INSTITUTO TECNOLOGICO Y DE ESTUDIOS SUPERIORES DE MONTERREY

CAMPUS MONTERREY

DIVISION DE INGENIERIA Y ARQUITECTURA

PROGRAMA DE GRADUADOS EN INGENIERIA

TECNOLÓGICO DE MONTERREY

MANUFACTURING TACIT KNOWLEDGE CLASSIFICATION

TESIS

PRESENTADA COMO REQUISITO PARCIAL

PARA OBTENER EL GRADO ACADEMICO DE

MAESTRO EN CIENCIAS

ESPECIALIDAD EN SISTEMAS DE MANUFACTURA

POR:

JOSE LEGORRETA MACIAS

MONTERREY, N. L. MAYO DEL 2010

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Al Dr. David Guerra por su apoyo y constante motivación para la realización de la presente tesis. Ver tanta pasión por la investigación y el desarrollo realmente me empujó a tratar de hacer mejor mi trabajo.

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DEDICATORIA

Antes que a nadie a mis padres que con su ejemplo y constante superación me enseñaron lo valioso de siempre querer más. No hay palabras que puedan expresar mi eterna gratitud por todo lo que han hecho por mí. Cualquier logro que obtenga es un reflejo de su esfuerzo constante.

A mis familiares y amigos que hacen que este viaje llamado vida sea más interesante y placentero.

Al conocimiento y a la vida.

ABSTRACT

Knowledge is considered one of the main possessions a company have. Companies need to better identify, obtain, store and reuse knowledge. A Manufacturing Tacit Knowledge Classification is proposed divided in two main categories Internal and External, the first one has to do with the worker and his perspective, the external is focused on the context, tools and environment the worker has. Internal category is divided in three child classes named motor, cognitive and subconscious Manufacturing Tacit Knowledge. External category is divided in two main child classes named general and specific Manufacturing Tacit Knowledge. Case studies are developed to validate and support these categories.

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CHAPTER 1

1. Introduction:

Knowledge is considered one of the main possessions a company have. It is labeled as intellectual capital and it is used to gain competitive advantages. Nowadays, to be competitive in this global market manufacturing companies need to find better ways to identify, obtain, store and reuse knowledge with the only purpose of avoiding knowledge loss.

A clear example of loosing knowledge can be seen in the U.S. Defense Department civilian workforce of 675,000; between 2002 and 2008 75% of its workforce is expected to retire. Another example is NASA's engineers and scientists older than 60 outnumber those under age 30 by almost three to one (DeLong 2004). These are only two examples of what is happening worldwide. So how will this affect knowledge loss in companies? Not positively for sure.

With each passing generation new technologies arise giving the opportunity to knowledge seeking companies to use it more efficiently. However in order to understand knowledge we should study the different types of knowledge classifications that we currently posses.

There are several types of knowledge classification but it all comes to the same key issue, the company that is eager to obtain and share that knowledge it is highly likely to succeed over the company that does not.

Knowledge acquisition and maintenance does not compete with a company that is mainly focus on innovation, whether it is in the design or manufacturing process. It has been proved that innovation and a good knowledge management processes combine in a way that gives the company following that scheme an advantage.

In previous years manufacturing knowledge was contained mainly in the most experienced workers the company had, but what happened to the company when the person responsible for doing a task does not longer work there? Most of the time that knowledge was lost, and the company had to wait for a new expert to come forward. Naturally that takes several years and time is one of the resources a company values the most.

In recent years companies are becoming more interested and familiar with different knowledge management techniques and methods. Several knowledge models have been created in order to make it easier to understand knowledge related subjects. Computers also have been an enormous help storing and accessing knowledge in what it is commonly referred as a Knowledge Based System. These systems help the user make the more adequate decisions in less time.

1.1 Research Environment:

This thesis is relates the research presented in (Guerra 2004) and (Rodriguez 2007) and their subsequent work. The main topics discussed in such publications are Knowledge Management, Knowledge Classification and Manufacturing and Design Decision Support Systems.

Guerra (Guerra 2004) developed a knowledge structure for a manufacturing facility to identify the knowledge associated to the manufacturing processes available. Rodriguez (Rodriguez 2007) used the Knowledge life cycle as a Knowledge Management method, the knowledge was then stored within a structure for use and reuse.

Flores focused mainly on developing a case study applying Guerra's Knowledge structure in a manufacturing tacit knowledge environment (Flores 2007). Siller's research contributed exploring and developing models and UML (Siller et al 2008) and González research focus on Knowledge Mobilization and Measurement (González 2008) see Figure 1-1.

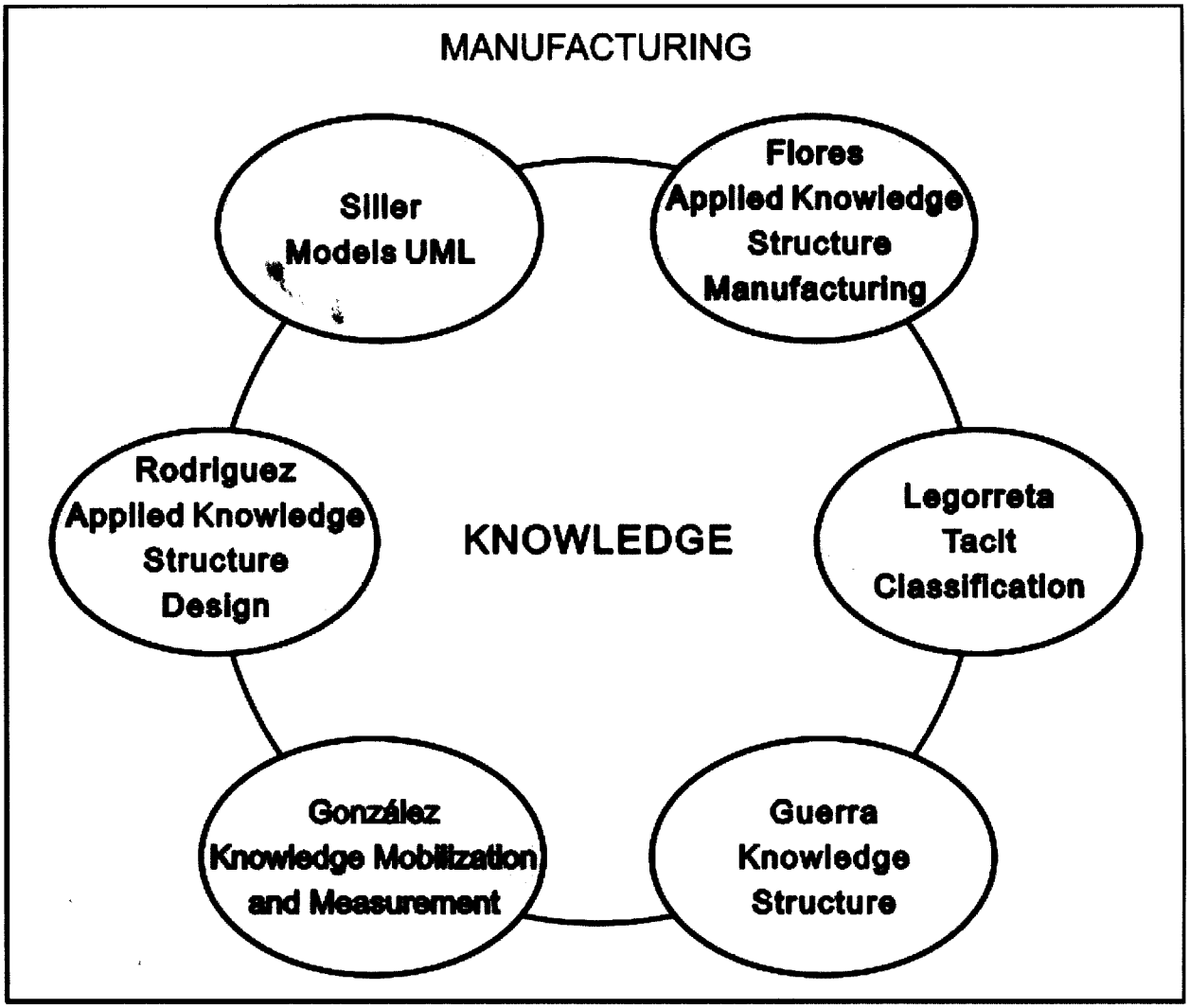

Figure 1-1 Research Environment

1.2 Problem Definition:

Among the types of knowledge one that has to be studied in more depth is tacit knowledge. Tacit knowledge is an important type of knowledge that generates value for the companies. An important issue is that it takes an amount of time and resources to obtain it and it is not as easy to access, structure, store or reuse. Furthermore the term Tacit Knowledge is usually used as an equivalent of Implicit Knowledge (Guerra 2004); in order to differentiate both types of knowledge a need to create Tacit Knowledge Classification was detected. If Tacit Knowledge is to be used and extract all of its

potential it will have to be further broke down in to sub categories. Some attempts to subdivide Tacit Knowledge have been done but neither of them focused its context in a manufacturing situation but only in a social way.

1.3 Research Questions:

How to access, categorize, structure, store and reuse tacit knowledge?
Is there a Tacit Knowledge Lifecycle defined?

1.4 Aims and Objectives

This thesis aims to develop a Tacit Knowledge Classification that will add value to manufacturing companies by further understanding this type of knowledge and the methods used to access, structure, obtain, store and reuse it.

In order to achieve these aims, the main objectives of the thesis are as follows:

To explore the different types of tacit knowledge

To define a Tacit Knowledge Classification

To develop a Case Study to validate this thesis proposal

To show value added by exploring tacit knowledge

1.5 Scope of the thesis

This research deals and explores Knowledge Management focusing on Tacit Knowledge Classification from a manufacturing point of view. It does not include the design process even though some comments and concepts will be used to support some of the assumptions presented.

The Tacit Knowledge definition that it is going to be used in this thesis is the one proposed by Nonaka. This thesis does not intend to differentiate Tacit Knowledge from Implicit Knowledge. This work does not want to demonstrate how Tacit Knowledge transforms into Explicit Knowledge and vice versa. It does not intend to measure and acknowledge where, when or how much knowledge is created.

Case studies will be applied in an electrical transformer facility (Power Transformers). A conceptual representation of a knowledge repository will be presented to validate the classification and its value, however it will be only in a conceptual way, and further work has to be done if fully operational software is to be developed. None of the system tools and software used in this thesis are in a final stage of development it is not the intention of this thesis to accomplish that.

1.6 Structure of the thesis:

The structure of the thesis is organized into five chapters. Each chapter with its unique content listed as follows:

Chapter 1 portrays the tasks of this research thesis; it includes an introduction, background, justification, aims, objectives and scope.

Chapter 2 presents a literature review intended as the backbone of the research with state of the art concepts and methods used for this thesis development.

Chapter 3 provides the main proposal of this thesis, a complete Tacit Knowledge Classification from a manufacturing point of view.

Chapter 4 presents a Case Study which validates the proposed Tacit Knowledge Classification in Chapter 3.

Chapter 5 discusses results obtained from the Case Study, as well as conclusions and states some recommendations for further research work.

CHAPTER 2

2. Literature Review:

As previously mentioned in Chapter 1, this chapter presents the main topics considered the most relevant in order to have a state of the art background support while presenting a solution to our problem definition.

2.1 Data, Information, Knowledge

In order to understand knowledge we should first differentiate it from data and from information. Several authors have studied data, information and knowledge and the definitions we are going to a bid for this thesis are as follows:

According to Harding (Harding 1996) data are simply words or numbers that given a certain context its meaning changes. Furthermore, in product realization process, data is just the numbers and symbols used in describing a line, a vertex, material, machine capacity etc, (Mills and Goosenaerts 2001)

On the other hand information is structured data in a way that it has a particular meaning (Harding 1996). In a manufacturing context "5 inches from vertex A" will indicate for most manufacturing personnel a relationship between the distances of vertex A to the next point. Symbols written in this way, give a particular meaning to the reader (Mills and Goossenaerts 2001). Data has the ability to evolve into information to further evolve into knowledge and so on as depicted in Mills and Goosenaerts model (Mills and Goosenaerts 2001) see Figure 2-1.

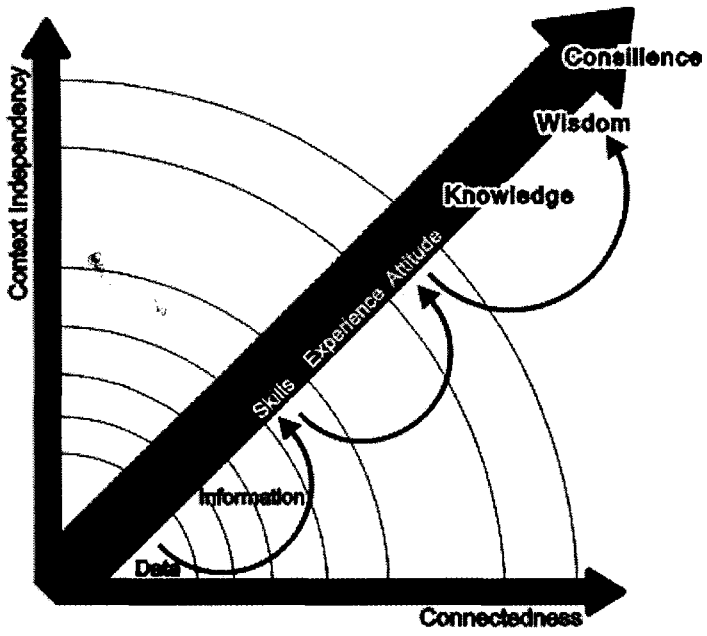

Figure 2-1 Data, Information and Knowledge Representation
(Mills and Goosenaerts 2001)

Finally knowledge would be information with added detail relating how the information may be used or applied (Harding 1996). For example, in order to calculate the perimeter of a triangle we know that we need to add the length of its three sides, data would be the numbers, information would be the numbers assigned to each side and knowledge would be the mathematical calculation that results in the triangle perimeter.

