

The Role of Knowledge Artifacts in Innovation Management: The Case of a Chemical Compound Designer CoP

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Abstract. The paper describes how the experience we gained in the interaction with a community of professionals, the Compound Designer CoP (involved in tire production), led to the identification of the role Knowledge Artifacts can play in the definition of computational supports of innovation management in the specific domain of chemical formulation for rubber compounds. The paper reports on an experience gained in a project we are involved in and on the technology that has been designed to support knowledge and innovation management in the involved company.

Introduction

The paper describes the experience we gained in the last years in cooperating with people involved in innovation processes at a specific industrial setting with the aim to develop a Knowledge Management (KM) project and deliver a computer-based KM support system¹.

¹ Truck Business Unit of Pirelli Tires; P-Truck Project.

The aim of the project is the development of a Knowledge Management System to support the expert in their decision making about the *design of rubber* compounds for truck tires. The need of this support was phrased by the top management of the company both in terms of a better understanding of how innovation is achieved in the company in order to improve its effectiveness in front of market competitiveness, on the one hand, and in front of turn-over and new generation professionals in the organizational structure, on the other hand. This goal is fully in accordance with the trend that sees companies increasingly concerned with the *management of innovation* as a fundamental aspect of their ability to be competitive in turbulent markets (Prahalad and Hamel, 2000).

In order to tackle this problem and define the space of intervention to solve it, it is useful to recall how innovation is interpreted by these companies. Innovation loosed the characteristics of being a series of isolated events, generating revolutionary changes in products and processes, to become a continuous activity generating smaller scale improvements of both of them in order to answer the continuous request of new products coming from the market. Revolutionary innovation events are spots that are embedded and rooted in this continuous, permanent and pervasive activity. In this way, innovation plays a leading role in competitive advantage, as the core ability to create new products or significantly modify by adaptation products without ignoring production constraints. It means to valorize and exploit the core competencies owned by a company, namely focusing on its own core knowledge. Here, innovation management and knowledge management share the same complex territory.

In this view, an effective management of innovation is on the one hand fruitful to reduce the time to market of the innovative products and the related costs, but very challenging on the other hand. In fact, innovation is the result of the cooperation of skilled professionals owning valuable core knowledge, whose activities are dispersed in the business processes that cross the organizational structure in flexible ways. The emphasis on business processes and to the identification of technologies supporting them, that characterized the past decades, let companies pay less attention to the innovation process that, in turn, crosses business processes. Consequently, business processes and the related technologies are not able to support innovation management in an adequate way, although they often define the organizational and technological context in which it is generated. Hence, the understanding of how the innovation process happens and how it can be supported still requires new investigation and investments.

Actually, this was the leading idea of the P-Truck project. The construction of a technological support is one of the final goals. An equally important goal is to improve people consciousness of the mechanisms governing innovation in the company as a preliminary effort to make the technological support useful and usable within the company. The second goal deeply influenced the way in which the project was conducted. On the one hand, the main characteristics of the

innovation process in the domain of designing rubber compounds for truck tires at Pirelli were uncovered through a strong cooperative interaction with company's stakeholders. On the other hand, we didn't impose an a priori theoretical construction in the accomplishment of this interaction. In other words, we let the conceptualization be derived from the discovery of the mechanisms used to govern innovation. In so doing, we empirically recognized the role of two main concepts and how they are instantiated in the concrete situation: the notion of *community of practice* (CoP) and of *knowledge artifact*.

The following sections illustrate the above points. Specifically, we describe how a specific knowledge artifact has been discovered, designed (following a knowledge engineering approach), incorporated in a computational tool and used as a basis for the definition of additional functionalities as part of a KM system supporting the compound designers' CoP. The paper ends with the discussion of the next steps we are going to undertake to capitalize this experience towards a more comprehensive KM support as well as a deeper understanding of how the notion of CoP can play a role in this effort.

The method and context of innovation

The collection of the data necessary to achieve the goals of the project was organized in two different phases. First, a series of meetings were planned and organized as *learning sessions* where different managerial roles illustrated the main features of the product (truck tires) and the various phases in which their design and production is achieved. The audience was composed of members of the research team and of stakeholders who were increasingly identified as necessary to collect the required information. This approach testifies the kind of investment the company put in the project, in terms of both preparation and participation to the sessions by qualified managerial roles. These sessions played the basic role of creating a mutual learning process among the participants who actively contributed to build a common view of how innovation is articulated in their every day work. Second, the various managerial roles were individually *interviewed* to complete and deepen the specific aspects under their responsibility on the basis of incremental descriptions of the collected data constructed by the research team. In addition, the data collection was completed by observations in the field. In the following, we outline the main features characterizing the product and its life-cycle in order to make the context of innovation at Pirelli more precise.

