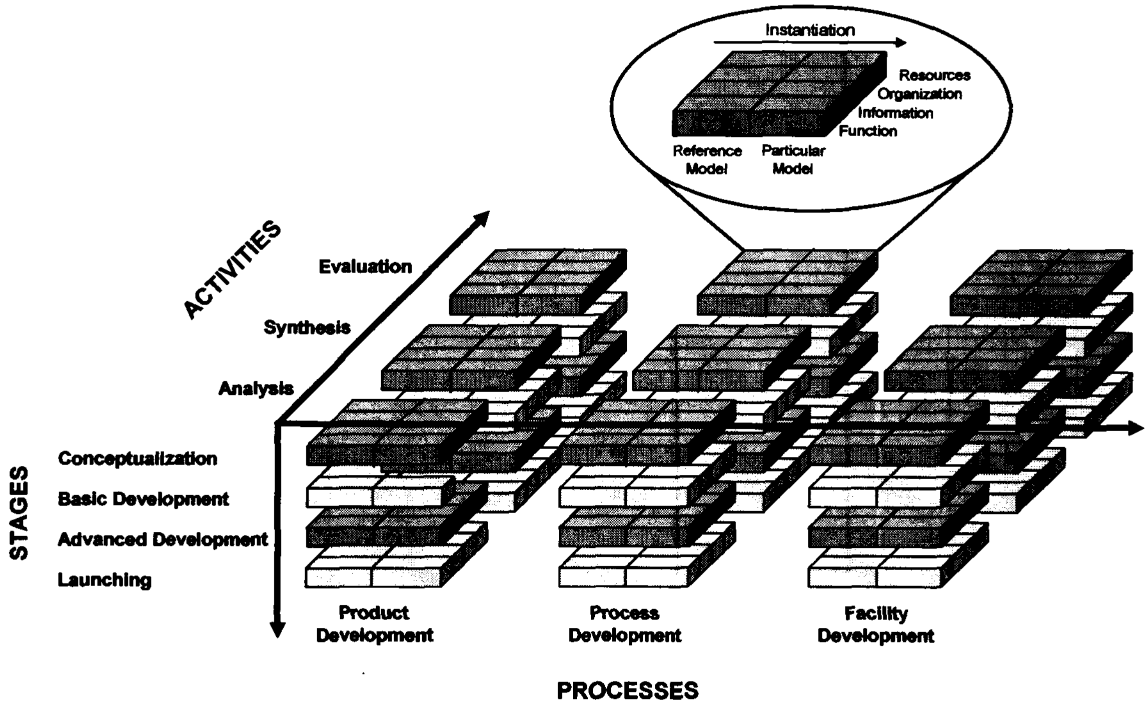


Figure 4-1 Reference Model for Integrated Product, Process and Facility Development

Product Life Cycle during engineering stages is the complete arrangement of Processes, Stages and Activities is show in Figure 4-2. In order to implement the IPPFD in a company it is important to define following concepts:

- *Reference Model* contains generic building blocks and building block types as the elements of the modeling language (or modeling language constructs) to express any model (particular model).
- *Particular Model* is the instantiation of Generic Model; this contains company specific models of parts of a given enterprise.

In next section it is going to be explained how to perform an instantiation from the Generic Model to obtain a Particular Model in order to implement IPPFD concept in any company.

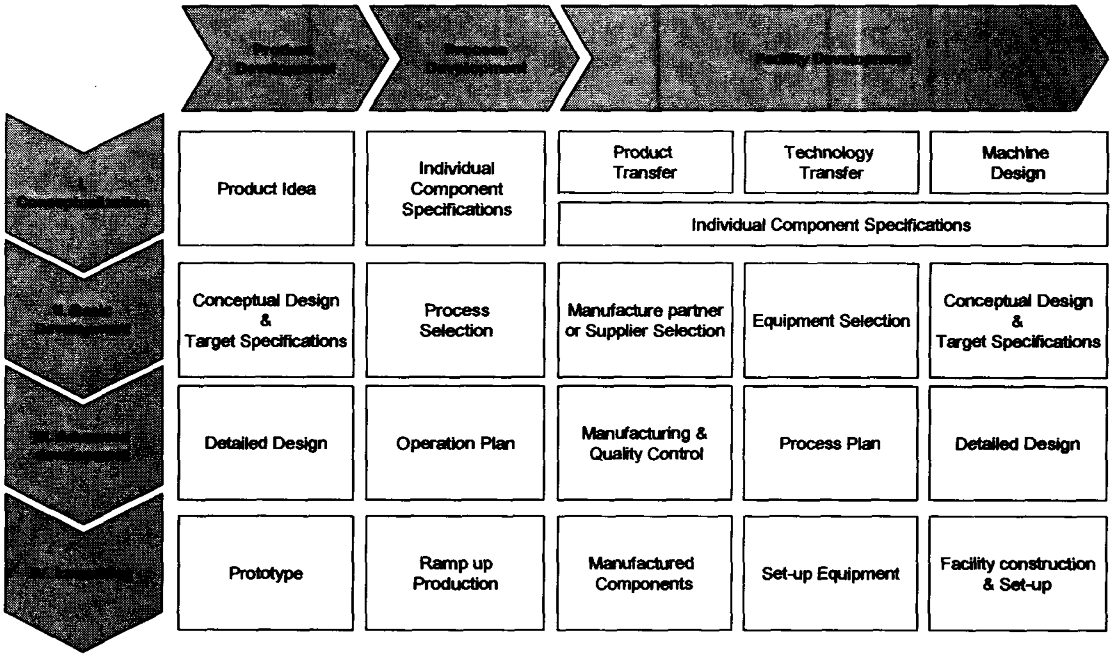


Figure 4-2 Proposed map for engineering stages of Product Life Cycle (PLC)

The Activity is the basic Cell or Building Block of the proposed Reference Model. Particular Models are constructed using Activities as basic blocks. Activities are associated to the following features (Figure 4-3):

- Function: represents enterprise functionality and behavior (i.e. events, activities and processes).
- Information: represents enterprise objects and their information elements.
- Resources: represents enterprise means, their capabilities and management.
- Organization: represents organizational levels, authorities and responsibilities.

In addition, Activities are classified in three types:

- *Analyses Activities* are oriented to diagnose, define and prepare information.
- *Syntheses Activities* are oriented to laying together elements to produce new effects and to demonstrate that these effects create an overall order.
- *Evaluation Activities* are oriented to test those solutions against the goals and requirements.

Besides, for documentation purpose Activities are supported for to documents:

- *Instructive*: describe the activity, that is, objective, responsible, input information, use of tools and techniques and results of the activity.

- *Format*: is a standard document used to write down results of the activities, after it is filled it becomes in a Record or evidence that the activity has been executed. The Record is the input information for next activity.

Before the elements of the Reference Model for Integrated Product, Process and Facility Development have been described, the properties of this Reference Model are:

- *Configurability,* Methodology obtained from Reference Model is a Particular Model which is an instantiation from a Generic Model. The basic Cell of the Generic Model is the Activity, that is, Methodology is a set of concurrent Activities ordered to get a specific goal in the Product Life Cycle.

- *Reusability*, the methodology resulting from the Reference Model is supported by a Activity Asset Library (Cells) that can be reused at different stages and Processes on depend of the type of product in development.

- *Variability*, the methodology derived from the Reference Model is able to develop different products (mechanical, electronic, etc.) at different Processes and Stages due to its properties of Configurability and Reusability.

- *Expansion-ability,* due of its structure the methodologies obtained from the Reference Model are able to adopt new methods and tools and increase their Variability.

- *Robustness,* Reference Model is based on proved methods and tools in product development process in order to assure information flow among product development stages and avoid the lack of collaboration between design engineers and manufacturing engineers. Besides Information Management based on Formats and Records facilitates the information access for team members and as consequence facilitates changes in product design and reduce the impact in time development.

4.2 Methodology for Particular Model Configuration

In this section of the chapter it is going to be described how to configure the Particular Model from Reference Model for implementation of IPPFD concepts in a company. In order to configure Particular Model it is necessary to achieve three basic phases (Figure 3):

i) *Phase I – Project Definition*, during this phase company requirements are identified and scope of the project is defined in accordance with the Reference Model map.

ii) *Phase II – Activity Sequence Definition*, after the project has been defined, throughout this phase the Reference Model is breakdown in Activities in order to evaluate them and select those that are going to be used during the project execution.

iii) *Phase III – Activity Sequence Mapping*, once the set of activities has been defined it is necessary to translate each one of the Activity Features (Function, Information, Resources and Organization) from the Reference Model domain to the Company Domain.

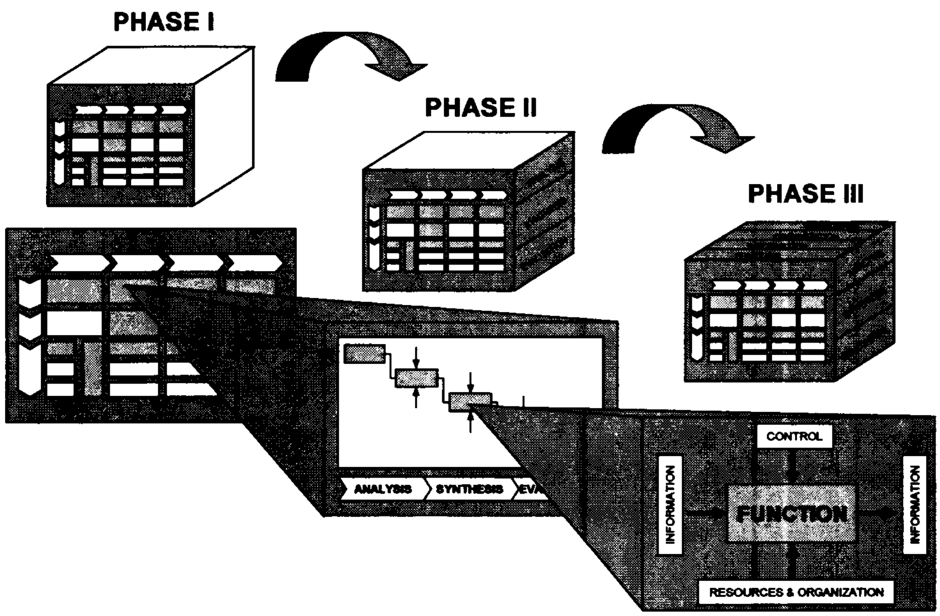


Figure 4-3 Phases for Particular Model Configuration

In order to configure a Particular Model the proposed systematic approach has been structured in Table 4-1. This structure comprises three Phases defined previously and in addition includes following elements:

- *Tasks*, activities that must be executed in order to achieve a tollgate within a Phase.

- *Tollgates*, results obtained after execute a set of Tasks, they indicate the end of a Phase.

- Instructive & Formats, documents that provide to the user a systematic from to execute Tasks and reflect their results (Tollgates).

Following a detailed description of Tasks and Tollgates for defined Phases is given. Documentation of this methodology (Instructive and Formats) is showed in Appendix A.

Table 4-1 Systematic approach for Methodology Configuration.

PHASE	TASK	TOLLGATES	DOCUMENTATION
I. PROJECT DEFINITION	1 Identify Company Requirements 2 Identify process path 3 Verify process path information	3 Concurrent Map	IMC-01, FMC-01
II. ACTIVITY SEQUENCE DEFINITION	4 Activity Breakdown 5 Activity Selection	4 Activity Program	IMC-02, FMC-02
III. ACTIVITIES MAPPING	6 Company Evaluation	6 Particular Model	IMC-03, FMC-03

4.2.1 Phase I – Project Definition

During this phase company requirements and identified and scope of the project is defined. This phase is composed by three tasks and one tollgate; following they are described following.

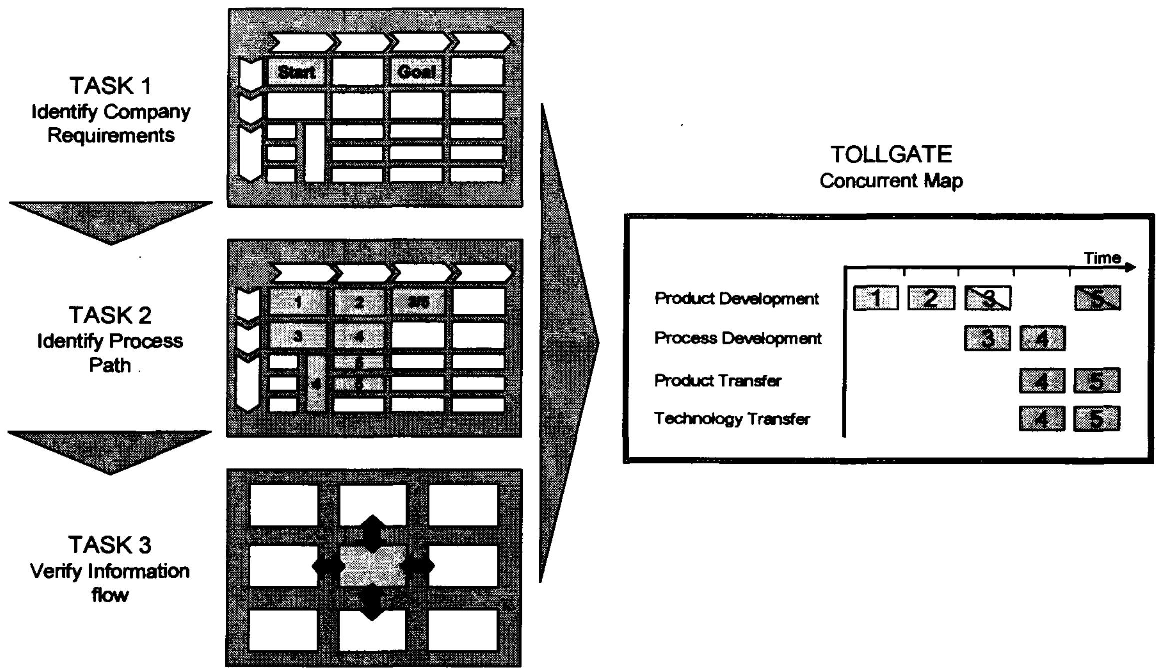


Figure 4-4 Phase I – Project Definition: Tasks and Tollgate.

4.2.1.1 Task 1 – Identify Company Requirements.

The objective of this task is the collection of company requirements in order to identify which kind of project is going to be developed and define scope of the project. This task is based in the map for engineering stages of Product Life Cycle (Figure 4-2); in this map it is necessary to identify which are initial Tollgate and goal of the project.

In order to select the start and target boxes the instructive includes a brief description of each one of the boxes proposed in Figure 4-2.

4.2.1.2 Task 2 - Identify process path.

Second step is to identify a path from Start Tollgate to the Expected Goal. This path must be traced and must reflect the company capabilities and capacities, that is, technological and human resources from the company. Numbers are added to the boxes to indicate a tentative sequence of the project.

4.2.1.3 Task 3 – Verify Process Path Information

Once the process path has been selected it is necessary verify information flow among each one of the boxes. All boxes has two list associated, for input and output information. These lists allow determine when boxes can exchange information among them. If the proposed path is not feasible, then it is rechecked whit information list and a new path is proposed.

