Technological Trends in Context of Industry 4.0 and Their Industrial Applications

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***Abstract*—In the course of the fourth industrial revolution, a rapid technological change takes place in the production industry. Numerous new technologies and multiple opportunities for industrial applications emerge. These already lead to a fundamental change in industry. In order to keep pace with this development, companies are forced to cope with this new technologies and arising technology trends. At the same time the progressive increase in the amount of available and potentially relevant knowledge exacerbate the identification, evaluation and interpretation of new technologies. Thus a transparent and structured overview of new technologies and technology trends including the evaluation of readiness and industrial impact is required. In this context, the Fraunhofer IPT and EPIC CoE work on a systematic technology trend scouting in order to identify relevant future changes and possible opportunities for production industry. Based on existing concepts in technology intelligence, a procedure for systematic trend scouting of technology trends in context of Industry 4.0 and their industrial applications was developed and initialized. The identified sub trends are visualized in fact sheets and aggregated in a web-based trend radar. Within the first scouting period 52 sub trends where identified, elaborated and evaluated according their readiness level for industrial application and impact on the current production industry.**

Keywords—Trend Scouting, Technology Intelligence, Industry 4.0, Cyber-Physical-Systems

I. Introduction

The importance of trends in the technology planning process has increased significantly in the last years. In the past, companies could often plan years into the future. Nowadays the focus is on short-term planning adjustments caused by the dynamic development of technology and decreasing product lifecycles [1].

Especially in the context of the fourth industrial revolution (industry 4.0), multiple new technological developments and possibilities arise. These already lead to a fundamental change in the design of production systems as well as their planning and control, which will continue to increase in the future. While in Western Europe the impact of technological change is already widespread and new technologies are in use in several industry, this development is still in its beginning for the Eastern Europe industry [2].

To increase and support the technological change in Eastern Europe production industry, the European Union founded the Centre of Excellence in Production Informatics and Control (EPIC CoE) in context of the Horizon 2020 research and innovation program. EPIC CoE was established with the objective to be a leading-edge knowledge center of cyber-physical production systems focused on accelerating innovation, realizing industrial solutions and training new generations of highly qualified professionals.

In order to fulfil this task, it is necessary for the EPIC CoE to have comprehensive understanding of current and upcoming technology trends in the field of production organization, planning and control. For this purpose the department of technology management of the Fraunhofer Institute for Production Technology (Fraunhofer IPT) developed a trend scouting approach for the EPIC CoE based on existing scientific concepts and industrial best practices. Based on the developed approach, Fraunhofer IPT together with EPIC CoE established and conducts a trend scouting in order to identify threats and opportunities from outside the existing center's core competences to support the technological change in Eastern Europe production industry.

In the scope of the present paper, the scientific methodology of the developed trend scouting approach is outlined. Furthermore the boundary conditions of the developed approach, such as the evaluation criteria for the identified trends and technologies are presented as well as first results of the technology trend scouting.

II. Related Work and Research Methodology

A uniform understanding of relevant terms marks the beginning of a scientific examination [3]. Therefore, the current chapter briefly introduces and defines relevant terms in the field of technology intelligence and trend scouting.

A. Trend

A trend describes the general direction of a development in a certain area and can thus include the coherent development of different variables in this area. Trends often arise from the interaction of different factors. With the increasing importance or influence of the trend, it becomes apparent. If a trend has been identified, it is possible to evaluate its influence on different areas, to forecast the further development of the trend and to align the organization's actions accordingly. By aligning the actions of the actors, who are in environment of the trend, the trend is often strengthened in the sense of a self-reinforcing effect or a self-fulfilling prophecy [4].

B. Technology Intelligence

Technology scanning, scouting and monitoring represent the basic activities of technology intelligence [5]. Basically,

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influencing factors such as the familiarity of an organization with certain technology fields, the depth of the search within these fields (degree of detail of the search), the intended purpose of the information to be collected and the addressees of the search results must be differentiated. All three-search perspectives have the common goal to avoid being surprised by upcoming technologies or trends and the basis for decision-making regarding potential technological options [5].