A truck tire is a chemical device made up of both chemical components and other elements (Cussler and Moggridge, 2001). In particular, a truck tire is composed of rubber compounds (the chemical part), that is responsible for all the thermal-mechanical characteristics of the tire, and metallic reinforcement, that provides the tire with the necessary rigidity.

The life-cycle of a chemical device is centered on the product innovation, in order to meet the requirements of evolving markets they are devoted to. In the case of truck tires, it is necessary to optimize several aspects that concur to the overall performance (e.g. tensile strength, resistance to fatigue and so on), the importance of each of them varying according to the kind of market the will be sold on (e.g. North America, Europe, etc.)

The life-cycle of a truck tire is made up of a procedure consisting of phases. The main ones are:

- *Design* of rubber compounds: a rubber compound is a blend of different ingredients, both natural (e.g., natural rubber) and synthetic (e.g., carbon black, oils, and so on), chosen with the goal of achieving predefined performances, such as tensile strength, resistance to fatigue and so on. The Design phase decides the composition of the blend, identifying ingredients to be adopted and their amount;
- *Mixing*: the ingredients must be suitably mixed in order to obtain a homogeneous blend;
- *Semi-manufactured production*: metallic reinforcements are added to rubber compounds, getting the different parts the tire will be composed of;
- *Assembly*: semi-manufactured parts are assembled into a semi--finished product, in jargon called green-tire;
- *Vulcanization*: the green-tire is "cooked" in order to give it the required thermal-mechanical features.

At the start of the procedure, very important inputs come from marketing and research while in the last phases the role of engineering is predominant. However, the entire effort can be best considered as a whole, carried out by interacting teams drawn from marketing, research and engineering departments.

This procedure is the key for the generation of innovative solutions: since it takes care of marketing inputs, and then of market requests, chemists, that in the case of truck tires design are called *compound designers*, are forced to think to new solutions for meeting them. Moreover, they are requested to find solutions that can be processed by machinery, so that their decisions in the design of products must consider process design aspects too.

The first phase of the tire cycle of life is very critical: compound designers must choose ingredients composing the blend in order to guarantee a low level of viscosity; otherwise, for instance, the blend could be not easily mixed. Moreover, compound designers must be able to quickly modify the composition of the blend, due to problems arising during the mixing or other following process phases, in order to save production times and costs. Compound designers activity can be described as follows: they start a new project to meet the request of marketing, or to change one or more performances of an existing product; then they produce a list of possible recipes and choose one of them after an evaluation of benefits (i.e.

they evaluate if all the requirements have been satisfied) and drawbacks (i.e. what kind of side-effects have been generated). During the evaluation, compound designers can decide that marketing proposals are not realizable: a few years ago, the marketing suggested that the production of colored tires could be a promising choice to extend the competitiveness on tire market. This possibility was rejected by compound designers, due to the necessity to add synthetic or natural pigments that could negatively interact with other, and more important, elements of the blend.

Since the following phases of the life-cycle concern the manufacturing of the rubber compounds, compound designers takes care of this issue, avoiding to increase their level of viscosity (that could make the blend difficult to be mixed) or to let chemical reactions among ingredients happen too early or too late.

The above description shows (and confirms) that innovation is a continuous process (*continuous innovation* involving both product and production processes modifications) that requires the involved professionals a problem solving capability that is deeply rooted in their skills and *experiences*. Their experience is derived from the direct application of knowledge in problem solving on a specific competence domain, and allows them to structure explicit knowledge and to accumulate tacit knowledge. Experience means having dealt with several *cases* during time, regardless whether successful or not. Any solution that can be invented by applying professional skills has to be checked against the organizational, production, managerial context characterizing the company. Optimal solutions from the first point of view can be simply impractical from the second point of view. Moreover, this check requires the skills and experiences that are collected and put at work in different business processes. The main question to answer was how continuous innovation can happen in presence of a not specifically focused institutional support. In fact, the latter is often based on face-to-face meetings that of course are fundamental for the creation of the mutual understanding necessary to the collective problem solving activity and to the solution of the inherent conflicts. However, meetings are not able to create a persistent support to innovation management since they are oriented to plan future actions and not to record the experiences generated in between them. Moreover, they are often formal steps that have to be planned in advance (especially in a dispersed organization like Pirelli), they collect representatives of the whole set of involved professionals, and serve the mixed aim to promote solutions and check them against the requests of the market and the overall goals of the company. Hence, usually the real cooperative problem solving happens outside and is based of mechanisms that are invisible and self-organized.