4.2.1.4 Tollgate: Concurrent Map

Results from previous tasks are reflected at this Tollgate. The results is a tentative schedule indicating which boxes are going to be executed and the concurrency between stages of different Processes.

4.2.2 Phase II – Activities Sequence Definition

After the project has been defined, throughout this phase the Reference Model is breakdown in Activities in order to evaluate them and select those that are going to be used during the project execution. This phase is composed by two phases and one tollgate; they are described following (Figure 4-5):

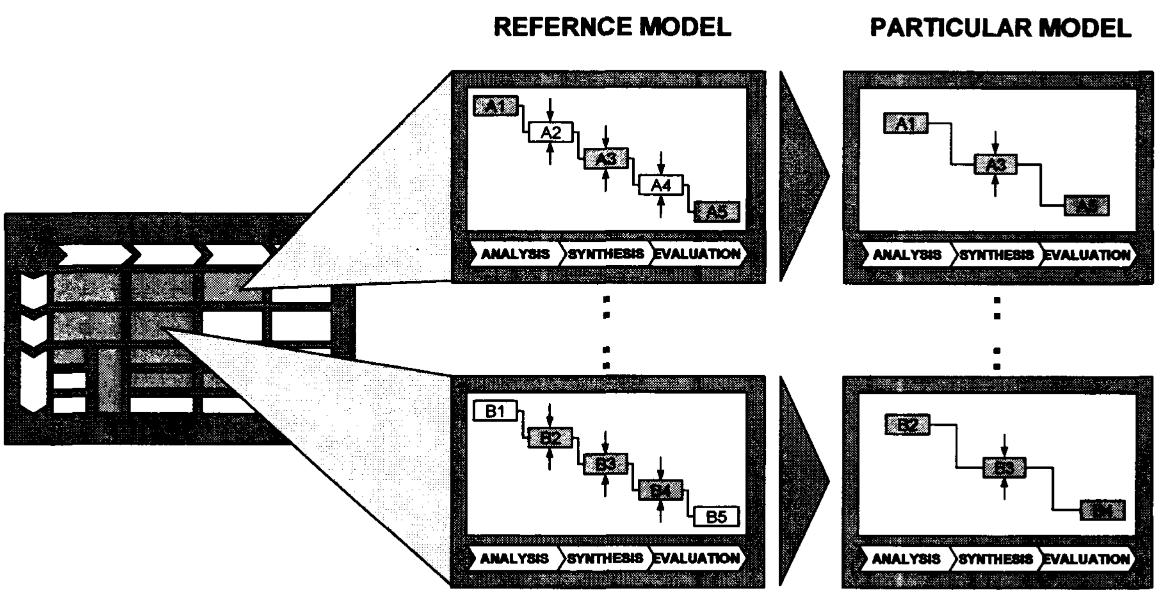


Figure 4-5 Phase II – Activities Sequence Definition

4.2.2.1 *Task 4 – Activity Breakdown*

Once the process path has been identified and information flow verified, it is necessary to decompose each one of the selected Tollgates in order to identify the set of activities proposed by the Reference Model.

4.2.2.2 *Task 5 – Activity Selection*

A standard method for evaluation and selection of activities has been proposed in this section. Through this method the four main objectives of the activities are evaluated in order to evaluate if they impact positively (Right Arrow) or negatively (Left Arrow) to the present project (Figure 4-6); if the activity is evaluated with at least 2 Right Arrow (50%) then the activity is selected to be achieved in the present project.

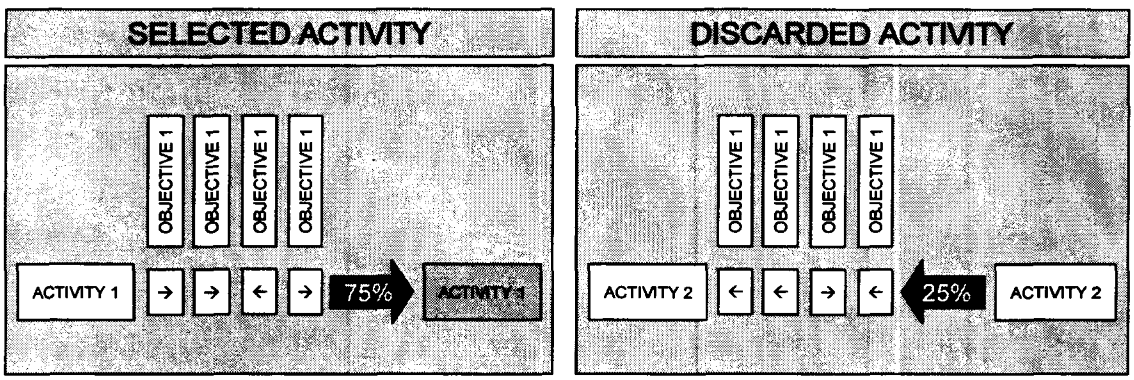


Figure 4-6 Standard Method for Activities Evaluation and Selection.

4.2.2.3 *Tollgate: Activities Program*

Results from previous tasks are reflected at this Tollgate. The result is a tentative schedule indicating list of activities to be executed and the concurrency between activities of different Processes.

4.2.3 Phase III - Activities Mapping

Once the set of activities to be achieved have been selected it is necessary to translate each one of the Activity Features (Function, Information, Resources and Organization) from the Reference Model domain to the Company Domain. This phase is composed by two tasks and one tollgate; they are described following (Figure 4-7):

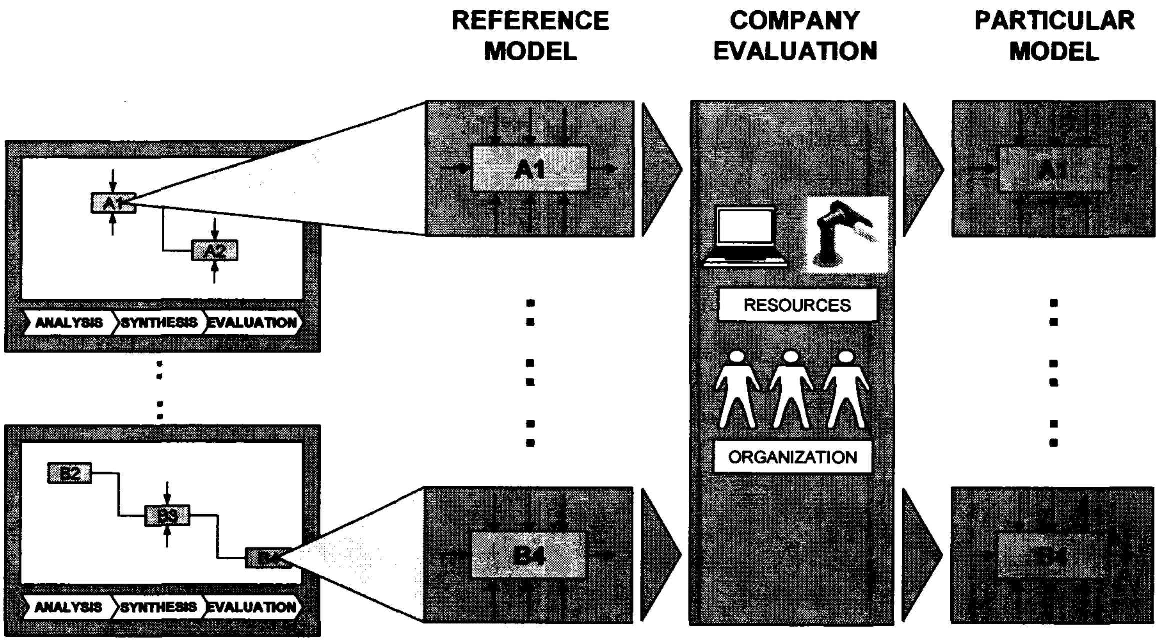


Figure 4-7 Phase III – Activities Mapping

4.2.3.1 Task 6 – Company Evaluation

After the information company has been captured it is necessary to identify which technological resources from company are going to be used during the execution of the activities. Also company members are identified within development team in order to assign responsibilities during the project execution. The first task of this phase is capture and document Human Resources, Computer Technology and Production Technology.

- Human Resources or Organization are classified using the development team proposed by [Ulrich and Eppinger 2000] (Figure 4-8).
- Computer Technology is classified in accordance with Supporting Services introduced in section 3.2: Functional, Methodological, Coordination, Collaboration and Information/Knowledge Management (Table 4-2).
- And Production technology is classified by process accordance with classification proposed by [Alting 1993]: (i) Shaping: Mass Reducing, Mass Conserving and Joining; and (ii) No shaping Heat Treatment and Surface Finishing (Figure 4-9).

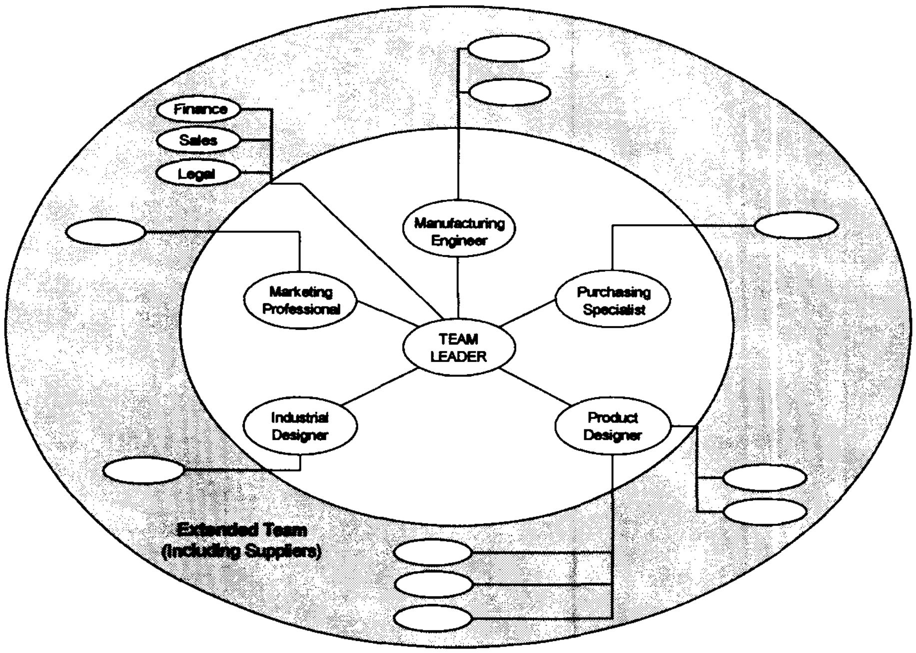


Figure 4-8 Composition of a product development team [Ulrich and Eppinger 2000]

Table 4-2 Classification of computer applications that support the Product Development Process

		DEFINITION	AVAILABLE TOOLS
SUPPORTING SERVICES	**Functional**	Function oriented systems that support engineers in specific tasks.	• CAD / CAM / CAE • ICAD Knowledge Based Engineering Systems • MAS / SPEED • Rapid prototyping
	Methodological	Proved methods used in Concurrent Engineering as standardized best practices	• QFD / AMEF / IDEF0 • DFM / DFA
	Coordination	Coordination systems to support sequencing of activities and flow of information.	• Project management • Workflow • Groupware • e-management • e-project
	Collaboration	Collaboration systems to foster cooperation among engineer i.e. CSCW - Computer Supported Cooperative Working	• Net meeting • Forums • Chat • Multicasting • e-mail
	Knowledge & Information Management	Product information management systems and Knowledge Based Engineering Systems to enable the exchange of product and manufacturing information and knowledge	• PDT – Product Data Technologies • PLM – Product Life Cycle Management Tools • Product Model • Manufacturing Model

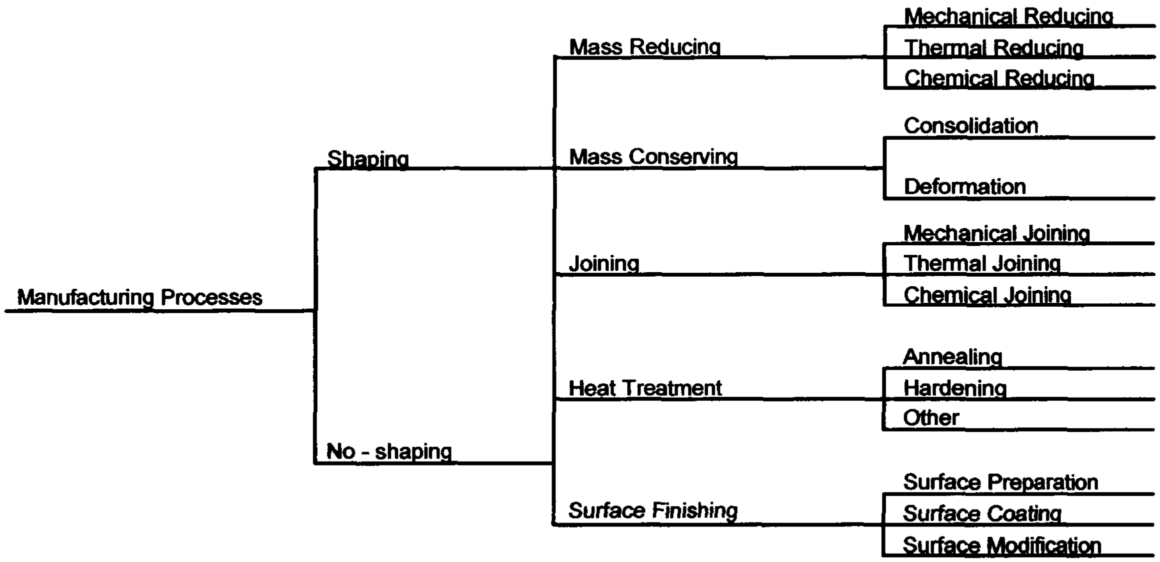
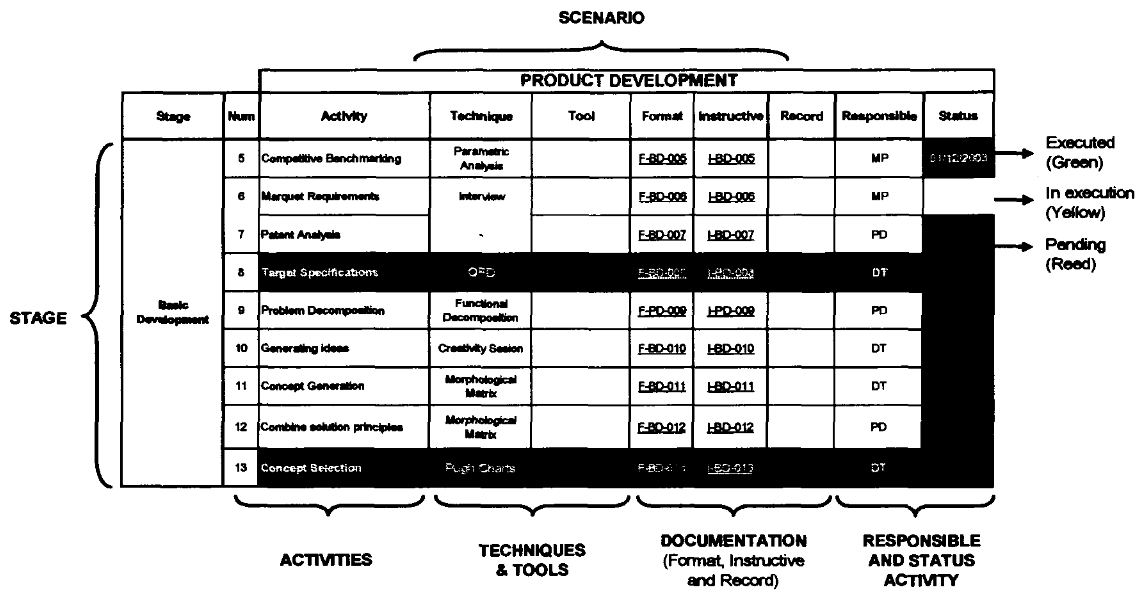


Figure 4-9 Classification of manufacturing processes that support the Product Development Process [Alting 1993]

4.2.3.2 Tollgate: Particular Model

The final result is captured in an Excel file where de users can manage different activities and identify the deliver time, responsible and support documents, techniques and tools. In Figure 4-9 is shown the structure of this kind and their feature.



