Track title: *Information Technology and Management*

A Knowledge-Based Model For The Analysis Of Manufacturing Problems

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Abstract

This paper proposes a model to analyze manufacturing problems according to a knowledge management perspective. The analysis is based on the main cognitive processes involved in a problem solving process. The considered processes are knowledge generation, memory, transfer and codification. Each of them can be assessed by one or more variables, such as uncertainty, space-dependence, time-dependence, knowledge codification level. Given a specific manufacturing problem, the model allows to analyze possible actions of organizational improvement by analyzing the problem cognitive characteristics, and to identify suitable information technologies aimed to support problem solving.

Introduction

Knowledge management has gained in the last years a more and more crucial role in competition. In fact, knowledge is largely recognized as a fundamental asset to provide stable competitive advantages (Pralahad and Hamel, 1990; Nonaka and Takeuchi, 1995). For example, in the industries characterized by frequent technological changes, it is critical the ability of developing new knowledge and competencies (Bohn, 1994). The enlargement of the product functions can be also interpreted as the enlargement of the technological knowledge and of the expertise incorporated in the product. This often requires the integration of competencies from different departments through an effective product development process (Fine and Whitney, 1996). Similarly, for companies competing on the quality of their customer services, the competitive advantage largely depends on the knowledge about the customers' needs and on the ability to exploit it (Reicheld, 1996). Also the competitiveness of some firm networks (such as the virtual organizations) is often related to synergies among different knowledge assets rather than to cost reduction (Chesbrough and Teece, 1996). Moreover, the effectiveness of downsizing policies is often related to the ability of avoiding the erosion of the firm core competencies. Similarly, policies of personnel turnover and job rotation can expose the firm to the risk of weakening the core competencies embedded in the organizational routines rather than in individuals, thus reducing the effectiveness of organizational interfaces and communication channels (Fujimoto, 1994). In this scenario, it becomes clear the importance of every managerial action directed to support companies in the knowledge management processes.

Among the different streams of a dynamic and still diverse literature, that overlaps to some extent other well-established fields of studies, such as the learning organization, decision support

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systems, business process reengineering, three main directions can be highlighted, at least for the aims of this research.

The first concerns the analysis of the knowledge nature, i.e. the shapes in which it can be recognized and utilized in the organization. There exist several analyses that adopt different perspectives and lead to different classifications. For instance, Nonaka (1991) stressed the difference between tacit knowledge, usually embedded in individuals or in procedures and informal organizational relationships, and explicit knowledge, that one can find in written documents or electronic files. Bohn (1994) developed a knowledge taxonomy related to the ability of problem solving and to the nature of the information used. He distinguished eight levels of knowledge, from the awareness of a problem, to the ability of locally controlling a phenomenon, up to the capability of producing formal and general models. Faulkner (1994) analyzed the innovation processes, by reviewing the work of scholars committed to clarify the difference between scientific knowledge and engineering knowledge. She came to define five categories of knowledge, each characterized by two extreme types: tacit and explicit, observable and non observable, simple and complex, elementary and systemic, context-specific and context-free.

The second research stream concerns the study of the knowledge management processes. For instance, Nonaka (1994), according to his model of knowledge nature, defined four basic processes: socialization, externalization, combination, internalization. Coombs and Hull (1998), moving the unit of analysis from knowledge to knowledge management practices, identified the processes of knowledge generation, transfer and use, as the most important and analyzed in the literature. The same authors distinguished also some additional processes, such as identification, extraction from memory, codification, validation, contextualization. Davenport et al., (1998), by analyzing some successful cases of organizational reengineering aimed to improve knowledge management, stressed four main managerial goals: developing organizational memories, sharing knowledge, improving information access, making culture and environment more suitable for knowledge management. Finally, Ruggles (1997) classified three main categories of knowledge management processes: knowledge generation, codification and transfer.