Identifying a Community of Practice

The notion of Community of Practice (CoP) naturally applies in the above context since it explicitly focuses on practice, that is experience, and on the above officially unrecognized and self-organizing capability. This immediate correlation however, may crash with the difficulty to identify the *boundaries of the community* itself. This is necessary not to raise barriers since openness is a basic property of a CoP but to characterize it in order to identify the organizational and technological means that are most adequate to support the innovation process the CoP is involved in. The difficulty we meet in using this concept was generated by the following factors. First, looking for a shared “practice” without an identification criterion of the CoP itself can generate a sort of “domino effect”, paradoxically including the whole organization. Second, people are not always conscious to be part of a CoP and are very influenced by the formal structure of their company: hence, they often tell their experiences in terms of the latter and the involved processes, although they recognize the existence of a “parallel” cooperation structure.

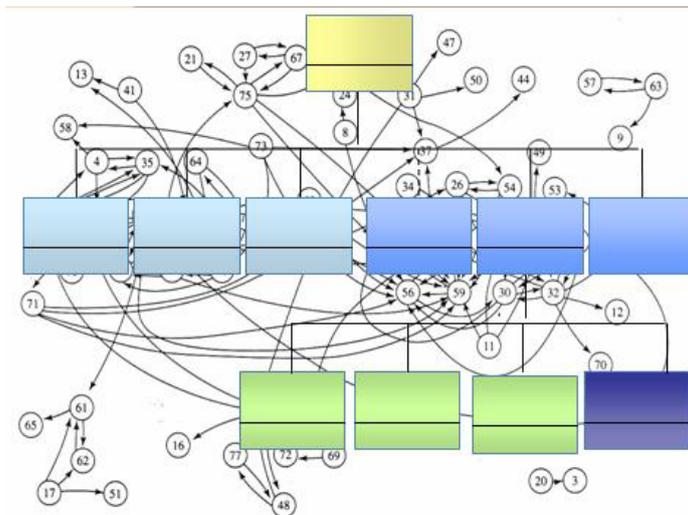


Figure 1: The synergy relation between Formal structure (the hierarchical boxes) and Informal Systems (Communities of Practice) (Katz, 1997)

Figure 1 shows a picture used by a stakeholder during one of the sessions to illustrate, in qualitative terms, how he perceived this synergy. Within an organization it is possible to recognize a formal structure (the stained hierarchical boxes), that characterizes its behavior and strategy, and an informal system (the graph), the *CoP Context*, which is made up of a network of social relationships among people living and working in the organization. Finally, the mechanisms supporting the latter are immersed in the practice and too ready at hand to be consciously perceived, being generated for practical purposes and not to build a

control structure. A possible way to tackle the problem of the identification of the *boundaries of the community* (in order to find new approaches in innovation management) is to look for the means by which people collect their experiences, organize the related pieces of knowledge and make them sharable. To this aim, it is useful to consider a Community of Practice (CoP) as characterized as *a group of professionals informally bound to one another through exposure to a common class of problems, common pursuit of solutions, and thereby themselves embodying a store of knowledge* (Hildreth and Kimble, 2000). This definition implies the existence of a *shared repertoire* among the members of CoPs, that is a set of methods, tools, ways of doing things, gestures, symbols, and so on, produced by the community during its existence.

Looking at the features of the shared repertoire we recognized it as characterized by a *professional language*, used in two very important ways:

- *Locality*: the language is adopted by each member of the CoP for speaking to another one;
- *Boundary*: the language is adopted by the whole community to communicate with other communities.

Both kinds of usage are fundamental and emerged during the “learning sessions“. In fact, if a CoP would use a language not characterized by boundary it would be isolated within the organization, with no contribution to the organization’s growth; on the other hand, a CoP couldn’t exist if the locality principle would be negated, since there would be no sharing of experiences and competencies among its members. The professional language spoken by compound designers is strongly oriented to boundary, since they have to interact with other CoPs (e.g. other professionals working on Mixing or Vulcanization phases) in order to design rubber compounds that can be easily processed. On the other hand, their language is oriented to locality as it incorporates the knowledge and the methods they use in their cooperation.

Although the locality and boundary principles of CoPs’ languages are well known from the theoretical point of view (see for instance Smethurst, 1997) there are still few efforts in the development of tools and methods to support them. During the interaction with the compound designers, we discovered that the professional language they developed was used to give a structure to their shared repertoire thanks to the *well defined syntax and semantics* characterizing it, although in an often implicit way.