		PRODUCT DEVELOPMENT							
Stage	Num	Activity	Technique	Tool	Format	Instructive	Record	Responsible	Status
Basic Development	5	Competitive Benchmarking	Parametric Analysis		F-BD-005	I-BD-005		MP	[illegible]
	6	Marquet Requirements	Interview		F-BD-006	I-BD-006		MP	
	7	Patent Analysis	-		F-BD-007	I-BD-007		PD	
	8	Target Specifications	QFD		[illegible]	[illegible]		DT	
	9	Problem Decomposition	Functional Decomposition		F-PD-009	I-PD-009		PD	
	10	Generating ideas	Creativity Sesion		F-BD-010	I-BD-010		DT	
	11	Concept Generation	Morphological Matrix		F-BD-011	I-BD-011		DT	
	12	Combine solution principles	Morphological Matrix		F-BD-012	I-BD-012		PD	
	13	Concept Selection	Pugh Charts		[illegible]	I-BD-013		DT	

Figure 4-10 Example of final documentation for a configured Particular Model

5 Implementation: Reference Model Definition

In order to describe the Reference Model it is necessary to define following for each one of the Processes:

i) Definition of Process and Stages
ii) Process Model
iii) Activities, Techniques and Responsible Definitions

5.1 Product Development Process

5.1.1 Definition of Process and Stages

Product Development Process represents the origin of the Product Life Cycle. It process begin whit the product idea and the final result is a functional prototype.

Four stages of Product Development Process are defined as follow:

- *Conceptualization*, before a commercial product can be designed there has to be a product idea; that is, one that promises to lead to technically and economically viable applications, then, it is the systematic search for selection and development of promising product ideas. The scope of the project and the project plan are defined.

- *Basic Development*, this phase involves the collection of information about the customer requirements to be embodied in the solution and also constrains. It is the identification of essential problems by the establishment of function structures and by the search for appropriate solution principles. The basic solution path is laid down through the elaboration of a solution concept.

- *Advanced Development*, this is the phase of the design process in which the arrangement, form, dimensions and surface properties of all individual parts are finally laid down, the materials specified, the technical and economic feasibility rechecked and all the drawings and other production documents are produced.

- *Launching*, the purpose is work out any remaining problems in the prototype construction and test it in order to check the functionality and potential design modifications.

5.1.2 Product Development Model

The Process Modeling was achieved using IDEF-0 Technique. Results from this activity are reported in Appendix A. In Figure 5-1 is show partial results of this activity.

5.1.3 Activities, Techniques and Responsible for Product Development Process

Results from Modeling Activity for Product Development are reflected in Table 5-1, this table is the representation of the Reference Model for Product Development Process.

Table 5-1 Reference Model for Product Development Process

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Ideation	F-PD-001	Competitive Intelligence	TL	I-PD-001
	2	Product Selection	F-PD-002	Pugh Charts	TL	I-PD-002
	3	Product Definition	F-PD-003	-	TL	I-PD-003
	4	Project Planning	F-PD-004	Gant Diagram	TL	I-PD-004
Basic Development	5	Competitive Benchmarking	F-BD-005	Parametric Analysis	MP	I-BD-005
	6	Patent Analysis	F-BD-006	-	PD	I-BD-006
	7	Market Requirements	F-BD-007	Interview	MP	I-BD-007
	8	Target Specifications	F-BD-008	QFD	TL	I-BD-008
	9	Product Analysis	F-BD-009	Parametric Analysis Patent Analysis	PD	I-BD-009
	10	Problem Decomposition	F-BD-010	Functional Decomposition	PD	I-BD-010
	11	Ideas Generation	F-BD-011	Brainstorming	TL	I-BD-011
	12	Concept Generation	F-BD-012	Morphological Matrix	PD	I-BD-012
	13	Combine Concepts	F-BD-013	Morphological Matrix	PD	I-BD-013
	14	Concept Selection	F-BD-014	Pugh Charts	TL	I-BD-014
Advanced Development	15	Establish constraints	F-AD-015	Embodiment design	PD	I-AD-015
	16	Define design variables	F-AD-016		PD	I-AD-017
	17	Performance analysis	F-AD-017	FMEA – Design	PD	I-AD-018
	18	Bill of materials	F-AD-018	Product decomposition	PD	I-AD-019
Launching	19	Purchasing	F-LA-019	-	PS	I-LA-020
	20	Construction	F-LA-020	FMEA – Process	ME	I-LA-021
	21	Test	F-LA-021	-	TL	I-LA-022

5.2 Process Development Process

5.2.1 Definition of Process and Stages

In this Process the product has been designed and it is necessary to decide if the individual components are going to be purchased, manufactured or if it is necessary to design a new facility to manufacture a specific component. Each one the product components must yield in one of the three proposed cases. The final result of this Process is the integration of all individual components in order to assembly the final product.

Four stages of Product Development Process are defined as follow:

- *Conceptualization*, product design is received and it is decomposed in order to identify all individual components. Customer requirements are identified plainly in three aspects: geometry, material and production rates. Finally scope of the project and project plan are defined.

- *Basic Development*, in this phase all individual components are classified as standard parts or manufactured parts and all components yield in one of next categories: Product Transfer, Technology Transfer or Facility Transfer, all of them are going to be individual new projects in Facility Design Process. The criteria to classify the components is as follow:

  - *Product Transfer*: if the component is a standard part or the component is manufactured by a conventional process and a supplier is found and fulfill requirements in cost, time and quality.
  - *Technology Transfer*: if the component must be manufactured by a conventional process, the supplier is not found but the technology is available.
  - *Facility Design*: if the component is not standard and the technology to manufacture this product is not available, then it is necessary to design new facility to get the component.

- *Advanced Development*, once the individual components have been purchased or manufactured, then it is necessary to define the layout for the production and assembly. Computer applications for simulation are used to evaluate and refine the proposed layout up to reach the awaited performance.

- *Launching*, it represents the beginning operation of entire production system and evaluation of production output.

5.2.2 Process Development Model

The Process Modeling was achieved using IDEF-0 Technique. Results from this activity are reported in Appendix A.

5.2.3 Activities, Techniques and Responsible for Process Development Process

Results from Modeling Activity for Process Development are reflected in Table 5-2, this table is the representation of the Reference Model for Process Development Process.

Table 5-2 Reference Model for Process Development Process

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Capture Requirements	F-CO-001	-	ME	I-CO-001
	2	Product Disassembly	F-CO-002	Physic Decomposition	ME	I-CO-002
	3	Features Decomposition	F-CO-003	Group Technology	ME	I-CO-003
	4	Capture Specifications	F-CO-004	QFD	ME	I-CO-004
Basic Development	5	Quantitative Analysis	F-BD-005	QNAF	ME	I-BD-005
	6	Qualitative Analysis	F-BD-006	QLAF	ME	I-BD-006
	7	Process Capacities Analysis	F-BD-007	Process Catalog	ME	I-BD-007
	8	Process Selection	F-BD-009	Pugh Charts	ME	I-BD-008
	9	Manufacturing System Selection	F-BD-010	-	ME	I-BD-009
Advanced Development	10	Process Description	F-AD-011	-	ME	I-AD-010
	11	Process Analysis	F-AD-012	-	ME	I-AD-011
	12	Operation Plan	F-AD-013	Process Flowchart	ME	I-AD-012
	13	Performance Evaluation	F-AD-014	AMEF - Process	ME	I-AD-013
Launching	14	Production system Set-up	F-LA-015	-	ME	I-LA-014
	15	Pilot Test	F-LA-016	-	ME	I-LA-015
	16	Product Evaluation	F-LA-017	-	TL	I-LA-016

5.3 Facility Development

5.3.1 Definition of Process and Stages

This project involves three different projects to get all individual components of the product: Product Transfer, Technology Transfer and Facility Development. In this Process the product has been designed and the manufacturing process has been selected.

5.3.1.1 Product Transfer

If the component is a standard part or the component is manufactured by a conventional process and a supplier is found and fulfill requirements in cost, time and quality.

- *Conceptualization*, Identify all product information. The Bill of Materials (BOM) is carried out in order to identify materials, standard components, quality requirements and delivery times.

- *Basic Development*, Manufacturing capacities and capabilities from different companies are evaluated in order to integrate their competences develop the project. At the end of this stage, manufacturer partners and suppliers for standard parts are selected.

- *Advanced Development*, during this stage the component is manufactured by the selected partners. Control variables are defined and controlled along the manufacturing process.

- *Launching*, after the partial controls are carried out components are delivered to the facility and finally quality controls are done and documented. The component is packed and delivered to the customer.

5.3.1.2 Technology Transfer

In this Process, the component must be manufactured by a conventional process, the supplier is not found or the technology is available. Then it is necessary to develop the manufacturing process using the technology available in the company.

- *Conceptualization,* the information about component or family of components is captured in three aspects geometry (drawings), materials (specifications) and production rates (batch size).

- *Basic Development*, the technology available is evaluated in order to select the best equipment available to manufacture this component.

- *Advanced Development,* the process chart is elaborated to define raw material, tools, fixtures, gages and other devices necessary to manufacture the component. Also documents for control quality in the process and for standard operation are elaborated.

- *Launching,* it represents the beginning operation of technology and evaluation of production output.

5.3.1.3 Facility Development

In this Process the component that is going to be manufactured is not standard and the technology to manufacture this product is not available, then it is necessary to Development new facility to get the component.

It case can be considered as a special case of the Product Development Process where the product to be designed is a Manufacturing Facility, then this kind of project is transfer to the first Process defined: Product Development Process

5.3.2 Facility Development Model

The Process Modeling was achieved using IDEF-0 Technique. Results from this activity are reported in Appendix A.

5.3.3 Activities, Techniques and Responsible for Facility Development

Results from Modeling Activity for Facility Development are reflected in Table 5-3 form Product Transfer and Table 5-4 for Technology Transfer. These tables are the representation of the Reference Model for Process Development Process.

Table 5-3 Reference Model for Product Transfer

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Information Reception	F-PD-001	-	ME	I-PD-001
	2	Drawing Analysis	F-PD-002	-	ME	I-PD-002
	3	Material Analysis	F-PD-003	-	ME	I-PD-003
	4	BOM Elaboration	F-PD-004	-	ME	I-PD-004
Basic Development	5	Suppliers Search	F-BD-005		PS	I-BD-005
	6	Supplier list Analysis	F-BD-006	-	PS	I-BD-006
	7	Suppliers Evaluation	F-BD-007	Pugh Charts	PS	I-BD-007
	8	Supplier Selection	F-BD-008	Pugh Charts	PS	I-BD-008
Advanced Development	9	Process Planning	F-AD-009	CAPP	ME	I-AD-009
	10	Control in Process 25 %	F-AD-010	FMEA – Process	ME	I-AD-010
	11	Control in Process 50 %	F-AD-011	FMEA – Process	ME	I-AD-011
	12	Control in Process 75 %	F-AD-012	FMEA – Process	ME	I-AD-012
	13	Control in Process 100 %	F-AD-013	FMEA – Process	ME	I-AD-013
Launching	14	Inspection	F-LA-014	FMEA – Process	ME	I-LA-014
	15	Packing	F-LA-015	-	ME	I-LA-015
	16	Storing	F-LA-016	-	ME	I-LA-016
	17	Shipment	F-LA-017	-	ME	I-LA-017

Table 5-4 Reference Model for Technology Transfer

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Information Reception	F-PD-001	-	ME	I-PD-001
	2	Drawing Analysis	F-PD-002	-	ME	I-PD-002
	3	Material Analysis	F-PD-003	-	ME	I-PD-003
	4	BOM Elaboration	F-PD-004	-	ME	I-PD-004
Basic Development	5	Manufacturing Capacities	F-BD-005	-	ME	I-BD-005
	6	Equipment list Analysis	F-BD-006	Matrix Analysis	ME	I-BD-006
	7	Equipment Evaluation	F-BD-007	Pugh Charts	ME	I-BD-007
	8	Equipment Selection	F-BD-008	Pugh Charts	ME	I-BD-008
Advanced Development	9	Operation plan	F-AD-009	CAPP Tools	ME	I-AD-009
	10	Layout Design	F-AD-010	CAD Tools	ME	I-AD-010
	11	Performance Analysis	F-AD-011	CAE Tools	ME	I-AD-011
	12	Tool selection	F-AD-012	-	ME	I-AD-012
	13	Fixtures selection	F-AD-013	-	ME	I-AD-013
	14	Gages Selection	F-AD-014	-	ME	I-AD-014
	15	Process Plan	F-AD-015	CAPP Tools	ME	I-AD-015
Launching	16	Production system Set-up	F-LA-016	-	ME	I-LA-016
	17	Pilot Test	F-LA-017	AMEF Process	ME	I-LA-017
	18	Inspection	F-LA-018	AMEF Process	ME	I-LA-018

6 Case of study

6.1 Background

The customer in this case study is a Mexican company founded 40 years ago. The metalworking company produces industrial equipment and diverse parts with casting, metalworking and machining processes. Initially this company was oriented to maintenance activities for sugar making companies in southern Mexico. Shortly, the option of parts and components manufacturing for the sugar-making market arises and afterwards to the general industry. The equipment obtained and the experience allows the company to be one of the most important equipment and spare parts makers in the metalworking industry.

However, few years ago, the company detected a reduction on sales, having serious impact on costs and idle capacities, because of the low demand. In order to solve this situation, the company starts with IECOS a "New Product Development Program", which is an isolated engineering service. At this stage, an analysis of their Products, Markets, Customers and Suppliers was carried out. The company wants to introduce new products to produce in mass production, including (if possible) its capabilities (Machining, Casting and Metalworking).

After the evaluation, three potential products were identified according to the enterprise capabilities and expertise: 1) Structure design for an industrial facility, 2) Sugar cane harvest design and prototype fabrication, and 3) Dry-Freight van for trailer design and engineering specification.

The first project selected to be developed was the Dry Freight Van and IECOS was selected to implement the New Product Development in the company.