The third research stream concerns the role of Information and Communication Technologies (ICTs), and more in general of Information Systems, in the new perspective of knowledge management (Hansen et al., 1999). Some of the most interesting debates, such as the change of managerial policies due to the adoption of information technologies or their organizational impact, which was already popular in the ‘80s, are today discussed under a new light. Despite the large variety of the existing technologies, it is possible to draw up some general observations. First, the development of technologies for managing knowledge is strictly related to the research on knowledge management processes and practices, previously mentioned. For instance, some technologies are oriented to build effective organizational memories (Abecker et. al, 1998), others support communication and information sharing within organizations (O’Leary, 1998), others aim to improve the access to the information stored (Davenport et al., 1998), while more difficult attempts have been done to support the knowledge creation process (Ruggles, 1997). Second, the support to management activities, which in the past was strictly related to effectiveness and efficiency of data gathering and processing, is today much more centered to cognitive processes, i.e. to the ability of supporting the typically human processes of giving meaning to information and using information to solve problems. It can be stressed that the research in the knowledge management field considers the role of ICTs quite different than in the past. For instance, the early aim of Artificial Intelligence (AI) was that of replacing the human intelligent information processing (in its elementary forms) with artificial information processing. In the current perspective, the main aim becomes to integrate technology with the individuals' cognitive processes, as well as to foster and support the same processes at an organizational level. The focus then shifts from «managing information» to «managing knowledge».

In manufacturing, in particular, emerging models like *lean production*, *agile manufacturing* and *world-class manufacturing* have restored the emphasis on human capabilities and organizational skills and led to rethink the role of information technologies (Schonberger, 1986; Hayes et al., 1988; Womack et al. 1990; Bartezzaghi et al., 1994). This witnesses how effective problem solving processes in manufacturing are more and more dependent on decision makers' creativity and experience, and on information systems able to support, more than automate, decision making.

This paper proposes a cognitive approach to the analysis of manufacturing problems. The approach is aimed to identify the characteristics of the cognitive processes involved in a given manufacturing problem. The analysis of such processes is important to evaluate the effectiveness and efficiency of problem solving with respect to both organizational activities and the use of information technologies.

A Cognitive Approach To Manufacturing Problems

Manufacturing problems can be analyzed from several perspectives. The main are probably the technological and the managerial ones. From a technological point of view, the relevant descriptive factors are operation features, work methods, tools, equipment (Chryssolouris, 1992). The managerial point of view considers factors such as manufacturing strategies, organizational structure, information flows (Voss, 1992).

Among the most remarkable perspectives, there is the socio-technical approach, which is more oriented to cognitive processes and represents the attempt to integrate the technological and managerial approaches (Klein, 1994). As an example, Karwowski e Salvendy (1994) base the analysis of manufacturing also on learning curves, man-machine interaction, individual competencies and experience. This research track is a significant reference to develop a cognitive approach to manufacturing problems, in a perspective more oriented to knowledge management. To this aim, it is necessary to define the unit of analysis and consequently to properly identify the cognitive processes.

To define the unit of analysis, it should be noted that focusing the observation on the characteristic elements of cognition does not necessarily mean focusing only on human actions. In fact, since knowledge management technologies are designed just to support cognitive processes, also the activities where the information technology prevails over human actions can be included in the unit of analysis. Usually, the activities which require exclusively human skills, like intelligence or creativity, are those related to unique problems, non repetitive and unstructured; conversely, repetitive and well structured operations can be more effectively carried out by technology and allow drastically reducing human actions. What makes routines and innovative problems different is the predictability of some environmental conditions. As a matter of terms, a «process», which often identify the research unit of analysis in the manufacturing field, mostly refer to standard or routine operations. On the contrary, a «problem» usually does not refer to the routine activities of a process, but it deals with «problem solving» as a particular case (the highest level) of learning. As stated by some relevant pedagogist (for instance, Gagné 1970), facing problem solving individuals develop new behavioral rules in a complex way, i.e. dependent on many factors, becoming subjects of a learning process.

The unit of analysis which this paper considers, i.e. the manufacturing problem, is then necessarily a complex term, including both routines, corresponding to problems already faced in the past with solutions now embedded in the organization's behavior and knowledge, and innovative situations which require an intelligent problem solving process. While in the former kind of situation information technology enables automation, the latter one can be effectively supported by the same technology, but more consistently with the knowledge management aims.

