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Proposal and experimentation of an analysis grid to map knowledge of the factory of the future

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ABSTRACT

An industrial change is necessary to respond to the environmental, societal and economic challenges. The aim of this paper is to offer and test a methodology that will identify and structure studies that are relevant to the industrial mutation. This scientific approach is based on the analysis of state-of-the-art definition of the factory of the future. A specific grid and three different data collection methods have been experimented in three universities of technology in France. The results of this study lead us to prepare a comparative analysis of the obtained results. They show the interests and limits of this approach and its clarity.

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1. Introduction

Production systems have considerable economic, environmental and societal significance. In 2018, manufacturing contributes some 14% of European gross value added (World Bank national accounts data, and OECD National Accounts data files s. d.), employs around 24% of the European workforce. In 2017 (ILOSTAT database 2019), the sector "industrial processes and product use" is responsible for around 8 % of the total greenhouse gas emissions (eurostat 2019). Also, the over passing of planet boundaries is admitted (Gouvernement francais 2017) and industrial activity is impacted by several issues like the diminishing of non-renewable resources, the loss of biodiversity, the climate change, the stricter regulations related to the environment but also for health and safety, or the increasing consumer preference for environmentally friendly products.

In the face of these societal challenges, various studies have been conducted to support the ongoing industrial change. Although structure and identify appropriate knowledge in that way is still difficult, especially if it needs to be understandable by manufacturers.

To address this problem, this paper offers a methodology that will identify and structure studies that are relevant to the industrial mutation, or named in research "factory of the future". In order to offer a wide and exhaustive grid, this scientific approach is based on the analysis of state-of-the-art definition, but also the scope and dimensions of the factory of the future. This specific grid is a table with evaluation criteria. It has been fill in by data collected in three universities of technology in France. Collection methods combine brainstorming activities with researchers, but also interviews, and direct analysis of productions in existing databases according to the specific contexts of the different universities. To this end, this paper discusses the interests and limits of this approach and its clarity.

2. Methodology

To establish the methodology needed to identify and structure scientific output related to the factory of the future, we started to think about the form of the result we would like. This result was a mapping of scientific productions on factory of the future in the three university. With the result in mind, we thought about the information needed. We set out four stages, see Fig. 1. The first stage consists in a state of the art to grasp the dimensions of the factory of the future and the perimeter. This stage finished with the set out of an analysis grid. The second stage is the data collection part

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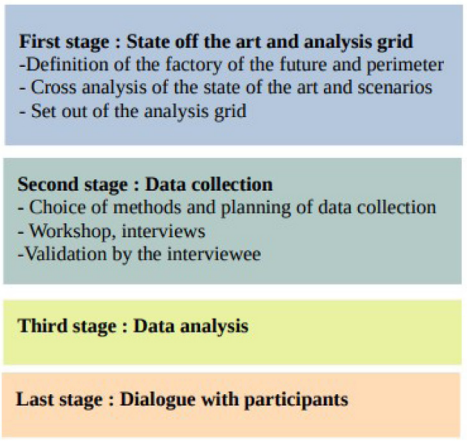


Fig. 1. Stages of the methodology

and the third stage is data analysis. The last stage is a period of dialogues with the people involved about results and prospects.