6.2 Specific Objective

The specific objective of this case of study is:

- Configure a Methodology (Particular Model) from the proposed Reference Model using the systematic approach proposed in Chapter 4, in order to a Mexican company can develop a Dry Freight Van as a new product.

6.3 Methodology Configuration

6.3.1 Phase I – Project Definition

6.3.1.1 Task 1 – Identify Company Requirements

Company requirements are captured in Table 6-1; from these results it is possible to determine Goal Tollgate and Start Tollgate in the proposed map for engineering stages of Product Life Cycle (Figure 4-2).

Table 6-1 Company Requirements for Dry Freight Van Development

Product Description	• Dry Freight Van: transport system oriented to support low weight and high volume. The main function of this kind of transport is to isolate the freight from humidity
Key Goals	• Systematic method for product development • Time to market: 6 months
Goal Tollgate	• *Product Development → Advanced Development → Detailed Design*: this is the phase in which the arrangement, form, dimensions and surface properties of all individual parts are laid down, the materials specified, the technical and economic feasibility rechecked and all the drawings and other production documents are produced.
Start Tollgate	• *Product Development → Advanced Development → Product Idea*: this is the phase in which a product idea that promises to lead to technically and economically viable applications is selected to be developed.
Assumptions	• Systematic methodology that support Dry Freight Van Development: design, configuration and engineering analysis of the body. • The metalworking company is responsible of the product manufacture and assembly. • The company wants to include in productive process, if possible, its capabilities: *Machining, Casting and Metalworking.* • This project dces not include purchase of new equipment for manufacture the product.

6.3.1.2 *Task 2 – Identify process path*

From previous task are identified Start Tollgate and Goal Tollgate in the in the proposed map for engineering stages of Product Life Cycle and in accordance with the assumptions defined in previous task a process path is sketched as show Figure 6-1. The small number in upper left corner indicates a tentative sequence.

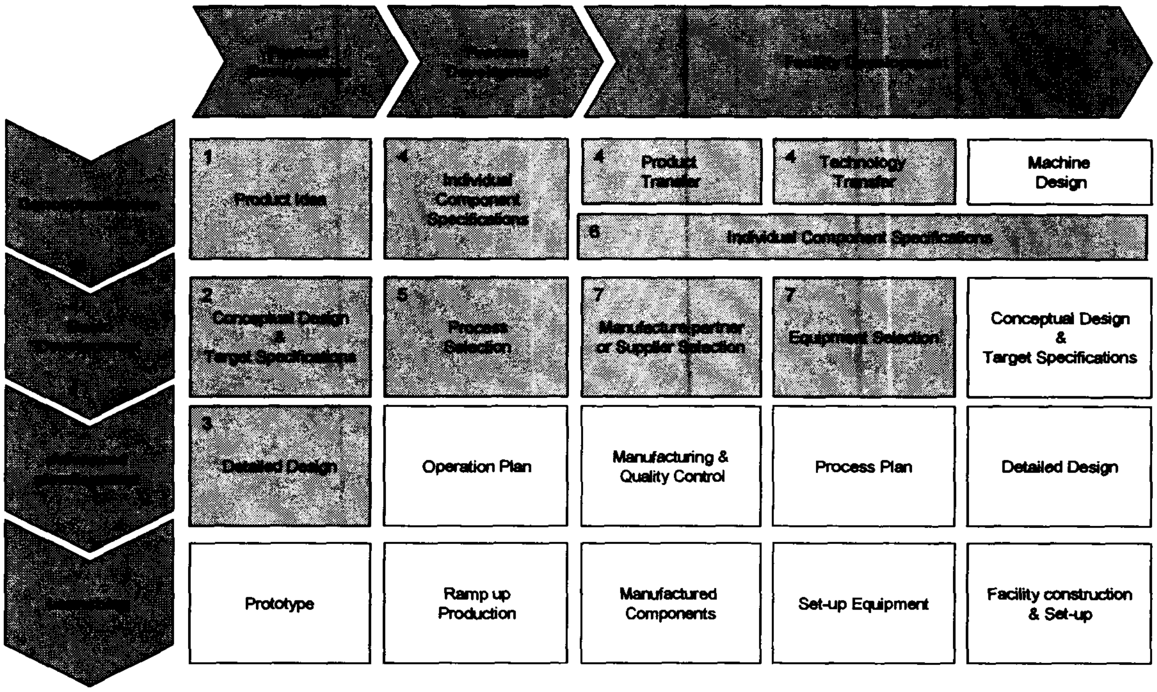


Figure 6-1 Process path selected for Dry Freight Van Development

6.3.1.3 *Task 3 – Verify process path information*

In previous task a process path has been proposed, in this section a direct comparison between boxes must be done in order to verify the feasibility of information flow in the proposed path. In accordance with Figure 6-1, using the tentative sequence proposed by numbers, the verification process is show in Table 6-2.

Each one of the boxes has a Table with associated list of Input and Output Information, also in this list is indicated from which Tollgate comes Input Information. Tables for proposed sequence are show in Tables from 6-3 to 6-9 and are identified by its number and name of Tollgate.

Table 6-2 Verification Process for a proposed path

Ref.	From	To
1 → 2	Product Idea	Conceptual Design and Target Specifications
2 → 3	Conceptual Design and Target Specifications	Detailed Design
3 → 4	Detailed Design	Individual component specifications
4 → 5	Individual component specifications	Process Selection
5→ 6	Process Selection	Product Transfer: Component specifications
		Technology Transfer: Component specifications
6 → 7	Product Transfer: Component specifications	Supplier Selection
	Technology Transfer: Component specifications	Equipment Selection

The verification process is achieved verifying if Input Information for each one of the boxes can be obtained from a previously Tollgate, using the proposed sequence. As is indicated in Table 6-2 the verification process is achieved and described bellow;

- *Product Idea (1) to Conceptual Design and Target Specifications (2).* Table 6-4 Indicates that in order to complete *Conceptual Design and Target Specifications* it is necessary to define previously Product Idea and Target Market; Table 6-3 Indicates that results from Product Idea includes Product Idea and Target Market. Then, this proposed sequence is feasible.

Table 6-3 Input and Output Information for *Product Idea* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
01 - Product Idea	CE	Market opportunities	Product idea
	CE	Manufacturing capabilities	Target market
	CE	Company knowledge	Key business goal
	CE	Economic analysis	Time to market

*CA: Company Evaluation

Table 6-4 Input and Output Information for *Conceptual Design & Target Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
02 - Conceptual Design & Target Specifications	01	Product idea	Target specifications
	01	Target market	Conceptual design

- *Conceptual Design and Target Specifications (2) to Detailed Design (3).* Table 6-5 requests four inputs for this activity: Target specifications, Conceptual Design, Suppliers Information and Equipment Information. First two are output from previous activity *Conceptual Design and Target Specifications.* However, Suppliers Information and Equipment Information are results from next activities: *Manufacture Partner or Supplier Selection and Equipment Selection.* It means an important implication: At this time information output from *Detailed Design* is not the definitive until *Manufacture Partner or Supplier Selection* and *Equipment Selection* become complete.

Table 6-5 Input and Output Information for *Detailed Design* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
03 Detailed Design	02	Target specifications	Geometric Information
	02	Conceptual Design	Material Information
	06	Suppliers Information	Production Information
	06	Equipment Information	BOM

- *Detailed Design (3) to Individual component specifications (4).* Table 6-6 request three results from *Detailed Design* Activity, all of them are partial results. Considering this detail, the sequence is valid.

Table 6-6 Input and Output Information for *Individual Component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
04 – Individual Component Specifications	03	Material Information	Component Description
	03	Production Information	Drawing No.
	03	BOM	BOM

- *Individual component specifications (4) to Process Selection (5).* Table 6-7 request four results: Geometric Information, Production Information, Material Information and Component Description. From first to third are going to be obtained from *Detailed Design* Activity and last one is obtained from *Component Specifications* Activity. Then proposed sequence is valid.

Table 6-7 Input and Output Information for *Process Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
05 – Process Selection	03	Geometric Information	Manufacturing Process
	03	Production Information	
	03	Material Information	
	04	Component Description	

- *Process Selection (5) to Product Transfer - Individual component specifications (6).* After Manufacturing Process has been selected the information must be prepared in order to select a supplier for those components that are going to be purchased or manufactured out of the company. All information comes from *Detailed Design* and *Process Selection Activities;* although information from Detailed Design is partial the proposed sequence is valid (See Table 6-8).

- *Process Selection (5) to Technology Transfer: Component specifications (6).* After Manufacturing Process has been selected the information must be prepared in order to select the company equipment where components are going to be manufactured. All information comes from *Detailed Design* and *Process Selection Activities;* although information from Detailed Design is partial the proposed sequence is valid (See Table 6-9).

Table 6-8 Input and Output Information for *Product Transfer - Individual component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
06 – Product Transfer: Individual Component Specifications	03	Geometric Information	Component Description
	03	Material Information	Drawing No.
	03	Production Information	BOM
	03	BOM	Standard / Manufactured
	05	Manufacturing Process	

Table 6-9 Input and Output Information for *Technology Transfer - Individual component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
06 – Technology Transfer: Individual Component Specifications	03	Material Information	Component Description
	03	Production Information	Drawing No.
	03	BOM	BOM

- *Product Transfer: Individual Component specifications (6) to Supplier Selection (7).* In order to select suppliers it is necessary to have information from *Detailed Design*, *Process Selection* and *Component Specifications*. Results from this Tollgate are feedback to the *Detailed Design* activity, and then it forms an iterative cycle and involves changes proposed sequence (See Table 6-10).

Table 6-10 Input and Output Information for *Manufacture Partner or Supplier Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
07 – Supplier Selection	03	Geometric Information	Supplier Information
	03	Material Information	Price
	03	Production Information	Delivery time
	05	Manufacturing Process	
	06	STD / MFT	

- *Technology Transfer: Individual Component specifications (6) to Equipment Selection (7).* In order to select the Equipment from the company where selected components are going to be manufactured, information comes from *Detailed Design* and *Process Selection* Activities, and then it forms an iterative cycle with *Detailed Design* Activity and involves modifications in proposed sequence (See Table 6-11).

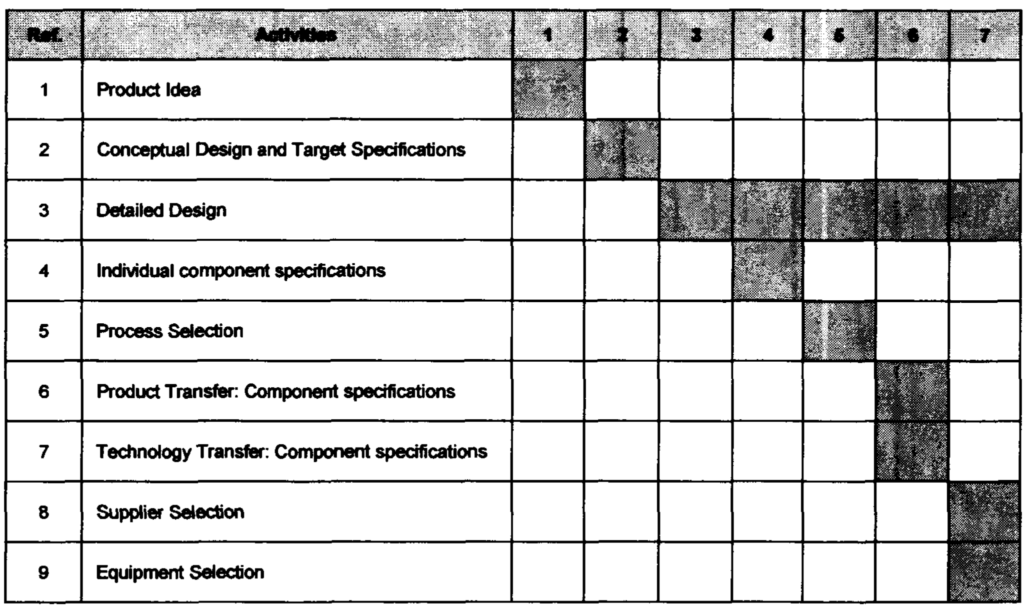
After all proposed sequences have been verified, it is possible to propose changes to the proposed sequence and reflect them in a concurrent map in the next tollgate and final task of the Phase I.

Table 6-11 Input and Output Information for *Equipment Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
07 – Equipment Selection	03	Geometric Information	Equipment Information
	03	Material Information	Price
	03	Production Information	Delivery time
	05	Manufacturing Process	

6.3.1.4 Tollgate: Concurrent Map

On this stage of the Methodology Configuration the Company Requirements has been captured and Activity Sequence has been proposed and verified. The final result of this Phase is a Concurrent Map or a first approach of the Methodology Schedule (Figure 6-2) .



*Product Idea Activities are executed by the Company

Figure 6-2 Concurrent Map or Tentative Schedule for Development of Dry-Freight Van Development

6.3.2 Phase II – Activities Sequence Definition

6.3.2.1 Task 4 - Activity Breakdown

In accordance with results from previous phase, present methodology is going to be a combination of next Processes and Stages (Table 6-12):

Table 6-12 Combination of Processes and Stages used in Dry–Freight Van Methodology Development

	Conceptualization	Basic Development	Advanced Development	Launching
Product Development	CA	X	X	
Process Development	X	X		
Product Transfer	X	X		
Technology Transfer	X	X		

*CA: Company Analysis

Reference Model Activities were proposed in Chapter 5 (Tables 5-1 to 5-4); on this section the objective is to identify all activities that must be executed in accordance with the Reference Model and the proposed activities sequence proposed in previous phase.

Four lists of activities represent the activities proposed in the Reference Model in accordance with the proposed sequence, however, the Methodology for Dry-Freight Van Development does not require the execution of all activities, and then in next task an evaluation is achieved in order to select those that are effective in the particular case of the product development and the company objectives. In this case, Product Idea was responsibility of the Company that is the Conceptualization in the Product Development is achieved, but it is not within the Methodology Configuration.

6.3.2.2 Task 5 - Activity Selection

In previous section four lists of activities where selected from the Reference Model: Product Development, Process Development, Product Transfer and Technology Transfer. These lists are going to be evaluated in order to select and configure and effective list for this project.

For example, for Product Development Process in Basic Development Stage the Reference Model propose 10 Activities, each one of the Activities is evaluated and just three of them are selected to be implemented in the Particular Methodology for Dry-Freight Van Development (Figure 6-3). Next the selection method is illustrated with two examples: *Competitive Benchmarking* and *Patent Analysis*.