Once the unit of analysis is defined, the following step is identifying the cognitive processes involved in a manufacturing problem. The literature analysis leads to identify four basic cognitive processes: generation, memory, transfer and codification.

Knowledge generation involves several activities (which the literature often reports as separate cognitive processes, like acquisition, creation, synthesis) which produce new behavioral or decisional rules, as well as new individual or organizational problem solving strategies (Ruggles, 1997).

Knowledge memory involves activities like data and information storing, and their retrieval from knowledge bases to be applied to a context (Walsh and Ungson, 1991). Memory is clearly an individual cognitive process, but it is usually extended to the whole organization, representing a basic element for information systems design (Kim, 1993).

Knowledge transfer refers to communication processes among individuals or organizations. It is a complex process because knowledge is often local, that is specific with respect to the individual which embeds it or to the context where it is applied («sticky» is the term used by von Hippel, 1994). This implies that knowledge can change its format or contents after the transfer, since it is applied by a different individual or in a different context. More generally, the data transfer occurring among information systems can be considered as knowledge transfer too, if it is viewed as an elementary activity in a broader process including data interpretation and their application to actual contexts.

Finally, knowledge codification means the process of changing the knowledge state or representation. Typically, the literature identifies as tacit and explicit the two extreme states that knowledge can assume (Nonaka, 1994), and sometimes the term «explicit» is replaced by «codified». Actually, a «code» identifies both a format by which knowledge can be managed, communicated and processed, and a means of communication and/or processing. While the tacit form can be associated with non-codified knowledge, explicit knowledge can be codified in several forms, such as for instance written documents, electronic database, input-output rules or analytical models.

The literature, as cited above, is rich of typologies of knowledge management processes. Many of them (use, capture, sharing, organization, diffusion) can be included in the considered four types, as synonyms, sub-sets or super-sets. It is worthy noting that the term «learning» is note explicitly present in the model. The reason is that it is usually considered too complex to be used as an elementary process of knowledge management. Although knowledge generation is clearly very close to a learning process, it is not the only one. For instance, effective learning is always associated with the memory of the rules produced by problem solving. Moreover, learning often needs the content codification (such as in the use of different teaching means). Finally, it can involve knowledge transfer rather than autonomous generation (such as in many cases of teaching).

A manufacturing problem can then be characterized by the identified four cognitive processes. An examples is useful to clarify this statement. Let us consider a new product design. It is strongly associated with knowledge generation, but also other processes can be involved, depending on some specific context factors. For instance, as the firm size increases, the knowledge transfer among organizational units can intensify. Depending on the industry or the production system, memorizing the generated information can be more or less required (retaining problem solving solutions can be more critical for high-tech companies or project oriented productions). Moreover, the new product design can also be affected by the nature of the knowledge involved: in companies which more tightly make use of personal interactions and team-based design, knowledge can flow tacitly. This can modify both the transfer policies and the way knowledge is memorized by the organization.

A Model For The Analysis Of Manufacturing Problems

The cognitive processes described in the previous section, i.e. knowledge generation, memory, transfer and codification, can be used to define a knowledge-based model for the analysis of manufacturing problems. These processes can allow classifying a specific manufacturing problem, providing elements to evaluate, according to a cognitive perspective, the performance of the considered problem solving.

However, the evaluation of the contribution of the cognitive processes to the solution of a manufacturing problem is not a simple task for the management, for two main reasons. The first is that operations managers usually do not have the conceptual tools to analyze those cognitive processes, which are particularly complex even for knowledge management experts. The second is that a knowledge-based analysis must consider the cognitive processes which really take place in a manufacturing problem solving context independently on the human and technological resources available in that context. However, the evaluation of the consistency between the cognitive characteristics of a manufacturing problem and the actual resources involved is an important subsequent aim of the analysis, since it leads to the evaluation of the efficiency and/or effectiveness of the decision making process carried out in the practice.

