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# Towards a knowledge-based framework for digital chain monitoring within the industry 4.0 paradigm

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## Abstract

The industry 4.0 paradigm is currently one of the domains that presents various problematics with high challenges for research and manufacturing experts. Among the industry 4.0 topics, digital chain monitoring has a great impact on the performance of the company. Indeed, less connection of enterprise information systems and data sharing between business departments of the company can result on over costs and serious delays regarding the operational planning. In manufacturing companies, virtual barriers can exist between the operational management and the shop floor due to security, confidentiality, and interoperability issues. Consequently, feedbacks about the real activities and events in the shop floor are not regularly transferred to the decision making departments (i.e. process engineering, maintenance, etc.). In this context, this paper discusses the potential of knowledge structuring through a common repository as a solution to support the continuity of the whole digital chain. A knowledge-based platform is proposed as part of the SmartEmma French research project with the aim to provide actors with relevant contextual information and useful indicators based on data collected from machines and other information systems.

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*Keywords:* Industry 4.0, Digital chain, Knowledge management, Structuring

## 1. Introduction

The fourth industrial revolution is currently affecting increasingly various technological fields. It requests complementarity and collaboration between several scientific disciplines. This is manifested through the emergence of new computer technologies, cyber physical systems, artificial intelligence, decision support, and data science in industry [1][2].

Among the areas affected by this revolution, and in which the present research work is integrated, concerns the high-speed machining of mechanical parts in aeronautic industry.

The major challenge in this sector is to produce good quality parts from the first time, while minimizing working time and reducing manufacturing costs.

The specificity of aeronautical parts results from the fact that they have very high added value, are quite expensive and must satisfy quality and safety constraints that are too high.

Currently, several research studies are interested in the study of the industrial digital chain in order to understand the flows of information generated and exchanged, and this, by trying to capitalize and manage data as much as possible.

As part of this research work, we are interested in studying all aspects of the digital chain, its interruption problems, as well as the existing solutions to ensure the different forms of interoperability in industries.

The issues of digital chain monitoring are not limited to data, but concern also the capitalization of all kinds of useful industrial knowledge. Knowledge models and meta-models are useful to support semantic interoperability between heterogeneous data bases within the whole digital chain. To achieve this goal, this paper introduces a knowledge-based framework that aims to support intelligent reasoning and decision making. This framework addresses the traditional issues of knowledge management: capitalization, structuring, analysis, reuse and reintegration. Connected to all decision

levels of the factory, the ambition is to use the proposed framework as a backbone of the digital chain to support interoperability between involved tools. To do so, the structure of the knowledge repository is based on the well-known STEP-NC standard.

The remaining of this article is organized as follow. The next section explains the main elements that compose the industrial digital chain. Section 3 examines the most frequent and defective failure problems that can affect this digital chain. Then, we will discuss the state of the art on existing solutions to face these problems. Finally, this article describes the scientific proposal which is in the form of a knowledge-based Framework. The structuring solution, the layers that compose it and its utility to ensure interoperability will be detailed.

## 2. Digital chain in a machining industry

### 2.1. The phases of the industrial digital chain

In order to describe the industrial digital chain of the machining of mechanical parts, it is necessary to start by distinguishing its three main phases: Design, industrialization and production. Design is the first phase of the realization process of a mechanical part. This step begins at the design office, it consists on the definition of the 3D geometry of a part based on the needs and the requirements of the customers, and using Computer Aided Design (CAD) software. Industrialization is the intermediate phase, which represents the task of the methods office, which consists in generating the manufacturing range, choosing the tools to be used during machining, carrying out trajectories, etc.

The programming service, transforms the data provided by the design office into a G code (ISO code) through the programming of parameters and trajectories to be carried out by the Numerically Controlled Machine Tool (NCMT), and then transcribe them into machine language at through the Post-Processor.

It is possible to find a simulation step, which consists in simulating the G code and validating its operation and therefore the conformity of the machined part with customer requirements. This operation allows also the detection of possible collision problems of the tool. The last phase is the production, it is a step planned by the CAPM software (Computer Aided Production Management) that starts when the NCMT executes the ISO program after having received the manufacturing order. Once the part is machined, a first control phase is applied to validate its conformity. If a defect occurs, the part is processed to ensure its conformity and finally an inspection is established in order to have a finished part ready for delivery [3].

After studying the industrial digital chain, as well as all the software resources and materials used in the various stages of manufacturing a mechanical product, we can notice the enormous amount of data generated. This article, details just a part of the digital chain of the production system, but do not forget all the other services: administrative, commercial, strategic, distribution, etc. The variability of these data sources

inevitably results in a large difference in types, frequencies, formats, etc.

