Technology foresight for digital manufacturing: Russian case

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**Abstract.** The technological foresight plays a significant role in promotion of the emerging technologies. The paper investigates technological prospects of priorities implementation indicated in the ‘Strategy for the Scientific and Technological Development of the Russian Federation’. More precisely, we examine the advanced digital and intelligent production technologies deployment by applying foresight methods and new solutions such as an advanced text-mining. The main goal of the study is to define a range of the most promising technologies with respect to markets and products within the priority. We identified five large cross-cutting areas manifesting physical and digital convergence. These clusters include computer modelling and flexible manufacturing systems from the production side, and sensor technologies, virtual/augmented reality, the Internet of Things from the IT side. The revealed technological trends correspond to global patterns and unveil a range of sectoral applications. Product development technologies are confessed to be the core of digital manufacturing. During the analysis we uncovered 350 prospective products and services that should be exposed to further expert evaluation. Our results offer a new insight on science and technology policy-making by adjusting technology development across industries. A suggested framework allows expanding current boundaries of forecasting activities at the national level in order to boost Russian scientific performance.

1. **Introduction**

The technological planning and foresight become currently a routine for national players in order to respond to the emerging global trends. Such expertise delivers a crucial insight on how technologies transform products, processes, business models, innovative behaviour and more broadly socio-technical systems. Furthermore, these changes affect policy-making, providing new tools and mechanisms to priorities setting [1, 2]. Currently transformation induced by digital technologies stands for the major technological trend. As before, manufacturing preserves its significance for the economy being the major driver of productivity growth [3].

The Government participation in the deployment of the new technological shift estimated as a crucial, since it stands for a policy-driven discussion in the academic literature digitalization [2, 4, 5].

In this regard, the purpose of the study is to apply methodology of technology foresight to the area of advanced digital and intelligent production technologies within the framework of the ‘Strategy for
the Scientific and Technological Development of the Russian Federation’ in order to define a set of most prospective technologies in conjunction with application. The study integrates both traditional methods and new approaches related to digital solutions.

2. Technological trends and impact thereof on manufacturing

A new technological paradigm is associated primarily with the digitalization that represents interplay of operational technologies (OT) and information solutions. The cyber-physical systems (CPS) constitute the core of digital manufacturing enabling human-machine interaction, based on a set of technologies, like automation and robotics, 3D-printing, Internet of Things (IoT) and other. The convergence of physical and digital assets provides a plethora of gains in terms of productivity, product quality, production time, flexibility, interoperability and communication [2, 6].

The digital manufacturing gives new opportunities for the value chain management during the product lifecycle [7]. A possibility to capture the online streams of data and to analyze them in real-time opens up new ways of decision-making process and structure organization [8, 9]. Capturing and processing large volumes of data from sensors and installed devices enable production optimization on the production floor and in the supply chain [10]. This drastically enhances the possibilities in maintenance and repair services, energy and design optimization, as well as management and performance of physical assets [11].

At a great extent digitalization brings structural changes in manufacturing industries related to high interoperability, enlarged communication capacities across the value chain, decentralization of production capacities, modularity, high rate of customization, and overall stakeholders’ integration [9, 12].

3. Methods

Several documents were elaborated during the last decades, mainly the Russian long-term science and technology foresight [18], the Strategy for the Scientific and Technological Development [19], the National technological initiative [20]. A particular importance is attributed to the Program Digital economy, which is currently transforming to a national project [21].

The study reveals the results of the foresight for one of seven priorities, indicated in the Russian Strategy for the scientific and technological development. Such approach helps identify perspective technological fields regarding relative markets and products. This paper presents an integral perspective on technological trends in the area of advanced digital and intelligent production technologies.

Our methodology combines traditional methods of strategic forecasting like monitoring, discussions, interviews, surveys, strategic sessions, expert validation, foresight approach and advanced text-mining in order to get a holistic view of scientific and technology landscape. The advanced methods of text-mining serve for taxonomy and investigation of technological trends in scientific and technology domains, discovery and evaluation of emerging research areas.

The research process consists of three major stages: 1) data processing; 2) outcomes mapping and interpretation; 3) results validation and elaboration of recommendations. We structured data and specified the framework for its further refining based on advanced text-mining mechanisms at the first stage. The outcomes of the study were presented in several types of maps. We introduced a semantic map that covers products, technologies, relationships among them in the context of related scientific and technological field based on academic publications in this paper.