Starting from this structure, looking for who contributes to its maintenance, identifying whom is accessing it and when, we claim, is a constructive way to identify the community whose practice is stratified in the structure itself. In addition, this is a very natural way to let people become aware of participating to the community they (possibly, unconsciously) contributed to build. This is consistent with Wenger’s description (Wenger, 1998) of the dynamics that regulate the identity strengthening within a Community of Practice: the legitimate

participation of the members to the negotiation inside the community, takes place through the sharing of a common repertoire. The awareness of belonging to a CoP through the sharing of the repertoire, and most importantly its structure, let the involved people tell their *stories*, (namely narratives arising from experiences and cases) increasingly in terms of community, by stepping away from the formal structure, and coming back to it, when necessary, to understand the constraints and affordances the formal structure provides the community with.

The emergence of a knowledge artifact

A deeper investigation of the above structure let us make explicit the way in which the professional language was used to construct it and to envisage a way to support its formalization and usage.

It is a common practice that people, spontaneously and often implicitly; identify structures that make their cooperation and problem solving activities more effective. When these structures are sufficiently worked out and put at work, they are usually materialized in *artifacts* (conceptual, linguistic and/or modeling tools, whose structure is strictly shared by the members of a well defined community), which incorporate a language that is collectively understood and provides sufficient information to be useful for sake of mutual understanding and cooperative problem solving (namely, a “formal” jargon of a community, comprising very precise syntactic and semantic rules and conventions).

The role of artifacts in coordination is well recognized (e.g. see Heath and Luff, 1996). They are informational structures describing the current state of affairs in terms of responsibilities, current activities, plans for future actions and so on, and support the coordination in a group of cooperating actors. Let us call them *coordinative artifacts*. They can also play the role of *boundary objects* (Bowker et al., 1997) living at the border between different groups (CoPs) and supporting the coordination of the activities performed by the actors constituting them.

The artifact identified in our investigation at Pirelli, called *T-Matrix*, shares several properties with coordinative artifacts but is constructed for a (slightly) different purpose: it objectifies the way people organize the memory about their experiences and the involved knowledge as a resource supporting their cooperative problem solving. It was natural to identify the notion of *knowledge artifacts* to characterize them and to distinguish them from the coordinative ones.

The term “knowledge artifact” has been proposed in (Seiner, 2001) as one of the basic components characterizing knowledge flows within an organization or a community. Our characterization of the term shares many of the properties this proposal identifies to describe the role of knowledge artifacts in decision making. However, it particularly focuses of the collective definition of the specific artifact, on the ad hoc nature of its usage which distinguishes it from other typical artifacts

like reports or data files, and finally on the goal to retain the experiential core knowledge that characterizes the “collective agent” defining and using it. In other words, our characterization is more strongly related to the notion of community of practice that in the above proposal where it is only marginally considered since the argumentation seems more oriented to organizations where the identity and mutual awareness of the participants in the knowledge flow are more shaded.

The knowledge artifacts we are considering still play the role of boundary objects but not necessarily across CoPs. They can play this role within the same CoP to mediate cooperation among actors with different professional skills and involved in different business processes, but anyhow contributing to the same goal within the innovation process: for example, to adapt components of a product or of a production process to the new requirements imposed by the market. The presence of a commonly identified goal is a complementary way to identify the CoP and to understand the nature of the practice that makes sense to it. *Knowledge artifacts* incorporate the core competences as well as the experiences of actors who are professionals skilled in possibly different disciplines, each of them characterized by a specific professional language. Notice that, even in the case the reference discipline is the same for all members of the CoP, the fact that people apply it in different business processes can give them a different perspective on the common discipline and on the language they use to express their competences.

The detail of the T-Matrix will be explained in the next sections. However, in relation to the theme of the identification of a CoP, it is interesting to observe how the language used to build it is related with the languages that are owned by each individual professional and reflect their specific competences. While the latter are rigorously used to solve (sub)problems in charge of each professional actor, the former is characterized by a (high) degree of *under-specification*: it describes technical aspects in a more qualitative way. This seems to be a common characteristic of languages incorporating conventions concerning knowledge as well coordination means. A typical example of this qualitative jargon is the one adopted by stock traders: by the use of simple gestures they are able to express quantitative and complex concepts about the trading of stocks that will be easily understood by colleagues.

Under-specification is a mean to have a not expensive management of the artifact avoiding details that could hinder mutual understanding without making the artifact useless. This accounts for the locality aspect of the language and consequently of the artifact we mentioned in the previous section. The capability to maintain this delicate equilibrium is the very asset of a CoP and distinguishes its legitimate members from the peripheral ones. Competences and experiences allow the former to use the knowledge artifacts in an effective way, by interpreting the contents provided by other members and by reformulating the

under specified information in terms of their own rigorous professional language in order to put it at work in the realm of their responsibility.