2.1. State of the art

For several years now, the term «factory of the future» became popular in the industry, but also in research and politics. For the French government, the factory of the future answers to the necessity of upgrading the productive apparatus and support industrial companies to change their business model, their organization, their way of design and marketing by digital (Preuveneers and Ilie-Zudor, 2017). The term factory of the future has been quickly associated with the 4th industrial revolution (Xu et al., 2018). This industrial revolution would follow the mechanization and the steam engine, the development of electricity, mechanics, oil, chemistry, and means of communication, the rise of telecommunications, computing and nuclear. It is named "Industry 4.0". This concept appeared first in an article published by the German government on November 2011, as a high-tech strategy for 2020. It is based on the integration of information and communication technologies and industrial technology, and for some researchers it is mainly dependent on building a Cyber-Physical System (CPS) to realize a digital and intelligent factory, to promote manufacturing to become more digital, information-led, customized, and green (Lichtblau et al., 2015). Industry 4.0 is a fusion between a physical world and a virtual world where four dimensions have been identified: smart factor, smart products, smart operations, data-driven services (Agence National de la Recherche 2015). Dimensions approached in the definition of Industry 4.0 are found in the 5 priority directions identified by the French National Research Agency (ANR) concerning the challenge of industrial renewal (Herrmann et al., 2014). Mostly these dimensions are technological, few are organizational and environmental. Industry 4.0 is just one point of view of the factory of the future, and other dimensions can be considerate as social and economic dimensions. Some authors think that more than today, future production has to address all three dimensions of sustainability - economy, ecology, and society (Arousseau et al., 2013). This three dimensions with manufacturing the product of the future are challenges for the factory of the future, identified by the European Factory of the Future Research Association (EFFRA) (Andreani and Conchon, 2005). These authors tried to have a holistic vision of the factory of the future, and one of the vision comprises four main aspects (Arousseau et al., 2013):

1 "Symbiotic flows and urban integration of the factory.
2 Adaptable factory elements: adaptive building shell, modular and scalable technical building services, and flexible production system.
3 Production cloud and cyber-physical systems.
4 Learning and training environments."

In our state of the art, we notice that the most dimension considerate when we discuss the factory of the future is the technological part. But it seems important to include all the dimensions we could identify to have a holistic vision of what could be the factory of the future.

The definition we give to the factory of the future is that is a term for name future production system who will have to handle economical, technological, organizational, environmental and societal issues to come. To handle these issues, the production system will have to be based on breakthrough innovations. The production model has to be reviewed, also companies and consumer relationships.

2.2. Definition of an analytical framework

Regarding our state of the art and our choice to work in a wide and exhaustive frame, we rely on report Prospective Reflection Workshop FUTURPROD (ARPFuturProd) [12] found in our state of the art. This report is the most exhaustive, even if it was published in 2013. It stems from a prospective reflection workshop who gathered experts, academics of production systems and industrial insiders.

Their goals were to imagine the industrial production system for 2030, to answer current major industrial changes, and to define priorities about research topics of ANR projects. From ARPfuturprod we work on three breaking scenarios:

1 Industry 4.0, see A Fig. 2.
2 Multi-scale circular organizations, see B Fig. 2.
3 Neo-industrialization, see C Fig. 2.

In the first scenario, «the French and European production systems strongly impacted by the financial crises of 2008 and 2011, are organized around generic technologies with high added value, the entire R&D, industrialization and manufacturing chain is carried out in France". In the second scenario, "the growing influence of social networks as well as non-governmental organizations contributes to a collective awareness of global humanitarian and environmental issues. This societal demand is part of the problem of manufacturers who have a lot of difficulty to source materials and energy. Circular organizations integrating the dual objective of producing closer to the territories while addressing the necessary global vision". In the last scenario imagined by the FuturProd working group, "the economic, social and environmental crisis that France has been experiencing for several decades is leading to a complete overhaul of social relations. Economic logic, social logic, and environmental logic are no longer antinomies". For each scenario, authors had set specific hypotheses and means who will characterize the production system, see Fig. 2.

For each scenario, we tried to identify key themes and the different associated aspects. Two internships on the project independently realized a cross analysis between the state of the art and scenarios. From this we established 12 research issues:

1 New intelligent technologies,
2 Design and organize production systems,
3 Produce and distribute closer to markets around the world,
4 Produce in an eco-efficient way,
5 New professional skills,
6 Safety and health,
7 Design more features than products,
8 New collaboration devices,

