MASTER THESIS KTH

PROCESS MANUFACTURING SELECTION MODEL
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1 ABSTRACT

The report developed for the end of the Master Program is about a theoretical analysis of a Model called IDEF 0 adapted to Process Manufacturing issues.

Firstly, there is a small introduction on the importance of modelling and why companies should emphasize the improvement and the investment in modelling techniques in order to make them more efficient. Moreover, in order to complete this Thesis, most of the information is taken from the National Institute of Standards and Technologies (NIST) and the program they developed: SIMA (The Systems Integration for Manufacturing Applications). Therefore, there is a quick introduction to the SIMA program. Three different potential techniques are selected (IDEF 0 technique, Flowcharts and UML diagram technique) and briefly described and finally there is a deeply analysis on the methodology and a development on a possible Process manufacturing selection Model. The several activities or the process selection model are analyzed and designed in boxes and flows as the IDEF 0 model indicates.

In order to complete the development of the model, several tools are introduced such as Prima Matrix for preliminary and criteria decisions and the GUI (Graphical Users Interface) tool and finally the algorithm to get make the calculations and get the results for process selection. This model is not proved in any manufacturing company as the GUI and algorithm has not been developed; it is just a theoretical model that could be adapted and then after several trials applied.

Finally, different potential benefits and improvement on the manufacturing sector are enumerated and future applications in real life. As well it is described that it could be applied in the future not just for a manufacturing process selection but also it could be applied for other purposes such as price estimation in a manufacturing company.
SAMMANFATTNING

Rapporten som är det slutliga resultatet av ett genomfört examensarbete av behandlar och redovisar resultatet från en teoretisk analys av en modell som heter IDEF 0 och är anpassad till Processtillverkningsfrågor.


För att slutföra modellutvecklingen introduceras flera verktyg som Prima Matrix, för preliminära och kritiska beslut, och GUI (Graphical Users Interface) verktyg och slutligen algoritmen för att göra beräkningarna och få fram resultaten för processvalet. Denna modell är inte verifierad i något tillverkningsföretag, eftersom GUI och algoritmen först måste utvecklas. Detta är i nuläget en teoretisk modell som kan anpassas och sedan efter flera försök implementeras och tillämpas.

Slutligen presenteras olika potentiella fördelar och förbättringsmöjligheter inom tillverkningssektorn och framtidiga tillämpningar i verkliga livet. I rapporten beskrivs också hur modellen skulle kunna tillämpas i framtiden, inte bara för ett produktionsprocessval, utan även för att användas för andra ändamål såsom prisuppskattning i ett tillverkande företag.
2 INTRODUCTION

2.1 Why do we model

“The word “model” is highly ambiguous, and there is no uniform terminology used by either scientists or philosophers.” (Kopersky, 2016)

A model intends to be a representation of some object that is trying to be understood, in this regard we can find a great variety of models.

Some models are used in physics and other sciences that aim to give a better insight of how nature works in its various aspects. These kinds of models are used also in engineering allowing the engineers to get a better approach of how machines work.

A simulation is the implementation of a model. A steady state simulation provides information about the system at a specific instant in time (usually at equilibrium, if such a state exists).

A dynamic simulation provides information over time. A simulation brings a model to life and shows how a particular object or phenomenon will behave.

Such a simulation can be useful for testing, analysis, or training in those cases where real-world systems or concepts can be represented by models.

Simulation Tools are also used in order to model processes in several areas of engineering, building, production or even the simulation of the patterns that people follow in several daily routines such as queuing in the supermarket or in a Sports event.

Models are also used in logistics, production and finance among several areas of Management.

The reason that makes modelling so relevant is that in order to understand an object or a process the information about it needs to be segmented and displayed in a schematic way so that only the variables that are of our interest are used and the information remains manageable.

Models are important due to the next points:

- They help understand the situation or system.
- They make the conceptualization of the solution easier.
- Communication is improved.
- Double interpretations are avoided.

Production companies and factories in order to be efficient divide their productive systems in processes with the aim of improving and knowing these productive systems from the base.

Productive models are continuously changing and being updated in order to remain useful. Models used in previous stages may not remain useful for nothing else that check where mistakes had taken place and avoid falling in the same errors.
2.2 How models are used in the Industry

In industry widely used methods require precise models, for example, decision making methods AHP require the implementation of a hierarchy that represent the structure of the problem which we are approaching.

Financial models are also used in order to simulate different possible situations before making a change or implementing a new feature in a product with the purpose of checking whether this situation will be profitable for the company or it is not worth taking the risk that implies. An expected profit and loss account that give a certain balance shit at a certain date could be an example of a financial model used in industry.

However, when we talk about models in industry we may be referring to the flowcharts that, as said previously, bring the whole productive system to the most basic.

Figure 1 represents an example of a manufacturing activity process model.
3 FRAME OF REFERENCE

The manufacturing process decision model has been developed after several analysis and gathering information from different frameworks. Therefore, once the analysis are made, the technique is decided.

In order to complete the model, the different techniques analyzed are IDEF0 technique, flowcharts and UML modelling technique. With the support of the National Institute of Standards and Technologies (NIST) and the program they developed: SIMA (The Systems Integration for Manufacturing Applications), the activity model for manufacturing process decision has been successfully developed for the manufacturing industry.

3.1 NIST SIMA

The unprecedented growth of information and communication technologies happening since the late 80’s, driven by the evolution of hardware and software allowed the industry to receive and compute all different kinds of information and to identify key performance indicators that would be crucial for the quest of efficiency in manufacturing.

Richard Nolan, famous author and professor in Harvard Business School developed a theoretical model for the growth of information technology in a business of similar organization. That theory had a great impact over the process or resource planning and IT activities within the companies. His theory is that IT in organizations is evolving through various steps (Nolan, 1982):

- **Stage 1 – Initiation**: Information technology is first introduced into the organization. Due to the unfamiliarity of personnel with the technology, users tend to take a “hands off” approach to new technology. This introductory software is simple to use and cheap to implement.

- **Stage 2 – Contagion**: Adoption of computers in a range of different areas, system sophistication requires employing specialized professionals.

- **Stage 3 – Control**: No reduction of computer use, IT’s division importance to the organization is greater, centralized controls are put in place.

- **Stage 4 – Integration**: Adoption of new technology to integrate systems that were previously separate entities.

- **Stage 5 – Data administration**: Data processing department now serves more as an administrator of data resources than of machines.

- **Stage 6 – Maturity**: Systems now reflect the real information needs of the organization, greater use of data resources to develop competitive and opportunistic applications, data processing now emphasizes data resource planning.

The aim of every organization in order to reach its objectives faster and with the help of information technology systems is to reach the maturity stage as soon as possible in order to be more efficient and to grow. So the states started to get interested in order to help national companies to be more competitive and, in 1994, a non-regulatory agency of the United States Department of Commerce: The National Institute of Standards and Technology (NIST) decided to undertake an intramural effort creating SIMA: The Systems Integration for Manufacturing Applications.
The objective was to support the application of information technologies to the manufacturing domain through integration in order to promote innovation and industrial competitiveness of US Companies. That program is since then working with industry in order to develop technology solutions enabling integration of the systems used in the engineering and manufacturing of various kinds of products.

The Program is organized into three technology areas: Interface Standards, Information Access, and collaboration Mechanisms and performs three different activities:

- The development of standards for information exchange and interface protocols addressing interoperability problems in manufacturing systems.
- Provide online access to NIST-resident capabilities supporting manufacturing technologies
- Develop collaboration technologies enabling industry researches, practitioners, and NIST staff to remotely work together

These efforts will allow manufacturing industries to make use of computer networks as a mechanism for communicating information of activities such as:

- The research conducted to devise new products and processes
- The design of products and processes
- The engineering analysis of prospective solutions
- The planning of manufacturing operations
- The scheduling of production operations
- The engineering of production capabilities
- The myriad of other information-intensive activities required in industry today

All such activities are conducted using manufacturing software systems and these systems require information interface in order to communicate with each other. Those information interfaces may be realized as specifications for application programming interfaces, for data exchange protocols, or even as human-computer interfaces. The primary focus of the SIMA Program is the development and testing of information interfaces that provide scientists, engineers, and manufacturing personnel with the capability to share information among different activities, among different application software components within manufacturing enterprises, and throughout the entire supply chain.