According to González, knowledge surpasses the mere information of the things, fitted to the comprehensive reflection of data, and allows the interrelation with contexts of meaning (González 2008).

Bender and Fish model focus more on the understanding of wisdom and expertise concepts in order to comprehend knowledge transformation (Bender and Fish 2000) see Figure 2-2.

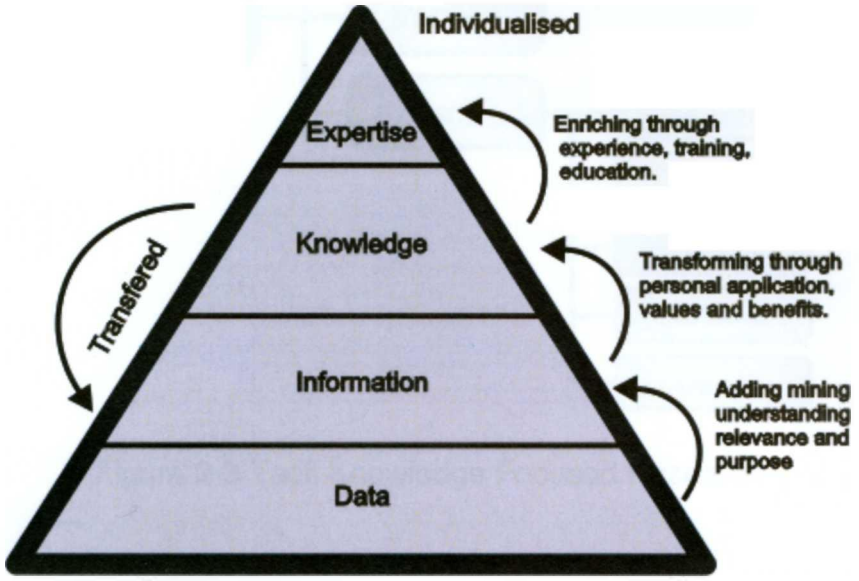

Figure 2-2 Knowledge Hierarchy (Bender and Fish 2000)

The author of this thesis will concentrate on dealing with Knowledge more specifically with Tacit Knowledge and ways that it is represented as seen in Figure 2-3.

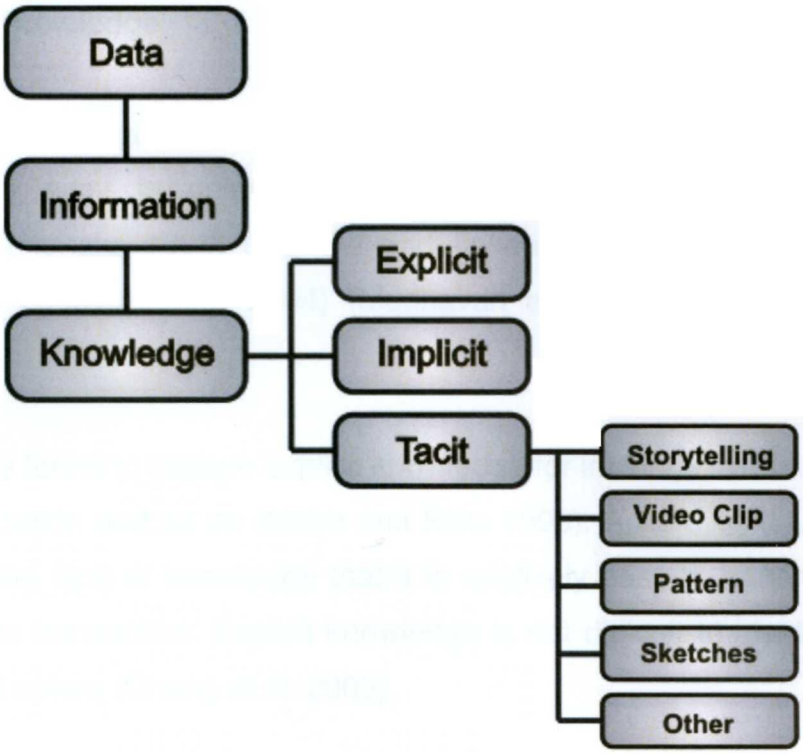

Figure 2-3 Tacit Knowledge Focused Research

2.2 Knowledge Types

Knowledge is a valuable asset that each organization has (Davenport and Prusak 2000), (Nonaka and Takeuchi 1995), (Menezes and Toledo 2004). This knowledge enables humans to make decisions (Markus 2001). Given that scenario what an organization knows is critical for its success (Karagiannis and Apostolou 2004). In order to be able to identify and use knowledge it is imperative to understand which are the different types of knowledge that have been categorized by the most respected authors.

2.2.1 Explicit Knowledge

This type of knowledge consists of formal policies and procedures, it is formal, systematic and easy to communicate because it does not rely on subjective interpretations (Nonaka 1998) (Nonaka and Takeuchi 1995) (Davenport and Prusak 2000) (Nickols 2003) (Guerra 2004) (Madhavan and Grover 1998) (Colombo et al 2005).

There are many forms to capture explicit knowledge for instance texts, tables, diagrams, product specification and so on (Mahe and Rieu 1998). According to Zheng (Zheng et al. 2001) it is the type of knowledge that it is relatively easy to transfer without losing parts of it in the transaction. Explicit knowledge is not difficult to identify and structure given its formal nature (Chung et al. 2003).

Examples of explicit knowledge are a) formulas; b) work instructions; c) standards etc. That is why explicit knowledge do not take on account any kind of demographic differences when it is transmitted a formula will still be the same formula no matter what country or company it is used.

2.2.2 Tacit Knowledge

As stated by Nonaka (Nonaka 1998) (Nonaka and Takeuchi 1995) tacit knowledge includes skills, personal experience, insights, personal values, perceptions, judgments, opinions etc. That is why tacit knowledge is a complex and crucial type of knowledge difficult to manage (Balconi 2002) and usually stays within the individual (Menezes and Toledo 2004).

It is difficult for the companies to understand tacit knowledge or its existence until the person containing that knowledge leaves the company. This is why it is imperative to identify this knowledge, classify it and use it. There have being some published tacit knowledge classifications but are focused on the social side (Linde 2001). That is why

there is still plenty to understand and learn about this knowledge type (Augier and Vendeleo 1999). As Hackley stated (Hackley 1999) this type of knowledge constitutes the major part of what we know and it is difficult for companies to benefit from it once the person is no longer within the organization. It has being proposed that tacit knowledge should be managed in tacit ways, thus making it manageable and separated from the employees (Stenmark 2000).

Tacit knowledge is not easy to articulate but it can be converted to other types of knowledge and then represented (Nonaka 1998) (Nonaka and Takeuchi 1995). It has been demonstrated by Guerra (Guerra 2004) (Guerra and Young 2007) that tacit knowledge can be represented by a video, storytelling, sketch or pattern. Even though tacit knowledge may be transferred and represented, skills and attitudes cannot be separated of the person that posses them. It represents greater value to the company if tacit knowledge is converted to explicit or at least shared (Haldin-Herrgard 2000).

2.2.3 Implicit Knowledge

Basically implicit knowledge is the type of knowledge that can be articulated but has not (Nickols 2000). It is sometimes considered as a link between tacit knowledge and explicit knowledge (Zheng et al. 2001). Other authors as Barth (Barth 2005) describe this type of knowledge as one that you acquire from interacting with other persons of the same team.

An example of this type of knowledge is from a pilot that can learn and improve how to maneuver his aircraft by observing an Olympic diver perform (Zheng et al. 2001) Figure 2-4 depicts the way explicit, tacit and implicit knowledge relate.

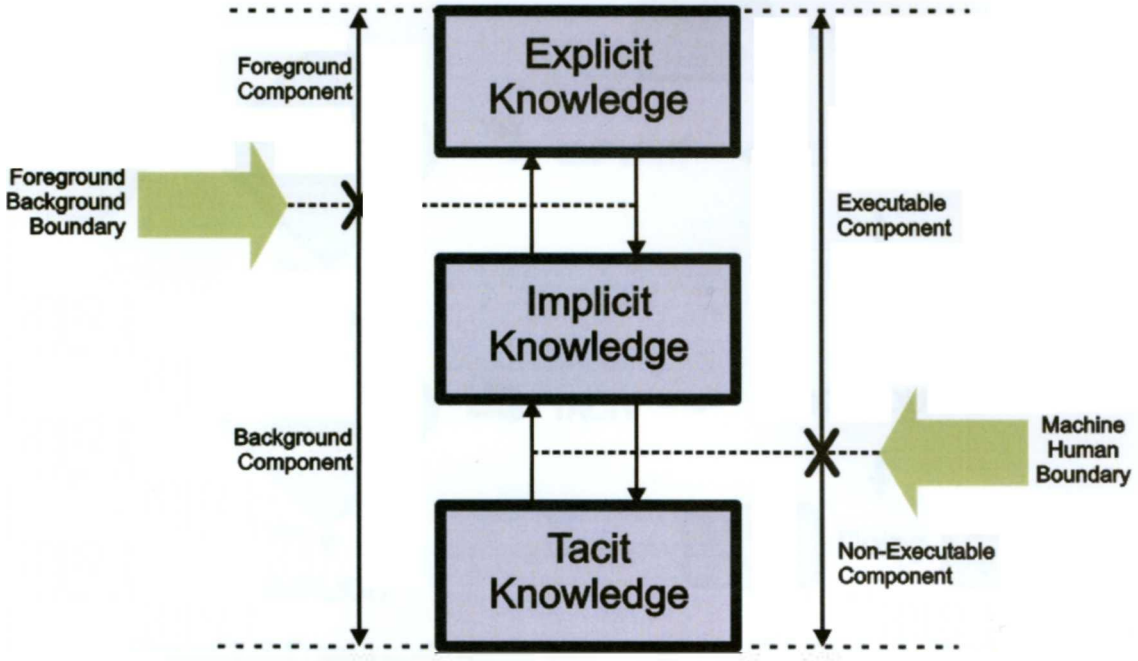

Figure 2-4 Executable Knowledge Model (Zheng et al. 2001)

2.2.4 Knowledge Types Discussion

There are still some authors that consider that the main difference between tacit knowledge and implicit knowledge is that one can be articulated and the other cannot. It is critical to differentiate these types of knowledge; this is due to the fact that some authors use tacit and implicit knowledge as synonyms. In Figure 2-5 Nickols (Nickols 2000) proposed a model that describes the three types of knowledge.

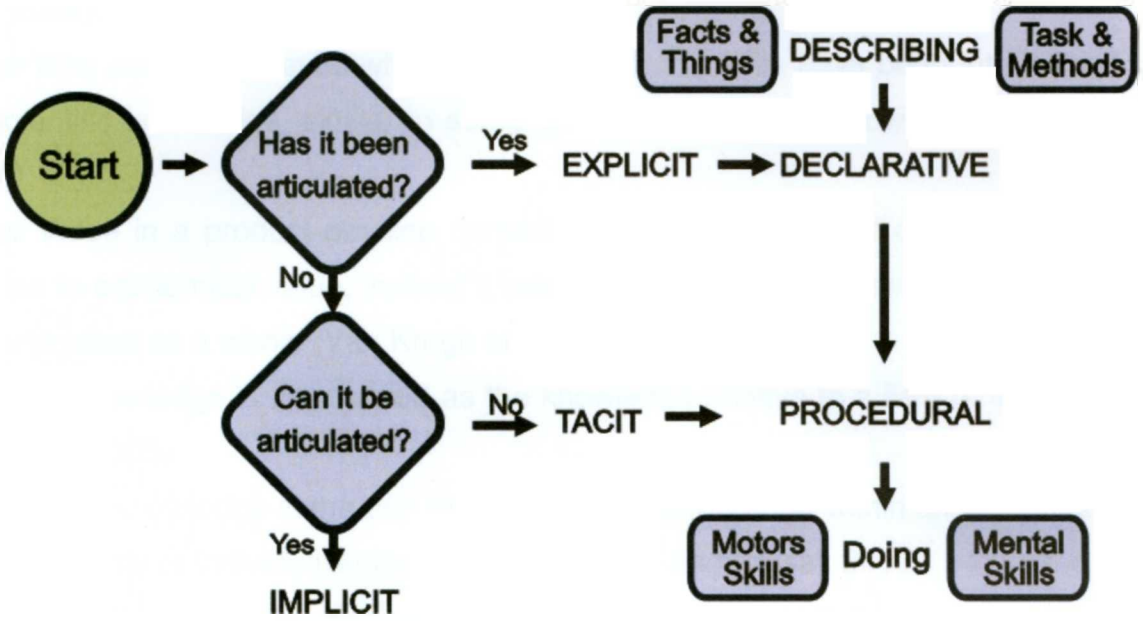

Figure 2-5 Framework About Knowledge in KM (Nickols 2000)

It is natural that the more we differentiate tacit and implicit knowledge the better companies and organizations may take advantage of their usage. In chapter 3 a Manufacturing Tacit Knowledge Classification is proposed to further distinguish between these knowledge types, also even though the authors claim that Tacit Knowledge cannot be structured the proposed model in this thesis will prove that a level of structure is feasible.