The final documents derived from the analysis serve as a strong analytical framework for further development of technological roadmaps at the micro- and meso-levels, giving a detailed action plan for perspective technologies development. To make decision about research projects and funding thereof, elaborated lists of products, services and technologies should pass expert validation and verification.

The refined catalogues of products, services and markets should be evaluated during a series of expert activities with participation of Russian and foreign experts, business, government agencies and
institutions. Such analytics serves as a basis for turning strategic technology priorities to a particular research project supported by the government. The technology development with its application technology roadmapping is frequently used to introduce recommendations and expected effects of [22, 23]. It serves as a useful tool for state innovation policy, orchestrating R&D activities, bridging financial decision and purposes at different levels - firm, sector or national level [24]. The technological roadmap comprises several layers, namely factors, methods and technologies, products and services, application areas, risks and limitations, as well as expected impact. Finally, such a visualization serves as a basis for investment decisions in R&D [25–27].

Figure 1. Methodology of study.

4. Results and discussion
We identified potential markets, products and technological fields for Russia within the priority applying the foresight approach and expert mechanisms.

The maps incorporate the most significant technological terms indicated during the analysis at the first stage. We detected five large clusters, i.e. a grouping of the same or close notions in the semantic map (figure 2). All trends indicated in the map could be divided into two large blocks that integrate physical and digital technologies. Mostly the production technologies, namely, the computer modeling and flexible manufacturing systems clusters are placed on the left side of the map. The informational technologies with a grouping of sensor technologies, virtual and augmented reality, the Internet of things are on the right side. Such an arrangement evidences the convergence between physical and digital dimensions with a deep transformation of manufacturing architecture almost in all sectors.

In line with this the digital modeling is the largest cluster, and that is not surprisingly given that simulation is the cornerstone for production industries. It comprises such solutions as new product development, life-cycle assessment, feature selection, homology and geometric modeling, etc. This cluster is closely tied with a pool of technologies that are not marked in a separate cluster, nevertheless, conceptually refer to design and engineering activities. Links in the map illustrate a complex interaction of technologies and its function fields. For instance, the presence of medical notions reflects applicability of intelligent manufacturing technologies in the healthcare and adjacent sectors. The advanced digital models contribute to adaptive and autonomous production systems. Thus, the product development becomes a holistic process that encompasses main steps in the whole
value chain and generates value added by change in organization architecture and production location patterns [28, 29].

Figure 2. Semantic map in the area of ‘Advanced digital and intelligent production technologies’ based on academic publications.

Figure 3. Preliminary list of expected products and/or services within the priority of ‘Advanced digital and intelligent production technologies’.
The sensor technologies and related issues form the biggest cluster on the right side of the map, since it comprises solutions enabling information capture, interchange and its translation in a relevant format. The virtual and augmented reality solutions serve as an intermediate layer between computational algorithms and physical connected devices. They provide a useful knowledge on manufacturing activities to a production floor with the help of ‘smart’ units. Finally, the Internet of things technologies integrates computing capacities such as brain-computer interface, autonomous solutions, etc.

A large share of the revealed technological trends represent rather mature directions. It is possible to define mature topics, growth leaders, niche trends and emerging areas based on importance and dynamic indicators. The production technologies concerning predominantly physical dimension, including computer modeling, sensor devices and others described as relatively mature trends with stable evolution pace are there among others. The growth leaders constitute a significant share of the Internet of things and the notions related thereto. This dynamics could vary from one particular sector to another. We identified about 350 prospective products and services during the analysis that are subject to further expert evaluation (figure 3).

5. Conclusions
The identified technological terms in the field of advanced digital and intelligent manufacturing technologies are going in line with global technological trends. The location of clusters and intersections thereof on the map illustrates its cross-cutting nature, as well as opens up new possibilities in terms of the science and technology policy-making, namely, by aligning a technological level throughout the sectors.

Russia is striving to attain strong technological position on the international scale in priority fields. This is supported by a range of strategic documents that intensify research activities. The main intention of this paper is to extend the foresight approach combined with a relatively new tool of advanced text-mining and data analytics at the national level, in order to specify the technology application fields. The obtained framework contributes to mapping a comprehensive set of products and services with respect to technologies, particular sectors and further implementation thereof. This facilitates consensus across different stakeholders of the innovation process in terms of technology areas, tools and cooperation benefits. The suggested methodology can be applied in similar research activities. A combination of strength of market approach with innovation policy instruments provides a new insight on socio-technology architecture in the face of global challenges. It ensures, thus, matching between the longstanding objectives, resources and Russian technological competencies. The overall application of this mechanism in sector and firm level can increase the country’s scientific and technological effectiveness.

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