To define the knowledge-based model, it is considered opportune to associate some operative variables (proxies) to the considered cognitive processes, in order to describe the manufacturing problem. Generally, the analysis of the characteristics of a cognitive process involves several aspects, dependent both on the process nature and on the specific context considered. Its complete description could then require the evaluation of many variables.

In the proposed model, one variable representing each cognitive process has been considered, selected on the basis of organizational and cognitive considerations about the generic manufacturing problem solving. The choice of this approach is due, first of all, to the aim of making the model simpler, proposing, at least in this phase of the research, a more operative model instead of pursuing a cognitive accuracy. Second, the possibility of subdividing each variable into more elementary variables, necessary to accurately analyze specific actual cases of manufacturing problems, has been rejected in this phase, aiming at building a general model for a manufacturing problem classification.

The variables considered are *uncertainty* (associated to the knowledge generation process), *time-dependence* (memory management), *space-dependence* (knowledge transfer), and *knowledge codification level* (knowledge codification). These variables can be considered dimensions of a *knowledge map* of manufacturing problems (Figure 1). The evaluation of the variables, that is the determination of the position of a real manufacturing problem on a specific axis, allows characterizing that problem in the map.

The first map dimension refers to the various forms and degrees of uncertainty that characterize the scenario in which the specific problem solving takes place. It is then related to missing or unreliable data, ambiguous interpretations (resulting in uncertain information), and limited human capabilities (resulting in uncertain knowledge) (Karwowski and Mital, 1986). The uncertainty of the scenario is connected to the repetitiveness of the decisions: the higher the former, the lower the latter (Simon, 1960). As a consequence, uncertainty can be regarded as a proxy of the knowledge generation process: while in certain, deterministic conditions, routine problems are addressed and no knowledge generation usually takes place, in uncertain conditions, characterized by high variability and complexity, problems appear unstructured and require new kinds of solution, which are at the basis of individual and organizational learning.

The second map dimension refers to the time-dependence of the problem solving. It can concern the need of information related to previous experience as well as to future scenario forecasting. Since also in the last case the problem is actually dependent on previous data, this variable is a proxy of cognitive processes related to memory management, such as knowledge *storage* and *retrieval* from memory (Walsh-Ungson, 1991).

The third map dimension, space-dependency, refers to the organization boundaries of the specific problem solving. In particular, this parameter defines the communication requirements of the problem with external sources (other organization units, IS, etc.). This proxy of the knowledge transfer process then ranges from local, in case of problem solving that does not need any external information, to integrated, for problem solving which strongly require external information and competencies.

Finally, the fourth map dimension refers to the knowledge nature mainly embedded in a specific manufacturing problem solving. In particular, in this model the knowledge codification level has been considered as a proxy of the codification process (Albino et al., 1998; Bohn, 1994). This variable also provides a measure of the human and organizational involvement in the specific problem solving. In fact, as reported in the literature, it ranges from a highly tacit level, where knowledge can be described by qualitative (e.g., input-output) and, to some extent, subjective models, since it is embedded in individual abilities or in organizational routines, to an explicit level, where knowledge can be described by more exact (e.g., analytical) and objective models.

In Table 1, the cognitive processes considered, their proxies (map dimensions) and, in correspondence of their extreme values (high or low), the main problem solving characteristics are briefly reported.

After the classification of a specific manufacturing problem based on the proxies representing each cognitive process, the analysis of the problem position on the map can be useful to understand some systemic aspect of the problem, such as the resources suitable to face it (actors and support tools) or the effect of eventual actions aimed at improving the problem solving performance. To make some considerations about these aspects without referring to specific manufacturing problems, it is necessary to make some hypotheses about the proxy values to be considered, and then on their possible combinations.