In the literature, several studies deal with the themes and the different definitions of the DIKW pyramid: data, information, knowledge, Wisdom, etc. [4],[5].

### 2.2. Breakdown problems in the digital chain

Despite the various existing information flow management tools, there are very serious breakthrough problems in the digital chain, and these are the origin of the emergence of the 4th industrial revolution.

The main cause of the breakdown of the digital chain in most industries is the lack of traceability. In the context of the industrial field we can define traceability as the identification of the product (the mechanical part in our case), as well as the analysis of its situation and the generation of reports, at each step of the manufacturing process, as soon as the raw material is acquired until the delivery of a finished product. Therefore, a better understanding of the specificities of the industrial information flow guarantees a good traceability of the implementation conditions, resources and the processes used, the standards that control their use, etc[6].

Traceability is crucial for production monitoring, and automatically ensures product quality, customer satisfaction and competitiveness of the industry. The lack of traceability in the aeronautical industry can take several forms, for example manual processing. When the technician detects a non-quality problem, he proceeds to the improvement of the quality of the part without describing the steps and methods used during the finishing process. This is a lack of capitalization of the technician's expertise and therefore a lack of traceability. Also when changing the ISO code due to non-conformity of the part, generally the modifications made by the programmer are not necessarily tracked and capitalized. An absence of traceability causes mainly a huge waste of time.

There are several other reasons for the breakdown of the digital chain, one of these major problems is the lack of communication between the various departments of the company. This is the phenomenon of data partitioning for each service.

In the industries, there is also a disconnection between the information system and the workshop's computer network. Unfortunately, these problems become much worse when industry is increasingly developed, such as the case of manufacturing industries with distributed production sites, which use an innovative strategy: the delocalization of manufacturing, and/or the subcontracting of one or more of its main activities (design, production, delivery), is the extended enterprise model. To obtain the best combination of resources and skills, the actors of an extended company can be geographically dispersed. This requires the implementation of advanced collaboration and information exchange systems. The recent and massive use of information and communication technologies in companies has facilitated these exchanges. We can conclude that the complexity of organizations generates the complexity of information

exchanges, hence the deficiencies in communication within the same industry.

Figure 1 represents some examples of these aspects of ruptures that have just been addressed. In the figure, the first example of rupture represents the lack of communication between the offices and the workshop. The second break is the one that encloses the machine in a black box. There is material entering, a program and a finished part. And the third rupture is for example in case of a lack of traceability following manual completion.

In all three cases the rupture is not completely over.

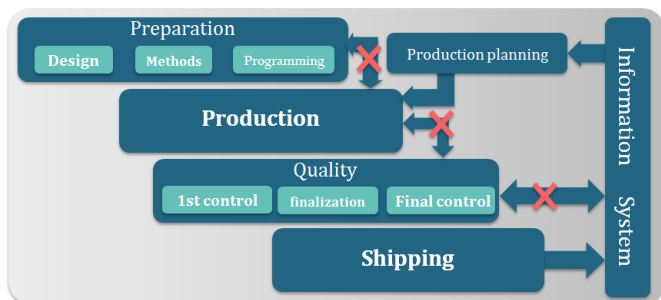


Fig. 1. Example of a breakdown in the digital chain

The development and delocalization of industries produces another one involuntarily causes of the breakdown of the digital chain. In an extended company there is a wide diversification of hardware and software technologies used computer networks, etc. This multiplicity of production methods generates a diversity of formats in the generated information flow, and especially a difference on the delay of these data due to the variation in sampling, acquisition, and processing frequencies.

This is therefore an incompatibility at the time of interoperability and/or collaboration.

### 3. Existing solutions for interoperability

#### 3.1. What is interoperability?

ISO 25010:2011, which replaces ISO 9126:2001 about software quality, defines the notions of compatibility and interoperability:

“Compatibility is the degree to which a product, system or component can exchange information with other products, systems or components, and/or execute its required functions, while sharing the same hardware or software environment. This characteristic is composed of the following sub-characteristics. Coexistence: The degree to which a product can perform its required functions effectively while sharing a common environment and their resources with other products, without negatively impacting any other product. Interoperability: The degree to which two or more systems, products or components can exchange information and use the information that has been exchanged.”

We can thus conclude that interoperability is one of the solutions to the problems of disruption in the industrial digital chain.