2.2.4.1 Other types of Knowledge Classifications

Other types of knowledge classifications have been identified these categories will not be used for the development of this thesis but it is important to acknowledge their existence.

Know How refers to skills and capabilities whether depicted tacitly of implicitly (Cheung et al 2006).

Know Why can be achieved when the principles and rules have been interiorized such as scientific knowledge, similar in some ways to the explicit knowledge (Cheung et al 2006).

Know Value in a product develop context is the knowledge that does not necessarily applies to economical value, instead it refers to the pieces of knowledge that add value to the product as a whole (Van Krogh et al 2000).

Domain Knowledge is understood as the knowledge relative to a field of expertise (Pan and Shen 2005).

Embedded Knowledge is the one identified as the knowledge within an organization and not a personal or individual knowledge (Davenport and Prusak 2000).

2.3 Tacit Knowledge Types

There have been some classes created for tacit knowledge, however most of the time these classes has nothing to do with a manufacturing environment. According to Linde (Linde 2001) tacit knowledge could be divided in social knowledge, physical knowledge ant "other" knowledge. Figure 2-6 shows the classification Linde (Linde 2001) worked with focusing on tacit knowledge from a social point of view.

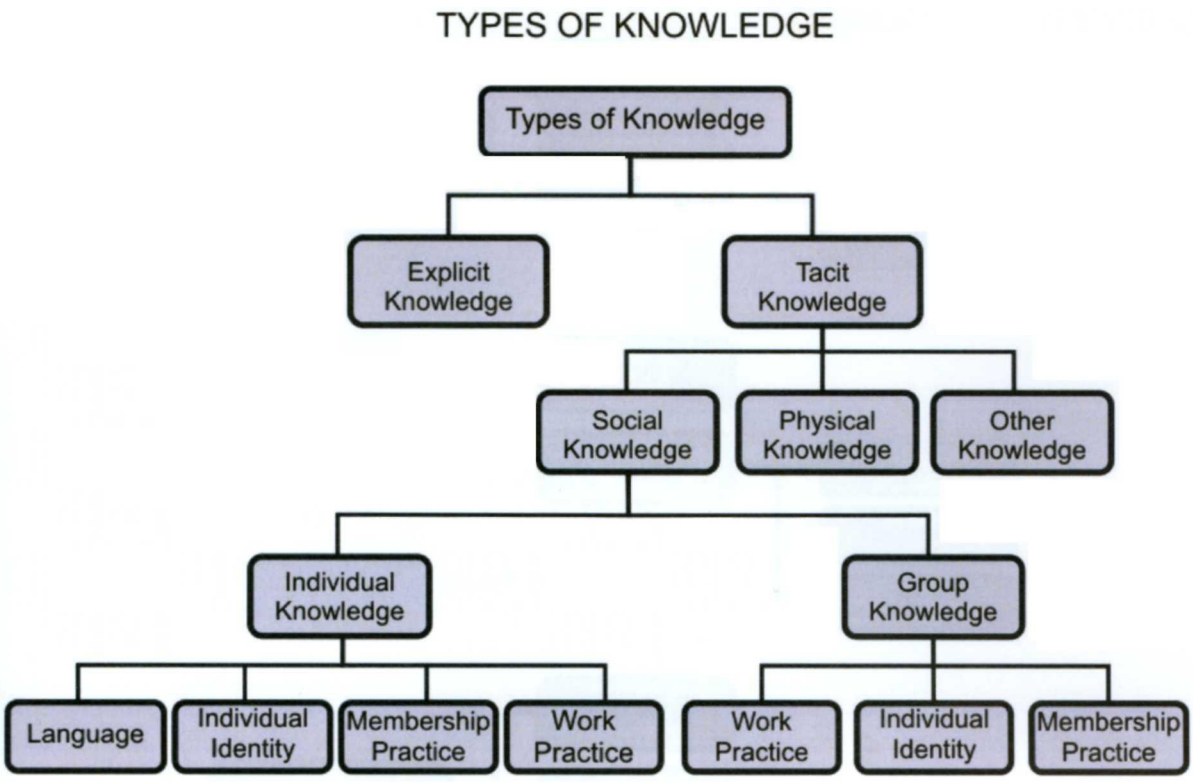

Figure 2-6 Taxonomy of Types of Knowledge Focused on Tacit Knowledge Social Type (Linde 2001)

The author of this thesis found this taxonomy interesting especially in the physical knowledge subdivision although not explored by the author of the article it created a background for a part of the subdivision of manufacturing tacit knowledge proposed in Chapter 3. A summary of the existing Tacit Knowledge Classifications is seen in Figure 2-7.

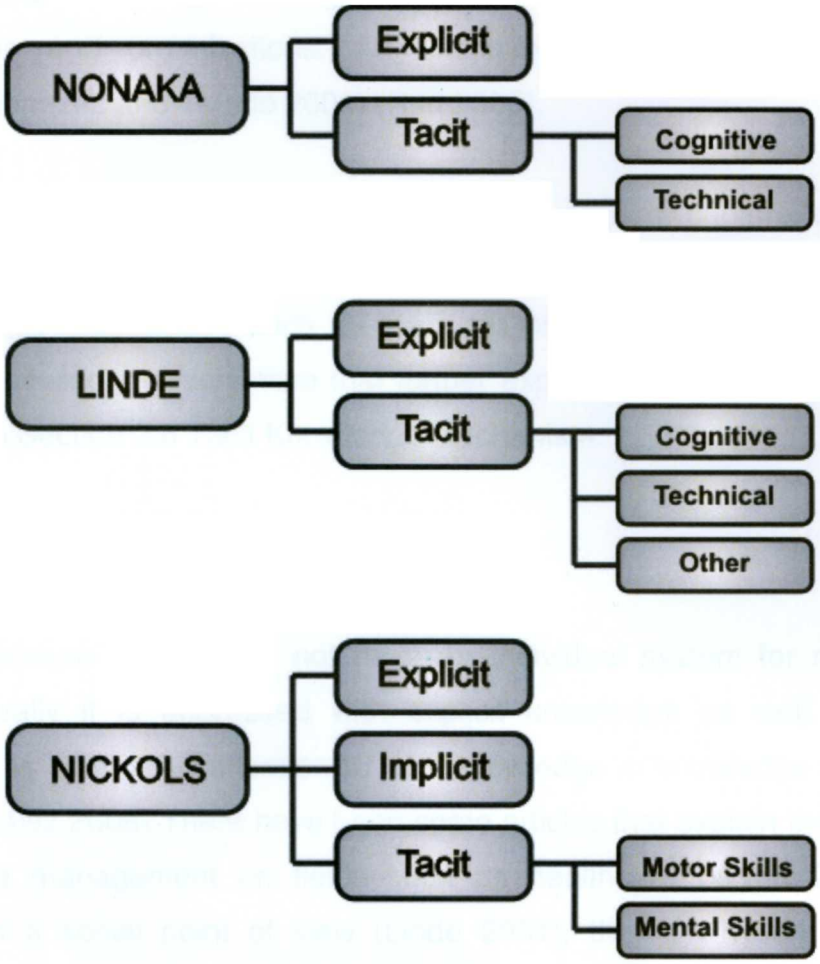

Figure 2-7 Existing Tacit Knowledge Classification Summary

2.4 Knowledge Management

With the definition of knowledge a new issue arose, once knowledge has been identified it should be managed in such a way that will bring value to the organizations.

Knowledge management according to Guerra and Young is the process of capturing the collective expertise and intelligence of a design and manufacturing organization, and then using it to promote innovation through organizational learning (Guerra and Young 2006) (Carneiro 2000).

There are several knowledge management tools that facilitate knowledge transfer between people and organizations. An example of these tools is information technologies (Menezes and Toledo 2004) (Rao 2005).

The key functions of the organizations are to create, acquire, capture, share and use knowledge (Wickert and Herschel 2001). There have been proposals to measure knowledge and its mobilization such as the ones presented by González (González 2008). A tacit knowledge mechanism that further explains each of these steps will be discussed in the Section 2.6 Tacit Knowledge Mechanism.

2.4.1 Tacit Knowledge Management

Most of the literature found does not have an individual system for managing tacit knowledge; usually it is addressed with explicit knowledge as well. According to Gonzalez there is little or no attention to tacit knowledge in knowledge storing related research (González 2008) There have been some articles that explain their approach to tacit knowledge management on fields such as healthcare (Wyatt 2001) or most commonly from a social point of view (Linde 2001), this is why an opportunity of expanding tacit knowledge management.

The author of this thesis believes that by creating a Tacit Knowledge Classification (See Chapter 3) it will drive the knowledge management community to further explore new ways of managing tacit knowledge from a manufacture context.

2.4.2 Tacit Knowledge Life Cycle

In order to understand a Tacit Knowledge Life Cycle first we have to position tacit knowledge in a knowledge life cycle. According to Birkinshaw and Sheehan (Birkinshaw and Sheehan 2002), knowledge life cycle has four main stages Figure 2-8.

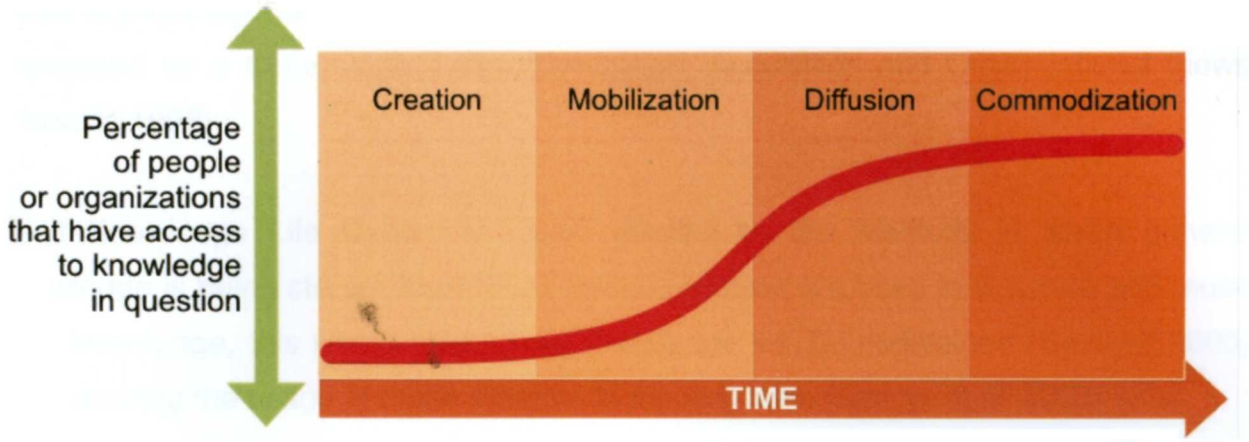

Figure 2-8 Knowledge Life Cycle S Curve (Birkinshaw and Sheehan 2002)

Knowledge could be easily represented with an S curve, where the four main stages are: creation, mobilization, diffusion and commoditization.

In the creation stage is where most of the Tacit Knowledge would be found and used. The essence of the creation stage is that no one fully understands the emerging idea.

Mobilization stage focus on exploiting the idea internally without letting know the competition in order to extract the idea's value.

The third stage is diffusion; here the company that created and developed the idea no longer tries to keep it a secret. It diffuses the idea and sells it to everyone in order to avoid losing money do to knowledge leakage and imitation.

Finally the commoditization stage arrives, this means that the idea has been fully transformed into knowledge. This stage requires more knowledge management in order to extract even more value to the original idea.

Other authors such as Howells believe that a specific tacit knowledge life cycle could be expressed as a three stage cycle: Generation, Acquisition and Organizational Flows (Howells 1996).

Tacit Knowledge Life Cycle has been affected by the methods in which general knowledge is being stored. Knowledge Based Systems are used to structure and reuse tacit knowledge, this would enable that knowledge will be maintained (Rezayat 2000) and assuring the usage of these systems in the long term (Sainter et al. 2000)

Guerra proposed a knowledge maintenance framework (Guerra 2004) which includes a knowledge maintenance life cycle Figure 2-9. Tacit Knowledge Life Cycle would be included in this framework but still no formal and specific Tacit Knowledge Life Cycle has been identified.