Only two values (high/low) for each variable are then considered. Sixteen classes of manufacturing problems are thus obtained, each one characterized by a different vector (combination of values) of the four proxies. To further simplify the interpretation analysis, the knowledge map has been divided in two parts, considering the set of problems characterized by low uncertainty (and knowledge generation) first and then the set of problems characterized by high uncertainty. In each set, the characteristics of the manufacturing problems are analyzed considering the values of the other three variables, that is knowledge codification level, time-dependence and space-dependence. This choice of representation is mainly guided by the simplification of reading, compared to the description of a four-dimension table. Moreover, this representation also allows focusing on the meaning of some planes of the map, particularly those related to a certain knowledge nature (codification level), as well as to show either possible interventions of knowledge management or the effects generated by the cognitive processes on a given problem solving. The choice of uncertainty, and then of the knowledge generation process, as the variable splitting the two sets of problems, is not casual, too. In fact, it is due to the influence that this type of variable, from a cognitive perspective, has on the tendency of the manufacturing problems towards, from one side, the problem solving automation (when the context is not very uncertain and the problem are quite repetitive), and, from the other side, the decision making support (when the context is more uncertain and the problems are less repetitive).

Let us consider first the case of a manufacturing problem characterized by low uncertainty, and then by limited generation of new knowledge (Figure 2). In the map, this kind of problems, where the explicit nature of knowledge is prevalent, are represented in the plane with a high codification level. In this plane, we can typically represent those problems which can be effectively automated, even giving up to flexibility (rigid automation), because the operational context can be mainly described by analytical models and can be generally determined *a priori*. Among these problems, there can be some strictly localized in a specific organizational unit, and some other that requires an integration among different organization units. In the last case, the problem solving can be supported by appropriate transfer tools, such as the *Electronic Data Interchange* (EDI). In this plane, the problems can also require information and knowledge previously gathered, or they have to produce and record information (for instance, for the process control and maintenance), so that a database or knowledge-base can be necessary. In this automation plane, the *Computer Integrated Manufacturing* approach can also be represented, in its original idea of automated process integration.

In correspondence of a low codification level, there are those problems located on the plan parallel to the previous one, including the origin of the diagram axes. This plan includes all those manufacturing problems that, besides being repetitive, are characterized by a mainly tacit nature of the knowledge used. In these problems, the human intervention is prevalent, and the activities carried out are not very rich of intellectual contents (in particular, they are poor of creative tasks). The problems of this class present different characteristics according to the required type of interaction among different organizational units. If this interaction is considerable, the tacit knowledge transfer mainly require personal interaction mechanisms (socialization) and organizational procedures (routines), which can be supported by standard (telephone, etc.) and multimedia communication tools. The eventual time-dependence of these problems puts in evidence the need of higher experience or qualification in the specific problem solving, which can become part of the firm intangible (cultural) assets when knowledge is spread and shared within the organization. It is also opportune to mention that time dependent problems can be supported by some artificial intelligence applications, such as those based on fuzzy sets and neural networks, that, describing by examples or input-output rules the typical way of reasoning of individuals, can be used to manage the tacit knowledge usually embedded in this kind of problems.

All the manufacturing problems previously analyzed, characterized by a low uncertainty context, have a common feature: they can be benefited by a knowledge codification process, particularly suitable to the repetitive and uncreative specificity of these problems, which improves the problem solving performance moving towards the process automation.
The manufacturing problems characterized by a high level of uncertainty, and then by a high generation of new knowledge, are reported in Figure 3. Usually the solution of this type of problems can not be completely automated, due to the necessary flexibility and creativity typically required by this kind of problem solving, where human resources have generally a fundamental role.
Among these problems, those characterized by a high codification level, where the explicit nature of knowledge is prevalent, can be effectively supported by information tools such as (Group) Decision Support Systems, Computer Aided Systems (such as CAD), and Intranet systems.
For problems that require a high integration with other organization units, the Communication Technologies become particularly important, while, in case of need of past experience or information, it can be stressed the relevant role of Expert Systems, which, through the experts' knowledge codification process, try to imitate and support the decision makers.
When innovative problems are also characterized by a low codification level, the role of human resources is generally fundamental, due to the tacit nature of knowledge. These problems can be very complex, and can be solved by the uncommon or outstanding ability of individuals, such as in the case of artisans and professionals. This is particularly true when the problem solving is also strictly dependent on the experience (time dependent problems). The artificial intelligence technologies (for instance, case-based reasoning and knowledge-based systems, but also neural networks and fuzzy logic) can be used in these contexts, but aiming more at supporting and capturing the expert's knowledge, than at the process automation. When there is a high requirement of organizational integration, the creative role of the inter-functional teamwork is emphasized, for which the ICT support is today widely investigated (Groupware, Multimedia, etc.).
In this second set of manufacturing problems, characterized by high uncertainty, the codification process of the tacit knowledge is more oriented to the development of problem solving support tools, more than to their automation. Moreover, these problems usually receive benefits by a deeper organizational integration, and then by the development of systems aimed to support new knowledge generation, such as Group Decision Support Systems.