It is also interesting to observe that under-specification accounts for the boundary aspect of language and artifact. In this case, under-specification is what makes the language and artifact usable across communities. It incorporates the enough information to make communication and cooperative problem solving possible. Interpretation does not require a full understanding of what is behind, rather a precise understanding of the part of the meaning that has been negotiated. This role has been recognized in the case of coordinative artifacts too (Sarini and Simone, 2000).

The genesis of the specific knowledge artifact

As anticipated, the interaction with the professionals involved in the design and production of truck tires was organized in learning sessions and in individual interviews. Actually, the two modes were intertwined since we had a session for each phase of the overall design and production procedure and the interviews were conducted after each of them by involving the pertinent professionals. In the following we describe the lesson learned from this interaction and how it led to the identification of a specific knowledge artifact that became the basis of the interaction itself as well as of the final computational support.

About the involved knowledge

We had the chance to experience in a concrete situation how the management of innovation is actually a continuous process. In fact, most of the successful achievements in chemical formulation of rubber compounds at Pirelli (as in several others tire companies) are based on transformations of previously experienced compounds. In general, most of chemical compound designers work consists in deciding about how to adapt a product (compound) in response to a series of performances the compound is supposed to feature. It became immediately evident that in order to be able to make such decisions it is not enough to be familiar with general chemistry. What is required is a non-bookish competence which derives from anything but experience. In the acquisition and representation of the knowledge involved in this decision making, the trouble in grasping these competences lies in their own volatility and informality, what Nonaka (Nonaka and Takeuchi, 95) has called *tacit* and *implicit* knowledge. The fact that this knowledge represents one of the more precious as well as the more volatile asset of a corporation contrasted with the lack of any well established policy at the corporate level to facilitate its creation and recording: however, this is not a surprise in the case of companies that are characterized by a long history (as also the case of the company we analyzed does) in which generations of

experts transmit competences between them almost in an oral form or directly through the involvement of the next generation professionals in the current problem solving.

The above situation makes particularly difficult the acquisition of the knowledge used by the experts when they select the proper adaptation of an existing product, depending on the market demand. This action requires bridging the gap between different professional languages: the market speaks of performances, the people responsible for the production processes speak of various aspects of feasibility while the chemical compound designers respond in terms of chemical formulations.

Since the very beginning, we have realized how experts of chemical formulation take decisions on the ground of a series of criteria which cannot be immediately converted into any physical-mathematical representation. Such criteria – even though they are expressed in the language of chemistry – are expressed in terms of a *common concept model* in which chemistry is translated: the competences and experiences held by chemical compound designers define the significance and interpretation of chemistry and not the opposite. During our work, we have observed that compound designers use a *tacit concept model* which translates chemistry into a jargon depending on a qualitative value of usage. In order to grasp this model which is implicitly and very effectively used in expert's routine work, it is therefore necessary to make an attempt to read out the semantic code by passing through the decoding of the jargon used by compound designers. In other words, the acquisition and representation of the involved knowledge concerned the comprehension of the specific language of the team and how it was used in a partial representation of the concept model, a paper based artifact, used by compound designers during their work. In this exercise, we have coped with a socially compact reality unified not only by a shared goal (an optimal chemical formulation) but also and especially by a shared jargon which is typical of that group. We could say that practice gets into the world of chemistry through the concept model and the jargon conveys the sound to a series of meanings.

The “T-Matrix” and its role

Let us go deeper in the structure of the discovered and jointly improved knowledge artifact. The fundamental entities considered in designing a formal structure (whose name can be here synthesized in “T-Matrix”) are *tire*, *recipe*, *blend* and *ingredient*. Formulations concerning rubber compounds - the object on which compound designers work on - are explained by recipes, that is lists of ingredients with related amounts. According to the jargon used inside compound designers recipes (i.e. the object of domain problem) are structured on the basis of three main concepts: *family*, *combination* and *system*.

Each ingredient can be considered an element of a set whose items are characterized by common physical and chemical properties: this set is called *family* and each ingredient can belong to exactly one family. A set of attributes is associated to each family for describing its ingredients. Examples of ingredient families are Natural Rubbers, Oils and Carbon Blacks. A *combination* is a set of ingredients belonging to the same family: hence, elements of a combination are described by the same properties and play a similar role in the blend. Each recipe can be structured as a list of combinations. For example a recipe can contain a combination of natural rubbers, a combination of oils, a combination of carbon blacks and so on. Some combinations cooperate to give blend particular properties, both chemical and concerning the processability in following manufacturing phases: such combinations are grouped together in a *system*. Each system has a specific *role* within the recipe. For example, polymeric system is made up of rubber combinations, both natural and synthetic, and its role is to provide tire components with properties, such as elasticity.