Technology scanning is a continuous, undirected search for information inside or outside an organization's domain. Technology monitoring observes the events in specific technology fields [6]. Technology scouting is the detailed search for specific technological topics and knowledge carriers within specific technology fields. The procurement of information is often order-related, e.g. within the framework of development projects [7]. Depending on the order, scouting contains elements of both, technology monitoring and scanning [8]. Signals that have already been recognized are used as a starting point to structure the detailed search and signals that have not yet been captured are searched for. The time frame of trend scouting is therefore limited in comparison to monitoring, since there is a clear goal, after which scouting is completed. Due to its order-related character, trend scouting has a small and clearly defined search field, with the aim of detailing and expanding the level of knowledge already achieved [9]. For defined technologies, a formalized search is used to obtain detailed information, which is typically very intensive [10].

The process of technology intelligence consists of the four steps *determination of information need*, *information procurement*, *information evaluation* and *communication of results* [11]. The process is continuously run through in the above sequence. The individual steps are shown in “Fig. 1” and explained in the subsequent sections.

Fig. 1. Technology intelligence process

1) Determination of information need

To be able to perform a targeted and continuous observation of trend and technology fields, a clear formulation of search strategies is crucial. Differentiated search strategies help to illustrate the own requirements to the desired search result and clear guidelines simplify the search and improve the results. Based on the defined search strategies, concrete search orders can be defined for the different technology fields and trends. Search orders include the expected goal of a search strategy, the needed information, the responsible actors or the budget [11].

2) Information procurement

After defining concrete search orders, a targeted search for technologies and sub trends is needed. This can be supported by the use of different methods, which can help to expand the solution space and eliminate predefined patterns of thought and solution [11]. The most relevant methods in the context of this paper are described in the following.

a) Lead user analysis

The aim of the lead user analysis is to identify future technological innovations from the customer's point of view and to define the innovation needs of key customers. Key customers are referred to the minority of particularly innovative customers [12].

b) Scenario technique

The scenario technique is a method for the integrated development of possible future scenarios [13]. The general aim is to derive recommendations for action, with regard to a multiple future, which are as flexible and robust as possible [14].

c) TRIZ methodology

The TRIZ-like methodology helps to focus on a general problem and enhances the solution space in order to identify as many technological solutions as possible. Finally, the possible solutions are transferred to a concrete problem [15].

d) Trend extrapolation

The aim of the trend extrapolation and the trend analysis is to derive the corresponding technological effects from the predicted development. For this purpose, an object of observation is selected and the basic trend is examined. There are no limits when selecting observation objects, but the uncertainty of the prognosis for some observation objects (e.g. customer behavior) and the sense of the analysis of these observation objects must be questioned [16].

3) Information evaluation

Subsequent to the information procurement, the technological solutions need to be evaluated in the context of the organization’s strategy. This can be done by using a portfolio matrix, considering technology and market attractiveness. First, it is important to make a statement from an internal organization perspective to decide to which extent the technology fits the organization's competition-relevant competencies or respecting in which way the technology is capable of supplementing or even expanding the organization's core competencies. This assessment is compared with the importance attached to the core competence itself. As a second perspective, the technology should be placed in relation to the external market view, e.g. in which target markets the technology is used and what is the contribution of the technology within the market? The expected future relevance of the markets themselves must also be assessed here. On the one hand, the resulting positions of the technologies serve as a benchmark for the future perspectives of the technologies in industry competition and on the other hand, they describe the specific position of the organization with regard to the technologies concerned [17].

4) Communication of information

After the evaluation, the collected information should be prepared and widely distributed to the organization. In order to maximize the impact for future developments and activities the information should be prepared in a structured and informative way. Therefore, standardized fact sheets are be used. The presentation of detailed information in standardized fact sheets leads to a better comparison of technologies and simplifies the communication of the findings. The fact sheets contain different factors like, maturity of the technology, key suppliers or relevant research partners [11].

Finally, the most relevant identified technologies and sub trends should be observed continuously to recognize relevant development and changes early. The continuous observation of the identified technologies and sub trends can be realized by the use of technology radars. The technology radar enables a clear presentation of the monitored technology fields and facilitates communication within the organization. The radar is divided into sectors for structuring the content and delimiting the search areas, e.g. into trends, technology fields, or applications. When classifying the search fields in the respective search area/sector according to their degree of technological readiness level or time horizon, their relevance for the organization is also mapped. The relevance can be derived from the relation of the search field to the core competencies or basic and cross-sectional technologies of the organization [17]. The constituent elements of a monitoring radar are shown in "Fig. 2".