Some Examples Of Manufacturing Problems: MRP and Process Planning

Let us consider a classical manufacturing problem such as the Material Requirements Planning. The definition of the MRP typically requires data from the Master Production Scheduling, the stock levels, the end item bills of materials, some parameters concerning the production and supply processes (such as lead times and batch sizes). Depending on the specific organization context, the problem can be addressed in many different ways.
In a medium or large organization, for instance, the problem can be typically characterized by limited uncertainty, mostly codified knowledge, wide organizational interaction, high dependence on past experience. In such contexts, in fact, due to the high job specialization, the information and knowledge used and generated by MRP (such as actual resource capacity, supply lead times, etc.) are mostly available, detailed and highly formalized, so that uncertainty is quite restricted. Moreover, interactions between different organization units (for instance,

among production planning and shop floor, procurement, logistics), as well as among different companies (e.g., suppliers and client) can be required, and historical data can be considered (e.g., the performance of the supplies and of the production process). This problem can then be effectively supported by information systems oriented to the automation of the process, as the knowledge map plane corresponding to a high codification level and low uncertainty suggests. Systems such as the MRP II can be considered suitable for this kind of problems, as well as a direct link (e.g., by EDI) between the suppliers and the production planning process of the client, aimed at the integrated management of the supply chain.

However, if this can be a typical knowledge map of the MRP problem in a medium or large enterprise, in other firms it can show different characteristics, such as, for instance, a limited reference to past experience or the absence of inter- and intra-organization interactions (low values of *time*- and *space-dependence*). These characteristics can be determined either by the organization context specificity, or by "pathological" aspects of the process. An example of the first case could be that of a small firm, such as a specialist supplier, where the managerial tasks usually in charge of few individuals (low job specialization) could require fewer organization interactions, while the limited product mix range could make the past experience less useful. An example of pathology could be that of a medium size enterprise where the characteristics of the MRP problem are similar to those of the large companies, but it is actually addressed inefficiently or ineffectively due to, for instance, an irregular memorization of the real production parameters, or to an unreliable control of the stock levels. Moreover, the MRP problem, apparently based on knowledge mainly codified, can be addressed in many contexts by methods not completely scientific or rational, where the contribute of tacit knowledge (individual beliefs and experience, organizational routines) can result determinant in the specific problem solving.

Generally, then, pathologies or context peculiarities which generate inefficiency and/or ineffectiveness in a specific problem solving can be caused by the poor quality of the processes as well as by inappropriate utilization of technology and human resources. The cognitive approach proposed for the analysis of the manufacturing problems is aimed at putting in evidence these wastes, evaluating both the presence of inconsistencies between the actors or tools involved in the problem solving process and those which would be more suitable to carry on the task required, and the support that some cognitive processes (for instance, in the case of the previous pathologies, memory and knowledge transfer) could offer to the problem solving in order to improve its performance.

Another example is that of process planning (PP), which can be considered a manufacturing problem consisting in developing a set of instructions regarding the processes, equipment and people to be involved in an item production. PP takes into account a number of factors which influence the selection of the different processes and their operating parameters (shape and size of the work piece, tolerance, surface quality, materials, quantity to be made). PP requires from a human the ability to interpret a particular design and find substantial familiarity with other manufacturing processes and equipment.