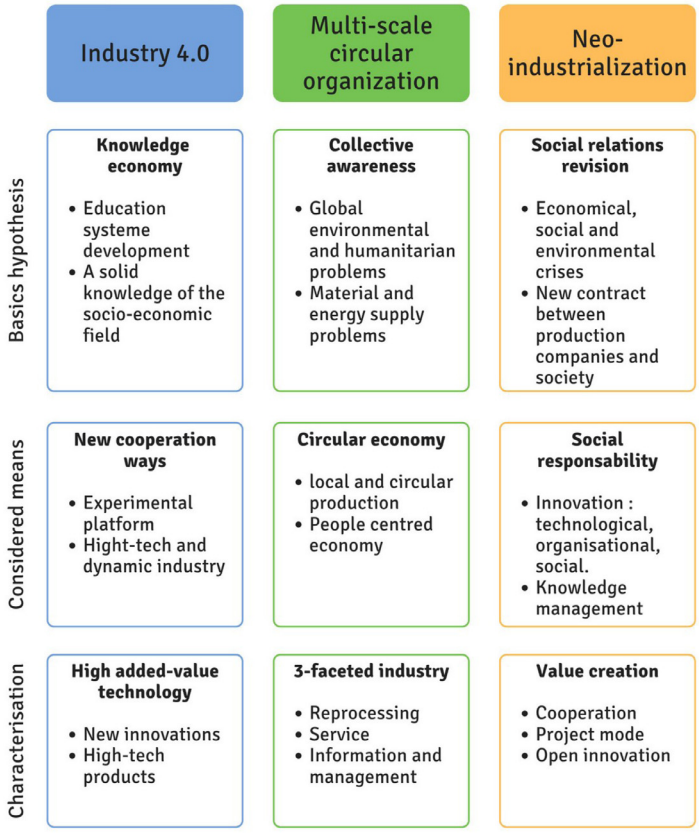


Fig. 2. Diagram of scenarios

9 Corporate responsibility,
10 Participatory innovation,
11 Economy of knowledge,
12 Social and solidarity economy.

Associated with these research issues we identify several scientific themes in our state of the art that we can see in Table 1. These themes constitute the analyze grid.

2.3. Analyze grid proposal

With an analysis grid, we wanted to categorize the data collected. The choice of its categories can be made based on information collected or determined in advance according to the objectives of the study. In the first case, we speak of an open and inductive approach, in the second case we speak of a close process of evaluation and translation of the study indicators (Andreani and Conchon, 2005). In our case, we chose to go on these two approaches, proposing categories, but leaving the possibility to add some.

This grid had to include the scientific themes related to the factory of the future, as well as the scenarios identified in the state of the art. By scientific themes, we wanted to be able to highlight the dominant scenario or scenarios. With this grid, we wanted researchers to position their scientific productions in one or several scenarios per theme. As scientific productions, we considered: scientific publications, contracted projects, Ph.D. theses, conferences, book chapters, software, and patents. This allows us to have a factual database.

3. Application

We had the opportunity to test the methodology we set out in the three French universities of technology:

- The University of Technology of Belfort-Montbéliard (UTBM),
- The University of Technology of Compiègne (UTC),
- The University of Technology of Troyes (UTT).

In these universities, researchers identify themselves in the factory of the future themes, but it is difficult for them to have an image of the existing situation

3.1. Data collection

To choose the appropriate collection methods, we looked at what kind of results we needed to complete the analysis grid. We had to ask the researchers to position their work about themes and scenarios, so we needed qualitative data, which could be transformed into quantitative data once placed in the analysis grid. Also, we had chosen to take into account the scientific productions from 2014 for the reason that this is the year following the publication of the ARPfuturprod report and because it seemed relevant for us to have a vision of 6 years.

We adapt our collection methods to the context of the different universities. We did workshops with researchers to explain them the analytical framework of our study and what we needed of them if they felt concerned about this topic. A study has been done for known which research team will be interested to participate in these workshops.

At UTT, all research team leaders were present, but few of them felt finally concerned by the topic of the factory of the future.

At UTC, we did not succeed bring all research team leaders. Those who were there gave us the contact of researchers of their team who may have worked on the topic.

At UTBM, we chose to do the workshop after a big event which gathers many researchers at the same place.