Blends of rubber compounds are described by a set of Blend Features (BFs), such as tensile strength or hardness, while tires are described by means of Tire Performances (TPs), such as wet handling and mileage. As family attributes, BFs and TPs could be either qualitative (i.e. descriptions or comments given by experts) or quantitative (i.e. test results). In addition a set of interventions on the recipe (RIs) modify its composition.

TP 1	⊙↓	○↑	⊙↑	○↑
TP 2	▲↑	⊙↓	☒	▲↑
TP 3	⊙↓	○↑	⊙↓	○↓
	BF 1	BF 2	BF 3	BF 4
RI 1	☒	○↑	⊙↓	▲↓
RI 2	▲↓	☒	○↑	☒
RI 3	▲↑	○↑	⊙↓	○↓
RI 4	○↓	⊙↓	▲↓	⊙↑

Table 1: A T-Matrix example

The very important knowledge about chemical compounding for truck tire stands in two relationships, called Compounding Relation and Design Relation. The first relation binds RIs and BFs, while the latter describes the correlation existing between BFs and TPs. Instances of these relations are the reification of the experiences of compound designer CoP members. To describe the elements of these relations a vocabulary as been defined: it is made of symbols describing the correlation level and the proportionality of the involved items.

Table 1 reports an example of a T-Matrix containing compounding relations (upper part) and design relation (lower part). Symbols describing correlations and proportionality and their meanings are reported in Table 2. They represent the core meaning of the T-Matrix as a knowledge artifact.

	Symbols	Meaning
Correlation	⊙	Strong
	○	Good
	▲	Weak
	☒	No
Proportionality	↑	Direct
	↓	Inverse

Table 2: T-Matrix symbols

It is possible to observe that the level of description of a very complex activity (such as briefly illustrated above) is summarized in a small set of “qualitative” relations among the components involved in the design of the blend. The very “poor” vocabulary represented in Table 2 is the core of the knowledge artifact allowing the CoP to share the essentials of their knowledge that is useful in compound design activity.

If you observe the CoP at work (as done in the knowledge engineering activity) you can see that the behavior of the members of the CoP reflects in a strict way the syntactic rules synthesized in the T-Matrix language. If some explanation is required by people not belonging to the CoP (the knowledge engineer or someone belonging to other CoPs) the language becomes more articulated and explanatory: the professionals come back to the language expressing their deep competences. For instance, the three values *strong*, *good* and *weak* are very qualitative in their nature. This doesn't mean that these values represent a shallow approach in the design of chemical compounds. On the contrary, precise quantities must be calculated in order to reach the right product to be obtained through this design.

The role of the components in the T-Matrix is not assigned on the ground of merely chemical requirements as owned by certain elements of the compound but it depends on their role within a production cycle of the compound itself. Thus, this role is strongly influenced by the way compounds are designed and by the experience gained in this specific production site. In other companies, the same chemical compound may play different roles and in any case would be described through a different concept model.

As we have remarked above, the innovative activity carried out by chemical compound designers at Pirelli consists of modifying previously experienced chemical compounds. In fact, their jargon is focused on compounds as organized in accordance with historically recognized classification criteria and in reference to possible actions on the compounds themselves. These criteria are reified in the T-Matrix which testifies a sort of practical learning on compounds – so different from theoretical knowledge of mathematics and chemistry – and is an example of representation of core knowledge acquired in the course of product innovation.

Moreover, the T-Matrix is the result of explicit disclosures transmitted by compound designers as chemists: therefore the T-Matrix is given an important value by members of this CoP. In fact, well-defined language identity, a shared language as molded to practice, dialogues and negotiations intended to cope with and discuss related matters, a shared documentary repertory come up as distinctive elements of the experts we have worked with. It was just during the work of acquisition and representation that they got aware of their own cohesion. Our mutual cooperation was enhanced by this constructive exchange. On the one hand, chemists were invited to show the rationale of their work in the field and consolidated their belonging to a community; on the other hand, we were given a chance to reflect upon an action of knowledge engineering within a community (we will come back to this point in the next section).