Current approaches to PP are (Chrissolouris 1992): 1) *Manual PP*, which is completed assigned to operators' abilities, 2) *Workbook approach*, that, like the manual method, is based on the planner experience, preference, extent of shop knowledge, interpretation of design requirements and many other judgmental factors, and involves cataloging sequences of operations for given families of items, 3) *Variant PP systems*, that allows rapid generation of process plans through comparison of features with other known features in a database of standard process plans (in this approach, group technology can support a database of standard process-grouped family plans where information is easily managed, retrieved and implemented in computer algorithms), 4) *Generative process planning*, that relies on a knowledge base to generate process plans for a new design, independently of existing plans. The knowledge base is a set of rules derived from the experience of a human process planner (only for few specialized applications). Artificial intelligence techniques like formal logic, for describing components, and expert systems, for codifying human processing knowledge, are also applicable.

The four approaches present different cognitive characteristics. These characteristics are also dependent on the specific organization context, since the PP approach adopted by a company usually is only partially classifiable as one of those evidenced, due to the specific organizational, technical and managerial peculiarities of the environment.

Among the common elements of the different approaches, the problem uncertainty, i.e. the relatively low repetitiveness of the problem, which usually places the PP among those problems characterized by high knowledge generation, and the high time-dependence, because the PP is a problem generally based on the past experience and the knowledge memory, can be mentioned. In particular, time-dependence appears different according to the approach considered, and is interwoven with the knowledge codification level. Referring to the knowledge map, the PP can then be positioned, for the first three approaches, at high time-dependence levels and increasing codification levels (up to Computer Aided Process Planning), while the fourth approach is based, more than on standard cycles previously recorded, on rules (*knowledge-base*) useful to support the codification of the experts' way of reasoning. Finally, the space-dependence seems to be characterized more by the specific context than by the adopted approach. It is usually characterized by the interaction between the production and design areas, and the more organizational and managerial practices (such as concurrent engineering) are used in a specific context, the stronger the interaction.

Conclusions

In this paper, a cognitive approach for the manufacturing problem analysis has been proposed. A knowledge map has been defined based on the main cognitive processes embedded in the problem solving process. Knowledge generation, memory, transfer and codification are the cognitive processes represented by the proxies of uncertainty, time-dependence, space-dependence and knowledge codification level, respectively. The location of a specific manufacturing problem on the map allows to identify its cognitive characteristics, so that, for instance, suitable ICTs can be selected to support and/or automate the problem solving process. Moreover, considering the possible changes of the cognitive characteristics of a given problem solving context, it is possible to evaluate the effects of eventual interventions aimed to improve the process. Some examples have also been provided to show the possible implementations of the model.

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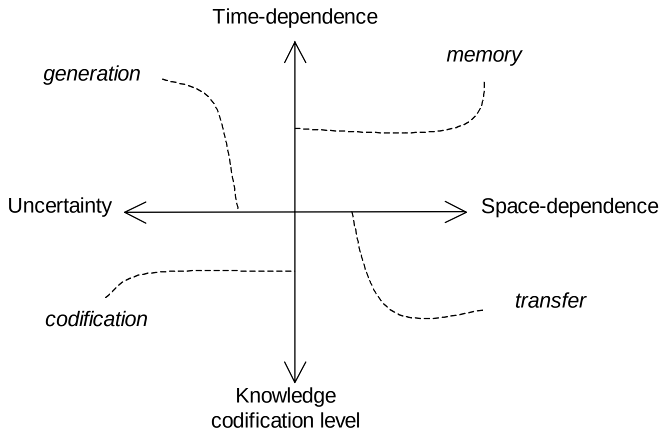

Figure 1. Knowledge map of a manufacturing problem.