Table 2
Data collection information's

	UTBM	UTC	UTT
Number of researchers	121	299	140
Number of researchers contacted	51	33	140
Number of participants	32	16	16
Number of participants in workshops	11	6	7
Number of interviews	21	12	7
Number of valid positioning sheets	24	106	81
Number total of positioning sheets	53	108	114

Conscious of not being able to reach all the researchers who could be potentially concerned by the topic of the industry of the future with workshops, we decided in addition to do semi-structured interviews. This type of interview helps to guide the speeches of the interviewees around various themes defined in advance by the investigators, in our case that was themes and scenarios of our grid. This way of proceeding allowed us to remain focused on the subject and to treat all the points of the grid, to be able to compare the results of different interviews.

At the same time, we read the internal documents that were available, such as the High Council for Evaluation of Research and Higher Education (Hcéres) evaluation reports from the different laboratories. We also analyzed productions in databases, to target and establish contact with the researchers in order to exchange with them about their scientific productions. Positioning sheets were created to formalize the results of the individual interviews with the researchers, see Fig. 3. They include their positions on their productions, information about them, as well as the standard information about the person interviewed. These sheets include four key variables, which are: the type of production, the year, the positioning in themes and that relative to the scenarios. These variables will be important for the analysis of the results.

3.2. Results and analysis

Among the sheets collected, some are still waiting to be validated by the authors of the productions, as we can see in Table 2. Also, the number of researchers is the number of person who might produce scientific productions in these universities.

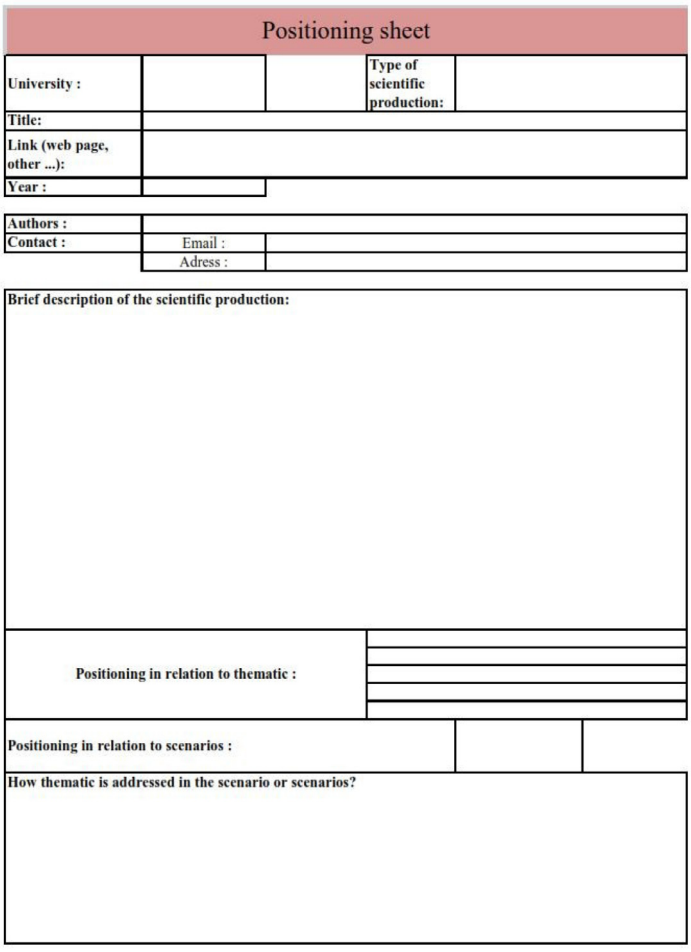
We choose to present only the valid data. But we checked that the results obtained with only the valid positioning sheets do not differ of the global results.

As we see Fig. 4 the dominant scenario is the Industry 4.0. This is an expected result in the light of interviews and trends at the national level. Also, it seems that researchers at UTC and UTT are more focus on aspects of Industry 4.0 regarding the factory of the future. On the other hand, researcher at UTBM seems interested in the same way by all scenarios.