SIMA technology efforts stem from both the short- and long-term needs of U.S. manufacturers and their software suppliers. Industry needs evolve in response to technology and market realities, thereby resulting in corresponding changes in the SIMA Program’s project portfolio over time (Fowler J. E., 1998).

Twenty-five (25) projects comprised the SIMA Program in 1997 and 1998. These projects addressed a wide range of industry manufacturing domains: chemical products, electrical products, materials, mechanical products, and constructed facilities. In this section, the focus is on the technology areas addressed in the projects.
3.2 Modelling Techniques

There are different activity model methods which are useful and efficient in terms of organizing and planning a company goal or objective. In this section a various number of methods will be described in a general way without entering in further explanations.

A. IDEFo (Integrated DEFinition method o)

The IDEFo is a modelling technique which is based on the Structured Analysis and Design Technique (SADT) originated in the 1970’s in the U.S. Air Force under the Integrated Computer Aided Manufacturing (ICAM) program (Kim & Jang, 2002).

The main purpose of this function modelling method is to model the several decisions, performances and the activities that take place in a manufacturing organization. The method is structured in a graphical form and was originally created to describe the relation of activities. Therefore, it provides a clearer understanding and a simplified path for organizing complex decision problems. As an analytical tool, the method assists the analysts in identifying the functions performed and what is further required to perform them. The general structure represents a top down decomposition to accomplish a suitable solution to the problem. The documentation created in IDEFo has a high degree of detail in order to be used as a basis by analysts. Basically, the method is a diagram integrated by boxes (functions) which are connected using arrows (data or materials).

The method help analysts agree and clarify in several company aspects such as the functions needed to reach the set of goals, the different tools that will perform the function and the rules that must be followed (legal requirements, tolerances). However, IDEFo has different limitations in terms of generating a database (IDEF1 needed) or does not describe quantifiable sizes (Jorgensen & Member of Coopers&Lybrand Consulting Group).

IDEFo is the method selected in the Manufacturing Process Selection project. The different terminology and concepts of the method are described below in the report.

B. Flowcharts modeling technique

The Flowchart modeling technique is one of the most common and popular. The main reason people use this technique is related to the simplified standard symbols used that makes it a powerful and easily understandable tool. Moreover, there are some modern modeling techniques such as BPMN which are an advanced version of the Flowchart technique.

For instance, flowcharting is one of the most suitable techniques in order to back programmers to develop programs faster and in a more efficient and organized way. Basically the flowchart is a graphical plan created in order to follow the several action or steps for a global activity.

In a general way, the flowchart modeling technique is a graphical representation of the sequence of the different operations which take part of an activity. The way of transforming a complex activity into an organized flowchart is to start by creating a flowchart containing just the task. Then, this task can be divided into more specific steps. These steps will be subdivided into more specified and detailed steps. Finally, the flowchart is completed when all these sub operations cannot be simplified more. In this way, the flowchart technique shares some similarities with the IDEFo technique.

As many other modeling techniques, it uses boxes with a variety of shapes. Inside these boxes the different instructions are written in a clear and concise statement. The arrows are
drawn in order to connect the boxes. Therefore, arrows represent the flow of operation which helps to follow the sequence of the instructions step by step.

The symbols used in flowcharting are universally recognized and understood. In terms of communication and process organization, the information can be followed effectively, accurately and succinctly. Generally, three shapes are differenced in a basic flowchart:

- **Ellipse**: also known as the terminator shape. Indicates whether the flowchart ends or begins. When the end or beginning is clear, the terminator shape can be avoided.
- **Rectangle**: it is the flowchart more used and represent the operation/action that is taken.
- **Diamond**: represents a stage where a decision needs to be taken. Usually answering the decision will lead to a path or another.

Moreover, the flowchart model should be read from top to bottom (vertically) or from the left to the right (horizontally).

The figure 2 shows an extended version of symbols from conceptdraw.com (flowchart design).

![Figure 2: Flowcharts symbols](image)

For instance, figure 3 (Nakatsu, 2010) is a simple flowchart which illustrates and describes a prototyping process. There the different activities for prototyping are described in simple sentences and sequenced:

1. Identify basic requirements.
2. Develop working prototype.
3. Get feedback from users.
4. Revise and enhance prototype.
5. Repeat steps 3 and 4 until the end user is satisfied.
Nowadays there are some variations in the use of flowcharts, such as the PERT charts used to show the sequence of the different activities that take place in a project. Another example would be the Data flow diagrams (DFGs) which is used by systems designers in order to know how data flows into the system and moves between several processes. Additionally, applications with real-time or time-critical processes require dynamic process modeling. Software such as ProcessCharter or Optima help costumers create complex flowchart models and find out how the processes perform over time.

C. UML modelling technique

The UML modelling technique it is basically used for specification, development, visualization and documenting software systems. Nevertheless, it has been adapted as a powerful technique in business process modelling. Even though the can be some similarities between software systems and business systems, there are also some differences which lead to complex arguments about how this technique should be used.

Martin Fowler (Fowler M. , 2004) came up with the description of the three ways in which people work with the UML:

- Sketch
- Blueprint
- Programming language

From those three modes, UML used as sketch is the most common. For instance, sketches can be used in a forward-engineering or a reverse-engineering direction. In the first case a UML diagram is used before writing the code while in the second one you build and UML diagram from an existing code in order to understand it. The UML technique it’s a way of simplifying a complex situation.
According to its characteristics, the 14 different UML diagram types (figure 4) make this technique a more flexible and dynamic way to visualize almost any process. In the other hand, with all the different type of diagrams, in some cases there can be a difficulty when understanding the diagrams. Moreover, different UML diagrams can model the same process. That is the reason why analysts often reject this choice.

Figure 4: 14 different UML Diagram Types

In the case of manufacturing process modeling, the type of diagram that fits best is the activity diagram. The activity diagram is a kind of behavior diagram which represent the workflow or object flow and where the conditions and sequence of the flows are very relevant. In the activity diagram the actions can be initiated when another actions has been completed, when there is more data available, or in case there occurs an event external to the flow.

Figure 5: Example of UML Activity Diagram
Figure 5 (Eshuis & Wieringa, 2004) shows an example of an UML activity diagram. The syntax of the activity diagram is as follows. First of all, oval boxes describe activity states while rounded rectangles represent wait states. A diamond shape represents decisions and the black bars the start (split) or end (join) of concurrent activities. Finally, the black circle represents the initial state, the start of the workflow and the encircled black circle means the final state, when the workflow ends.

It is important to know how a modeling technique fits into the different processes. For instance, the way of using the UML modeling process depends on the type of process used. At the beginning it more relevant to discuss about the process in order to see the context in which UML can be used.

### 3.3 Modelling IDEF0/SADT

IDEF0/SADT is the activity modeling method followed in order to develop a successful model to engage the problem of manufacturing process decision.

#### 3.3.1 Methodology

There are a number of basic concepts and rules to model in IDEF0. This general description of the method is valid to organize projects from different areas.

The fundamental objects of an IDEF0 model are activities, information flows and resources. The model is developed in diagrams using components such as boxes and arrows with several rules.

![Figure 6: IDEF0 Fundamental Syntax](image)

In the model, the activities are the functions and operations planned to execute. In the diagram, each activity is represented by a box. When modelling an activity, this can be developed into lower-leveled activities or child diagrams that provide additional information about the parent box. Therefore, each box must have the name of the activity and number for a correct understanding. By convention, the model should have a highest-level context diagram. This is called the A-0 diagram. A0 is a single box that establishes the model context and also sets the model scope and purpose. The second diagram page represents the first decomposition, and each page represents the development of a single activity on some previous page.