The need of collaboration between the different actors of the company imposes the necessity of sharing a set of data which are shared by several resources and can be managed by several information systems. We can therefore deduce that the need to ensure interoperability is very crucial.

There are many meanings and types of interoperability, and the large number of definitions that we can find with a literature review is the proof.

The definition most frequently cited in the literature is the IEEE one, which presents the basis of interoperability:

“The ability of two or more systems of elements to exchange information and to use the information that has been exchanged”.

Facing these varieties of definition, the literature proposes several classifications of interoperability [7] [8], and we can mention the four main ones:

1. Technical interoperability that concerns the software and hardware communication, data formats, standards and telecommunications protocols. This first type deals with the technical problems of linking systems.
2. Semantic interoperability allows to define a common semantic reference. Here, it is more the semantic level and the meaning of the information exchanged that is treated. The objective is to provide the exact meaning of the information exchanged so that it can be understood by any other application.
3. Syntactic interoperability concerns the way in which data is coded and formatted, defining in particular the nature, type and format of the messages exchanged. It offers an open system allowing the heterogeneity of components.
4. The interoperability of organizations and processes facilitates communication between organizations, components of the same company, and between several companies. The principle of this type of interoperability is to define rules and principles to facilitate synchronization and connections between processes.

The AISBL (Association Internationale Sans But Lucratif) association INTEROP-VLab (the European Virtual Laboratory for Enterprise Interoperability) was created in order to capitalize and link the community working on the field of interoperability in Europe. the objective of its foundation is to develop the research network through improving visibility on other projects in this field.

To ensure interoperability in the industrial digital chain, several research projects are working daily to find solutions.

In the context of industry 4.0, the capitalization, reintegration, and reuse of heterogeneous knowledge in the digital production chain are essential to ensure interoperability. In the literature we find several works that deal with the subject of interoperability in the industrial context. The analysis of these research studies shows the use of two major solutions: standards or protocols for information exchange, and ontological models for knowledge capitalization.

### 3.2. Ontologies

Ontology is a technique for representing and organizing knowledge in a specific field of application using reasoning and inference mechanisms [9] [10].

In the literature, several definitions of ontologies have been proposed, including those proposed by [11]: "Ontology is an explicit specification of a conceptualization" and also those proposed by [12]: "An ontology provides the tools to explicitly describe the conceptualization underlying the knowledge represented in a knowledge base".

According to [13], "ontologies have the role of providing a system of fundamental concepts of the field in order to build a solid base on which are developed sharable and usable knowledge bases". All these fundamental concepts are described in [11][12].

1. Concepts or classes: the notions that describe a task, function, action or reasoning process. They can be abstract or concrete, elementary or compound, real or fictional. Usually, concepts are organized in taxonomy. It's a hierarchy of concepts linked together according to specific semantic criteria.
2. Relationships: the interaction between two or more concepts. Examples of relationships are "subclass-of" or "connected-to".
3. Functions: a special case of a relationship with n elements where the last element of the relationship is unique for the first n-1 elements.
4. Axioms: allow to define the semantics of terms (classes, relations), their properties and any constraints regarding their interpretation. They are defined using well formalized formulas of first-order logic using ontology predicates.
5. Instances: used to represent the elements.

### 3.3. Standards

In the ISO standards catalogue, Part 25 contains a set of definitions that standardize the manufacturing environment. In this category, there are several sub-categories and mainly:

- 25.040 - Industrial automation systems
- 25.060 - Machine tool systems
- 25.080 - Machine tools
- 25.100 - Cutting tools

In the mechanical parts machining industries, the most commonly used standard, especially for the optimization of production and feedback is: STEP-NC (ISO 14649).

STEP-NC (ISO 14649) (STEP compliant Numerical Control) has been developed following the implementation of several industrial and academic research projects carried out by organizations working in the field of machining (Milling, Turning). But finally it was developed by International Standard of Organization and published on June 2006. The standard It was a replacement for G-Code (ISO 6893) and improved the STEP (ISO 10303) (STandard for the Exchange of Product model data).

The STEP-NC standard, by covering the different types of information, allows their propagation over all the stages of the digital chain [5]. The problem with the STEP-NC protocol is

that it does not allow either communication with the company's information systems or the capitalization of knowledge. In the literature, the research focused on product data modeling, manufacturing processes in production industries has highlighted the usefulness of ontological models for capitalization and information exchange. A literature review, provided some examples of production-oriented ontological models: "Product Design Ontology" (PDO) [14], MASON (Manufacturing's Semantics ONtology) [15], ONTO-PDM [16], PRONTO (PROduct ONTOlogy) [17], "OntoSTEP-NC" and the "Closed-Loop Manufacturing" process [5].