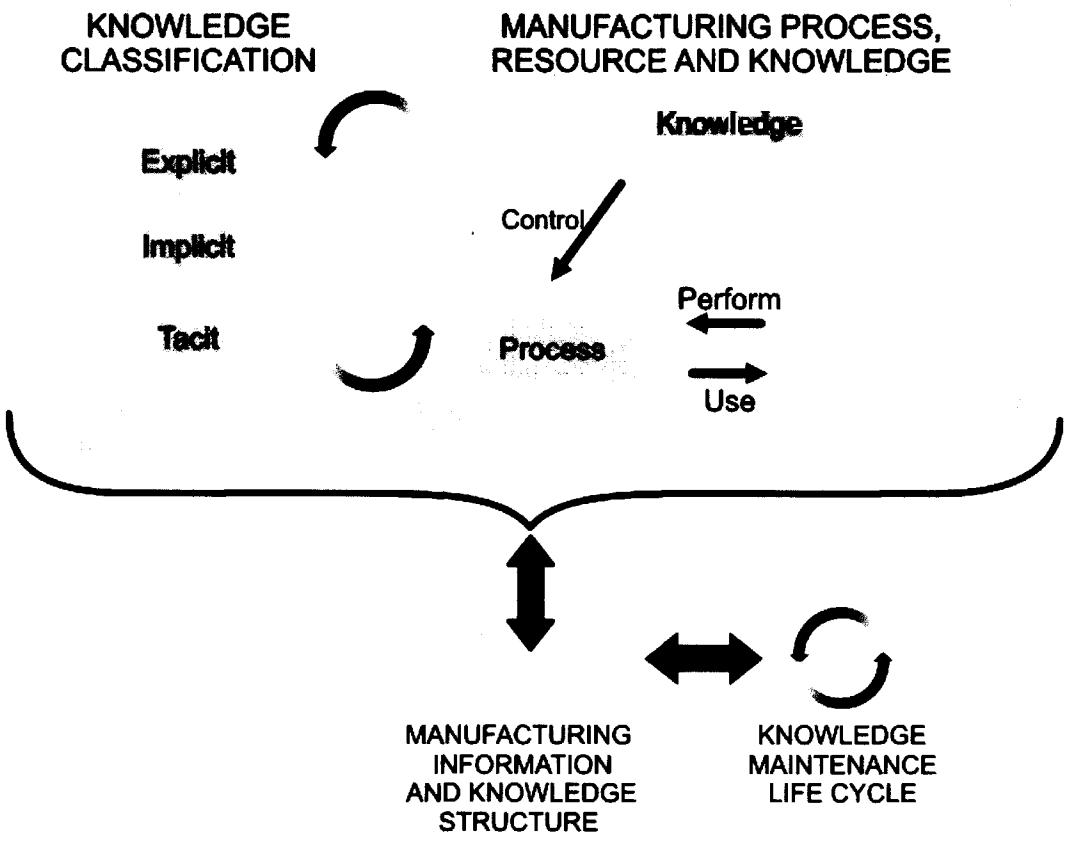

Figure2-9 Knowledge Maintenance Framework (Guerra 2004)

Guerra also proposed a Knowledge Maintenance Life Cycle (Guerra 2004) which includes the other major types of knowledge, Explicit, Tacit and Implicit Figure 2-10.

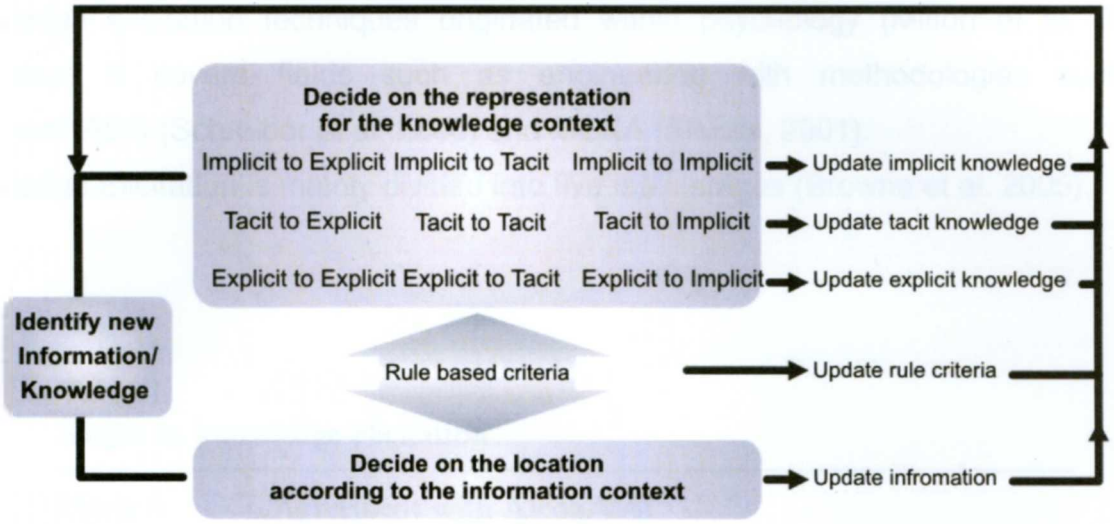

Figure 2-10 Knowledge Maintenance Life Cycle (Guerra 2004)

Still, there is not a model that depicts the way that manufacturing tacit knowledge is accessed, structured, stored and reused. This is why the author of this thesis believes that there is still a gap in defining and modeling a formal Manufacturing Tacit Knowledge Life Cycle.

2.5 Tacit Knowledge Mechanism

Based on the basic functions of knowledge life cycle to access, structure, store and reuse of tacit knowledge we can identify the first major step in order to work with manufacturing tacit knowledge.

The first thing to do while searching for new knowledge is to identify it, once it is identified the next step would be to subs tract that knowledge no matter what is the recipient that contains that knowledge.

2.5.1 Access/Elicitation

Knowledge elicitation techniques originated within psychology (Milton et al. 2006). Nowadays it covers fields such as engineering with methodologies such as CommonKADS (Schreiber et al. 2000) and MOKA (Stokes, 2001).
Knowledge Elicitation is mainly divided into five main stages (Browne et al. 2005).

Table 1
Stages in knowledge-elicitation

Phase 0	Agreement with Alcoa/VAI
Phase 1	Initial presentation
Phase 2	Knowledge engineers questioned by experts
Phase 3	Separation and identification of topics, issues and concerns
Phase 4	Focused discussions, conflicts, gaps and expansions
Phase 5	Structured feedback/follow up
	Commissioning of Expert System (ES) system
	Use and benefits of ES system

Phase 0 is the starting point of elicitation, it is more of a political requirement but still very critical.

Phase 1 involves the introduction of concepts to the people that will collaborate in the project in order to create a culture of openness and honesty.

Phase 2 offers the opportunity to focus mainly in what the important areas should be according to plant operators.

Phase 3 in this phase the rules are discussed and created.

Phase 4 considers conflicts and gaps within the knowledge.

Phase 5 is the feedback stage where new complex interactions may be discovered and further analyzed in order to reformulate some of the rules.

Tacit knowledge elicitation may be achieved using indirect techniques by placing an expert in a problem situation context and through observation and post-completion analysis, attempt to determine the underlying process (Bradley et al 2004).

This led to believe that problem solving is not done only by reading operational data but instead of working with that data by structuring and processing it.

Chan proposed that the eliciting stage of knowledge is part of a major stage named Knowledge Acquisition (Chan 2000). Knowledge Acquisition involves three stages which are:

1. - Knowledge Elicitation which is the process of obtaining information from an expert.
2. - Knowledge Analysis is the process of making sense of the data collected.
3. - Knowledge Representation would be the process of expressing the analyzed data into an understandable and usable form.

The author of the thesis noticed that a three staged eliciting process may have some trouble due to the fact that knowledge is not static so a knowledge maintenance stage is missing from the previous stages.

Other authors such as Hamilton and Hoffman claimed that in order to extract as much knowledge as possible in any given situation several experts should be involved, thus ensuring the validity of the knowledge base (Hamilton and Breslawski 1996) (Hoffman 1987).

Hoffman also divided the knowledge elicitation techniques into three categories: analysis of the tasks that experts usually perform, various types of interviews and contrived tasks which reveal an expert's reasoning (Hoffman et al. 1995).

Still several of the techniques developed are mainly focused on extracting procedural knowledge in order to create a rule based system (Moody et al. 1996).

According to Barret and Edwards knowledge elicitation is divided into two major eliciting stages (Barret and Edwards 1995) see Figure 2-11.

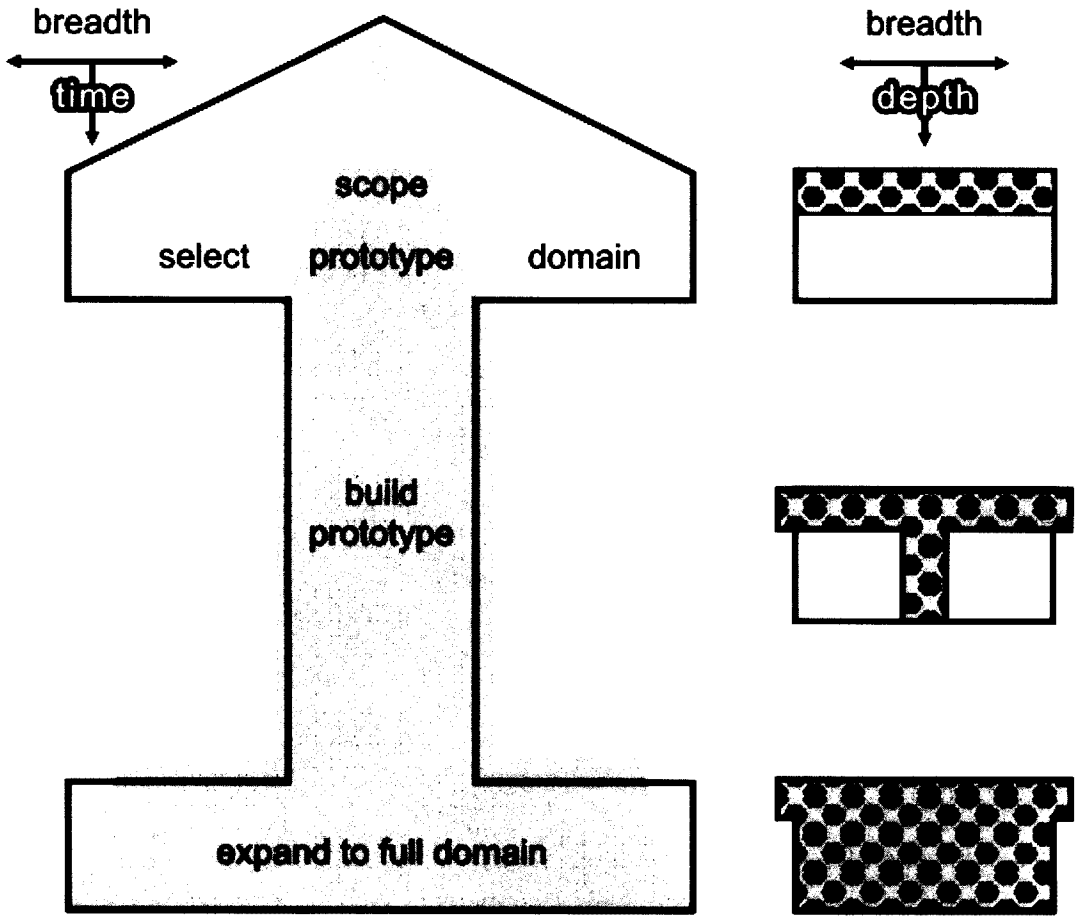

Figure 2-11 Phases of Knowledge Elicitation (Barret and Edwards 1995)

The author of this thesis concludes that there are several ways to conduct and divide knowledge elicitation, but still the common factor in most of them is that experts should be involved since the beginning of the process. Most of the literature found is mainly focused on the explicit knowledge type.

2.5.2 Structure/Categorization

A knowledge structure organizes and classifies intellectual capital that will feed knowledge based systems in the decision making processes (Guerra and Young 2006) (Young et al 2005).

There have been some knowledge structures and categorizations according to several authors, however the general knowledge structure and categorization used as a base for this thesis work is the one presented by Guerra (Guerra 2004) see Figure 2-12.

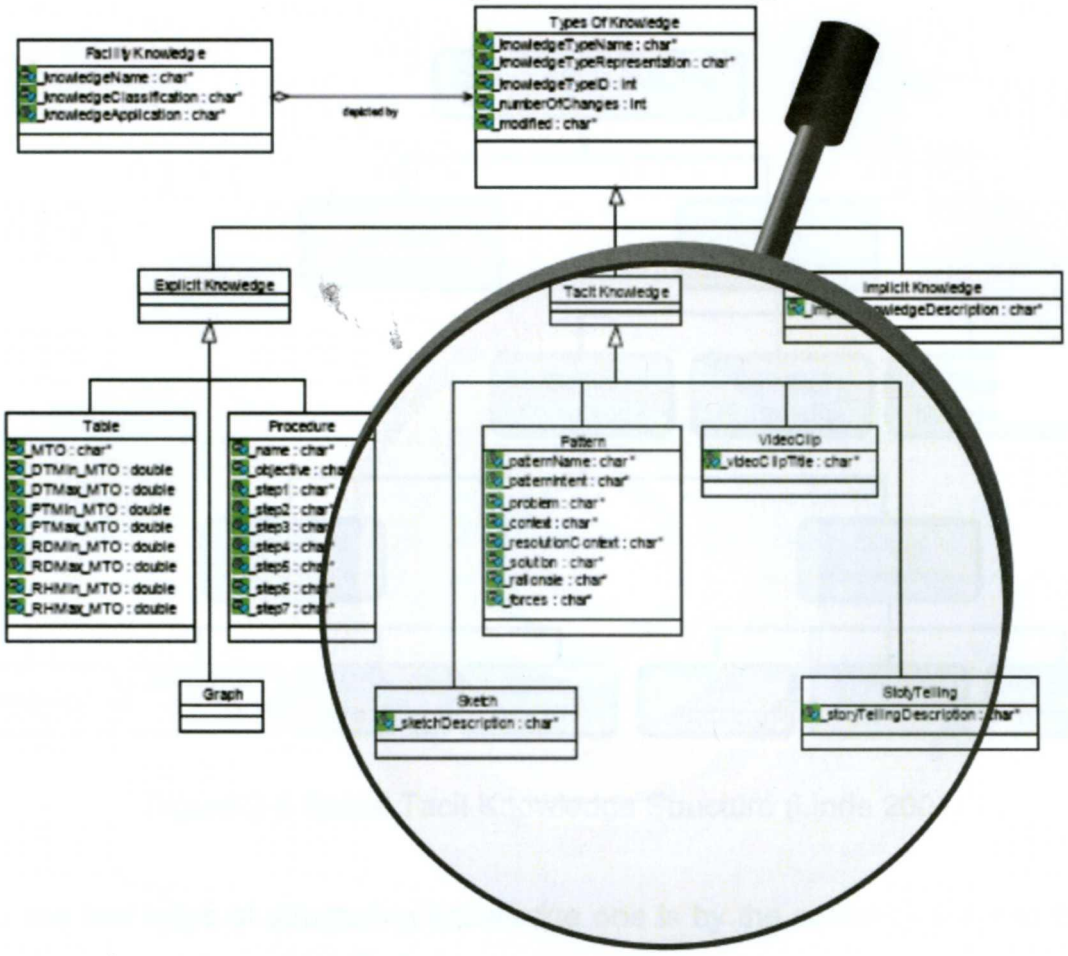

Figure 2-12 Knowledge Structure (Guerra 2004)

Nevertheless no particular tacit knowledge structure has been created so far in a manufacturing environment, as discussed in section 2.4 some attempts have been done to further structure and categorize tacit knowledge but on a social context see Figure 2-6.