The activities in the first decomposition are designated A1, A2, ... For each sub activity a digit will be added, A11, A12, ...

All the necessary information used in the activities must be accounted in the sub activities. Thus, the information must flow into or out of one or more of the sub activities. Similarly, the different
resources required by the activity must be required by one or more sub activity. Conversely, these sub activities must not introduce information and resource requirements that are not necessary in the main or parent activity.

![Figure 7: Example of an Activity Divided into Subactivities](image)

It is important to add that the timing of each activity is not modelled. The numbers for each activity does not imply time or precedence. IDEF0 does not distinguish among once-only, repeated and continuous activities (Barkmeyer, 1998). There are many cases when activities are repeated. For example, when manufacturing a product, the activities can be repeated until the technical quality and requirements of the output are adequate. Activities may occur in parallel if there is information flow between each other.

The information flows represent information objects which have a common purpose and are collected together to provide a complete information set. One or more activities are producers of information flows and other activities are consumers. To connect the activities, information flows are modeled by arrows in the diagram leading from de producer to the consumer.

An arrow represents the data or object used in order to complete the activity. They do not represent sequence as in a process model (Chen, 2009).
The rules used for arrows are as follows:

- Arrows should be represented as solid line segments.
- Arrows must be drawn vertically or horizontally
- It is just possible to bend an arrow in 90 degrees arcs.
- Arrow end should touch the outer part of the activity box, but not cross inside the box.
- Arrows should be connected to the sides of the activity box, not to corners.
- Arrows can be connected if they describe the same information.

According to a single activity, the information flows are divided into four different categories:

- Input: represents the information or material which may be used or transformed in order to perform the activity. There is a possibility where there might be no need of input arrows in certain activities. Input arrows are used in the left part of the box.

- Output: the information or material that is modified (or produced) in a previous activity. The output from one activity can be the input of the next activity. Every activity must create at least one output. If the activity does not generate any output will not be modeled. The output arrows are represented at the right side of the box.

- Control: represent the rules, regulations, politics or/and standards that should be followed in order to fulfill the requirements for the planned output. The control or constraints arrow regulate the activities but cannot be modified or transformed. In case regulations may be added or modified in an activity, they will be used as input arrows. Every activity must have at least one control arrow. This arrow is positioned on top of the activity box.

- Means/mechanisms: represent all the resources used to perform an activity. It includes humans, machines and/or equipment, software/hardware resources. The mechanisms are all the tools that can be gathered to execute effectively a determined activity. In the diagram, the means arrows are positioned below the activity box.

In IDEF0 model arrows cannot be labeled as Input1, Control 2, ... The arrows must be labeled with name which describes the information flows. In order to label the arrow properly, a “squiggle” may be used to link the arrow with its associated label.
4 THE MANUFACTURING PROCESS SELECTION MODEL

This section contains a detailed description of each activity in order to decide which process in the most effective and efficient to manufacture a product. The information flow will also be described in this section.

The complete node tree for the process decision model is as follows:

A0: Manufacture Product
   A1: Process Requirements Specification
      A11: Consolidate Relevant Product Properties
      A12: Process Flexibility Requirements
      A13: Developing Process Requirements Specification
   A2: Develop Decision Criteria
      A21: Generate List of Criteria
      A22: Criteria Redundancy and Overlapping Review
      A23: Organize in Hierarchy
      A24: Assign Weights
   A3: Explore Candidate Processes
      A31: Candidate Process Listing
         A311: Select Stock Materials
         A312: First Step Selection
         A313: Preliminary Process Listing
      A32: Determine Manufacturing Sequences
         A321: Specify Operations
         A322: Sequence Operations
         A323: Specify Part Routing
         A324: Optimize & Validate Plan
      A33: Process Capability Assessment
         A331: Derive Manufacturing Features
         A332: Analyze Data Distribution
         A333: Calculate Capability Index
      A34: Process Cost Assessment
         A341: Preliminary Cost Estimates
         A342: Tooling Cost Assessment
         A343: Develop Final Cost Estimates
      A35: Process Integration and Environment Assessment
         A351: Tool Environmental Impact
         A352: Facility Environmental Impact
         A353: Utilities Environmental Impact
         A354: Consumables Environmental Impact
         A355: Raw Material Environmental Impact
      A36: Engineer New Process
   A4: Comparative Feasibility of Processes
      A41: Select Reference Processes or Values
      A42: Compare Processes to each other
      A43: Score the Comparative Values
      A44: Select Candidates
   A5: Test Run and Evaluate
      A51: Create GUI (Graphical Users Interface)
      A52: Generate Comparison Algorithm
      A53: Test GUI & Algorithm
      A54: Run Process Comparison
      A55: Rank Processes
A6: Cost Analysis and Selection
A61 Calculate Fixed Cost
A62 Calculate Variable Cost
A63 Calculate Total Cost
A64 Select Candidate Process

Figure 8: Activity 0: Manufacturing Process Selection Model
4.1 ACTIVITY 1: Process Requirements Specifications

The activities that are performed during the requirements phase largely focus on two areas, problem analysis and product description. Gathering requirements involves obtaining all relevant information that will help in understanding the customer's requirements.

The subactivities that take place in A1 are:

A11 Consolidate Relevant Product Properties
A12 Process Flexibility Requirements
A13 Developing Process Requirements Specification

An analyst is responsible for the creation of a detailed document with the defined product properties and the final design of the product for processing. The relevance of this document is vital in order to secure the correct and specific development in further activities. In addition, the document is used as a contract so that there are no misinterpretations between the original specifications and the final solution. Units can be produced in low volume with very high complexity or high volume of low complexity so it is necessary to specify the process flexibility requirements. During the process requirements specifications there must be included a specific time schedule and the cost limitation required in order to manufacture the product.

Finally, after describing an analyzing every parameter that should be written down in the document it is possible to move forward to the next step. Otherwise, a new analysis must be done so that any
specification is forgotten in the document. The document of the process requirements specifications will be consulted in every further activity to follow satisfactorily all the detailed information given.

- INPUT
  - I1 Product Design: The design inputs are typically the initial requirement for the product to be manufactured. Product design is a conceptualization of an idea about a product and transformation of the idea into reality.

To transform the idea into reality a specification about the product is prepared. This specification is prepared by considering different constraints such as production process, customer expectation, etc. In product design every stage aspects are analyzed. Also final decision regarding the product is taken on the basis of the analysis. By using 3D modeling software system, designers develop a computerized model of a new product and analyze its design parameters.

The design parameters are the qualitative and quantitative aspects of physical and functional characteristics of a product that are input to its design process. Determine cost, design, risk tradeoffs in the product development. Moreover, in order to decide on the process to manufacture the product, it is important to gather the design specifications which are the essential qualitative and quantitative characteristics that set criteria (such as performance requirement, dimensions, weight, reliability, ruggedness).

Each design specification which the analyst needs to analyze in detail is:

- Material type: describe the type of material, depending on the density strength and hardness. As materials get harder, denser and stronger, they become much harder to machine and take much longer, thus less manufacturable.

- Material form: The size and the shape of the component may determine which form of material must be used. So although the material form isn’t directly related to geometry of the component, cost can be removed at the design stage by designing the least expensive form of material.

- Tolerances: Tolerances must be specified on a feature by feature basis.

- Design and shape: using 3D modeling software systems.

- OUTPUT
  - O1 Process Requirement Specification: Once all the parameters and specifications are evaluated and analyzed and every constraint is taken into account and there is an agreement between both parts, the document with the process requirements specification is developed and completed. This document, used as a contract will be checked in every further step in order to meet all specifications detailed.

The process requirement specification output will include the consolidate material properties after being revised with the relevant legislation. Variants and volume with different material appear to describe the process flexibility requirement restricted by time and budget constraints and the limitations of the existing processes to manufacture the material.