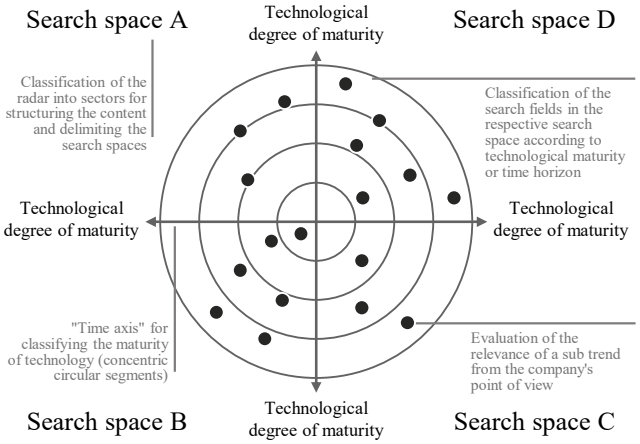

Fig. 2. Constituent elements of a monitoring radar

III. Approach and Results of the Case Study

Based on the related work, a systematic technology trend scouting was developed and performed by Fraunhofer IPT to identify relevant technology sub trends and their containing threats and opportunities for EPIC CoE. The identified technology sub trends will be analyzed regarding their impact on center competencies, on the functionalities provided by technologies developed by the center, and on applications for the center's technologies. Based on this analysis, inferences for the further development and adoption of the defined technology strategy, including needed competencies and development projects, will be drawn.

A. Developed procedure

Based on the knowledge and experiences of the department of technology management of the Fraunhofer IPT, a process for the approach of the trend scouting was designed. This process is subdivided into three phases in accordance with the general approach presented in "Fig. 1". The evaluation and communication phase is combined in one phase because of the limited number of employees of the EPIC CoE. Also feedback loops for a continuous scouting process are in place.

The *determination of information need* takes place periodically every two years to be aligned with the strategy review for the EPIC CoE. Between the *information procurement* and the *evaluation and communication of results*, a continuous feedback loop is considered to guarantee a focused information procurement and the generation of valuable results. The developed approach is shown in "Fig. 3".

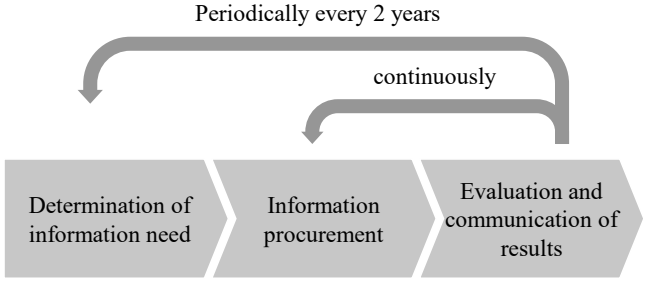

Fig. 3. Process for definition and review of search fields for the trend scouting as well as transfer of gained results for the development and adoption of the technology strategy of the EPIC CoE

B. Approach

1) Determination of information need

The determination of information need is done according to the center's overall strategy. This includes the definition of relevant search fields for the scouting as well as the definition of the information need for each search field. The technology fields and technology trends were selected and identified according to the elaborated strategy for the EPIC CoE based on prioritized research fields, which had been defined prior the establishment of the EPIC CoE. The considered technology fields within the trend scouting are shown in table I.

TABLE I. Technology Fields

Technology fields
Digital factory
Prodcution planning and control
Machine learning and data analytics
Production networks and supply chains
Robotics

While the technology fields are strongly related to the existing competencies of EPIC CoE, the trends mainly focus on the desired application fields of the center in production. Considered are relevant technology trends for the target industries of EPIC CoE. These target industries are the automotive industry and their suppliers (mainly tier 1), tool making industry and energy sector. The technology trends considered within the first scouting period are shown in table II. Bothe, the technology fields and the technology trends are defined as search fields for the first scouting period.

TABLE II. Technology Trens

Technology trends
Additive manufacturing
Future workspace
Advanced materials
Sustainability
Simple industry 4.0 solutions
Blockchain and distributed ledger

2) Information procurement

After the definition of the search fields, the operative trend scouting is executed. For the information procurement is done by screening of scientific and non-scientific papers, by participation in conferences and fairs or within expert interviews. To guarantee a structured information procurement within the operative trend scouting, the Fraunhofer IPT designed a fact sheet to describe the identified trends and technologies in a systematic way. This template contains a short description of the sub trend, the advantages and disadvantages of the sub trend in the context of EPIC, a sample picture as well as a pre evaluation of the identified technologies and applications.