After processing all these solutions for ensuring the interoperability and communication of knowledge between industry departments, we notice that most of these works are oriented towards partial communication, mainly between the services involved directly in the realization of the product: design, production, assembly, etc.

There is also another form of lack of communication in industry is that between the different information systems in companies. Our project fits perfectly into this context, offering solutions to the various aspects of the breakdown of the industrial digital chain.

## 4. The knowledge-based framework "A solution to the digital chain interruption"

The main objective of our research work is to ensure evolution in the field of high-speed machining through the implementation of intelligent and connected machine tools. This project is therefore integrated into the problems of industry 4.0, through the monitoring of machining, the extraction of key performance indicators (KPIs), and the piloting of the different knowledge in the industry, in order to be able to plan failures, making decisions, etc.

The development of the framework revolves around four axes: data capitalization, data analysis and knowledge extraction, business rules definition, and finally the bidirectional piloting of information between the workshop and the various services of the industry.

The complexity and specificity of the technological architectures adopted and the resources used, require us to efficiently choose the best management tactics. In our project, we identify two types of piloting, a first ascendant which allows, after a traceability and a capitalization of knowledge, to clarify the visibility to services on the functioning of the workshop. And a second one, descending, which consists mainly on the communication and the continuous enrichment of the knowledge base, through decisions taken by offices or preventive improvements, in order to ensure a better quality of machining, and consequently a good productivity and competitiveness.

Multi-agent system technology has been chosen to ensure knowledge piloting in the framework and is therefore in continuous interaction with the knowledge base.

This system uses analysis and reasoning algorithms to produce decisions, which are considered new knowledge, and to do this, this system communicates with databases and knowledge in writing and reading.

The knowledge base represents the central core, necessary for an optimal functioning of the decision support system, which implies the importance of an optimal structuring of this base. The main objective of the implementation of this knowledge-based system is to ensure interoperability.

As already mentioned at the beginning of this article, the solutions to ensure interoperability consist in the use of standards and ontologies. Our scientific proposal consists in merging these two approaches to develop a knowledge base.

Concerning the standards used in the project, we start by using STEP-NC (ISO/FDIS 14649-10 Data model for computerized numerical controllers -Part 10: General process data) which was presented at the beginning of this article.

The Step-NC standard was chosen for several reasons, the first and most obvious being that it represents one of the most widely used standards in the field of mechanical parts machining. The STEP-NC standard provides the standardized data set that makes up the industrial digital chain. The part used for the development of this layer of our knowledge base, is mainly interested in manufacturing feature and manufacturing operations. The definitions of the names, parameters, and concepts used, as well as the relation between them, are defined through several methods (Express, Express-G, etc.)

The second part of the work consists on the use of ontologies. For the development and implementation of our ontology, the choice was made on the software “protégé” [18].

It is a free, open-source ontology editor and framework for knowledge-based solutions in different fields such as pharmacy, medicine, computer science, e-commerce, industrial engineering, etc.

The advantage of the software “protégé” is its flexibility because in addition to the possibility of implementing rules, this software is also open to the communication with other reasoning systems and other computer technologies, and this implies the ability to integrate these ontologies into intelligent and expert systems.

Within the framework of our research work, the ontology developed brings together all industrial knowledge and represents a common repository. This database is therefore composed of several layers that bring together and capitalize on, the different sources of knowledge recovered directly through the study of the as-is situation of the industrial partners, and also through the study of the literature. This study made it possible to choose to use the standards (STEP-NC, MANDATE, ISO 13399, etc). This article focuses on the implementation of the STEP-NC standard in ontology.

The ontology construction consists in the transformation of the express diagrams of the STEP-NC standard using the software “protégé”. After studying the elements that compose the standards and methods of ontology development, we can describe the basic elements of it.

The first rule is that the notions of classes correspond in express-G to the entity and also to the attributes and therefore in “protégé” they will be represented by classes and data properties. The G-express relationships correspond to the objects properties at the “protégé” level.

To make instances we can add individuals in “protégé”. Example: from an Express-G graph to ontology in “protégé”:



Fig. 2. Example Express-G graph

The first step is to create classes that represent the basic concepts. Figure 3 shows the translation of the Express-G graph to an “OntoGraf” on “protégé”.