- O2 Feedback to product design: Gathering every specification is necessary, but a deep analysis should be done according to all the data collected from the product design and the constraints. A design review is a milestone within a product development process whereby a design is evaluated against its requirements in order to verify the outcomes of previous activities and identify issues before committing to further work. Most formalized systems
engineering processes recognize that the cost of correcting a fault increases as it progresses through the development processes.

Additional effort spent in early stages of development to discover and correct errors is therefore likely to worthwhile.

- **CONTROL**

  - C1 Volume: Volume influences many characteristics when manufacturing a material. Parameters as manufacturing cost, time to manufacture and quality of the product are related directly to volume capacity. Depending on the volume variations the flexibility of the process could change. There are other parameters less relevant that are related to volume: cost per unit, labour productivity, machine efficiency, system reliability, adaptability to CAD operations, production rate, cost to implement, pre-planning, requirement skill of labour, complexity of the process.

  Low volume production means more specified with higher quality products, the cost per unit increases and more processes appear in manufacturing. In the other hand, high volume production will move for standardized products where costs reduction and quality decrease considerably compared to low volume production.

  - C2 Budgetary Constraints: The budgetary constraint is a key aspect in the future process of manufacturing the product desired. In the same way as volume, the less budget capacity the less quality for the product will be expected. There will be a necessity to fix the ideal processes to the budget limitation.

- **MEANS**

  - M1 Process Requirements Document (PRD): The purpose of the document is to clearly and unambiguously articulate the product’s purpose, features, functionality and behavior. The team will use these specifications to actually build and test the product, so it needs to be complete enough to provide them the information they need to do their jobs. It is important to write the document as a list format and the parameters must be quantified so that the information is clear and detailed enough.

  Here are a few of the problems which can be avoided (or at least lessened) by having a good requirements document:
  - Building to requirements which do not really reflect the needs of a stakeholders
  - Building a project from inconsistent or incomplete requirements
  - Making changes to requirements during development, which is costly
  - Misunderstandings between costumers or end users and developers which result in a product that is not what was wanted.
  - Forgetting plans for the project
  - Feature creep

These information flows will be the most relevant in the whole manufacturing model and a further description is avoided in order to eliminate repetitiveness.
4.2 ACTIVITY 2: Develop Decision Criteria

Specify a list of criteria according to the list of the detailed process requirements specifications completed in the previous activity. The wide analysis made to the product and the specific constraints helps to create a list of different criteria based on the final product. Thus, the stakeholders’ preference added to the requirements are taken in to account to generate the weights for each criteria.

- **INPUT**
  - I1 Process Requirements Specifications
  - I2 Product model
  - I3 Stakeholders Preferences

- **OUTPUT**
  - O1 Criteria with weights

- **CONTROL**
  - C1 Process Requirements Specifications

- **MEANS**
  - M1 Structured Criteria Decision Model: One of the most important criteria decision models is Analytic Hierarchy Process (AHP)

Figure 10: Acitivity 2: Develop Decision Criteria
One of the most important techniques used for organizing and analyzing complex decision is the analytic hierarchy process (AHP), developed by Professor Thomas L. Saaty (1980) as a solution to decision making problems in the USA defense department. The AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions (Majumber, 2015). The fundamentals of the AHP method will not be explained in this document but it can be found in (Saaty, 1996), (Saati, 1999) and (Figueira, Greco, & Ehrgott, 2005). On the other hand, the method general steps are described below obtained from (Aznar Bellver, Guijarro, & Moreno-Jiménez, 2009). The AHP general steps are:

I. Analyze the problems and define the main goal.

II. Specify a list of different criteria that will be used for the selection process. These criteria should be structured in different levels.

III. With the final purpose of assigning the weights for each criteria, construct a set of pairwise comparison set of matrices to compare the different criteria for every level.

IV. Once the weights are assigned, the comparison is made with the different alternatives selected.

V. The weight of each alternative in the last level criteria is multiplied to the weight assign to each criteria to finally obtain the overall weight for the decision making.

VI. After calculating the overall weight, the best alternative is decided according to the specified criteria and its relative importance.

In this activity the subactivities related to criteria specification and ponderation is carried out (alternative comparison is made in activity 4):

A21: Generate a list of criteria
A22: Criteria redundancy and overlapping review
A23: Organize in Hierarchy
A24: Assign weights

**A21: Generate List of Criteria**

Once the product model is analyzed and decomposed into a list of different valid requirements to achieve the final design, this document is reviewed. The purpose is to generate a list of different criteria that describe the requirements for the product. To achieve the final product successfully, the criteria must be specific and cover in detail all the requirements described in the product model. This list of criteria is compared in order to make a decision. Therefore, the criteria need to be numerically quantifiable.

**A22: Criteria Redundancy and Overlapping Review**

Conduct a thorough review of the list criteria in case there can be found possible criteria redundancy. Thus, every criteria that means similar or repetitive may be eliminated from the list. Redundancy in the criteria least can lead to failures in the comparison method used.

**A23: Organize in Hierarchy**

The list of criteria should be structured from the lowest level of sub-criteria to the top level of criteria. This is an effective method when it comes to compare different criteria.
The criteria have to be organized depending on the degree of importance and developed from the global criteria to the more specific subcriteria.

**Figure 11: AHP method**

Figure 11 and figure 12 represent an example to explain the AHP hierarchy for the technical and ecological assessment of process chains (Reichel & Rünger, 2013).

**Figure 12: Example AHP for Technical Assessment of Process Chains**

**Figure 13: Example AHP for Ecological Assessment of Process Chains**
A24: Assign Weights

To compare the criteria, we have to indicate how many times more important or dominant one element is over another. It is used a scale of numbers to compare the importance between criteria. In this activity, we create a pairwise matrix to compare criteria to generate the weights. In order to give the scale of importance, it is necessary the revision of the requirements made by a group of experts joined with the stakeholders' preferences.

Table 1 represents “The fundamental scale of absolute numbers” (Saati, 1999)

<table>
<thead>
<tr>
<th>Intensity of Importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Importance</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Weak or slight</td>
<td>Experience and judgement slightly favour one activity over another</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgement strongly favour one activity over another</td>
</tr>
<tr>
<td>4</td>
<td>Moderate plus</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Strong plus</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very strong or demonstrated importance</td>
<td>An activity is favoured very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>8</td>
<td>Very, very strong</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one activity over another is of the highest possible order of affirmation</td>
</tr>
<tr>
<td>Reciprocals of above</td>
<td>If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i</td>
<td>A reasonable assumption</td>
</tr>
<tr>
<td>1.1–1.9</td>
<td>If the activities are very close</td>
<td>May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities</td>
</tr>
</tbody>
</table>

The necessity of assigning a numerical value to each variable of the problem helps decision makers to maintain cohesive thought patterns and to reach a conclusion.
4.3 ACTIVITY 3: Explore Candidate Processes

The main purpose in this activity is to provide a list of a selection of processes that may be suitable candidates for a component. For the process list created, each one of them is described. The description is detailed and consists of a detailed tooling description, the different process operations and a variety of assessments.

- **INPUT**
  - I1 Process requirements specification
  - I2 Product model

- **OUTPUT**
  - O1 Candidate processes

- **MEANS**
  - M1 Conventional Processes
  - M2 Emerging Processes

- **CONTROL**
  - C1 Process requirements specification
  - C2 Legislations

The activity is subdivided by four sub activities:
- A31 Candidate Process Listing
- A32 Determine Manufacturing Sequences
- A33 Process Capability Assessment

Figure 14: Activity 3: Explore Candidate Processes
A31: Candidate Process Listing

According to the previous Process Requirements Specifications list created in activity A1 (Process Requirements Specifications), a various number of processes are collected and listed. This list of processes is a general list of candidates that fit with the material properties of the component which is intended to be manufactured.