For what concerns the first aspect, to work with and be tightly close to this kind of social realities means to cope with an extremely informal way of working, which is transversal to the protocols governing the formal structure of the company. The T-Matrix is both a thesaurus of core knowledge and a conceptual instrument to assess the inclusion into a community: it defines a community through the representation of the jargon adopted within the community itself to perform negotiation of meanings. On the other hand, the interaction with compound designers brought to our attention that part of the knowledge involved in the negotiation activities within the community are, in fact, negotiated with members of other communities. An example is given by the role of a specific group of chemical elements producing the mixture for the vulcanization system, which plays a major role in a subsequent phase of the tire production process, namely the vulcanization (curing process). The vulcanization phase, in fact, imposes specific conditions on the chemical formula of the blend. Moreover, the knowledge about vulcanization incorporated in the T-Matrix expresses the boundary permeability between the community of vulcanization technologists and the community of chemical compound designers: the degree of permeability is given by an agreed upon jargon, although limited to the specific knowledge.

The T-Matrix as knowledge artifact not only formalizes a jargon and constitutes the linguistic code that defines a community of practice but also helps identifying the boundaries that define the relations with other communities that are possibly geographically separated (e.g. a tire chemical formula defined in Italy and maybe physically produced in Brazil).

About the design of a supportive tool

Before concluding this section we argue about the implications on the design of a technology supporting a CoP acting in the above scenario.

To give a stable and rigorous shape to a complex knowledge based on informality has pointed out an almost paradoxical aspect which characterizes the

work of a knowledge engineer. He is inevitably confronted with partial and incomplete representations of knowledge (Davis et al., 1993), which is a real limit for his work. On the other hand, reluctances and resistances as shown by experts while explaining the motivations leading to their decisions are interpreted as factors and symptoms of the solidity of the group. As an extreme case, if we would get experts say everything, if we would acquire the whole knowledge, we would require the community to lose its own identity and defenses. This way we would run the risk of making the community crumble and therefore the reason of knowledge engineer's work would definitively come to an end.

One of the findings of our experience regards a critical approach to the engineer's work especially if conceived within a CoP: it requires the formalization of knowledge which is often episodic and more often structured on practice and experience. The definition of a T-shaped matrix certainly implies a great simplification of knowledge required in the engineering of tire compounds. It is worth reflecting upon the fact that such a simplification reflects the contents of our interaction with the community. The T-shaped matrix may be considered as the outcome of what experts wanted to tell us about their work. Therefore it is a part of the reifications the community owns (Wenger, 1998) and from time to time the community goes back to in order to negotiate and participate as a group in the creation of meanings (Lave and Wenger, 1991). Reifications are normally taken as the final result of specific narratives and negotiations of meanings, but in our experience reification is a significant part of the knowledge involved in negotiation of the meanings themselves.

Since the innovation process is the place where core knowledge (competences and experiences) plays a primary role, the analysis of the target situation requires the competences of a knowledge engineer who possesses the conceptual and linguistic means to acquire and represent the relevant aspects of the domain knowledge supporting problem solving activities, and to construct computational tools accordingly. We recognized that the identification of knowledge artifacts has similar impacts on this construction as the identification of coordinative artifacts did have on the design of supports of articulation work (Schmidt and Simone, 1996). Specifically, it pushes the knowledge engineer to use her representation capability to respect the point of view of the "knowledge workers", to help them making it more explicit, to use conceptual and linguistic means to represent the needed under-specification, and finally to help them (especially, newcomers) in interpreting and using it in an effective way. Too often, the design of tools supporting the management of knowledge denies the value that under-specification has for the involved actors, and constructs for them an "ideal" support based on a rationalization of the discovered knowledge. Of course, computational tools cannot be ambiguous, but the awareness of the relevance of under-specification allows the design of supports that, interacting with the users,

recognize their unavoidable role in filling in the gap, in response to very specific contextual requirements.

KEPT: a Tool for Dealing with the T-Matrix

As anticipated in the introduction, one of the two goals of the project was the development of a knowledge management system supporting the management of innovation. The previous sections showed the main role of the T-Matrix artifact in supporting the CoP of the compound designers in the achievement of their main goal: the design of rubber compounds. Hence, it was natural to develop the knowledge based system on the basis of the knowledge it incorporates and the knowledge flow it supports. This results in a computer-based system integrating several knowledge based systems (KBS) that perform four basic functionalities: to *capture* (acquiring and maintaining) knowledge and *store* it in persistent way, and to *deploy* (sharing knowledge among users) and to *process* the captured knowledge, that is, the capability of the system (especially through its KBSs) to propose “optimal” solutions through inference based on the stored knowledge. Therefore the whole system is made up of three sets of software modules, built in order to provide the above functionalities. Accordingly, it is possible to identify a set of web user interfaces that perform knowledge deployment, a set of systems performing Knowledge Processing (KP modules) and KEPT (the Knowledge Elicitation module of P-Truck).