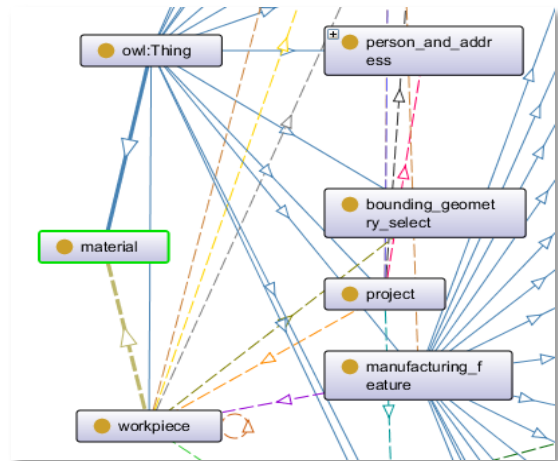


Fig. 3. Translation to an “OntoGraf”

Figure 4 explains that the relation between a part and its material is represented by an “ObjectProperty” and as concerns the attribute (material\_identifier) it is represented in the category of “DataProperty”.

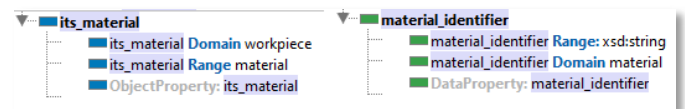


Fig. 4. Example of ObjectProperty and DataProperty

The development of this ontology has made it possible to integrate the STEP-NC standard into a knowledge based system.

The interest of this framework is that it respects an important level of standardization in terms of knowledge to be capitalized and this implies its genericity and the ability to exploit the results of this research work in other applications.

As mentioned at the beginning, the main problem of the machining industries is the lack of interoperability and the problem of the STEP-NC standard as it stands today is the lack of communication with the various higher levels of the company, and the information systems. The ontology developed, which represents our scientific proposal to face these problems, has made it possible to provide access to the entire set of knowledge and definitions of the parameters used throughout the digital chain.

The first one is the semantic interoperability since a common repository is set up which serves as a reference for all the elements of the global system and to ensure

communication through the exchange of information understandable by all the parties.

The second type is syntactic interoperability: the use of the STEP-NC standard has allowed defining fixed types, names and formats for the exchanged data (the names used by machine tools, CAD software, etc.) Through these names, the raw database records and the traceability bases of the global expert systems will keep the standard aspect by keeping the same names.

The cleverness of structuring the knowledge base and developing the different layers based on ontologies and standards facilitates the implementation of the expert system in the industry and thus simplifies communication between the different levels. As shown in Figure 5. This system will ensure interoperability between the workshop, the offices and the company's information systems.

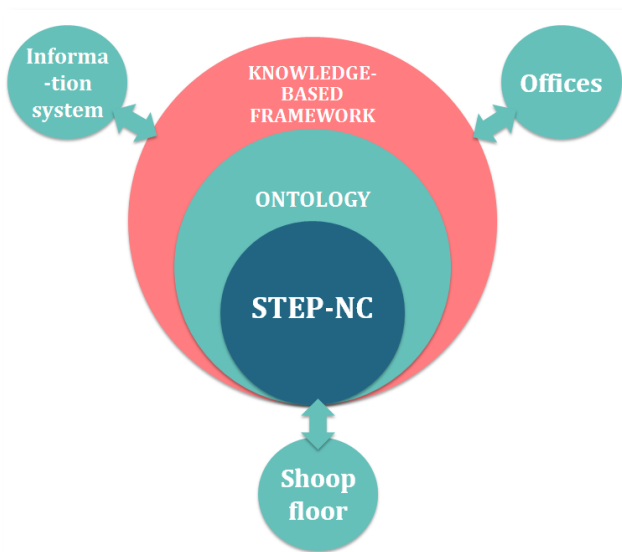


Fig. 5. Different layers of the knowledge-based framework

## 5. Conclusion and outlook

The use of knowledge-based frameworks is very trendy in the industrial field and represents one aspect of industry 4.0. The effectiveness, reliability and efficiency of this type of system depend heavily on how the knowledge base is structured. Our scientific proposal is proving to be very effective in setting up the global system. Actually, the project is in the phase of developing the knowledge base. Current research also includes the analysis of the techniques and tools for the implementation of ontology in the global framework. Several perspectives for the exploitation of this knowledge base can be mentioned. For example, the implementation of a diagnostic tool, to understand the causes behind the appearance of phenomena affecting the machining process. Also, the ontology will be used to ensure decision support during the manufacturing process, using traceability and artificial intelligence techniques.

The flexibility of the ontology development software "protégé" will facilitate the realization of these perspectives.

## 6. Acknowledgement

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