On Fig. 5, Fig. 6 for more readability we chose to show only thematics with a number of sheets superior to four, and for Fig. 7 only superior to two sheets.

In these graphs we see that the theme 4.1.Sustainable development and at the heart of new productive systems is common to all universities in scenarios Industry 4.0 and Multi-scale circular organization's. Also thematic 2.4.Digital machine in simulation and control is common in scenario Multi-scale circular organizations. Thematic 7.2.System Engineering is common in scenarios Multi-scale circular organization's and Neo-industrialization, and thematic 10.3.Place of the user in the design is common to all universities in scenario Neo-industrialization.

Through these graphs we see that there is a complementarity between the French universities of technology for the thematic of the factory of the future, and that some have specific themes. To-



Positioning sheet

University :		Type of scientific production:	
Title:			
Link (web page, other ...):			
Year :			
Authors :			
Contact :	Email :		
	Adress :		
Brief description of the scientific production:			
Positioning in relation to thematic :			
Positioning in relation to scenarios :			
How thematic is addressed in the scenario or scenarios?			

Fig. 3. Positioning sheets

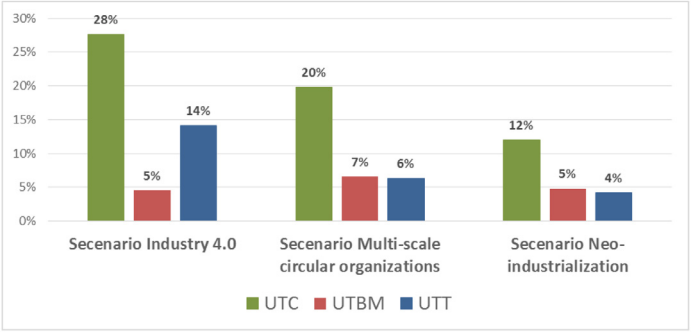


Fig. 4. Distribution of valid positioning sheets per scenarios

gether these universities of technology cover the different aspects of scenario.

3.3. Discussion

The collection data part adduces more uncertainty to this study. First of all, interviewers were two people, instead of one. Two interviewers will have a different way of conducting an interview, even if they have a common protocol, also according to their experience they will not react in the same way to what the interviewee said. Another factor to consider regarding the collection method is the relationship between the interviewer and the interviewee because if the two people already know each other this can affect the information collected. And in our case, this situation happened a few times.

With this methodology, we have identified and structured the scientific knowledge regarding the industry of the future in the French universities of technology, but we have not worked on the readability of scientific knowledge for manufacturers.

Also, we focused mainly on the industry of the future, but without taking into account any current constraints that we know will impact our lives in the coming years, and therefore the production systems. As, for example, climate change or rare metals that technology currently makes us completely dependent. The scenarios that we have worked on only approach them very succinctly. In scenario Industry 4.0 we just talk about environmental per-

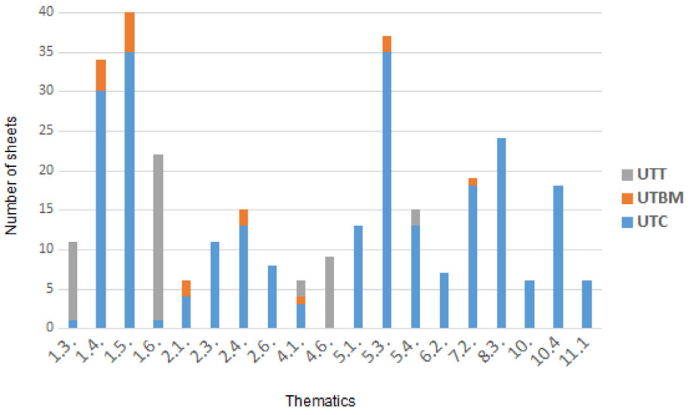


Fig. 5. Distribution of validated positioning sheets per scientific thematic for scenario Industry 4.0