- **INPUT**
  - I1 Product Properties
- **OUTPUT**
  - O1 Processes to be assessed
- **MEANS**
  - M1 Process References
  - M2 Stock materials
  - M3 Tooling/equipment used
- **CONTROL**
  - C1 Process requirements specifications

The activities that take part are preliminary activities by selecting the stock material or materials and volume of products manufactured. These sub activities are the initial part for manufacturing process selection:

A311 Select Stock Material
A312 First Step Selection

---

**Figure 15: Activity 31: Candidate Process Listing**
A311 Select Stock Material

Identify the material or materials which satisfy the product properties. There can be different materials suitable to process but at the same time the client’s specifications must be taken into account.

A312 First Step Selection

At this stage a first filter is used to select different processes. This filter does not collect all the information in the process requirements specification. As it is a preliminary selection, just a couple parameters will be used in this selection. There are many ways to make a preliminary list.

For example, according to a preliminary selection, a manufacturing process prima selection matrix could fit for this activity. The PRIMA matrix represents the main common industrial practice but there will always be exceptions at this level of detail. This matrix considers the component material and the volume of production. Thus, it combines technological and economic issues of relevant importance in a simple way. It is not intend to represent a process selection methodology itself. It is essentially a first-level-filter. This first filter is responsible for guiding final manufacturing process selection.


Table 2: Example of Prima Matrix

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>PCN</th>
<th>ICNO</th>
<th>PECO</th>
<th>STAINLESS</th>
<th>DIE CASTING</th>
<th>PRESSURE DIE CASTING</th>
<th>DIE FORGING</th>
<th>FORGING PRODUCTS</th>
<th>FORMING PRODUCTS</th>
<th>MACHINING PRODUCTS</th>
<th>NTH PROCESSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>QUANTITY</td>
<td>[A]</td>
<td>[B]</td>
<td>[C]</td>
<td>[D]</td>
<td>[E]</td>
<td>[F]</td>
<td>[G]</td>
<td>[H]</td>
<td>[I]</td>
<td>[J]</td>
<td>[K]</td>
</tr>
<tr>
<td>HIGH</td>
<td></td>
<td></td>
<td></td>
<td>[A]</td>
<td>[B]</td>
<td>[C]</td>
<td>[D]</td>
<td>[E]</td>
<td>[F]</td>
<td>[G]</td>
<td>[H]</td>
</tr>
<tr>
<td>MEDIUM</td>
<td></td>
<td></td>
<td></td>
<td>[A]</td>
<td>[B]</td>
<td>[C]</td>
<td>[D]</td>
<td>[E]</td>
<td>[F]</td>
<td>[G]</td>
<td>[H]</td>
</tr>
<tr>
<td>LOW</td>
<td></td>
<td></td>
<td></td>
<td>[A]</td>
<td>[B]</td>
<td>[C]</td>
<td>[D]</td>
<td>[E]</td>
<td>[F]</td>
<td>[G]</td>
<td>[H]</td>
</tr>
</tbody>
</table>

As it can be seen, for each type of material and production there are several processes suitable.

Bernardo Bello
A313 Preliminary Process Listing

Figure 16: Activity 313: Preliminary Process Listing

The matrix mainly creates a list enumerating all the possible candidate processes that can be used in order to manufacture the material decided for the product. According to this list, any process selected is described. The purpose of this activity is to get all the useful information for each process. In this way, this information is analyzed in the next activities to compare each process.

Thus, there is a general description made for each process, machinability data is gathered and a detailed description of every tool used.

- A3131 General Process Description
- A3132 Process Machinability data
- A3133 Tools & Equipment used

A3131 General Process Description
According to each candidate process from the list, general description is collected. The reason is to understand the general operation for every candidate process.

A3132 Process Machinability Data
This activity has more detailed information about each process. The machinability data includes all the tolerances, cutting, finishing, of every machine used in the process.

A3133 Tools & Equipment Used
Complete specifications for the required tooling for each process, including cutting tools, molds, dies, fixtures, etc. This includes the design and/or
assembly specifications for the tool, and may include special instructions for use and estimated in-service life. The labor cost is also relevant and the different equipment that can be used in each process.

A32: Determine Manufacturing Sequences

Figure 17: Activity 32: Determine Manufacturing Sequence

The activity is generated to define a routing plan, with the sequence of every workstation and the different machines that can fit each operation. Each manufacturing process is integrated by different operations that have to be described and validated. For that reason, it is necessary to create a plan with all the several operations and organize them in the correct sequence for each process. This includes fabrication, assembly, inspection processes and fixturing, setups or batching.

- **INPUT**
  - I1 Process Preliminary List
  - I2 Tooling Inventory
- **OUTPUT**
  - O1 Sequence Change Request
  - O2 Sequence Plan Validated
- **MEANS**
  - M1 Process Models and References
- **CONTROL**
  - C1 Process Requirements Specifications
There are several activities that determine the manufacturing sequences:

A321 Specify Process Operations
A322 Sequence Process Operations
A323 Specify Part Routing
A324 Optimize & Validate Plan

A321 Specify Process Operations
For every process in the preliminary list, specify the component operations of the process, including the manufacturing features and every parameter which characterize the operations. At this stage, generally the machining, assembly and inspection operations are described separately. Tooling requirements are identified for each operation.

A322 Sequence Process Operations
Specify the sequence in which the operations will be performed. In case any operation does not fit in the sequence, it will be necessary to make an operation change request and analyze it.

A323 Specify Part Routing
Merge the fabrication, assembly and inspection operation sequences to generate the routing plan for the part. Specify the sequence of workstation types required to implement the processing and inspection sequences, how workpieces will be handled into and out of each workstation, and possibly the means by which workpieces will be transported from one workstation to another. Specify for each workstation the (merged) sequence of operations to be performed in that workstation.

For the different operation sequences complete a routing plan for the plan. There has to be detailed specification of the sequence for each workstation type required to implement the processing and inspection operations. Moreover, a description is made on how workpieces will be handled in and out of each workstation, and the different transportation ways to move the workpiece from one workstation to another. Additionally, for every workstation the operation sequence to be performed is specified.

In case the routing plan does not satisfy the requirements, there will be a sequence change request for further analysis.

A324 Optimize & Validate Plan
Review and evaluate the plan according to the requirements and objectives described. Verify the draft process plan and the major resource requirements. Identify desirable modifications and/or approve the plans.
Manufacturing processes must meet or be able to achieve product specifications. Further, product specifications must be based on customers’ requirements.

Process capability is the repeatability and consistency of a manufacturing process relative to the customer requirements in terms of specification limits of a product parameter. This measure is used to objectively measure the degree to which your process is or is not meeting the requirements.

- **INPUT**
  - I1 Processes to be assessed
- **OUTPUT**
  - O1 Capability assessed candidates
- **MEANS**
  - M1 Process References
- **CONTROL**
  - C1 Process Requirements Specification

In order to get the capability of each process evaluated and analyzed, the activity is subdivided in 3 different activities:

- A331 Derive manufacturing features
- A332 Analyze data distribution
- A333 Calculate capability index
A331: Derive Manufacturing Features
Collect the information of the geometry and topology features that are required to manufacture the product with a successful result. Clarify zones of material to be removed from the stock material and assign the design tolerances to manufacturing features. During this activity, the design features, fabrication features and product model are analyzed and inspected in order to ensure the further processing operations and satisfy the quality of the resulting part.

A332 Analyze Data Distribution
First of all, for the capability analysis to be performed the process needs to be under statistical control.

The requirements specifications will report the specification limits. These can be: Upper Specification Limit (USL), the Lower Specification Limit (LSL) and eventually a target value. Specifications can either be two-sided or one-sided.

Using and histogram or probability plots, you verify that the process is following a normal distribution.

![Histogram example for Process Capability Assessment](image)

Figure 19: Histogram example for Process Capability Assessment

Once verified the data is distributed normally then overall capability analysis is performed.