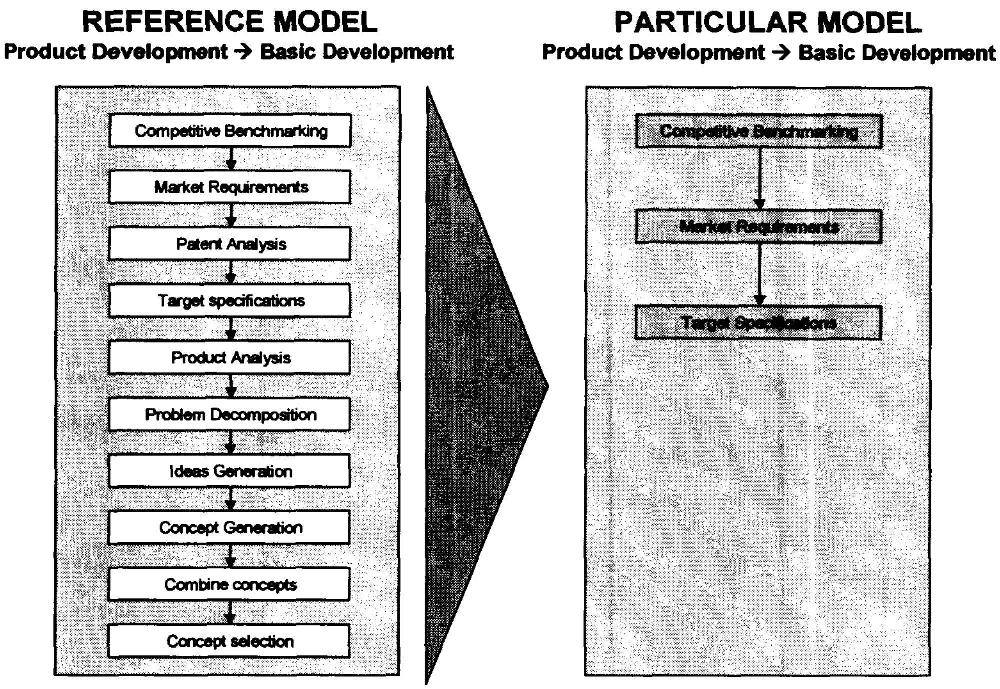


Figure 6-3 Activities Selection from Product Development Process and Basic Development Stage in Methodology configuration for Dry-Freight Van Development

For *Competitive Benchmarking* Activity four suggested questions are applied (Figure 6-4):

- *Product Variables are defined?* In the market exists a great variety of Dry-Freight Van and at this moment the company does not exactly which kind of Dry-Freight Van is going to develop. This activity allows clarifying different products in market and their features, therefore is recommended to execute this activity in the Particular Model.

- *Principal competitors are identified?* The company has potential customers to this new product; however, competitors have not been analyzed in order to analyze their advantages and restrictions. For this reason this activity should be added to the Particular Model.

- *Competence products have been analyzed?* Competence or Substitute products have not been identified, thus it is recommended to add this activity to the Particular model.

- *New Trends have been identified?* This activity is useful in order to identify which kind of Dry-Freight Van is most used in the region of the company and define which kind of product is going to be developed. Thus, the activity is added to the Particular Model.

From the four suggested questions to apply, four answers recommend to incorporate the Activity to the Particular Model. Then, this activity is added to the Dry-Freight Van Development methodology.

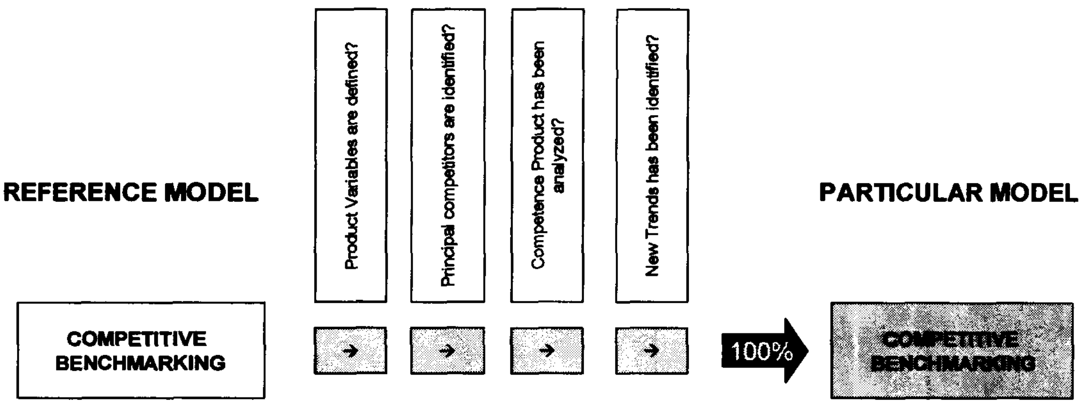


Figure 6-4 Selection Process for Competitive Benchmarking

For *Patent Analysis* Activity four suggested questions are applied (Figure 6-4):

- *Is it a standard product?* In this case Dry-Freight Van is a product highly restricted by government regulations, although it is not a strictly a standard product it is a rigid product and a Patent Analysis is not a considered as an important sources of information.

- *A re-design is going to be proposed?* At present time the company is interested in introduce a conventional new product, in future, a re-design could be considered. Then, now a Patent Analysis is not necessary because no innovation is planned.

- *A patent is a possible result from this project?* In this moment the company is not interested in obtain a patent. In addition, the product (Dry-Freight Van) is considered a rigid product, that is, a patent is not a feasible product from this project.

- *Product Function is clear?* Patent Analysis is useful also for identify a function structure of the product, however in this case, the product is considered as standard product and this analysis is not necessary to build the Functional Structure, besides this Functional Structure is not important in this project.

From the four suggested questions to apply, four answers recommend that the Analysis Patent Activity is not critical in the Particular Model development. Then, this activity is not going to be added to the Dry-Freight Van Development methodology.

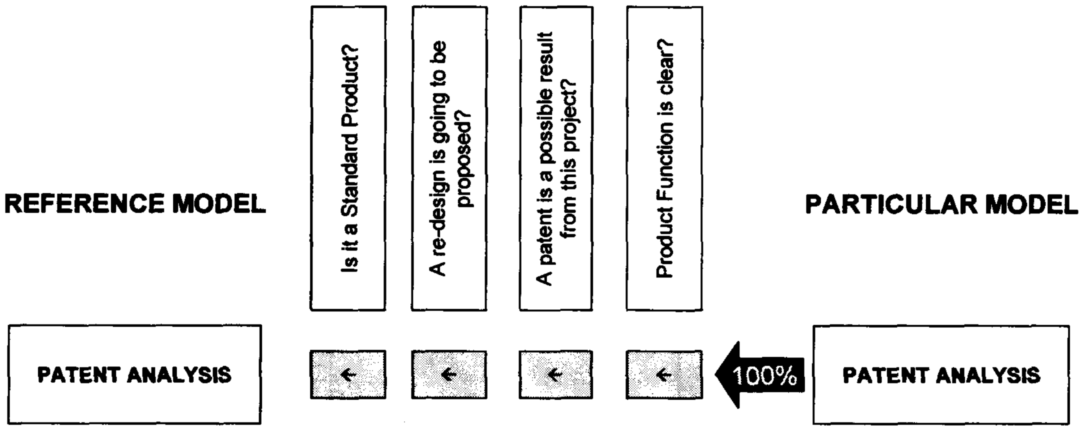


Figure 6-5 Selection Process for Patent Analysis

In similar form rest of the Activities proposed in the Reference Model must be evaluated and selected in order to incorporate them to the Particular Model. Activities selected goes to the next task where a partial project plan is going to be structured.

6.3.2.3 Tollgate: Activities Program

After all activities from Reference Model have been evaluated and selected, a first approach of the Particular Model is obtained. This Particular Model contains Activities that have been selected from the Reference Model. Using this result a tentative Project Plan is produced (Figure 6-6).

Figure 6-6 Trial Project Plan for Dry-Freight Van Development

		REF	ACTIVITIES	TIME
Product Development	Basic Development	1	Competitive Benchmarking	
		2	Market Requirements	
		3	Target Specifications	
	Advanced Development	4	Establish constraints	
		5	Define design variables	
		6	Performance analysis	
		7	Bill of materials	
Process Development	Conceptualization	8	Capture Requirements	
		9	Product Disassembly	
		10	Features Decomposition	
		11	Capture Specifications	
	Basic Development	12	Quantitative Analysis	
		13	Qualitative Analysis	
		14	Process Capacities Analysis	
		15	Process Selection	
		16	Manufacturing System Selection	
Product Transfer	Conceptualization	17	Information Reception	
		18	Drawing Analysis	
		19	Material Analysis	
		20	BOM Elaboration	
	Basic Development	21	Suppliers Search	
		22	Supplier list Analysis	
		23	Suppliers Evaluation	
		24	Supplier Selection	
Technology Transfer	Conceptualization	25	Information Reception	
		26	Drawing Analysis	
		27	Material Analysis	
		28	BOM Elaboration	
	Basic Development	29	Manufacturing Capacities	
		30	Equipment Analysis	
		31	Equipment Evaluation	
		32	Equipment Selection	

6.3.3 Phase III - Activities Mapping

6.3.3.1 Task 6 – Company Evaluation

At this stage of the methodology configuration company resources must be captured. In accordance with the proposed methodology two aspects must be captured: Organization and Resources. Organization or Human Resources are shown in Table 6-13; Resources are classified as Computer Technologies in Table 6-14 and Production Technologies in Table 6-15.

Table 6-13 Organization: Development team of Dry Freight Van

	Reference Model		Particular Model	
Development Team	Team leader	TL	Jorge Soto	JS
	Product Designer	PD	Luis Miguel Villares	LV
	Manufacturing Engineer	ME	Rodolfo Ramirez	RR
	Industrial Designer	ID	Javier Jacome	JJ
	Marketing Professional	MP	Javier Huerta	JH
	Purchasing Specialist	PS	Arturo Hernandez	AH
Extended Team	Finance	F	Javier Perdomo	JP
	Sales	S	Javier Huerta	JH
	Legal	L	Pablo Martinez	PM

Table 6-14 Resources: Computer Technologies in company

	Reference Model	Particular Model
Functional	CAD	Mechanical Desktop 6.0
	CAM	-
	CAE	Patran / Nastran
	Rapid Prototyping	-
Methodological	QFD	Qualisoft
Coordination	Project Management	Microsoft Project
Collaboration	e-mail	Company e-mail
Knowledge/ Information Management		FTP

Table 6-15 Resources: Production Technologies in company

Shaping	Mass reducing	• Horizontal lathe with 3000 mm between y 800 mm overturning • Horizontal lathe with 1900 mm between y 400 mm overturning • Horizontal lathe with 1150 mm between y 250 mm overturning • Horizontal lathe with 1050 mm between y 250 mm overturning • Horizontal lathe with 950 mm between y 200 mm overturning • Horizontal Band saw for 300 mm cutting • Automatic Column Drill • Brushing machine with hydraulic elbow and displacement of 760 mm • Brushing machine with mechanic elbow and displacement of 700 mm • Horizontal boring machine with 1.5 x 2.5m, table • Table brushing machine with 40" width and displacement of 3 m. • Pantograph for board cutting up to 4" • 2 Plasma cutting machine
	Mass conserving	• Cupola furnace with capacity of 3000Kgs • Cupola furnace with capacity of 2000Kgs • Cupola furnace with capacity of 1000Kgs • Crucible furnace for 1000 Kg • Crucible furnace for 500 Kg • Sand mixer for molding
	Joining	• 12 Welding Machines for 500 Amp • 12 Oxi-gas cutting equipment
No Shaping	Heat Treatment	-
	Surface Finishing	-
Others		• Sand-blasting equipment • Air compressor for 300 L. • Truck crane for 8 Tons. • MACHINING AREA • Bridge traveling derrick with capacity of 10 Tons.

6.3.3.2 Tollgate: Particular Model

This is the final stage of the Methodology configuration Process. The methodology was defined as the instantiation of Reference Model; it means a Particular Model Derived from the Reference Model.

The particular Model is conformed by a set of Activities that represents a Function within the company. In order to execute the Activities it is necessary to have defined resources (Techniques and Tools) and organization (responsible). Besides, the Activities have a Control, which is represented by the instructive.

The Particular Model derived for the Dry-Freight Van Development is show in Tables from 6-16 to 6-19.

Table 6-16 Particular Model for Product Development in Dry-Freight Van Development

Phases	NUM	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Basic Development	1	Competitive Benchmarking	Parametric Analysis	Internet	I-BD-001	F-BD-001		JH	
	2	Market Requirements	Interview	-	I-BD-002	F-BD-002		JH	
	3	Target Specifications	QFD	Qualisfot	I-BD-003	F-BD-003		JS	
Advanced Development	4	Establish constraints	Embodiment design	-	I-AD-014	F-AD-014		LV	
	5	Define design variables	-	Mechanical Desktop	I-AD-005	F-AD-005		LV	
	6	Performance analysis	FMEA – Design	Patran Nastran	I-AD-006	F-AD-006		LV	
	7	Bill of materials	Product decomposition	-	I-AD-007	F-AD-007		LV	

Table 6-17 Particular Model for Process Development in Dry-Freight Van Development

Phases	NUM	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Basic Development	1	Capture Requirements	-	-	I-CO-001	F-CO-001		RR	
	2	Product Disassembly	Physic Decomposition	-	I-CO-002	F-CO-002		RR	
	3	Features Decomposition	Group Technology	-	I-CO-003	F-CO-003		RR	
	4	Capture Specifications	QFD	Qualisoft	I-CO-004	F-CO-004		RR	
Advanced Development	5	Quantitative Analysis	QNAF	Excel	I-BD-005	F-BD-005		RR	
	6	Qualitative Analysis	QLAF	Excel	I-BD-006	F-BD-006		RR	
	7	Process Capacities Analysis	Process Catalog	Excel	I-BD-007	F-BD-007		RR	
	8	Process Selection	Pugh Charts	Excel	I-BD-008	F-BD-008		RR	
	9	Manufacturing System Selection	-	-	I-BD-009	F-BD-009		RR	

Table 6-18 Particular Model for Product Transfer in Dry-Freight Van Development

Phases	REF	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Conceptualization	1	Information Reception	-	-	I-PD-001	F-PD-001		RR	
	2	Drawing Analysis	-	-	I-PD-002	F-PD-002		RR	
	3	Material Analysis	-	-	I-PD-003	F-PD-003		RR	
	4	BOM Elaboration	-	-	I-PD-004	F-PD-004		RR	
Basic Development	5	Suppliers Search	-	-	I-BD-005	F-BD-005		AH	
	6	Supplier list Analysis	-	-	I-BD-006	F-BD-006		AH	
	7	Suppliers Evaluation	Pugh Charts	Excel	I-BD-007	F-BD-007		AH	
	8	Supplier Selection	Pugh Charts	Excel	I-BD-008	F-BD-008		AH	

Table 6-19 Particular Model for Technology Transfer in Dry-Freight Van Development

Phases	REF	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Conceptualization	1	Information Reception	-	-	I-PD-001	F-PD-001		RR	
	2	Drawing Analysis	-	-	I-PD-002	F-PD-002		RR	
	3	Material Analysis	-	-	I-PD-003	F-PD-003		RR	
	4	BOM Elaboration	-	-	I-PD-004	F-PD-004		RR	
Basic Development	5	Manufacturing Capacities	-	-	I-BD-005	F-BD-005		RR	
	6	Equipment list Analysis	Matrix Analysis	Excel	I-BD-006	F-BD-006		RR	
	7	Equipment Evaluation	Pugh Charts	Excel	I-BD-007	F-BD-007		RR	
	8	Equipment Selection	Pugh Charts	Excel	I-BD-008	F-BD-008		RR	

7 Conclusions and Further Research

7.1 Results

After developing and exploring the methodology proposed in this investigation the principal obtained results are:

i) A Reference Model for Integrated Product Process and Facility Development (IPPFD) was developed. This Reference Model describe how IPPFD can be achieved through three dimensions Process (Product Development, Process Development and Facility Development); Stages (Conceptualization, Basic Development, Advanced Development and Launching); and Activities (Analysis, Synthesis and Evaluation)

ii) A systematic approach was developed in order to instantiate a Particular Model from the proposed Reference Model. The systematic approach is proposed in order to configure Processes for successful Integrated Product, Process and Facility Development, independent of the industrial sector of a company, but dependent on its problems, market, constraints and declared goals

iii) A case study was developed to demonstrate how the Reference Model and Systematic approach can be used to develop New Automotive Products in a Mexican metalworking company oriented to the production of industrial equipment

7.2 Conclusions

7.2.1 Reference Model

- Benefits from IPPFD Reference Model uses are: configuration of processes for specific product development in short periods of time; and support activities during the project planning and execution stages for engineering projects.