Specifically, we want to focus on KEPT because of its strict relation with the T-Matrix. Moreover, even if it is specifically involved in knowledge capturing and storing it has an important role in all the other functionalities (both knowledge deployment and KP modules that need to retrieve knowledge from KEPT to provide their functionalities). Thus, KEPT is a relevant support of the daily work in the Truck Business Unit both when it is used as a stand-alone module to share and store knowledge and when it is implicitly used by other modules of P-Truck (for instance the KP modules incorporating the rule based system supporting compound designers).

Knowledge, such as compounding or design relations, is treated in KEPT using the same language of the T-Matrix. Since it is focused on the acquisition and maintenance of knowledge, it allows compound designers to manage (adding, removing or modifying) knowledge items (tire performances, blend features and recipe interventions) and relations among them (compounding and design relations). To this aim KEPT incorporates a formal model of the involved knowledge, the Abstract Compound Machine (ACM), described in (Bandini and Manzoni 2001) as the underlying computational mechanism supporting the implementation of the T-Matrix. The choice to use the same language of the knowledge artifact also in the software tool has been done in order to keep the locality and boundary roles of this language, that have been described in the

previous sessions. Hence, using KEPT it is possible to share knowledge both among compound designers' CoP and with members of other CoPs that are able to understand T-Matrix too. In fact, each compound designer can access the developed framework by mean of a web-browser to consult and update its knowledge base; on the other hand members of another CoP, such as mixing process designers or vulcanization experts, can obtain the desired information, for example, about ingredients role inside the blend formulation and their influences in the mixing or curing phase.

One of the main tasks of the whole knowledge system that is constructed around the T-Matrix knowledge artifact is to embody in a hidden way the translation from the qualitative values it contains into good and rigorous metrics so that knowledge can be processed in KBS to support experts in their daily activity. An example is the rule based system aimed to propose intervention on a recipe in order to achieve the desired features of the blend. Through this approach the whole knowledge based system plays a double role: it allows the sharing of the basic core knowledge (by the adoption of a common knowledge artifact), and the representation of the deep and formal knowledge to be capitalized in the system to support other functionalities. Since the emphasis of this paper is on the qualitative aspects characterizing the knowledge artifact of the considered CoP, the other aspects of the system have not been considered here.

Conclusions

The paper described how the experience we gained in the interaction with a community of professionals, the Compound Designer CoP (involved in tire production), led to the identification of the role Knowledge Artifacts can play in the definition of computational supports of innovation management in the specific domain of compound chemical formulation.

The need to acquire and represent the involved core knowledge focused our attention on a specific knowledge artifact, the T-Matrix, the compound designers created to identify and record their stratified and historically accumulated experiences and competences in the industrial case we presented. Moreover, this artifact allowed dealing with the identification of the boundaries of the compound designer CoP in terms of the capability to interpret and use the knowledge represented in the T-Matrix. This happens despite of the fact that the incorporated language expresses knowledge in a qualitative way and with a high degree of under specification with respect to the rigorous languages this class of professionals use in the accomplishment of their specific tasks.

The T-Matrix is incorporated in KEPT, a software module that is part of more comprehensive KM application developed within the illustrated project. KEPT supports the innovation management according to the actual practices of the

identified CoP and allows other professionals of the company to share these practices and the concept model created to capitalize them.

Moreover, the conceptualization objectified in the T-Matrix structure is used as a basis for the implementation of additional functions. Specifically, it served as the basis of the conception of a module supporting the learning process of new professionals joining the compound designer CoP in consequence of an increasing level of turn-over.

Our future work is about this specific functionality in order to take into account the learning process going on in this community, as a fundamental aspect of its effective functioning and survival. The educational approach follows the *learning by doing* paradigm (Kolb, 1984): young professionals can “play” with the T-Matrix in order to solve assigned compound design problems and check the adequacy of their solutions against the required performances on the basis of criteria that make sense in the CoP they are going to belong to. The possibility to access and put at work the value of the experiential knowledge incorporated in the T-Matrix knowledge artifact contributes to reduce the time newcomers need to become a legitimate participant. On the one hand, they can acquire the jargon used by the community in the context of the concept model it generated. On the other hand, they immediately become active since the T-Matrix objectifies the mechanisms governing the innovation process characterizing this community.

From the more general innovation management point of view, we are planning to monitor the results of the adoption of the proposed KM technology by observing its use within the P-truck project. Moreover, we will develop the basic concept of knowledge artifact and better understand its role in the identification of the boundaries of a CoP as a general approach to the design of KM applications supporting innovation processes and an effective innovation management.

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