- INPUT
  - I1 Processes to be assessed
- OUTPUT
  - O1 Process data analyzed
- CONTROL
  - C1 Requirements specifications list
- MEANS
  - M1 Histograms
  - M2 Probability Plots
A333 Calculate Capability Index (Cp, Cpk)

The aim of this activity is to calculate the capability index in order to verify whether the process is capable or not and the level of capability of each process according to the different specifications from the process requirements list.

Figure 20: Cp Values in a Normal Distribution

Cp differs depending of the process. The next table specifies the correct values of capable index and the products per million that could be out of the requirements limits depending on the process and whether is one side specification or two side specifications.

Table 3: Table of the correct values of Cp and PPM

<table>
<thead>
<tr>
<th></th>
<th>One-Sided Specifications</th>
<th>Two-Sided Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CP</td>
<td>PPM</td>
</tr>
<tr>
<td>Existing processes</td>
<td>1.25</td>
<td>88.42</td>
</tr>
<tr>
<td>New processes</td>
<td>1.45</td>
<td>6.81</td>
</tr>
<tr>
<td>Critical existing process</td>
<td>1.45</td>
<td>6.81</td>
</tr>
<tr>
<td>Critical new process</td>
<td>1.60</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Table 4: Equation for Cp and Cpk

\[
C_p = \frac{\text{high spec} - \text{low spec}}{6\sigma_x}
\]

\[
C_{pk} = \min\left[\frac{\text{USL} - \bar{x}}{3\sigma} \text{ or } \frac{\bar{x} - \text{LSL}}{3\sigma}\right]
\]

- INPUT
  - I1 Process data analyzed
- OUTPUT
  - O1 Capability assessed candidates
- CONTROL
  - C1 Requirements Specification list
- MEANS
  - M1 Cp, Cpk
  - M2 Valid Cp Values table: table () used above to make sure the Cp values follow the valid parameters.
A34: Process Cost Assessment

Figure 21: Equation for Cp and Cpk

The manufacturing process cost of a part is dependent on factors such as necessary equipment and installation, required tools, the time for processing and the operating procedures (Swift & Booker, 2003). During this stage, a cost assessment is created to specify the different cost parameters for each process. Cost is one of the most relevant parameters when it is time to make a wise decision.

- **INPUT**
  
  I1 Candidate Processes
  I2 Time Estimates: represents the time in terms of cost used per operation in each process.

- **OUTPUT**
  
  O1 Design Change Request: in case cost is crossing the limit line defined in the requirements, a new design may be created in order to reduce costs.
  O2 Cost Assessed Candidates

- **CONTROL**
  
  C1 Process Requirements Specifications

- **MEANS**
The subactivities that take part in the process cost assessment are:

A331 Preliminary cost estimate
A332 Tooling cost assessment
A333 Develop final cost estimates

**A341: Preliminary Cost Estimate**
Making a preliminary cost estimate is having a general cost view for each process using general parameters. Analyze the processing time, equipment, materials and manpower costs for the fabrication, assembly and inspection processes selected. This preliminary assessment is helpful in terms of reducing further cost due to design properties that should be modified.

**A342: Tooling Cost Assessment**
Estimate the cost of the tooling required for some volume of part production. For off-the-shelf tooling and assemblies, this includes materials, preparation, storage and handling, and decommissioning. For special tooling it also includes the cost of design, engineering and production of the tooling.

Regarding each process, a number of tools are required to complete the process tasks. It is necessary to make a tool cost estimate. This includes materials, preparation, storage handling and decommissioning: In case of using special tools in the process, there will be an added cost of design and production of the tooling.

**A343: Develop Final Cost Estimates**
Determine the manufacturing cost of the part in terms of materials, time and resources. Based on the time estimates for use of manufacturing resources and skilled labor, plus tooling, materials, handling and in-work transportation costs, estimate the total cost of production of the part.
A35: Process Integration and Environment Assessment

Economical manufacturing development, however, often has resulted in environment problems and concerns (Gutowski, Murphy, & Allen, 2005). Environmental issues have gained interest and nowadays are a relevant point into manufacturing decisions. In this activity and environmental impact is made for each candidate process.

- **INPUT**

  I1 Product & Process model

  I2 Candidate Processes

- **OUTPUT**

  O1 Environmental assessed processes

- **CONTROL**

  C1 Process Requirements Specifications

- **MEANS**

  M1 Assessment model: for example, using the software SIMA PRO 7 and the LCI data.
A successful method used is the Life Cycle Assessment (LCA). LCA is a method to quantitatively analyze the environmental impacts of products and systems (Goedkoop, Heijungs, & Huijbregts, 2009). In this activity the process-based manufacturing information used in the cost analysis is useful to generate the life cycle inventory (LCI) for the environmental assessment.

For example, Sima Pro7- a commercially available software tool- may be useful to create environmental impact assessment values from the LCI data. (Gao, Lizarazo-Adarme, Paul, & Haapala, 2015).

This environmental analysis consists of several subactivities:

- **A351 Tool Environmental Impact**
- **A352 Facility Environmental Impact**
- **A353 Utilities Environmental Impact**
- **A354 Consumables Environmental Impact**
- **A355 Raw Material Environmental Impact**

**A351 Tool Environmental Impact**
Represent the environmental impact of one tool for every part manufactured by the tool during its lifetime.

**A352 Facility Environmental Impact**
The environmental impact that come from the facility construction during the lifetime of the facility.

**A353 Utilities Environmental Impact**
In this subactivity may be included the impacts of the water needed, the water wastes and the electricity consumed for every process.

**A354 Consumables Environmental Impact**
This impact gathers the consumable devices used or, consumables like cutting gas or metalworking fluid.

**A355 Raw Material Environmental Impact**
Includes the raw or raw materials used to manufacture the product. It is also considered the recycling possibility the material could have.

**A36: Engineer New Process**
There is a possibility where the manufacturing requirements, such as fabrication, inspection and assembly plans calls for handling materials or performing processes which are completely new for the company. In the case, a new process should be engineered in order to satisfy the requirements for a successful final product. Thus, perform a new process means designing new or modified machines, the use of new tools and process control. After this new process is defined and engineered it can be used as a new process candidate for the manufacturing process selection. (No further developed in this cycle.)
4.4 ACTIVITY 4: Comparative Feasibility of Processes

The main purpose that take place in the referred activity is to generate a list of possible candidate processes. This selection is more precise and effective than in previous activities and can contribute to reduce the list into just a few number of feasible processes.

The methods used in order to make a selection are adapted to a more general and classical way of comparison between alternatives. Therefore, they are not still as effective as a technological method using algorithms and several software programs.

According to the previous activities, the assessed criteria and the assessed processes requirements are essential inputs in order to compare the list of different processes. Activities 1, 2 and 3 are the main part of the model and should have been precisely described, analyzed and reviewed. Otherwise, the comparison between the activities will be useless.

The comparative feasibility of processes is decomposed into four different sub activities:

- A41 Select Reference Processes or Values
- A42 Compare Processes to each other
- A43 Score Comparative Values
- A44 Select Candidates

The main inputs for these activities are as said above the criteria with the calculated weight and the different processes with all their characteristics assessed and listed specifically detailed. As in other activities the main constraint is the list of requirements analyzed in the first step of the process decision model. Finally, the means are the early selection methods that can be used to make the alternatives comparisons such as the “Pugh Matrix”.

In conclusion, activity 4 could be the second part for the Analytic Hierarchy Process (AHP) where the alternatives are compared and valued after the criteria is developed and has the weights assigned. This method is effective and simple but the time spent making the matrix is reduced using an algorithm in a software program.
A41: Select Reference Processes or Values
In order to make precise comparisons the different processes characteristics assessed in previous activities should be categorized. The purpose is to divide the process references into different categories which can match with the criteria generated to compare the different alternatives. For instance, the different categories could be cost, time, superficial aspects, material, physical aspects...
Each requirement or characteristic should have a value so when it comes to related to the criteria this can be compared and analyzed.