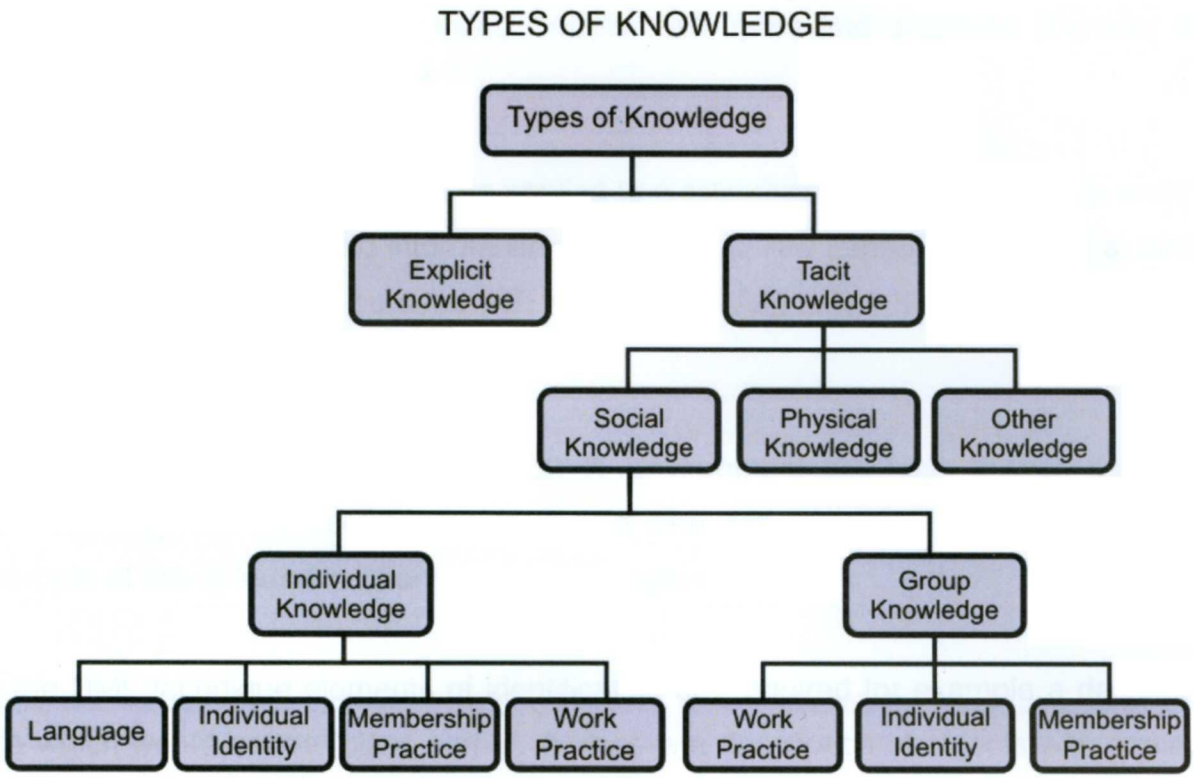

Figure 2-6 Social Tacit Knowledge Structure (Linde 2001)

There are two ways of structuring knowledge one is by the content itself and the other one is in the way it is represented.

2.5.3 Representation/Modeling

Information and knowledge modeling helps in the development of knowledge management systems (Theodosiou and Sapidis 2004). Booch tells us that a model is a simplification of reality (Booch et al 1999).

Modeling knowledge has become a key element within an organization in order to add and capitalize value (Malhotra 2006). An example of knowledge modeling is to represent knowledge structures in a UML (Unified Modeling Language) using object oriented concepts (Guerra 2004). O-O techniques are used to visualize in an easier way

information and knowledge by using models, data flows and diagrams (Dorador and Young 2000) (Young et al 2003).

Usage of the UML technique can be applied to a manufacturing environment in order to enhance manufacturing and information modeling and flow capability (Siller et al 2008). UML techniques can also be used with two types of diagrams which are use cases and sequence diagrams (Siller et al 2009).

The UML techniques are based on an IT environment but have proven that used correctly they can be useful even to people who are not considered IT experts. An example of this is found in Zhongtu work (Zhongtu et al 2006).

In the UML technique elements of identification are required for example a descriptive title which would be the "class name". A class is a description of objects with common properties, characteristics, behavior and relationships with other objects. The attributes of a class are a list of information that helps to identify and differentiate classes (Aifaoui et al 2006). The classes are represented as rectangles in which the name of the class is written with their attributes (Guerra 2004). The relationships between classes are represented using different types of lines and symbols.

Guerra's knowledge type model combines a knowledge structure with a way to represent each knowledge type (Guerra 2004) see Figure 2-12. However it is not the intention of this thesis to further explain what has been proposed and publish regarding Guerra's knowledge representation although some examples may be found in Chapter's 4 case studies.

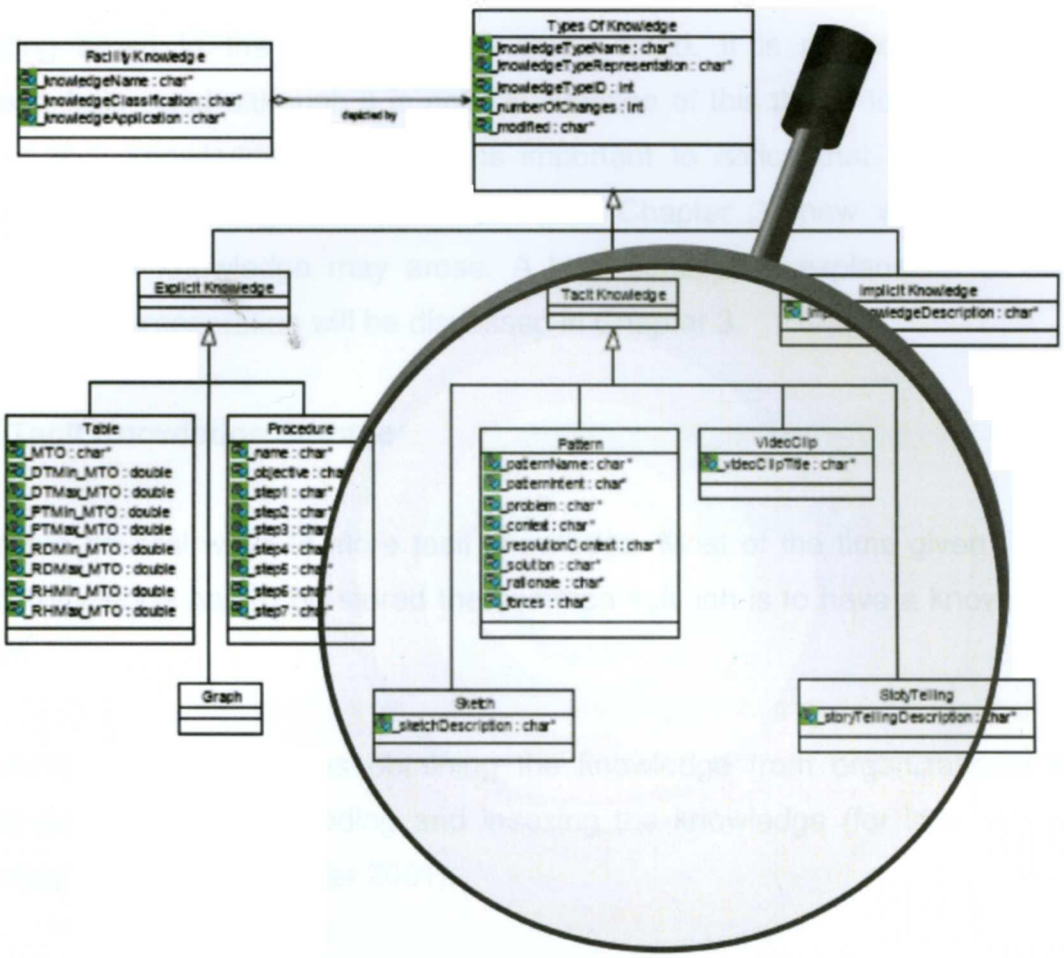

Figure 2-12 Knowledge Structure (Guerra 2004)

2.5.3.1 Tacit Knowledge Modeling Techniques

The main 4 types of tacit knowledge representation according to Guerra are: sketch, pattern, storytelling and video clip (Guerra 2009). All of these representations may include an expert while transforming the knowledge into something more comprehensible. One of the representations such as the video clip does not even require that the person being filmed is aware of the knowledge eliciting method. These methods are considered indirect knowledge elicitation.

A new knowledge representation technique proposed while studying tacit knowledge modeling arose in the author of this thesis head. It is named Motion Sequence Representation and although it is not the intention of this thesis to further explore this type of tacit knowledge modeling it is important to notice that by creating a more detailed tacit knowledge categorization (see Chapter 3) new ways to model and represent tacit knowledge may arose. A brief conceptual explanation of the Motion Sequence Representation will be discussed in Chapter 3.

2.5.4 Tacit Knowledge Storage

There are several ways to store tacit knowledge. Most of the time given the speed in which knowledge has to be stored the common solution is to have a knowledge based system.

Knowledge storage involves obtaining the knowledge from organizational members and/or external sources, coding and indexing the knowledge (for later retrieval), and capturing it (Alavi and Leidner 2001).

Knowledge based system is a software capable of supporting knowledge representations in some specific competence domain and exploited through appropriated reasoning mechanism in order to provide high-level problem solving performance (Guida 1994).

They are also described as expert systems that use knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution (Shi et al. 1999).

Knowledge based system may emulate the abilities of a human expert in a particular domain (Lovett and Bancroft 2000). Decision Support Systems are software that assist but not replace a person on making decisions (Turban et al 2005).

If we take the well known tacit knowledge representations and input them in software given a particular domain of knowledge we would have our tacit knowledge storage repository, as previously stated it does not have to be on a software basis but it will be definitively more efficient if it is. We can have several story telling representations in written on a paper format, but if we have those on a system searches may be conducted faster.

No matter what the system is digital or physical the author of this thesis recommends that a person should be in charge of the categorization of knowledge in order to make it easier to administrate the database.

2.5.5 Tacit Knowledge Reuse

Once we have established the knowledge's repository it is imperative that a mechanism of knowledge reuse is set in motion. It is relatively hard to formalize and reuse tacit knowledge (Noh et al 2000). An example of a way of tacit knowledge reuse is by creating Cognitive Maps as a main vehicle to formalize knowledge and create a case-based reasoning tool for storing the cognitive maps and retrieving them according to the case-base reasoning (Noh et al 2000).

Hatakama and Terano formalized knowledge sharing and reuse as shown in Figure 2-13 (Hatakama and Terrano 2001).

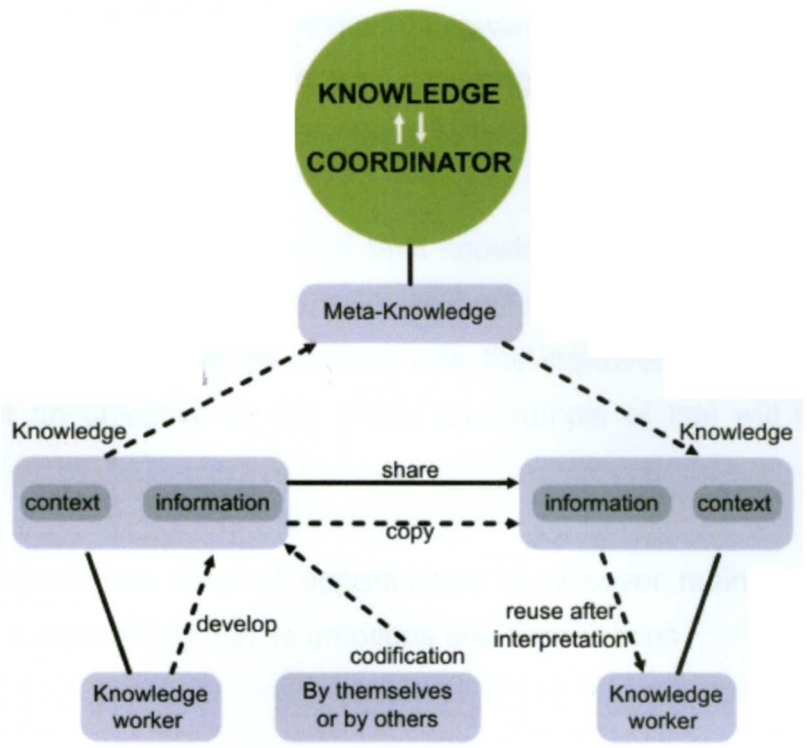

Figure 2-13 Knowledge Sharing and Reuse (Hatakama and Terrano 2001)

2.6 Tacit Knowledge Shortcomings

Manufacturing Tacit Knowledge needs further research and exploration. There are some researches regarding Tacit Knowledge but not always focused on the manufacturing context.