- Configurability of the IPPFD Reference Model allow to develop Programs for New Product Development independent of the product to be developed, however, in order to exploit fully configurability of the IPPFD Reference Model, Case Development is required to generate an Activities Library that allows reuse knowledge in future Process Configuration.

- The IPPFD Reference Model allows the integration of proved methods and tools available, as consequence the methodology gain in robustness and the scope is major than other research projects as was demonstrated in Chapter 3.

7.2.2 Methodology for Particular Model Configuration

- Particular Model Configuration requires a steep learning curve and the user must have basic knowledge in Product Development theory, but for its systematic structure in long terms the experience of the user results in a reduction of the configuration time.

- During the Particular Model Configuration a depth knowledge of the company is required in order select those techniques and tools that are going to support the Product Development Process in the company. This knowledge about the company avoids the technological and knowledge problem during the execution of the project caused for unknown of the technology or the technique selected.

- Information management based on formats, instructive and records derived from the Particular Model supports the team work in the sharing information to take decisions and improve documentation process in the company

7.2.3 Case Study

- Experience from Project Leader of the company is recommended during the Particular Model configuration in order to define the role of company members in the product development team and to prevent possible problems with techniques and technologies selected for Particular Model.

- Documentation process generated during the project execution aids to reduce delays caused by the rotation of personnel involved in the project during the project execution. Also this documentation helps to define company processes requested during implementation of standards like ISO-9000 or QS-9000.

7.3 Further Research

- Partial Models generation in order to reduce the configuration time and complexity of Particular Models. Particular Models must be created for specific industry (e.g. Automotive, Aeronautical) and should include specific techniques and tools used in standards of specific industries, for example, QS-9000 in automotive industry.

- The automation of the Reference Model and the Methodology for Particular Model configuration in a computer system. The system must consider two aspects: The Reference Model must be capable to adopt and identify new techniques and tools; and the Particular Model configuration must have an effective feedback based on previous configurations to support the user during the configuration process.

- Develop new cases is important in order to incorporate new activities, techniques and tools to the Reference Model and allow to exploit the property of Configurability.

8 References

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Appendix A – Methodology Documentation: Instructive and Formats

A-1 – Instructive for Project Definition IMC-01

A-2 – Format for Project Definition FMC-01

A-3 – Instructive for Project Definition IMC-01

A-4 – Format for Project Definition FMC-01

A-5 – Instructive for Project Definition IMC-01

A-6 – Format for Project Definition FMC-01

Appendix B - Integrated Product, Process and Facility Development using IDEF-0

I. Objective

During this phase company requirements are identified and scope of the project is defined in accordance with the Reference Model map. The final result of this phase is the Concurrent Map of Activities.

II. Task 1: Identify Company Requirements

Fill the table in order to identify the Company Requirements in accordance with next definitions:

- *Product Description*: This description typically includes the key customer benefit of the product but avoids implying a specific product concept.
- *Key Goals*: In addition to the project goals that support the corporate strategy, these goals generally include goals for time, cost, and quality (e.g., timing of the product introduction, desired financial performance, market share targets).
- *Goal Tollgate*: It is the target or final result
- *Start Tollgate*: It is the initial status of the project
- *Assumptions* and constrains that guide the development effort. Assumptions must make carefully; although they restrict the range of possible product concepts, they help to maintain a manageable project scope. Information may be attached to the mission statement to document decisions about assumptions and constrains.

III. Task 2: Identify Process Path

In this task the objective is to identify a path from Start Tollgate to the Target Tollgate. This path must be traced and must reflect the company capabilities and capacities, that is, technological and human resources from the company. Numbers are added to the boxes to indicate a tentative sequence of the project. Result from this list of the Tollgates selected in a tentative sequence.

IV. Task 3: Verify Process Path Information

Once the process path has been selected it is necessary verify information flow among each one of the tollgates selected. All Tollgates have two list associated, for input and output information. These lists allow determine when boxes can exchange information among them. If the proposed path is not feasible, then it is rechecked whit information list and a new path is proposed.

In previous task a process path has been proposed, in this section a direct comparison between Tollgates must be done in order to verify the feasibility of information flow in the proposed path. Using the tentative sequence proposed by numbers, the verification process must be reflected in the table.

A checklist is provided in order to check if all of the information exchanges are feasible. Standard lists of input/output information for each one of the proposed Tollgates are showed at the end of this document.

V. Tollgate: Concurrent Map

On this stage of the Methodology Configuration the Company Requirements has been captured and Activity Sequence has been proposed and verified. The final result of this Phase is a Concurrent Map or a first approach of the Methodology Schedule. Results from previous tasks are reflected at this Tollgate. The results is a tentative schedule indicating which Tollgates are going to be executed and the concurrency between Stages of different Processes.

STANDARD LISTS OF INPUT/OUTPUT INFORMATION FOR EACH ONE OF THE PROPOSED TOLLGATES

Table - Input and Output Information for *Product Idea* Tollgate

Tollgate	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Product Idea		Market opportunities	Product idea
		Manufacturing capabilities	Target market
		Company knowledge	Key business goal
		Economic analysis	Time to market

Table - Input and Output Information for *Conceptual Design & Target Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Conceptual Design & Target Specifications	01	Product idea	Target specifications
	01	Target market	Conceptual design

Table - Input and Output Information for *Detailed Design* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Detailed Design	02	Target specifications	Geometric Information
	02	Conceptual Design	Material Information
	06	Suppliers Information	Production Information
	06	Equipment Information	BOM

Table - Input and Output Information for *Individual Component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Individual Component Specifications	03	Material Information	Component Description
	03	Production Information	Drawing No.
	03	BOM	BOM

Table - Input and Output Information for *Process Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	**Description**	**Description**
Process Selection	03	Geometric Information	Manufacturing Process
	03	Production Information	
	03	Material Information	
	04	Component Description	

Table - Input and Output Information for *Product Transfer - Individual component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	**Description**	**Description**
Product Transfer: Individual Component Specifications	03	Geometric Information	Component Description
	03	Material Information	Drawing No.
	03	Production Information	BOM
	03	BOM	Standard / Manufactured
	05	Manufacturing Process	

Table - Input and Output Information for *Technology Transfer - Individual component Specifications* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	**Description**	**Description**
Technology Transfer: Individual Component Specifications	03	Material Information	Component Description
	03	Production Information	Drawing No.
	03	BOM	BOM

Table - Input and Output Information for *Manufacture Partner or Supplier Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Supplier Selection	03	Geometric Information	Supplier Information
	03	Material Information	Price
	03	Production Information	Delivery time
	05	Manufacturing Process	
	06	STD / MFT	

Table Error! No text of specified style in document.**-1** Input and Output Information for *Equipment Selection* Tollgate

TOLLGATE	INPUT INFORMATION		OUTPUT INFORMATION
	From	Description	Description
Equipment Selection	03	Geometric Information	Equipment Information
	03	Material Information	Price
	03	Production Information	Delivery time
	05	Manufacturing Process	

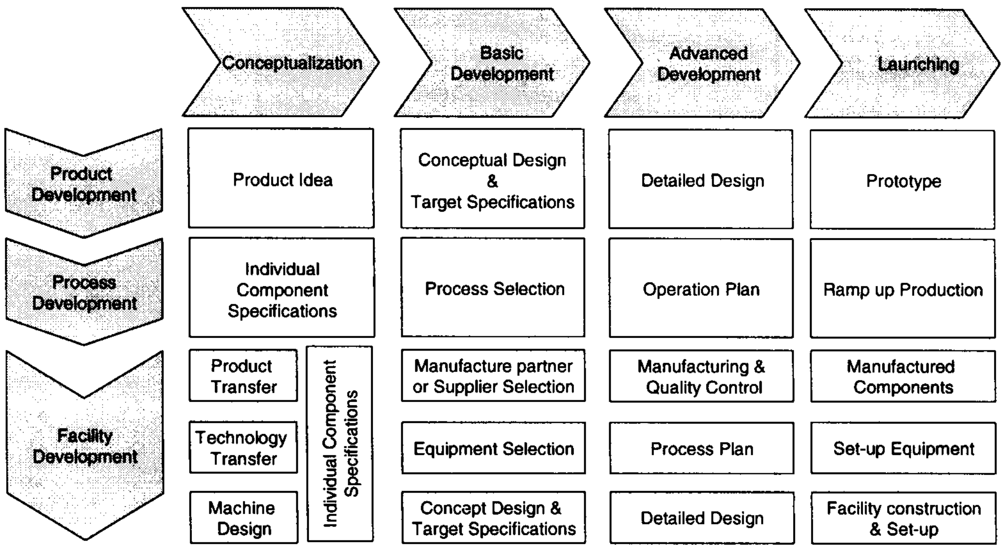
I. Task 1: Identify Company Requirements

Fill the table in order to identify the Company Requirements

Product Description	
Key Goals	
Goal Tollgate	
Start Tollgate	
Assumptions	

II. Task 2: Identify Process Path

Identify a path from Start Tollgate to the Target Tollgate and reflect the proposed path in a list of the Tollgates selected in a tentative sequence.



Reference	Tollgates Selected
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

III. Task 3: Verify Process Path Information

Verify information flow among each one of the Tollgates selected. Review list associated for input and output information at the end of the IMC-01 document.

Ref.	From	To	Feasible?

IV. Tollgate: Concurrent Map

Elaborate a tentative schedule indicating which Tollgates are going to be executed and the concurrency between Stages of different Processes.

Ref	Activities	1	2	3	4	5	6	7	8	9	11	12	10
1													
2													
3													
4													
5													
6													
7													
8													
9													
10													
11													
12													

I. Objective

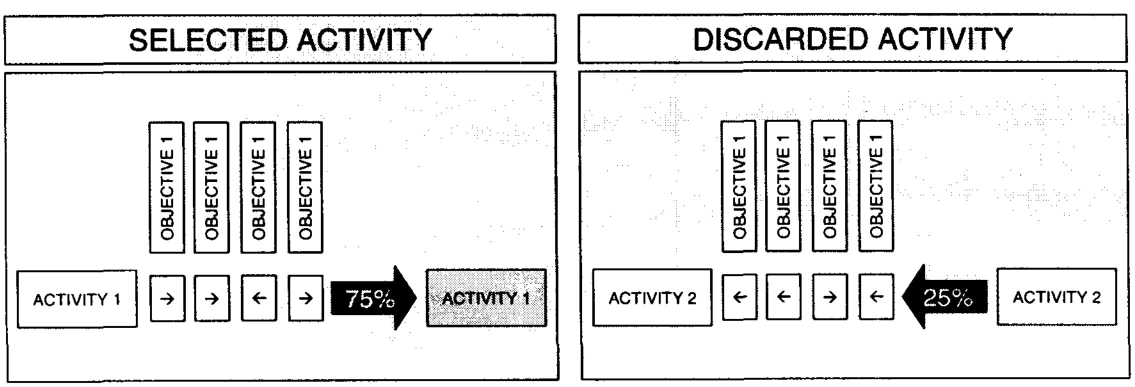
Throughout this phase the Reference Model is breakdown in Activities in order to evaluate them and select those that are going to be used during the project execution.

II. Task 4: Activity Breakdown

Once the process path has been identified and information flow verified, it is necessary to decompose each one of the selected Tollgates in order to identify the set of activities proposed by the Reference Model. The task is to fill the table in order to identify those Tollgates that must be breakdown. The lists of activities proposed in the Reference Model are given at the end of this Instructive for each Process and Stages.

III. Task 5: Activity Selection

A standard method for evaluation and selection of activities has been proposed in this section. Through this method the four main objectives of all activities derived from previous task are reviewed in order to evaluate if they impact positively (Right Arrow) or negatively (Left Arrow) to the present project ; if the activity is evaluated with at least 2 Right Arrow (50%) then the activity is selected to be achieved in the present project.



→ Help to the activity purpose

← No Help to the activity purpose

IV. Tollgate: Activities Program

Results from previous tasks are reflected at this Tollgate. The result is a tentative schedule indicating list of activities to be executed and the concurrency between activities of different Processes.