3) Evaluation and communication of results

For the evaluation, different methods based on the previous literature are used. These methods include a mixture of participative methods, such as structured interviews, expert panels and scenario planning, as well as information-oriented methods. The sub trends are analyzed according their impact on the center's competences, on the functionalities provided by technologies developed by the center, and on applications for the center's technologies. For production equipment, this includes mapping the trends to the produced goods in order to derive new requirements for production equipment.

A TRIZ-like methodology is used to identify synergies of the sub trend with regard to the center's development. Technology sub trends posing a threat of substitution of center-focused technologies will be collected and strategic recommendations for portfolio extension and competence building will be given.

The identified sub tends are evaluated according to seven criteria to outline the relevance of the sub trend for the EPIC CoE. The evaluation criteria where defined a joint workshop with representatives of the EPIC CoE and the department of technology management of Fraunhofer IPT. The defined criteria are shown in table III.

TABLE III. TECHNOLOGY FIELDS

Evaluation criteria	Short description
TRL	• Readiness level of the identified technology or solution
Industrial Impact	• "Weight" of the solved problems • Request/relevance of the solution
Availability	• Dissemination of the solution • Number of existing success cases
Implementation effort	• Implementation costs • Distance between existing and required maturity level of the company • Implementation risks
Indsutry focus	• Current target industries of EPIC CoE • Relation to existing fields of application
Existing Competencies	• Existing knowledge and competences with EPIC CoE
Number of Competitors	• Number of solution or technology providers in target markets

Finally, the gathered information are integrated in a trend radar. This radar is a web-based visualization, giving an overview of the defined technology fields and trends. The web-based implementation of the trend radar enables an easy dissemination of the trend scouting results within the EPIC CoE. Thus it can be guaranteed, that everyone has access to the latest information in daily business as well as for strategic decisions. Furthermore, information can be easily updated and new scouting results integrated continuously. The trend radar is provided by the Fraunhofer IPT and implemented on a subdomain of the EPIC CoE IT-infrastructure in the corporate design of EPIC CoE. The radar is structured with regard to "Fig. 2". It is subdivided into eleven segments, one segment per technology field and trend. The distance to the center of the radar illustrates the relevance of the identified technology sub trend for the EPIC CoE. The relevance is defined based on the evaluation criteria in table III. In order to aggregate the various evaluation criteria into one number representing the relevance, the method of pairwise comparison was used in combination with the method of use-value analysis [18]. The result of the pairwise comparison is shown in "Fig. 4".

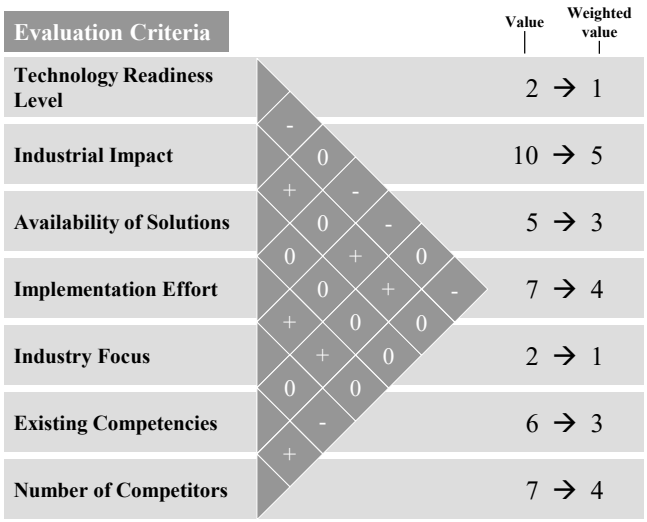

Fig. 4. Results of pairwise comparison

Based on the weighted value of the evaluation criteria from the pairwise comparison and the results of the trend scouting a use-value analysis is conducted [19]. The results of the use-value analysis defines the distance to the center of the radar.

C. Results

Within the first scouting period 52 technology sub trends where identified in the defined technology fields and technology trends. An overview of the identified sub trends is given in table IV and table V.