There is an area of opportunity to improve the way tacit knowledge is reused. Also knowledge managers need to propose better ways of eliciting manufacturing tacit knowledge.

The author of this thesis believes that in order to create or improve understanding and eliciting manufacturing tacit knowledge a deeper categorization of manufacturing tacit knowledge should be explored.

Nowadays as seen in the literature review if knowledge has not been articulated or if it is very difficult to do so it is labeled tacit knowledge. This gives the category of tacit knowledge a wide range of knowledge pieces to fall in that category.

If we create a deeper categorization of tacit knowledge we would be able to identify, elicit, store, access and reuse it in a more efficient manner. New ways of representing or elicit tacit knowledge would be created with the improvement of technology. Even though it is not an objective of this thesis an example of this will be discussed in Chapter 3.

Tacit knowledge still has a lot of opportunities to discover mainly because it is as complex as the human being and its emotions and experiences.

CHAPTER 3

3. Proposed Manufacturing Tacit Knowledge Classification

It has been mentioned already from the literature review that the need of managing tacit knowledge is critical for organizational success. It was noticed that by further exploring tacit knowledge new classifications would come up. These classifications would help distinguish tacit knowledge from the other types of knowledge. Tacit knowledge was previously subdivided but only from a social point of view, a novel classification from a manufacturing point of view is necessary in order to link all types of knowledge with manufacturing knowledge. Two main Manufacturing Tacit Knowledge classifications are created, one named Internal and the other one External see Figure 3-1. At the end of this Chapter some examples of the proposed classifications will be presented.

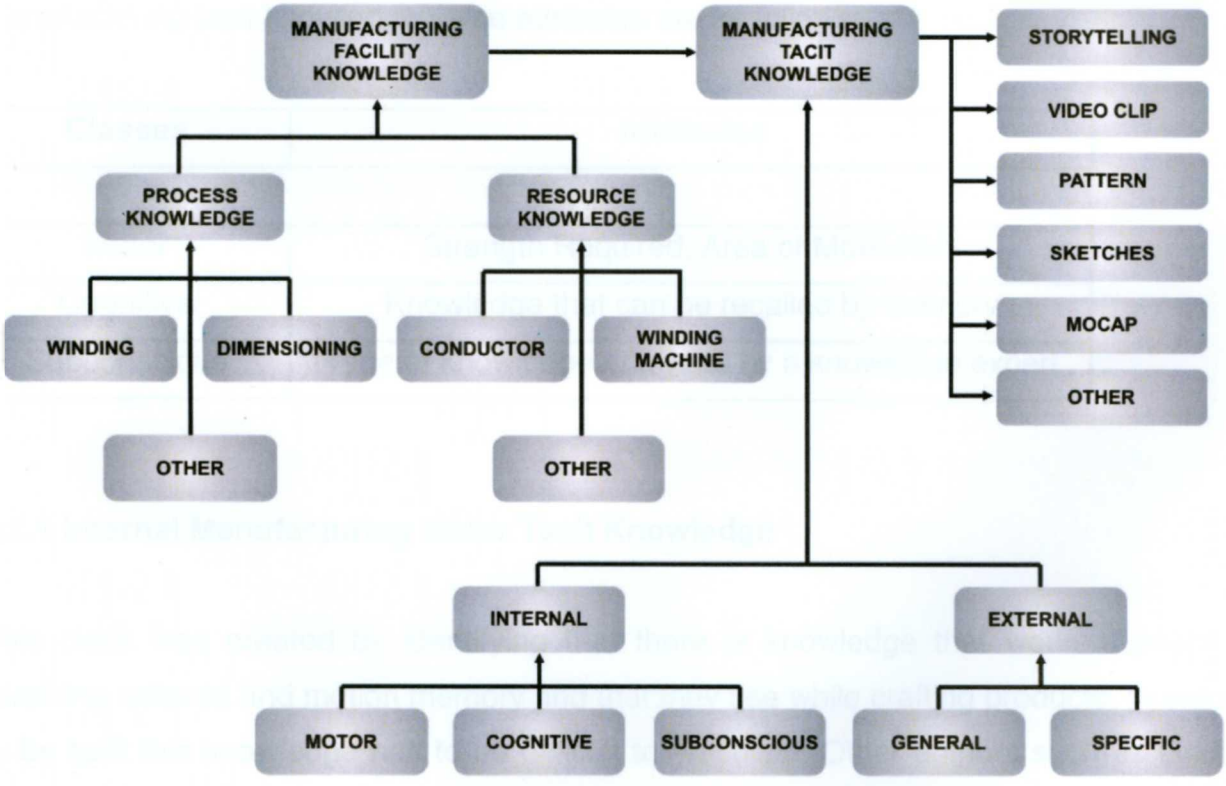

Figure 3-1 Proposed Manufacturing Tacit Knowledge Classification

Although a classification is proposed it does not explore in a formal way which sub categories comes first or how they would interrelate between each other. The author of this thesis believes that further research should be conducted regarding these matters.

3.1 Internal Manufacturing Tacit Knowledge

This main category comes within the individual, it involves his physical and mental abilities weather the individual realizes that he posses them or not. Three main child classes could derive from this branch, Internal Manufacturing Motor Tacit Knowledge, Internal Manufacturing Cognitive Tacit Knowledge and Internal Manufacturing Subconscious Tacit Knowledge.

In order to create a category attributes must be associated to each category, for internal manufacturing tacit knowledge these attributes are as follows:

Classes	Attributes
Motor	Strength Required, Area of Movement
Cognitive	Knowledge that can be recalled by memory
Subconscious	Type of knowledge analyzed by a knowledge expert

3.1.1 Internal Manufacturing Motor Tacit Knowledge

This class was created by identifying that there is knowledge that workers posses involving reflexes and motion memory and that they use while crafting products. In order to be tacit this knowledge has to be difficult to articulate. Other authors such as Linde 2001 (Linde 2001) divided and classified tacit knowledge but only from a social point of view, one of the classifications was physical knowledge, however the classification used in this thesis work was considered more of a motor type. Examples of this tacit

knowledge type are seen in sports and craftsmanship. They might already know the explicit rules and theory of their respective fields but only by practice they acquire the needed skills to be successful.

3.1.2 Internal Manufacturing Cognitive Tacit

This category refers to the type of tacit knowledge that involves the conscious part of our reasoning, the things that we can recall and remember that helps us while making decisions of any type. An example of this is when by studying manufacturing processes the person in charge of analysing the manufacturability of a product may predict to some extent without doing calculations the possible outcome of the process. This type of knowledge is based on experience and previously acquired knowledge.

3.1.3 Internal Manufacturing Subconscious Tacit

As the name implies this type of tacit knowledge is used by means of the subconscious. This is the instinctive reasoning and remembering. An example of this is when we make decisions with a "feeling" or "hunch"; these cases might be a subconscious recognition of the current situation matched against previous patterns experienced by the person. From a manufacturing point of view is when a worker is producing some kind of product and without consciously thinking he changes or adapts his rhythm of working because he is using a different machine to do his usual work, but subconsciously noticing that not all machines perform in the same manner.

In the examples presented we noticed that the Subconscious and Motor types are related from a manufacturing point of view (see Section 3.3)

3.2 External Manufacturing Tacit Knowledge

This main category refers to the knowledge received or triggered from external stimuli. If Internal Manufacturing Tacit Knowledge comes within the individual External Manufacturing Tacit Knowledge derives from the surrounding working environment.

Two main child classes are proposed for the external manufacturing tacit knowledge named External Manufacturing General Tacit Knowledge and External Manufacturing Specific Tacit Knowledge.

The attributes used in this category are as follows:

Classes	Attributes
General	Environment, Culture
Specific	Equipment type and model

3.2.1 External Manufacturing General Tacit Knowledge

This type of knowledge may be used no matter what the environment or situation is involved in the decision making process from a manufacturing point of view. Examples of these are the values or methods transferred from a company to a new branch of the same company. Companies located in different parts of the world can share their manufacturing tacit knowledge with the different types of tacit knowledge representation. The methods and values in order to overcome a situation in the company may be brought by a worker that collected those methods and values from a different company or department.

3.2.2 External Manufacturing Specific Tacit Knowledge

As the name implies this type of knowledge focuses on the tacit knowledge acquired specifically from a given situation or environment. An example of this is the knowledge acquired by a worker that has been using the same equipment from an extended period of time, he knows how to work with that equipment, the equipment flaws and limits, so this knowledge cannot easily be transferred to another worker even if it is doing the same type of operation but with a different equipment, thus the specific category.

3.3 Manufacturing Tacit Knowledge Examples

The author of this thesis work considers relevant to present some examples of the proposed categories discussed at the beginning of this chapter in order to clarify how this new categorization may apply in a manufacturing environment. These examples come from simple common manufacturing activities.

Activity	**Nailing**

Type of Knowledge	Description
Motor	Required Strength to complete task
Cognitive	To locate the easiest spot to hammer the nail
Subconscious	The exact moment to withdraw finger support
General	Quality inspection method
Specific	Tool's limits (hammer, roto-tool)

Activity	**Painting**

Type of Knowledge	Description
Motor	Pressure required on air-brush
Cognitive	To know the exact quantity required on the brush, knowing paint viscosity
Subconscious	To know when to get closer or farther away from the object being paint
General	Amount of paint required, Equipment life expectancy
Specific	Maximum pressure allowed for air-brush

Activity	**Welding**

Type of Knowledge	Description
Motor	Motion flow in order to avoid previous weld
Cognitive	Knowing feasibility of welding and critical points
Subconscious	Knowing if flame is not properly configured
General	Type of welding (hermetic vs. structural)
Specific	Maximum velocity to use while welding with a semi-automatic machine

Activity	**Bending**

Type of Knowledge	Description
Motor	Depending on material, angle and strength required in order to avoid spring back
Cognitive	Compensate sheet metal development caused by die
Subconscious	Speed required to bend in order to avoid mechanical damage
General	Maintenance cycles and usage of lubricants
Specific	To know when to recalibrate machine

3.4 Example of new Eliciting Method MOCAP

The new method proposed to use to obtain a Motion Sequence representation is Motion Capture. There are several ways to do a motion capture; systems ranging from visual to sonic are used nowadays. The amount of data obtained by each technique is derived from the technology used (Silaghi et al 1998). The basic way this technology works is by sensing the position of strategically placed markers in a 3D environment, collecting data of marker displacement in a given time thus obtaining velocity and acceleration as well. However not all motion capture techniques involves markers, video and mathematical techniques may be used (Bregler and Malik 1998). The advantage of using motion capture as a knowledge eliciting method is that it is already used for different purposes other than manufacturing knowledge. A clear example of this is that motion capture is used in the videogame, cinema and robotics industries.

3.4.1 Manufacturing Tacit Knowledge Motion Sequence Representation

Due to the visual and technological characteristics of the technique it is proposed that software is to be used to represent a virtual worker.

Figure 3-2 Example of Motion Representation (Vlasic et al Online Video 2007)

This way as previously stated the knowledge receptacle (worker in training, robot programmer etc.) may look at the virtual worker paying attention to whatever moment and movement he considers critical to learn and mimic.

Although it is not within the scope of this thesis this is an example of what could be achieved with a Manufacturing Tacit Knowledge Classification. The more types and classes we have the higher the probability of finding and creating new ways of eliciting knowledge and represent it.

CHAPTER 4

4. Case Studies

The author of this thesis has already presented the proposed structure and categorization of the manufacturing tacit knowledge however is with technique of case study how the author pretends to demonstrate and validate the proposed categorization.

Due to technological and economical limitations some of these examples may be applied in a conceptual o theoretical way. The area selected to develop the cases is the winding area of a power transformer manufacturing facility. The author of this thesis considered the winding area as a critical step in the manufacturing of a power transformer, with a lot of tacit knowledge potential due to the way the coils are constructed in a very handmade process.

In order to select the case studies interviews with the responsible engineer and coil experts and apprentices were done.

Francisco Javier Garibay Ramos
30 years working at the coil and winding department

Mentioned that to newcomers an introduction to the area usually takes place and last for two days. The people that have more experience give the newcomers tips on how to do the things their job demands. Currently there is no such thing as a training wind; all coils manufactured are "real" orders. Visual aids are at their disposals whenever necessary. Most of the instructors teach with a method that involves showing, explaining, then it requires that the newcomer do the same work and while doing it he has to explain to the instructor what is that he is doing. This requires practice in order to become experts in their fields.

Jose Guadalupe Jalomo
6 years coil winding + 7 years as instructor

His method relies on making the newcomer understand theoretically and practically what the job requires. This time last for approximately 3 months and his function is to solve all the doubts newcomers have. Newcomers are told the "tricks" in order to perform better but currently there is no formal method to document new methods or processes being developed by the personnel.

Francisco Torres
12 years working on coil winding

Learns through documented procedures, but his experience has gain him some "tricks" which he refers to his supervisor or superior. All the "tricks" are passed in an informal manner.