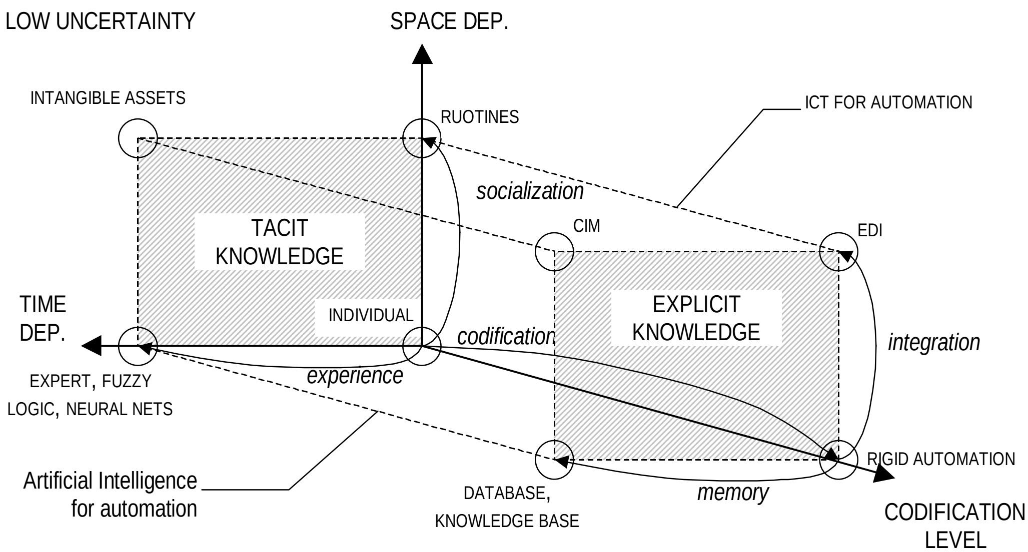

Figure 2. Three-dimensional knowledge map, for low uncertainty.

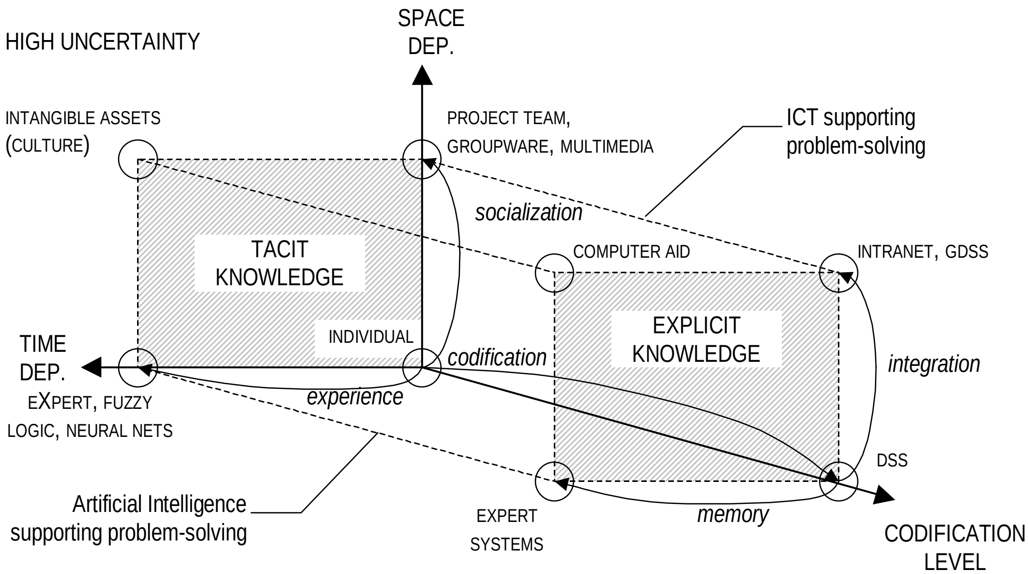

Figure 3. Three-dimensional knowledge map, for high uncertainty.

Table 1. Cognitive processes, map dimensions and typical proxy values.

Cognitive Process	***Map dimension (proxy)***	***Proxy values*** *Low*	*High*
Knowledge generation	*Uncertainty*	Routine	Unstructured
Memory management	*Time-dependence*	Time-independent	Experience or forecasts
Knowledge transfer	*Space-dependence*	Local	Integrated
Knowledge codification	*Knowledge codification level*	Input-output rules	Analytical models