A42: Compare Processes to each other
Once the processes references are compared with the criteria and given a value, the next step is to compare the list of processes. In AHP model is used a pairwise matrix to compare every alternative, in this case process, to each other.

For each criteria, every process is compared between them by developing a “Pugh Matrix”. The rules followed are similar as when comparing the criteria. A level of importance is given comparing two processes using the Fundamental Scale of Absolute numbers (Saati, 1999) in Figure X.

A43: Score the Comparative Values
Once the Pugh Matrix is completed and every process is compared to each other using the list of criteria, each process will be valued in order to analyze and find out which processes are the most suitable for the final product to be manufactured.

The global score (GS) is generated with the criteria weight (CW) and the score the comparison matrix for alternatives (SA) have been computed:

\[ GS = CW \times SA \]

According to this equation, each process gets a global score in every criteria. The final score is created after every criteria is compared. For instance, if you have 10 alternatives and 4 criteria requirements, to weight the criteria it is necessary \(4 \times 3/2= 6\) comparisons and \(4 \times (10 \times 9/2)= 180\) pairwise comparisons to build the score matrix.

A44: Select Candidates
Finally, every process has its own score for each criteria. A ranking is made for every criteria and then for the complete list of criteria.

The processes that have a similar ranking score and are in the top of the list are the candidates selected for the next step of the process decision model. The next step is the most important in order to decide the final and most suitable process that fits in the specifications analyzed for the final product result.

Activity 5 has the same goal as the AHP process, select the process. Nevertheless, the degree of accuracy is higher than AHP and with a reduced workload once the code is written in the program.
ACTIVITY 5: Test, Run & Evaluate

The method used to evaluate the processes uses an algorithm in order to rank each process according to the criteria selected by the interviews and the stakeholders’ preferences.

In this activity the feasible processes are ranked using virtual testbeds. For instance, Matlab is a precise program to implement the algorithm which evaluates and ranks the different criteria for each process. Therefore, tests are repeated so that the algorithm works using the detailed requirements.

The activity’s performance depends on the following subactivities:

- A51 Create GUI (Graphical Users Interface)
- A52 Generate Comparison Algorithm
- A53 Test GUI & Algorithm
- A54 Run Process Comparison
- A55 Rank Processes

The different parameters which perform the test run and evaluate activity are:

- **INPUT**
  - I1 Feasible Processes
  - I2 Criteria with Weights

- **OUTPUT**
  - O1 Feasible Processes Ranked

- **CONTROL**
  - C1 Process Requirements
MEANS

M1 Virtual Testbeds: For instance, using Mathlab GUI for the comparison algorithm
M2 Physical Testbeds

The approach of the virtual method is to compare the processes according to the criteria and requirements and finally rank these processes. In terms of cost, each feasible process is analyzed in the next and final activity.

The project is just a description of a general behavior model in order to maximize efficiency when manufacturing a product. The algorithm and the GUI is not developed in this project, there was a limit of time and finally was decided just to develop the manufacturing decision model using the IDEF0 technique with the support of the Systems Integration for Manufacturing Applications (SIMA) and describe it.

A51 Create GUI (Graphical Users Interface)

Create a graphical user interface in Mathlab. This display will enable users to perform a task. In our case, the criteria and process data must be introduced in order to compare the different manufacturing processes for a final selection.

A user interface (UI) is a graphical display in one or more windows containing controls, called components, that enables users to perform a variety of interactive tasks. The components can include menus, toolbars, push buttons, ... Generally, UIs created can also perform any type of computation, read and write data files and display data as tables or as plots (The MathWorks Inc., 2000). The UI waits until the user starts to manipulate the control, and once the user runs the control, the UI responds. There are two ways of building a GUI: using GUIDE or programmatically.

Figure 25 (The MathWorks Inc., 2000) represents an example which creates a GUIDE UI that accepts input parameters and plots data in two axes.

With the support of the GUI created, all the data is collected in a structured and organized platform generating a simple and interactive way to run the process comparison method.
A52 Generate Comparison Algorithm
Use all the requirements and criteria in order to create the algorithm. The main purpose of the algorithm is to create an exact and specific comparison of all the processes criteria. Thus, every process characteristics and the criteria developed is essential to generate the comparison parameters for the algorithm.

A53 Test GUI & Algorithm
Complete several testbeds in order to prove the results of the algorithm. In case the results of the tests are not as expected, analyze the graphical users interface and the algorithm. Once is analyzed modify them and finally complete new several tests.

Finally, when the results are favorable, the algorithm is ready for the process comparison.

A54 Run Process Comparison
Using all the processes references and the criteria selected in previous activities, run the algorithm to compare all the processes features. During this subactivity, the process comparison is repeated several times to check that the results does not differ from the first test.

The features of every process are compared one by one. The difference between the algorithm used in this subactivity and the manual AHP method is that the time spent in each comparison is faster and at the same time is more precise. The structure of comparison is similar but the time is reduced from one method to the other.

However, if the results differ from the tests conducted, the GUI and/or algorithm should be modified and tested again.

A55 Rank Processes
Finally, according to the different comparisons made, the processes are evaluated and ranked. The higher ranked process is the one which best carries out all the specifications to manufacture the final product. Thus, that process is the most suitable to meet the list of requirements. Nevertheless, in terms of cost, the company may not be capable of manufacturing the product using the most effective and precise process. For instance, they may not have the resources or there is a budget limit that makes the process unaffordable for the manufacturing company.

The activity just analyzes the features of every process and compares them according to the criteria and its weights. The cost analysis takes place in the further and last step or activity.
4.6 ACTIVITY 6: Cost Analysis & Selection

The final activity aim is to calculate the total costs for each feasible process selected in the previous activity. This is the last step to conclude with the model and where the selected candidate process is decided.

With the support of a cost brief developed for every process, the final process will be selected depending on the budgetary constraints and other factors. For instance, maybe the most effective and top ranked process is not the one selected because of its monetary restrictions. The company needs to analyze whether to give more importance to the cost or the effectiveness and the finished product characteristics.

- **INPUT**  
  I1 Process Cost Specifications

- **OUTPUT**  
  O1 Selected Process

- **CONTROL**  
  C1 Process Requirements

- **MEANS**  
  M1 Methods to estimate the total costs (Account Analysis, Engineering Approach, High-low Approach and Linear regression).

According to the basics of costing, the cost analysis is divided into different subactivities:

- A61 Calculate Fixed Costs
- A62 Calculate Variable Costs
- A63 Calculate Total Costs
- A64 Select Candidate Process

The model is a general approach for any manufacturing product. The manufacturing process decision model has not been tested, it is just a theoretical description.
**A61 Calculate Fixed Cost**

Develop a brief of fix costs. For a manufacturing process, the fixed costs include the purchase of the plant and equipment. The equipment represents every machine purchased with its maintenance, the workers’ equipment and all the necessary tools.

**A62 Calculate Variable Cost**

The variable cost brief will include the costs related to the costs that differ with output variations. The key variable cost is the cost of the raw material. There are other costs included in the variable cost such as utilities cost, which represents the electricity water or gas used to manufacture the units, and the workers’ salaries.

**A63 Calculate Total Cost**

Once the fixed and variable cost brief is developed, the total cost estimation is completed and a brief is created. The total cost estimation for every manufacturing process is compared and analyzed.

There are several ways of making a total cost estimation for manufacturing processes (Keegan, Daniel P., & Robert G. Eiler, 1994), in which the total costs are determined as a function of fixed costs per time period, variable costs per unit of output, and the level of output. The methods to estimate the manufacturing total costs are:

A) Account analysis: the costs are classified either as strictly fixed or variable costs. Using this method is simple to calculate the costs. However, the accuracy of account analysis depends on what is called semivariable costs or step costs (not strictly fixed nor variable costs). Over a range of output levels, some manufacturing companies find the account analysis accurate for the cost estimation.