Edgar Miguel Ortiz Menes
1 month coil winding

All the "tips and tricks" he received were done in a verbal non-documented way.

As we can read from the interview summaries all tacit knowledge is being passed in a verbal non-formal manner, all the explicit knowledge is already contained in all the procedures and documented training they already posses. But as discussed on previous chapters, tacit knowledge is one of the most important assets of the company so it should be identified, captured, stored and reused in order to unleash its unique potential.

It is in the nature of tacit knowledge to be difficult to articulate so new categories and methods should be developed in order to understand it better. This is the main reason the author of this thesis considered important and relevant to further classify tacit

knowledge. By separating tacit knowledge from other types of knowledge we are encouraging new researchers to discover new ways to capture manufacturing tacit knowledge.

4.1 Case Study 1: Internal Manufacturing Motor Tacit Knowledge

It was identified that a process that could explain motor tacit knowledge is the axial and radial coil dimension control process. Basically what this process intend to accomplish is to maintain the radial and axial dimension previously selected by the department of design.

This is achieved by hammering the coil's section into place with a rubber hammer, the people that will work with the coil are trained to do so, but the work instructions and documented knowledge fail to provide a motor training.

The expert hits the coil's segments in a way that the coil dimensioned in a more effective manner. The apprentice has to learn by experience how hard to hit the coil without damaging the insulation.

If we follow the proposed structure (Figure 4-1) an apprentice may find a previously recorded expert while he worked with a coil and all the data of his movements were recorded in video tape and MOCAP techniques (see Figure 3-2).

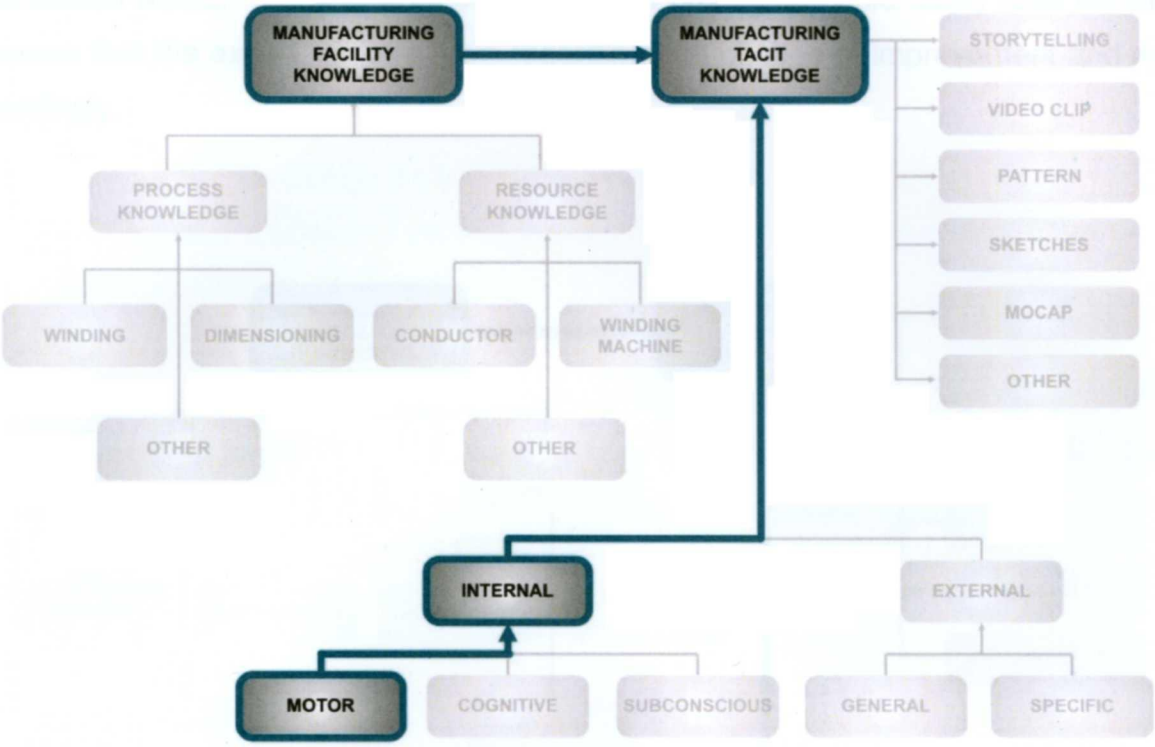

Figure 4-1 Internal Manufacturing Motor Tacit Knowledge

With this approach the apprentice does not require to learn all of the tacit and explicit material given this particular subject but instead he could in a more efficient manner go the category of motor tacit knowledge in order to improve his craftsmanship skills. This saved time to the company and the knowledge would not be lost if the expert craftsman leaves the company.

4.2 Case Study 2: Internal Manufacturing Cognitive Tacit Knowledge

If the company previously didn't had the opportunity to work with a bigger coil and for some reason decided to expand the offered products this type of knowledge would help to prevent and diminish all possible flaws and risks of creating a new product.

In this case scenario the company may elicit and store knowledge identified as cognitive (see Figure 4-2) due to the fact that cognitive knowledge is not an explicit knowledge but the type of knowledge that only experience gives you. So no matter if a less

experienced worker needs to work on that kind of project he could easily read the main concerns that the expert workers have regarding that change of improvement and work accordingly.

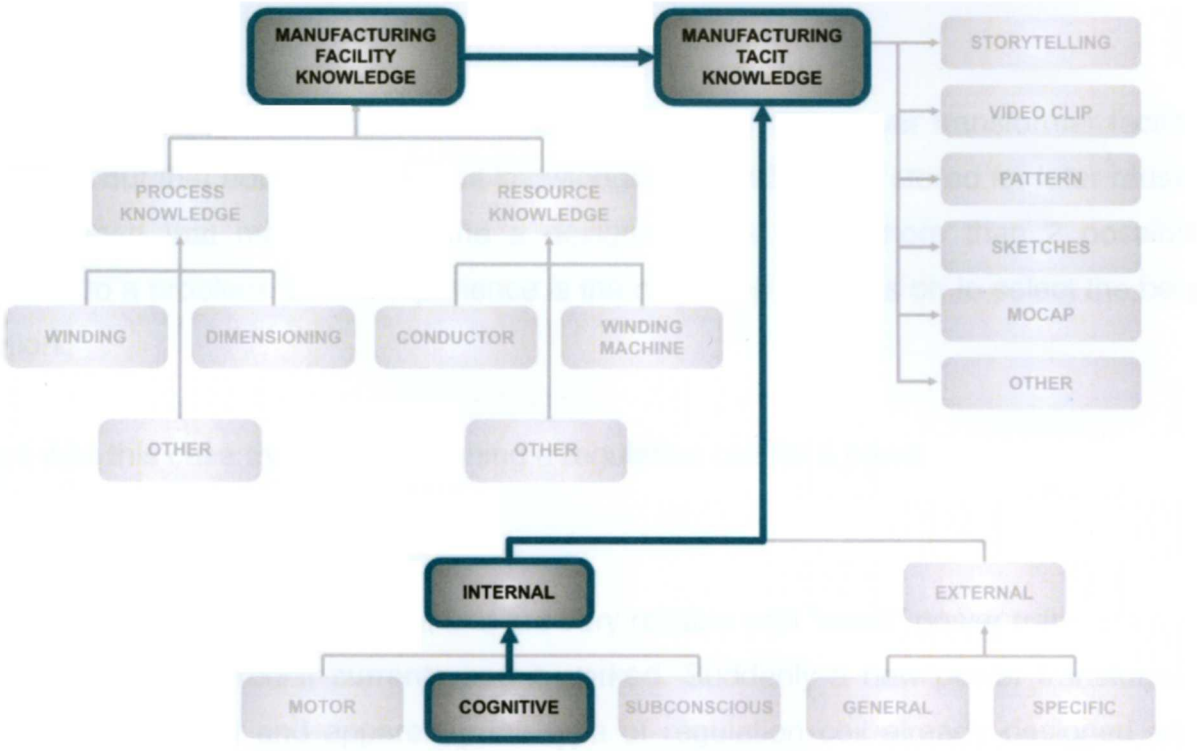

Figure 4-2 Internal Manufacturing Cognitive Tacit Knowledge

When asked to an engineer what cognitive tacit knowledge he would share if he had to start working with a bigger coil he answered that there could be an insulation failure due to the fact that once the coils are placed "vertically" the size increase may create more pressure and tear the insulation apart causing a major coil fail.

If this knowledge is stored and shared to the rest of the teams preventive actions may be taken or a more elaborate study of this case may be assigned. This will save money to the company and facilitate knowledge integration.

4.3 Case Study 3: Internal Manufacturing Cognitive Tacit Knowledge

We can't separate the design process from the manufacturing process that is why the author of this thesis decided to present a design-manufacturing process example using the proposed structure.

The author interviewed the Electrical Designer Expert of the power transformer facility and found out that not all of their tacit knowledge is identified and stored for later reuse. He explained that most of the time a designer would have more than 2 possible solutions to a problem. So his experience is the only thing he relies on to select the best solution.

There was this case that while designing a regulation coil for a power transformer a very expensive failure occurred.

Regulation coils have a lot of taps and are very reliable with "small" power transformers, it had the known circular currents and it worked. Suddenly a new power transformer design was needed and apparently the type of regulation coil already designed and tested might work with this bigger power transformer.

Everything was built but when the unit was tested a failure occurred which burned the regulation coil thus making the transformer unusable. While doing a post-mortem analysis it was discovered that the regulation winding burned probably due to the circular currents. These circular currents were known to exist but no one could predict the effects of the currents on a bigger transformer.

So it is very unlikely to create prototypes of a single sold unit that it is worth millions of dollars. However a rule of thumb was created on the designer mind and cognitive tacit knowledge. Regulation coils of a certain size and capacity does not work well on big transformers.

The incident required new coil designs, decontamination of the unit and a lot of remanufacturing costing the company an estimated $300, 000.

Lesson learned. But how could this incident is prevented to ever happen again? What happens to that knowledge obtained once the electrical designer no longer works in the company?

If this incident is to be structure in Knowledge Management software in order to identify, obtain, store and reuse of the knowledge new electrical designers could use it in order to make the right decision. Maybe by investing the $300,000 this tool could be created and maintained avoiding even more situation of this type to occur.

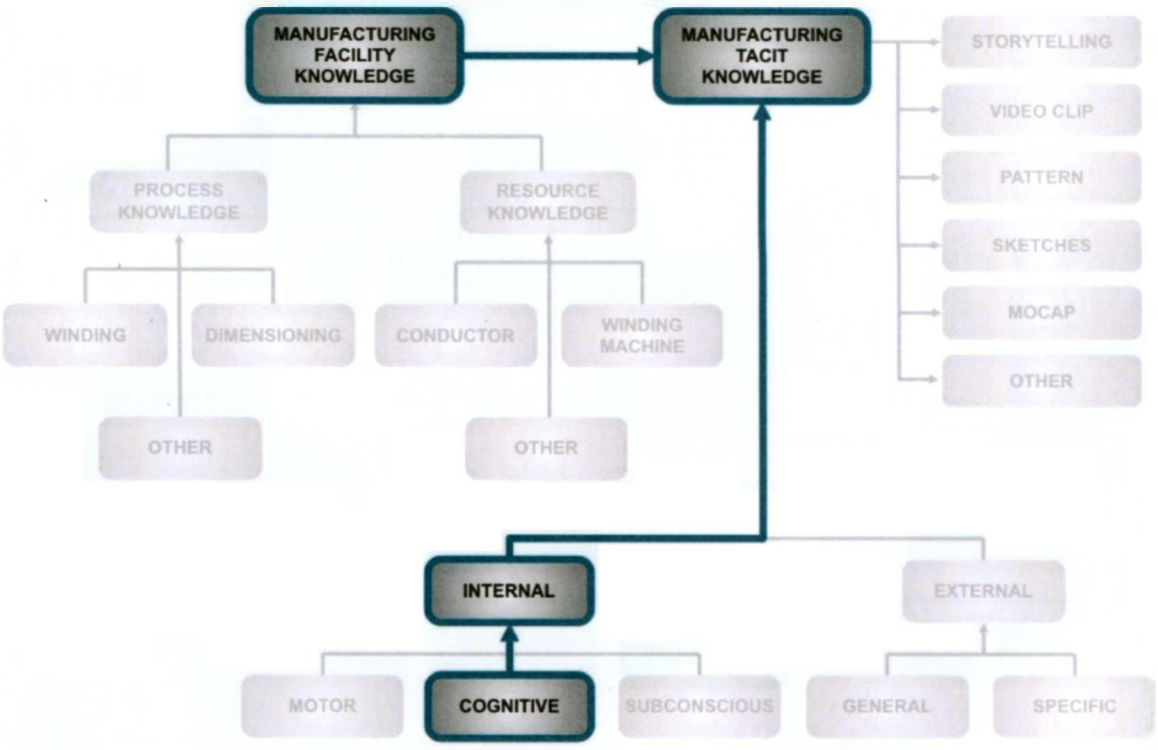

Figure 4-2 Internal Manufacturing Cognitive Tacit Knowledge

4.4 Case Study 4: Internal Manufacturing Subconscious Tacit Knowledge

The most difficult type of knowledge to identify and obtain, this type of knowledge (see Figure 4-3) maybe exemplified with knowledge obtained when one is not conscious about it, like when a person looking for a solution in his conscious state does not find an answer but once he liberates the subconscious in their sleep they "dream" of the solution.