REFERENCE MODEL FOR PRODUCT DEVELOPMENT SCENARIO

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Ideation	F-PD-001	Competitive Intelligence	TL	I-PD-001
	2	Product Selection	F-PD-002	Pugh Charts	TL	I-PD-002
	3	Product Definition	F-PD-003	-	TL	I-PD-003
	4	Project Planning	F-PD-004	Gant Diagram	TL	I-PD-004
Basic Development	5	Competitive Benchmarking	F-BD-005	Parametric Analysis	MP	I-BD-005
	6	Patent Analysis	F-BD-006	-	PD	I-BD-006
	7	Market Requirements	F-BD-007	Interview	MP	I-BD-007
	8	Target Specifications	F-BD-008	QFD	TL	I-BD-008
	9	Product Analysis	F-BD-009	Parametric Analysis Patent Analysis	PD	I-BD-009
	10	Problem Decomposition	F-BD-010	Functional Decomposition	PD	I-BD-010
	11	Ideas Generation	F-BD-011	Brainstorming	TL	I-BD-011
	12	Concept Generation	F-BD-012	Morphological Matrix	PD	I-BD-012
	13	Combine Concepts	F-BD-013	Morphological Matrix	PD	I-BD-013
	14	Concept Selection	F-BD-014	Pugh Charts	TL	I-BD-014
Advanced Development	15	Establish constraints	F-AD-015	Embodiment design	PD	I-AD-015
	16	Define design variables	F-AD-016		PD	I-AD-017
	17	Performance analysis	F-AD-017	FMEA – Design	PD	I-AD-018
	18	Bill of materials	F-AD-018	Product decomposition	PD	I-AD-019
Launching	19	Purchasing	F-LA-019	-	PS	I-LA-020
	20	Construction	F-LA-020	FMEA – Process	ME	I-LA-021
	21	Test	F-LA-021	-	TL	I-LA-022

REFERENCE MODEL FOR PROCESS DEVELOPMENT SCENARIO

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Capture Requirements	F-CO-001	-	ME	I-CO-001
	2	Product Disassembly	F-CO-002	Physic Decomposition	ME	I-CO-002
	3	Features Decomposition	F-CO-003	Group Technology	ME	I-CO-003
	4	Capture Specifications	F-CO-004	QFD	ME	I-CO-004
Basic Development	5	Quantitative Analysis	F-BD-005	QNAF	ME	I-BD-005
	6	Qualitative Analysis	F-BD-006	QLAF	ME	I-BD-006
	7	Process Capacities Analysis	F-BD-007	Process Catalog	ME	I-BD-007
	8	Process Selection	F-BD-009	Pugh Charts	ME	I-BD-008
	9	Manufacturing System Selection	F-BD-010	-	ME	I-BD-009
Advanced Development	10	Process Description	F-AD-011	-	ME	I-AD-010
	11	Process Analysis	F-AD-012	-	ME	I-AD-011
	12	Operation Plan	F-AD-013	Process Flowchart	ME	I-AD-012
	13	Performance Evaluation	F-AD-014	AMEF - Process	ME	I-AD-013
Launching	14	Production system Set-up	F-LA-015	-	ME	I-LA-014
	15	Pilot Test	F-LA-016	-	ME	I-LA-015
	16	Product Evaluation	F-LA-017	-	TL	I-LA-016

REFERENCE MODEL FOR PRODUCT TRANSFER

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Information Reception	F-PD-001	-	ME	I-PD-001
	2	Drawing Analysis	F-PD-002	-	ME	I-PD-002
	3	Material Analysis	F-PD-003	-	ME	I-PD-003
	4	BOM Elaboration	F-PD-004	-	ME	I-PD-004
Basic Development	5	Suppliers Search	F-BD-005		PS	I-BD-005
	6	Supplier list Analysis	F-BD-006	-	PS	I-BD-006
	7	Suppliers Evaluation	F-BD-007	Pugh Charts	PS	I-BD-007
	8	Supplier Selection	F-BD-008	Pugh Charts	PS	I-BD-008
Advanced Development	9	Process Planning	F-AD-009	CAPP	ME	I-AD-009
	10	Control in Process 25 %	F-AD-010	FMEA – Process	ME	I-AD-010
	11	Control in Process 50 %	F-AD-011	FMEA – Process	ME	I-AD-011
	12	Control in Process 75 %	F-AD-012	FMEA – Process	ME	I-AD-012
	13	Control in Process 100 %	F-AD-013	FMEA – Process	ME	I-AD-013
Launching	14	Inspection	F-LA-014	FMEA – Process	ME	I-LA-014
	15	Packing	F-LA-015	-	ME	I-LA-015
	16	Storing	F-LA-016	-	ME	I-LA-016
	17	Shipment	F-LA-017	-	ME	I-LA-017

REFERENCE MODEL FOR TECHNOLOGY TRANSFER

Phases	REF	Activities	Format	Technique	Responsible	Instructive
Conceptualization	1	Information Reception	F-PD-001	-	ME	I-PD-001
	2	Drawing Analysis	F-PD-002	-	ME	I-PD-002
	3	Material Analysis	F-PD-003	-	ME	I-PD-003
	4	BOM Elaboration	F-PD-004	-	ME	I-PD-004
Basic Development	5	Manufacturing Capacities	F-BD-005	-	ME	I-BD-005
	6	Equipment list Analysis	F-BD-006	Matrix Analysis	ME	I-BD-006
	7	Equipment Evaluation	F-BD-007	Pugh Charts	ME	I-BD-007
	8	Equipment Selection	F-BD-008	Pugh Charts	ME	I-BD-008
Advanced Development	9	Operation plan	F-AD-009	CAPP Tools	ME	I-AD-009
	10	Layout Design	F-AD-010	CAD Tools	ME	I-AD-010
	11	Performance Analysis	F-AD-011	CAE Tools	ME	I-AD-011
	12	Tool selection	F-AD-012	-	ME	I-AD-012
	13	Fixtures selection	F-AD-013	-	ME	I-AD-013
	14	Gages Selection	F-AD-014	-	ME	I-AD-014
	15	Process Plan	F-AD-015	CAPP Tools	ME	I-AD-015
Launching	16	Production system Set-up	F-LA-016	-	ME	I-LA-016
	17	Pilot Test	F-LA-017	AMEF Process	ME	I-LA-017
	18	Inspection	F-LA-018	AMEF Process	ME	I-LA-018

I. Task 4: Activity Breakdown

Fill the Table in order to identify those Tollgates that must be breakdown. The lists of activities proposed in the Reference Model are given at the end of the Instructive IMC-02 for each Process and Stages.

	Conceptualization	**Basic Development**	**Advanced Development**	**Launching**
Product Development				
Process Development				
Product Transfer				
Technology Transfer				
Machine Design				

II. Task 5: Activity Selection

Standard method for evaluation and selection of activities to be incorporated to the Particular Model.

Activity Name	Objective 1	Objective 2	Objective 3	Objective 4	Go / No Go

→ Help to the activity purpose

← No Help to the activity purpose

III. Tollgate: Activities Program

		REF	ACTIVITIES	TIME																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
PROCESS	Conceptualization	1																		
		2																		
		3																		
	Basic Development	4																		
		5																		
		6																		
	Advanced Development	7																		
		8																		
		9																		
	Launching	10																		
		11																		
		12																		

I. Objective

Once the set of activities to be achieved have been selected it is necessary to translate each one of the Activity Features (Function, Information, Resources and Organization) from the Reference Model domain to the Company Domain.

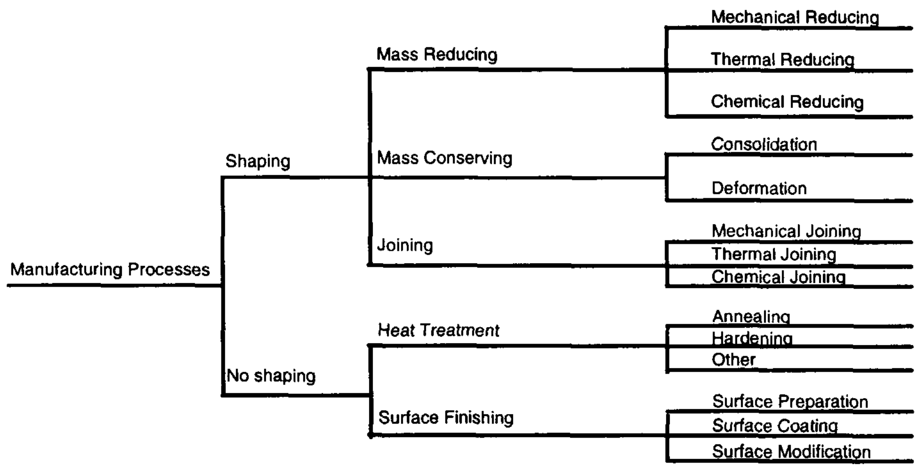
II. Task 6: Company Evaluation

Fill the tables in order to identify Human Resources, Computer Technology and Production Technology, use next guides:

ORGANIZATION: DEVELOPMENT TEAM

	Reference Model	
Development Team	Team leader	TL
	Product Designer	PD
	Manufacturing Engineer	ME
	Industrial Designer	ID
	Marketing Professional	MP
	Purchasing Specialist	PS
Extended Team	Finance	F
	Sales	S
	Legal	L

CLASSIFICATION OF PRODUCTION TECNOLOGY THAT SUPPORT THE PRODUCT DEVELOPMENT PROCESS



CLASSIFICATION OF COMPUTER APPLICATIONS THAT SUPPORT THE PRODUCT DEVELOPMENT PROCESS

		DEFINITION	AVAILABLE TOOLS
SUPPORTING SERVICES	**Functional**	*Function oriented systems that support engineers in specific tasks.*	• CAD / CAM / CAE • ICAD Knowledge Based Engineering Systems • MAS / SPEED • Rapid prototyping
	Methodological	Proved methods used in Concurrent Engineering as standardized best practices	• QFD / AMEF / IDEF0 • DFM / DFA
	Coordination	Coordination systems to support sequencing of activities and flow of information.	• Project management • Workflow • Groupware • e-management • e-project
	Collaboration	Collaboration systems to foster cooperation among engineer i.e. CSCW - Computer Supported Cooperative Working	• Net meeting • Forums • Chat • Multicasting • e-mail
	Knowledge & Information Management	Product information management systems and Knowledge Based Engineering Systems to enable the exchange of product and manufacturing information and knowledge	• PDT – Product Data Technologies • PLM – Product Life Cycle Management Tools • Product Model • Manufacturing Model

III. Tollgate: Particular Model

This is the final stage of the Methodology configuration Process. The methodology was defined as the instantiation of Reference Model; it means a Particular Model Derived from the Reference Model. The particular Model is conformed by a set of Activities that represents a Function within the company. In order to execute the Activities it is necessary to have defined resources (Techniques and Tools) and organization (responsible). Besides, the Activities have a Control, which is represented by the instructive.

PRODUCT DEVELOPMENT

STAGE

Phases	NUM	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Basic Development	1	Competitive Benchmarking	Parametric Analysis	Internet	I-BD-001	F-BD-001		JH	07/05/02
	2	Market Requirements	Interview	-	I-BD-002	F-BD-002		JH	[illegible]7/05/02
	3	Target Specifications	QFD	Qualisfot	I-BD-003	F-BD-003		JS	14/05/02
Advanced Development	4	Establish constraints	Embodiment design	-	I-AD-014	F-AD-014		LV	21/05/02
	5	Define design variables	-	Mechanical Desktop	I-AD-005	F-AD-005		LV	05/06/02
	6	Performance analysis	FMEA – Design	Patran Nastran	I-AD-006	F-AD-006		LV	25/06/02
	7	Bill of materials	Product decomposition	-	I-AD-007	F-AD-007		LV	07/07/02

ACTIVITIES | **TECHNIQUES & TOOLS** | **DOCUMENTATION** (Format, Instructive and Record) | **RESPONSIBLE AND STATUS ACTIVITY**

IN SCHEDULE
IN EXECUTION
OUT OF SCHEDULE

I. Task 6: Company Evaluation

	Reference Model		Particular Model	
Development Team	Team leader	TL		
	Product Designer	PD		
	Manufacturing Engineer	ME		
	Industrial Designer	ID		
	Marketing Professional	MP		
	Purchasing Specialist	PS		
Extended Team	Finance	F		
	Sales	S		
	Legal	L		

	Reference Model	Particular Model
Functional	CAD	
	CAM	
	CAE	
	Rapid Prototyping	
Methodological	QFD	
Coordination	Project Management	
Collaboration	e-mail	
Knowledge/ Information Management	PDM	

Shaping	Mass reducing	
	Mass conserving	
	Joining	
No Shaping	Heat Treatment	
	Surface Finishing	
Others		

II. Particular Model

PROCESS									
Stages	NUM	Activities	Technique	Tool	Instructive	Format	Record	Responsible	Status
Conceptualization									
Basic Development									
Advanced Development									
Launching									

USED AT: | AUTHOR: | DATE: 30 Nov. 2003 | ■ WORKING | READER | DATE | CONTEXT:

PROJECT: Model 1 | REV: 19 May 2004 | DRAFT | RECOMMENDED | PUBLICATION | TOP

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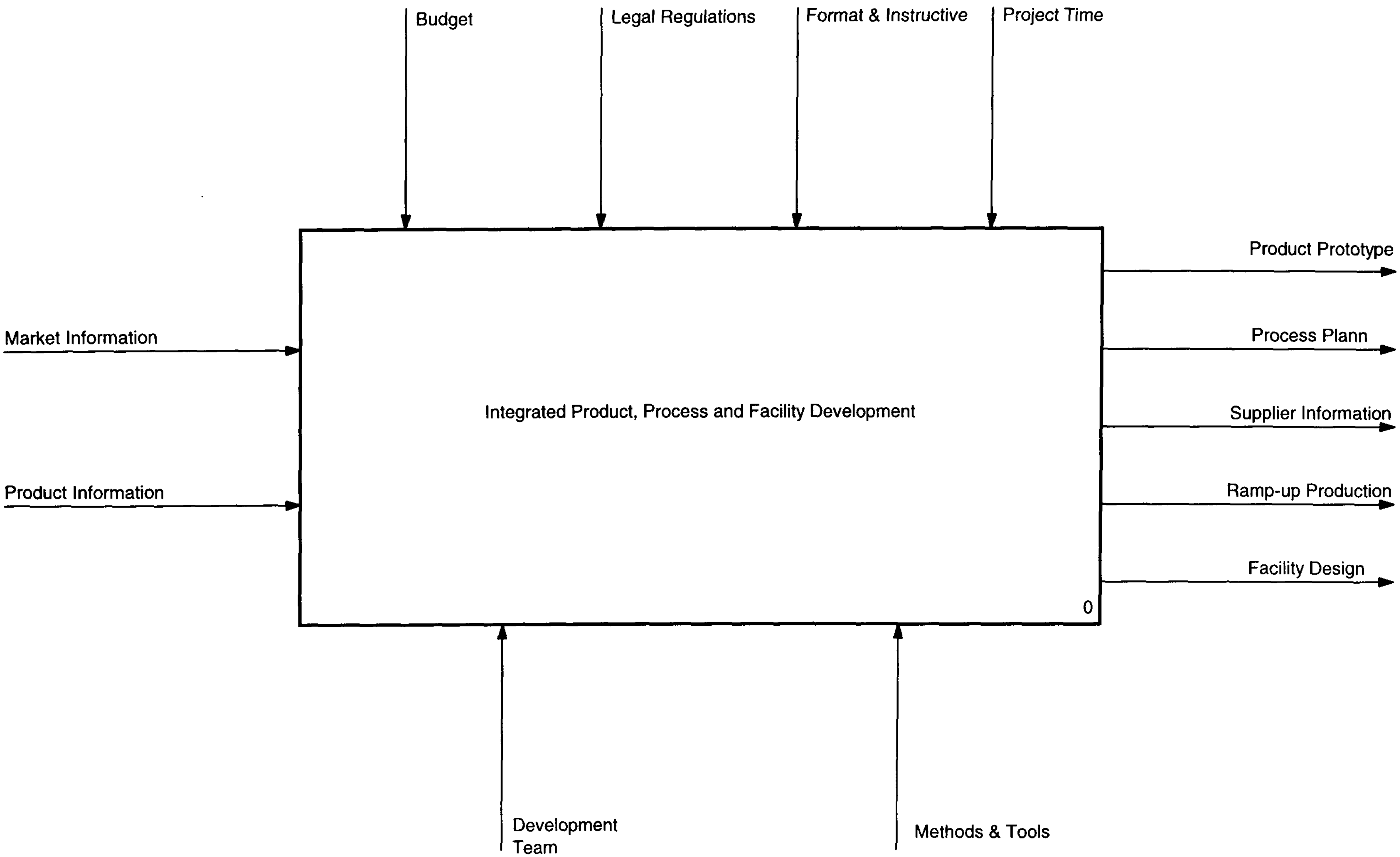