TABLE IV. TECHNOLOGY FIELDS

Technology trends	Identified sub trends
Additive manufacturing	• Rapid tooling • Rapid manufacturing • Rapid prototyping • Opportunity identifier • Material management • Printed electronics
Future workspace	• Self-adjusting workstation • Digital assembly instructions • Remote support • Picking assistance systems • Smart tools • Smart protective equipment • Exoskeletons
Advanced Materials	• Smart materials • Metamaterials • Digital materials • Graphene

TABLE IV. TECHNOLOGY FIELDS

Technology trends	Identified sub trends
Sustainability	• Energy monitoring • Energy demand management • Environmental footprint analysis
Simple industry 4.0 solutions	• Sensors boxes for retrofitting • Data science software platforms
Blockchain and distributed ledger	• Immutable documentation • Machine tools services • Immutable supply chain tracking • Energy grid management

TABLE V. TECHNOLOGY FIELDS

Technology field	Identified sub trends
Digital factory	• Smart workpiece • Modular production systems • Digital twin • Production logistics • Virtual reality • AGVs
Prodcution planning and controle	• Production performance monitoring • Advanced planning and scheduling • Self-optimizing production planning systems • Self-optimizing production and plant operation • Decentralized production control • Remote control
Machine learning and data analytics	• Diagnostic analytics • Predictive analytics for production processes • Predictive analytics for business processes • Self-optimizing machines • Self-learning systems
Production networks and supply chains	• Supply chain tracking • Supply chain collaboration • Smart warehousing • “Sharing economy” for the supply chain • PLM for collaborative manufacturing
Robotics	• Collaborative robots • Advanced control for robots • Cognitive robots • Optimized movements

The identified sub trends were evaluated by the use of the use-value analysis as outlined in the previous chapter. The evaluated sub trends are communicated within EPIC CoE using a web based trend radar. The trend radar, subdivided into 11 segments for the five technology fields and 6 technology trends is shown in “Fig. 5”.

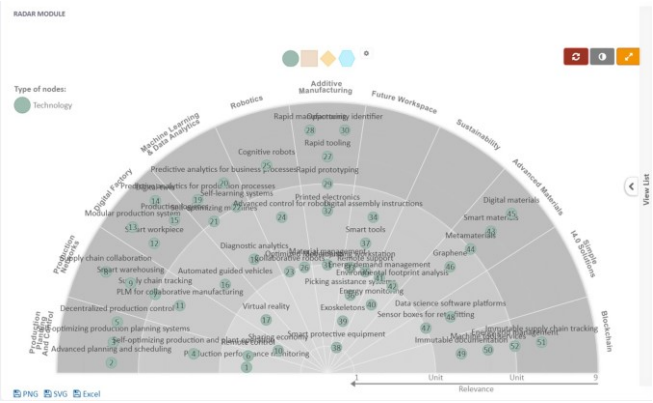

Fig. 5. Screenshot of trend radar with sub trends of the first scouting period

For each of the sub trends, a one till three days research study was performed within the information procurement. Within this studies, individual or multiple of the methods described above were used case-specific. The fact sheet *self-optimizing production planning systems* is shown exemplarily in “Fig. 6”.

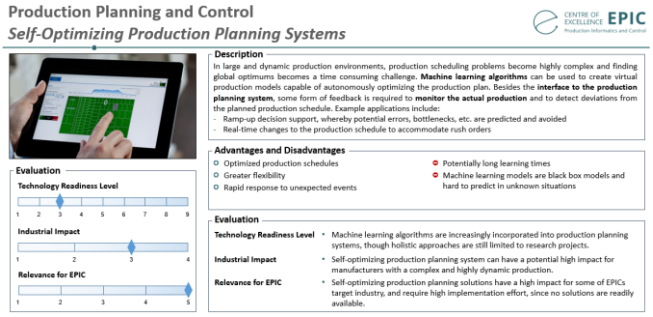

Fig. 6. Fact sheet for the technology field self-optimizing production planning systems

IV. CONCLUSION AND OUTLOOK

Based on existing concepts in technology intelligence, a procedure for trend scouting for technology trends in context of Industry 4.0 and their industrial applications was developed for the EPIC CoE. Based on the developed procedure, the trend scouting was implemented and initialized. Within the first scouting period 52 sub trends where identified, elaborated and evaluated according their relevance for EPIC CoE. First results of the scouting are presented within this paper.

In the next steps these results will be communicated among the project partners and the trend scouting will turn from a first (large) development process into a regular, continuous information gathering and consolidation by experts and as planned, at every two years the complete information requirements process will be repeated and the radar fields and items will be refreshed.

The process of trend scouting and analysis will be done continuously. During this evaluation, on the one hand the search fields will be evaluated and adopted, if needed. On the other hand, the gained results and their impact will be evaluated and considered in the strategic direction of EPIC CoE, which will be adapted periodically.

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