B) Engineering approach: This method infers costs from the specification of a product. It is suitable to determine the direct material costs rather than the direct labor costs and overhead costs. The advantage is that the cost of the product can be estimated without producing the product, while other methods are based on the cost of production when it has already occurred.

C) High-Low approach: the aim is to create a graph using the total cost against output by fitting a line through total costs points at high and low levels of output. If changes in the total costs can be described and linear regarding to the level of output, the slope of the line describes the modification in the variable costs. However, the method’s problem is that the two data points may not accurately define the relationship between total cost and output.

D) Linear regression: method to address the high-low approach shortcomings. In order to minimize the sum of square differences between total cost-output points and the line itself, a line is fitted through all total cost-output points. On the other hand, the linear regression method requires more data compared to the other methods.

**A64 Select Candidate Process**

Finally, analyzing all the cost information of every process, the manufacturing process selection is made. The process selected depends on the company’s budget limit or the cost limit estimations described in the requirements specification list. The process is selected is the one in charge of manufacturing the product following all the detailed requirements.
5 DISCUSSION

The implementation of a decision model for the manufacturing industries reduces the shortcoming that can exist when producing the output. For instance, to manufacture a hollow shaft for the car industry, the use of the process decision model implies a certain number of benefits for the company responsible for their production.

In a general way, the model aim is to reduce costs and time following the specifications for the desired final product characteristics. At the same time this will help to control environmental issues.

The main benefits of implementing a manufacturing process decision model are:

- Better management control and attitudes. Structured and planned basis of the production process. As the characteristics of every process is analyzed, the possibility to identify errors before the process is running is higher. Once you find the error, making modifications is simple, having the ability to respond to engineering changes. This implies reducing costs and time of stopping the process and then restart it after solving the problems.

- The possibility to increase the flexibility.

- Capability to analyze and evaluate all the process features before the product is manufactured. Therefore, there is an improvement in the integration of manufacturing information systems and the ability to implement different engineering changes that might be beneficial to adapt.

- Improved quality. Evaluate, analyze and improve the product characteristics following the specific requirements. The pre analysis made helps to evaluate the accuracy in tolerances, the material selected, the product roughness and finish. Finally, it also analyzes the physical characteristics for the product in every process, such as stress, fluency and resistance.

- In terms of reducing environmental problems, the model evaluates which process recycles more spare material. Furthermore, it assesses the tooling life and the energy expenses in order to find the most efficient process.

- As the work in progress is more efficient and the same time reduced, the work environment improves. Minimization in purchasing spare machines or tools.

- Reduced product development time.

- Overcoming existing skill deficiencies.

- Improved response in variation in product volume and response to variations in product mix.

- Improved workforce attitude

- According to time reduction, increase the efficiency optimizing the sequence in operations and the routing plan. Thus, waiting time spent when changing tools, moving the unit from one machine to another and the operating time is analyzed so that it can be reduced.

- Reduced changeover/set-up times.

- The model generates a simple way of comparing or solving complex decision problems. An intuitive method to compare the processes and can be followed even by unexperienced in the matter. Every rule is well structured and the activities are written with simple descriptions.
Even though the development on the model needs a detailed and exhaustive work and analysis to fulfill the requirements and take into account every characteristic, the tools created to compare and select a process are faster and more efficient. Respect to the other companies, the company may obtain competitive advantage in the manufacturing market.

6 FUTURE WORK

The thesis report is a research about modelling and a model development for the manufacturing industry. More specifically, manufacturing metal components for the automotive industry.

In this case, the model itself has been built after scientific research and in a theoretical analysis. There is no a real case involving a company and a specific product to manufacture. Thus, there is a lack of data and results to support the model.

The next future steps are to apply the model to a real situation in company giving evidence with data and results for a manufacturing problem. In this way, the simulation for the algorithm can take place and prove the structure of the model. At the same time, there could be some modifications depending on the results in the simulation. The model will be completed successfully after the real simulation with the comparison algorithm.

Another future modification could be adapting the model to an UML diagram. As it was explained in the Frame of Reference point, UML is a modelling technique applied to programming language. Therefore, adapting the model from IDEF0 to UML will be useful in order to complete the simulations with Mathlab or Java. Nowadays, the UML diagram is a better approach when using computer programs for simulation. It is less complex to adapt the diagrams to a programming language.

Many companies use a way to manage their projects but they do not use the specific data to compare using and algorithm and being more objective. What the company does is to accomplish each milestone for each area but without really analyzing the data and comparing each requirement. Everything is calculated to reach and complete the milestones but at the end there are always delays because the timing is not based in comparing different or potential issues that could happen depending on the part you are producing. There are always project delays because there is no anticipation.

For example, Faurecia, a company which develops seating, door panels and decorative parts in the interior of the cars already use a similar process in a more general way but it is kind of comparable. In this company they use the PMS (Program Management System) created by Ford, which connects all the different main actors involved in a project. Mainly, you will find the Program Manager, and the responsible for purchasing, sales, engineering, quality, and logistics. The system connects the timing plan for each area where different main goals need to be fulfilled. In a project you can find seven different phases from acquisition until start of production. To move forward to one phase to another you will need to fulfill all the different milestones for each area. For example, in terms of quality, the first milestone is according to measurements, then it will be according to surface finish, and at the end once the part is ok in terms of dimensional and surface the last part is according appearance approval and testing of the material. However, as this management program is so general, there are always delays due to any problem in regards any detailed area.

There are always many milestones to complete and for each part in terms of quality, price, logistics...In order to be more accurate in timing, quality and at the end in costs using the algorithm for each project would lead to anticipation in many issues where generally come out once the project is in process and there is no time and flexibility to solve the issues without any cost implication or timing delays. In Faurecia there are many projects already finished where to get data as there is a lot of know how that if it was translated to numerical data it would be profitable for a daily job.
In my particular case working in Faurecia Company, when I was in the acquisition phase it was necessary to make estimations on prices for new parts and moulds that were going to be sold to the customer. The main issue for me was to gather all the information on similar parts from other project already completed. In many projects you will find similar parts in terms of same material for injection, similar size, similar weight, same location of production (so it makes packaging and logistics the same), and similar yearly volume. However, it was really a time waste trying to find the most similar part to apply a similar cost from thousands of parts from different projects. In my opinion another way the method and algorithm application could support in some way gathering all the different characteristics for the parts from the different projects and solve the issue of price estimation for new projects because most of the time the estimation is based on the experience of the employee in the company and in the sector.

As this method could be adapted to many manufacturing companies taking into account the features which the companies are seeking in their specific area. Therefore, the method could be modified to a specific purpose.

Figure 27: PMS (Program Management System) from Faurecia Company
7 CONCLUSION

Nowadays companies have a complex structure and in order to have competitive advantage they need to invest in innovation and new systems to reduce cost and increase efficiency.

For the manufacturing industry even is more necessary to innovate and implement new technologies. Investing in new technologies will lead to a considerable reduction of costs and a notable improvement in product development reducing times.

In this thesis, the principal aim was to generate a model where it would be easier to select a manufacturing process depending on the specification and materials they required to produce a product.

The model has been developed using the method of activity modelling in IDEF 0 technique. This technique uses simple boxes and arrows to represent the flows and describe the activities that take place in each step. Therefore, it is a structure way of solving complex decision problems.

Moreover, the activities described and explained are focused in comparing all the different possible processes to manufacture a product. In other words, the model intends to select the most suitable and efficient process from overall processes compared. It is a route plan to the selection of the process that completes best all the requirements.

In order to make the different comparisons, an algorithm is meant to be used but it has not been proved neither the model.

Finally, the thesis does not give any example or specific case where the model is proved. There is an extend description and development of the model but without using any real case support, just with the help of different theoretical frameworks and models from the SIMA program testing of the material.
Bibliography