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USED AT:	AUTHOR:	DATE: 1 Dec. 2003	■ WORKING	READER DATE	CONTEXT:
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			RECOMMENDED		
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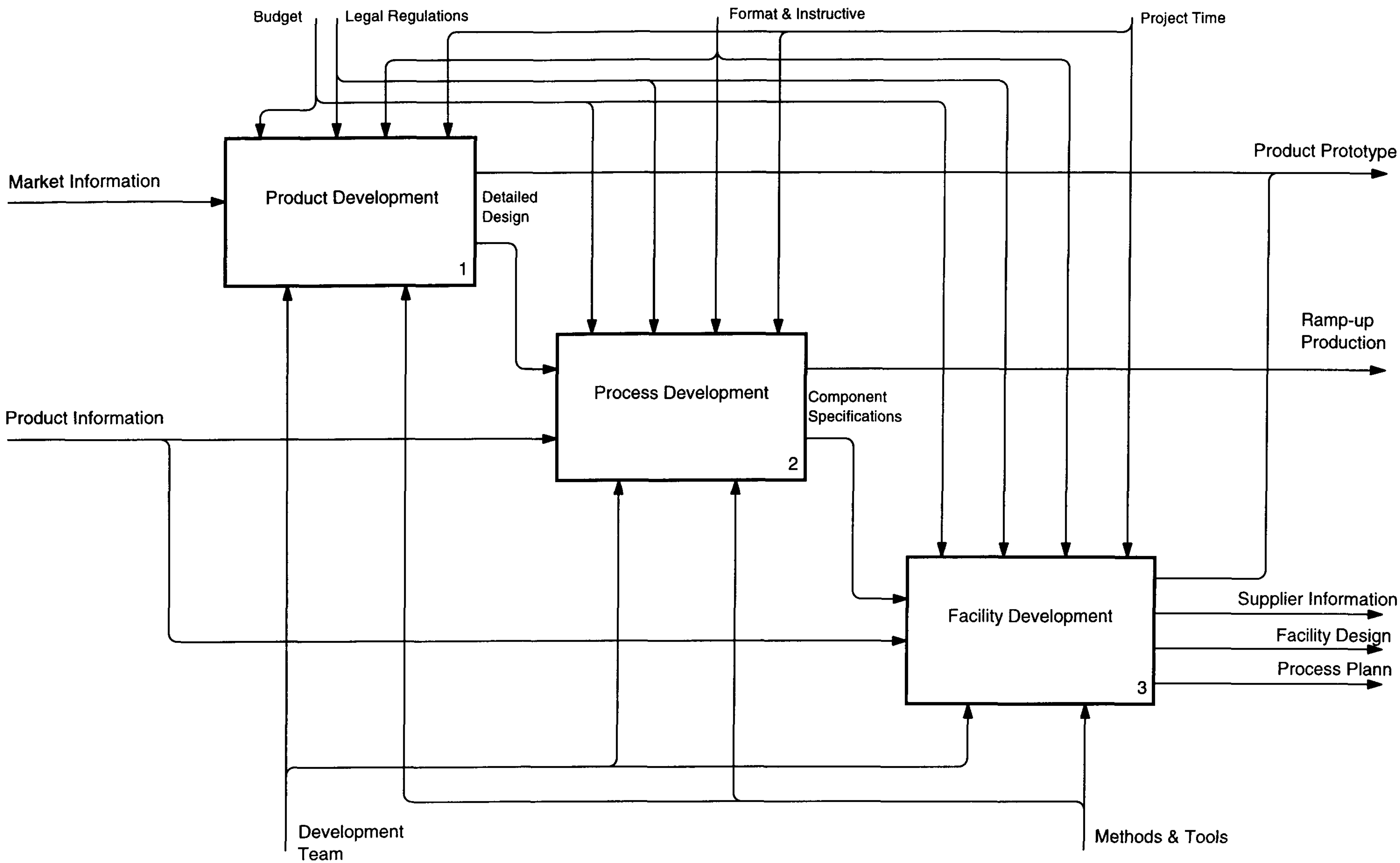

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USED AT:	AUTHOR:	DATE: 1 Dec. 2003	■ WORKING	READER	DATE	CONTEXT:
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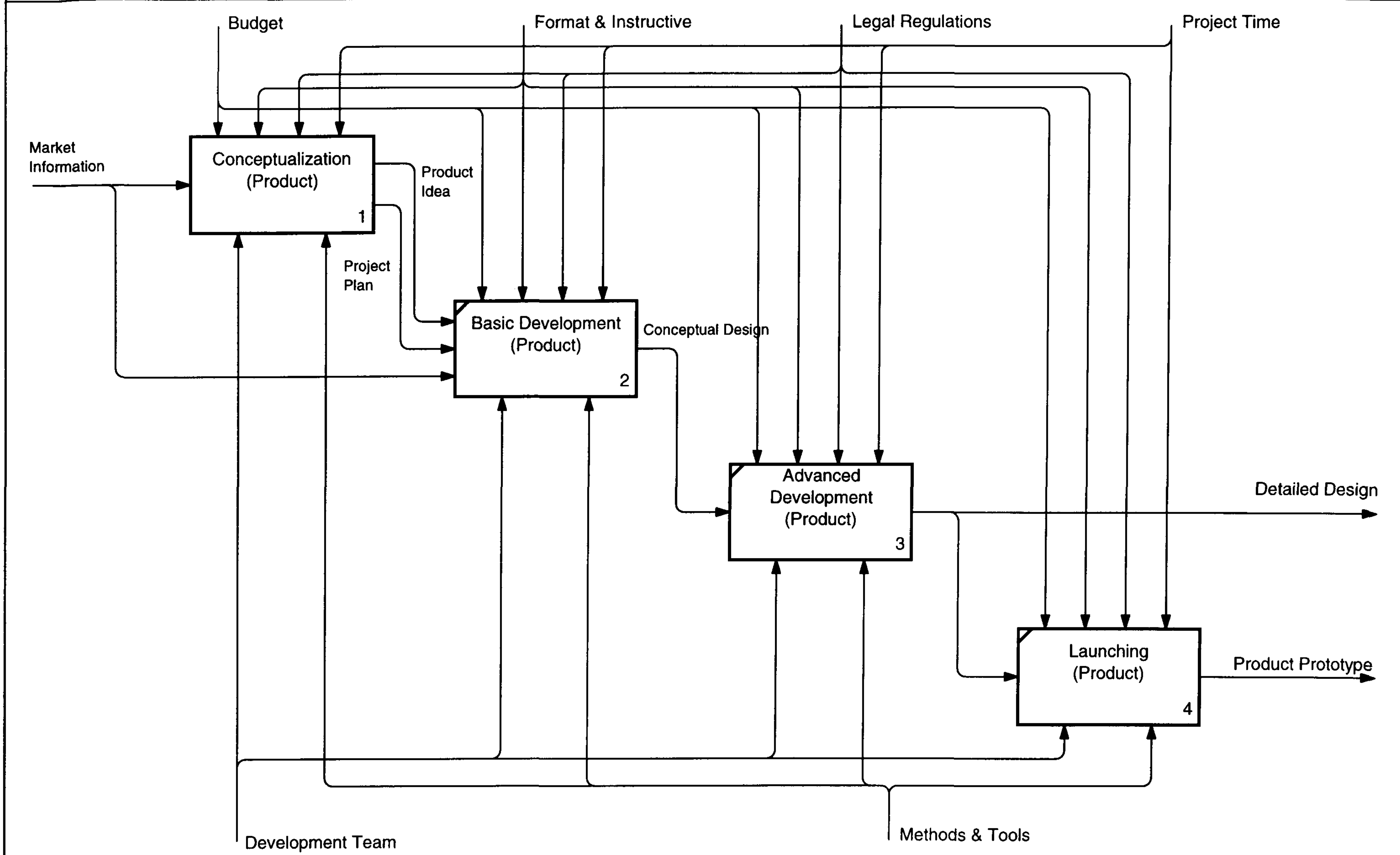

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USED AT:	AUTHOR:	DATE: 1 Dec. 2003	■ WORKING	READER	DATE	CONTEXT:
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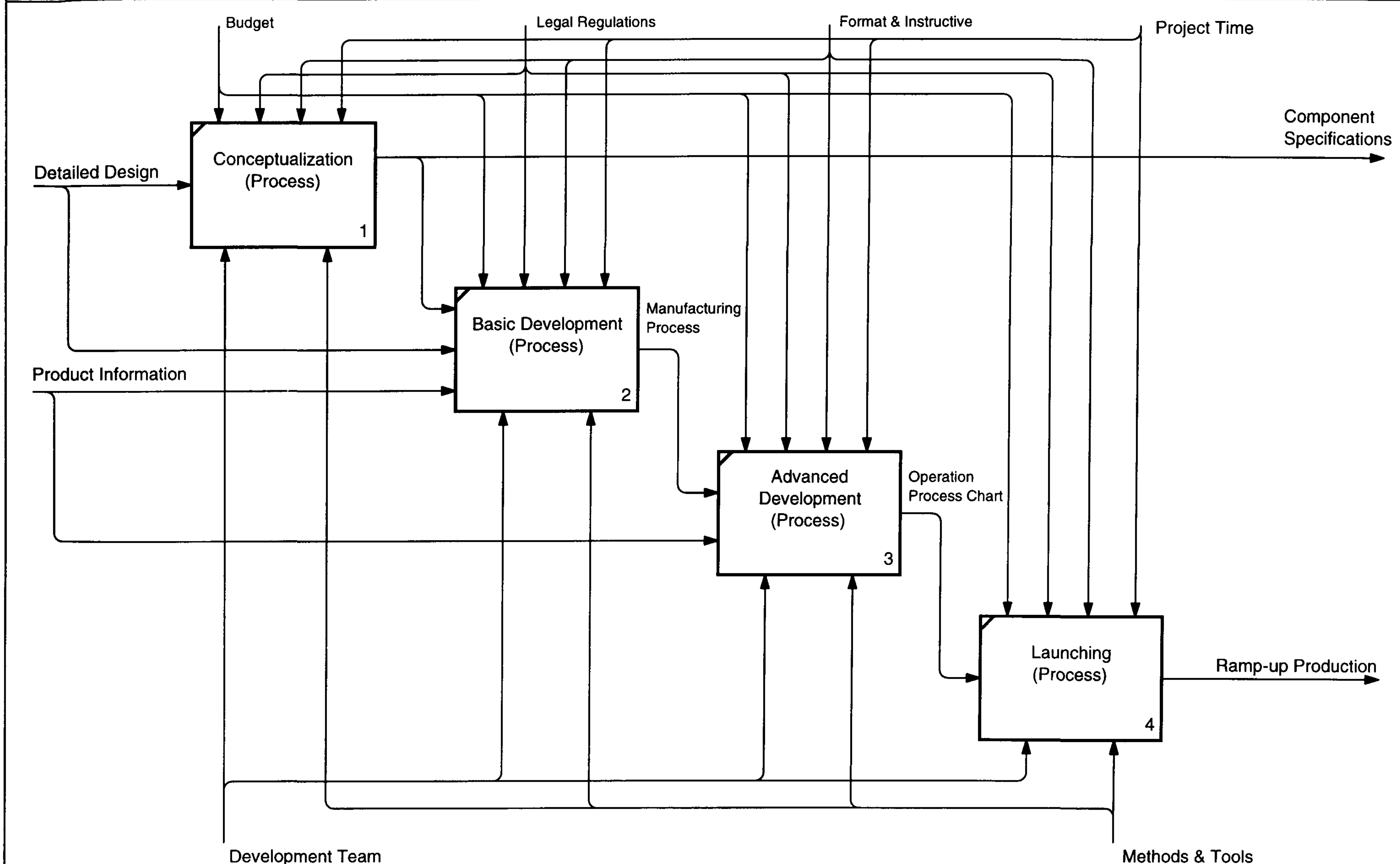

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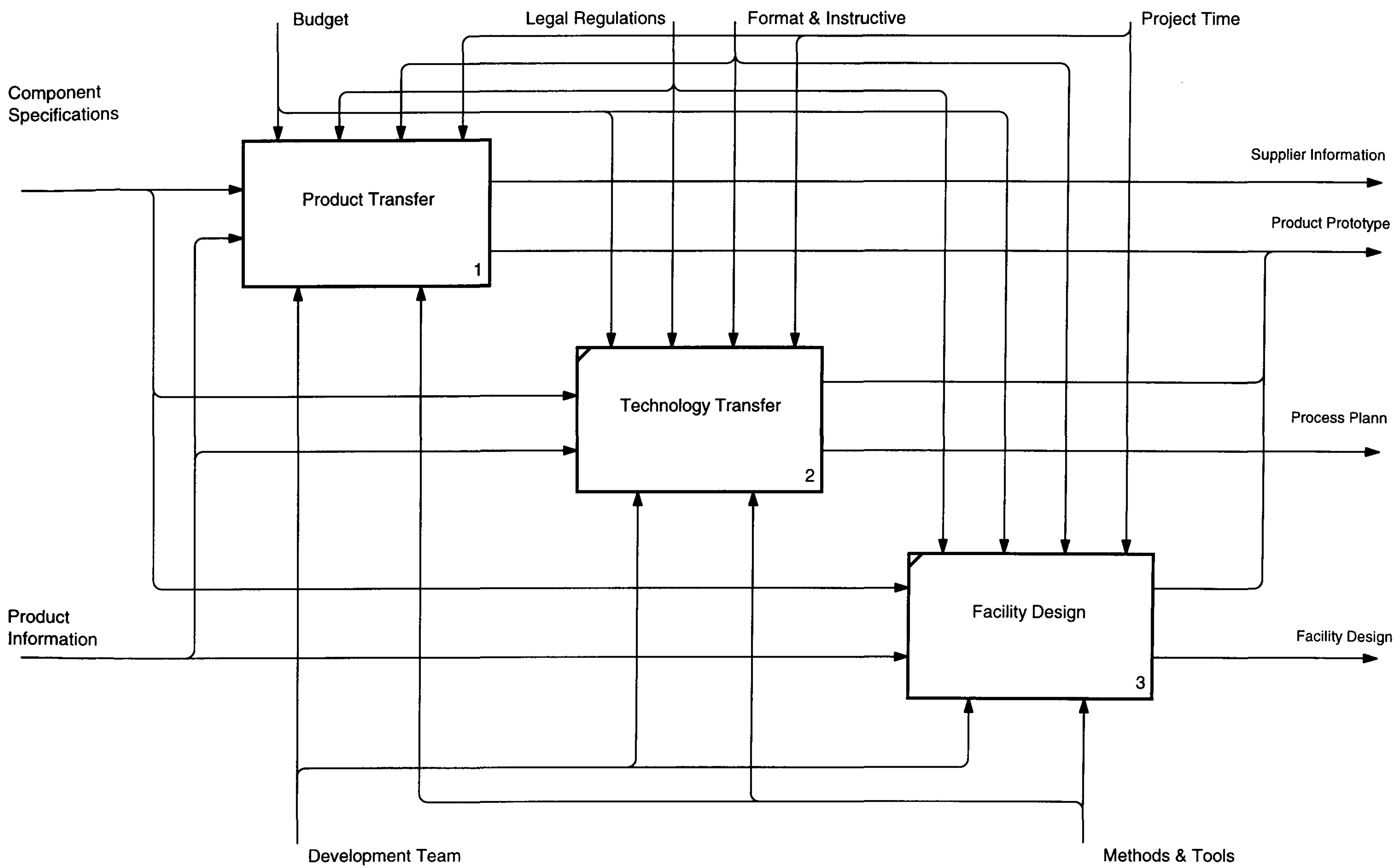

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