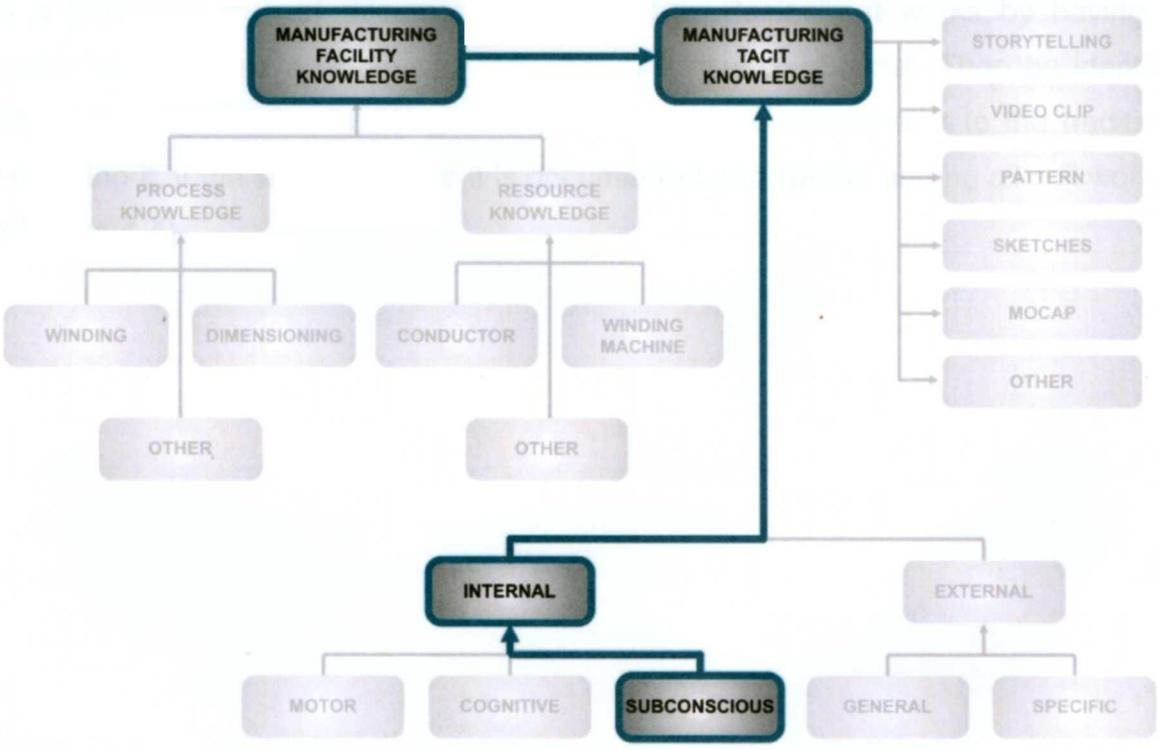

Figure 4-3 Internal Manufacturing Subconscious Tacit Knowledge

There have been several examples of this in science like Otto Loewi Nobel's Prize where he dream of the experiment necessary to prove his theory; Kekule structural theory also came from a dream; Elias Howe sawing machine design inspiration also came from a dream.

Although it is still very difficult to obtain this type of knowledge and reuse it, which does not mean it does not exists in our daily life, further researches should be conducted regarding this category.

4.5 Case Study 5: External Manufacturing General Tacit Knowledge

During an interview with the responsible of the coil department we identified that they used a particular way of documenting knowledge. Basically it works by having an instructor to supervise a whole day the work of a new coil builder. Then he identifies whatever the new worker is doing different and then he compares it to the traditional way of doing it, if the result is better it is documented and spread among all coil workers (see Figure 4-4).

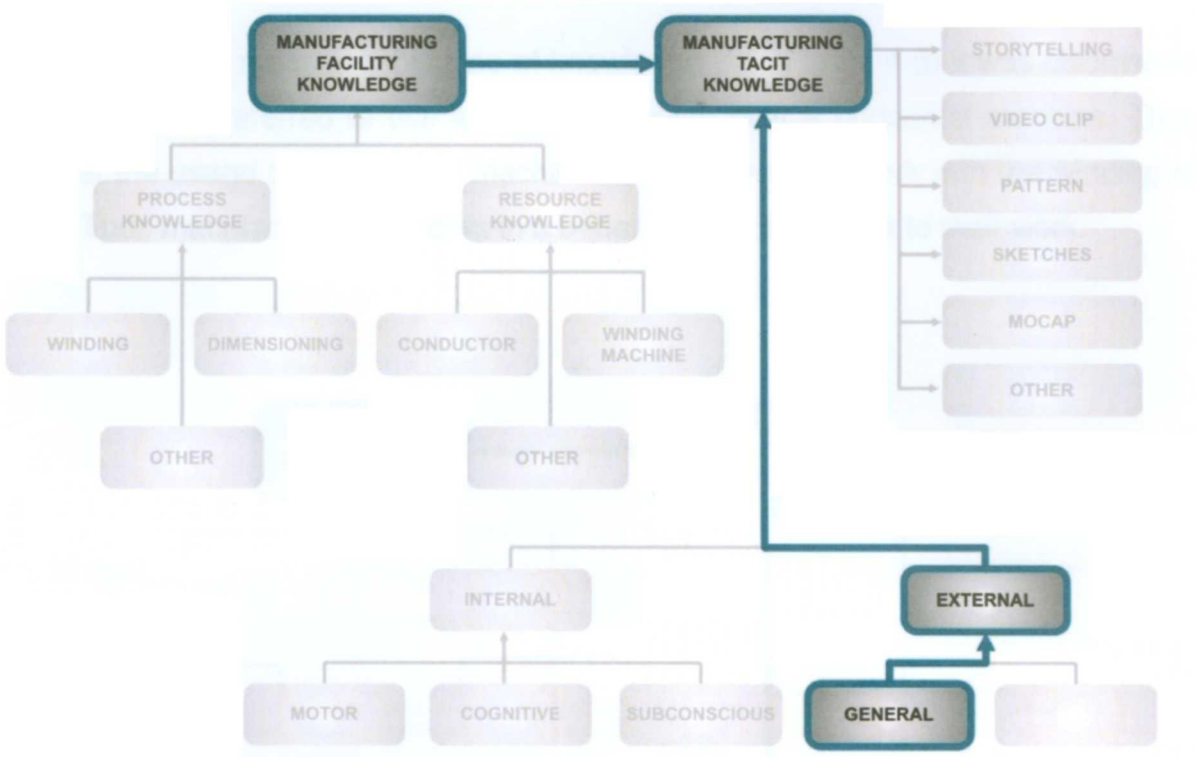

Figure 4-4 External Manufacturing General Tacit Knowledge

This type of philosophy maybe documented and brought it to a different department like design, a new designer maybe observed while he is working in his computer only to discover new ways of doing things in order to later document them.

This demonstrates that no matter the area whenever the knowledge is of the general type it might be used in a different place or context.

4.6 Case Study 6: External Manufacturing Specific Tacit Knowledge

During an interview regarding this type of knowledge (see Figure 4-5) it was discovered that coil workers preferred to use a vertical machine over a horizontal machine. They stated that the usage of the vertical machine made it easier to work with the winding of the coil. Thus manufacturing the coils in a better way adding value to their work.

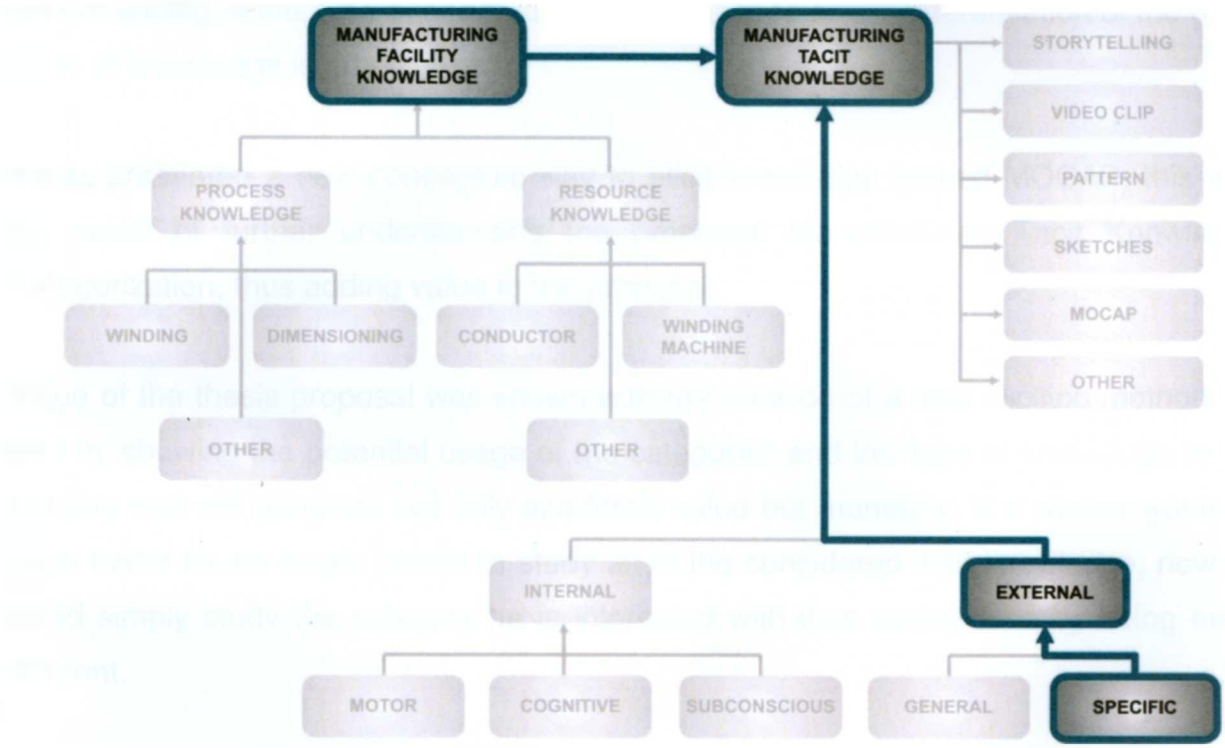

Figure 4-5 Specific Manufacturing Tacit Knowledge

Chapter 5

5. Results, Conclusions and Further Research

The author of this thesis developed some case studies applied in the Power Transformer Industry along with interviews to the key elements of the critical process of coil winding.

The case studies demonstrated that the proposed Manufacturing Tacit Knowledge Categorization will work in a manufacturing and design environment. With that, a better understanding of this type of knowledge was developed and a differentiation of the other types of knowledge is emphasized.

It was presented a new conceptual way to elicit knowledge named MOCAP; this was the result of further understanding the proposed Manufacturing Tacit Knowledge Categorization, thus adding value to the proposal.

Value of the thesis proposal was shown with the creation of a new eliciting method but also by showing the potential usage of the categories and this type of knowledge in the industry that will generate not only academic value but monetary. If a worker wants to learn faster he no longer needs to study all of the considered tacit knowledge, now he could simply study the category he is interested with thus saving time by being more efficient.

Existing paradigms that suggest that Tacit Knowledge cannot be structured or articulated are complemented with the fact that structuring levels exists and that a Tacit Knowledge structure is feasible.

The author of this thesis recommends that further research and software developments should be conducted such as:

To further explore the interactions between the proposed classifications. An example of this is that some knowledge is acquired in a cognitive manner, then it could be stored in the subconscious and the mixture of these elements may result in a motor interpretation of the feedback received during a procedure or process.

Creation of a method or model that will help reuse the knowledge acquired by the proposed knowledge classification. A method such as this could have three main agents; the human (worker/knowledge administrator), the user interface and the knowledge repository see Figure 5-1.

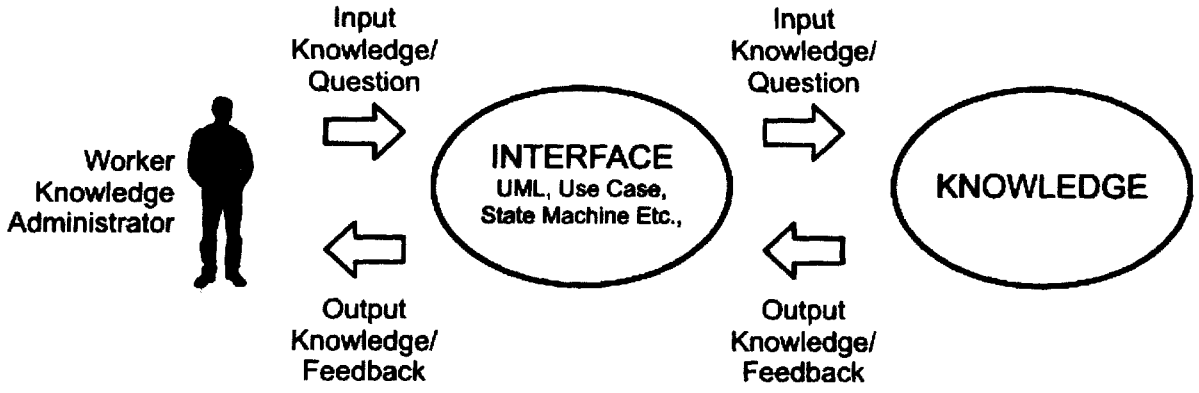

Figure 5-1 Example of a Software Development based on the proposed classification

To further explore the usage and implementation on other manufacturing knowledge facilities and industries of the proposed classification.

To further develop the research of the proposed MOCAP knowledge elicitation technique.

To propose new ways to represent and elicit knowledge according to the classification.

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