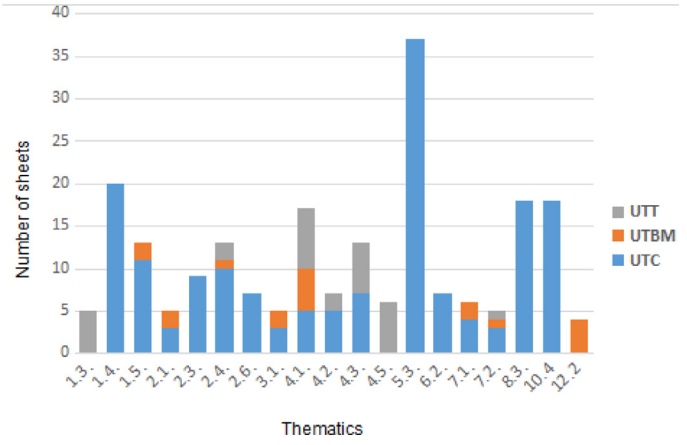


Fig. 6. Distribution of validated positioning sheets per scientific thematic for scenario Multi-scale circular organizations

formance, in scenario Multi-scale circular organizations, climate change, and limited resources are very important elements, but it offers an incomplete solution. Among all the scientific productions listed, we think that some can be useful for manufacturers to build a real strategy to face the industrial mutation. And the combination of themes and scenarios can enable them to identify the knowledge needed. But with the obtained results, we are concerned that manufacturers see only technological solutions with the dominant scenario industry 4.0.

4. Conclusion

The goal of this study was to offer a methodology that will identify and structure relevant knowledge for the ongoing industrial mutation. First of all, it was necessary to define the factory of the future and its perimeter. With a state-of-the-art analysis, it was possible to complete this work and construct an analysis grid that was used to categorize the data collected from researchers. In the definition phase, we have chosen to analyze researchers' scientific productions and to position these productions in relation to themes from our state of the art, and to three scenarios: industry 4.0, multi-scale circular organizations, and neo-industrialization.

When we tested our methodology in the three universities of technology, it appears that industry 4.0 was dominant in all universities. This also revealed that for each scenario, there is common themes between the universities and specific themes.

We obtained the results we expected. Indeed, we have a view of the concept of the factory of the future in the French universities of technology, and these universities have a mapping of which thematics they have knowledge on. It could be useful for scientific animation and further partnership between researchers of these universities.

We also identified the most relevant scientific productions which could be useful for manufacturers for identify the knowledge they need or researchers to work with . But this methodology needs to be enhanced for becoming accessible to manufacturers. It could also be interesting to study the societal impacts of the application of this concept in a country which has developed industry 4.0 like Germany, and see if this is a sustainable path or transition path to sustainability.

Credit Author Statement

Claudine Gillot :Methodology, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization **Nadège Troussier** :Conceptualization, Methodology, Validation, Review & Editing, Supervision **Julien Le Duigou** :Conceptualization, Methodology, Validation, Review & Editing, Supervision **Jérôme Favergeon** :Conceptualization, Methodology, Validation, Supervision **Christian Camelin** :Conceptualization, Methodology, Validation, Review & Editing ,Supervision

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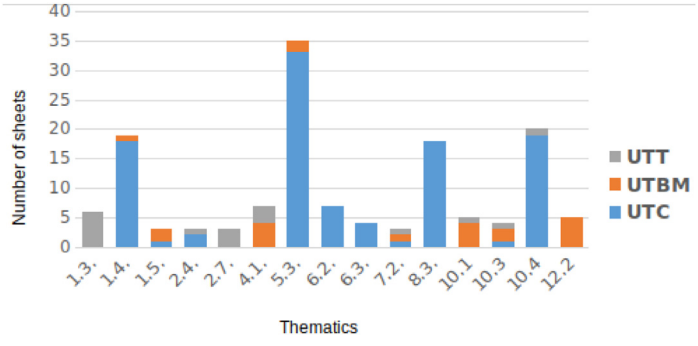


Fig. 7. Distribution of validated positioning sheets per scientific thematic for scenario Neo-industrialization

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