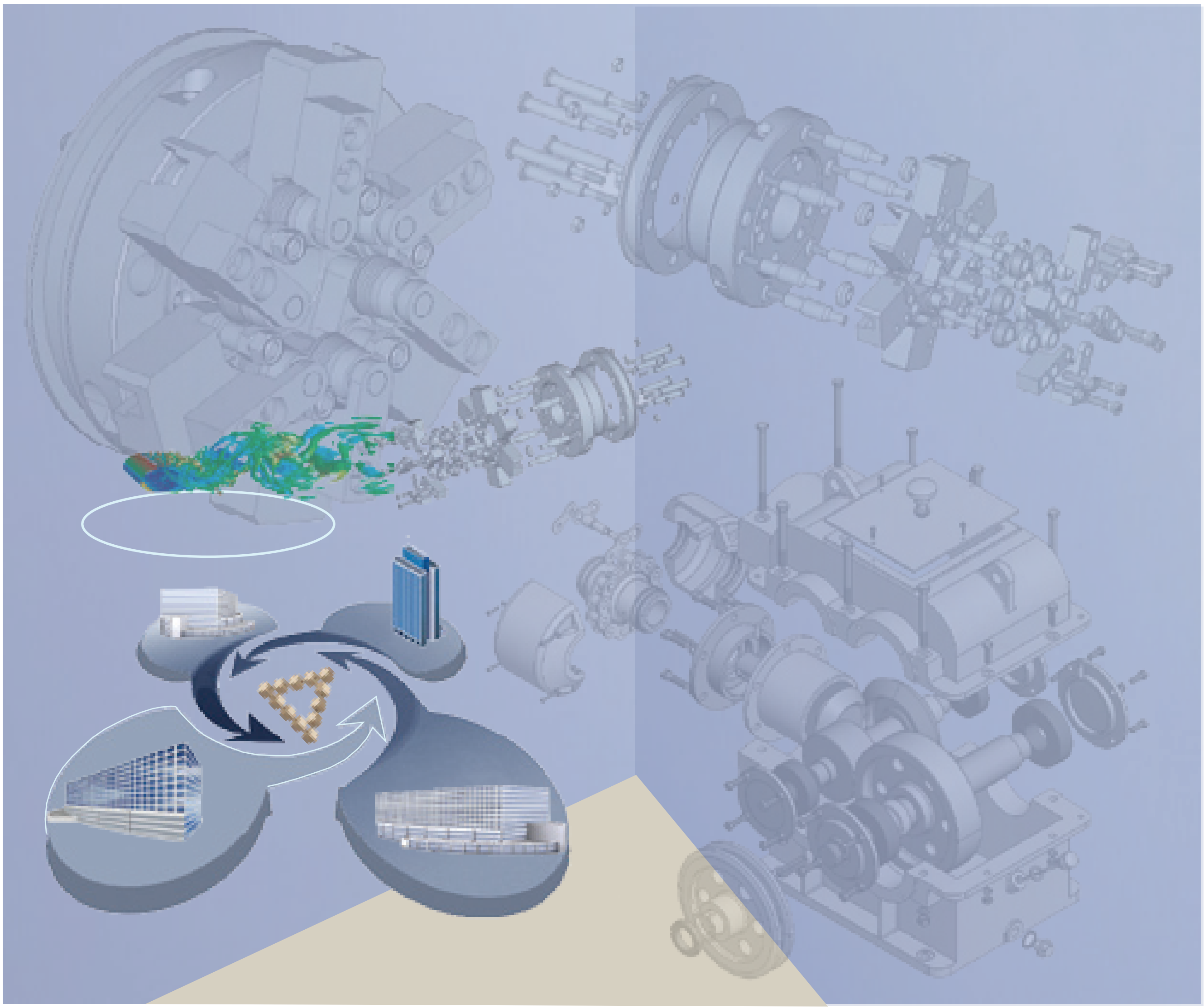
Advanced Manufacturing: New Emphasis in Industrial Development

Irina Dezhina, Alexey Ponomarev



The development of advanced manufacturing technologies produces tangible social and economic impacts and has strategic importance for strengthening competitiveness of a country's economy.

The article compares the capacities of Russia and the world's leading countries in the field of advanced manufacturing technologies, and outlines policy tools to support the development of such technologies.

Special attention is paid to the scientific and industrial consortia which aim to support promising developments at the pre-competitive stage.

Irina Dezhina — Head of Research Group on Science and Industrial Policy, Skolkovo Institute of Science and Technology (Skoltech), and Head of Economics of Science and Innovations Division, Institute of World Economy and International Relations, Russian Academy of Sciences (IMEMO RAS). Address: 23 Profsoyuznaya str., Moscow 117997, Russia. E-mail: dezhina@imemo.ru

Alexey Ponomarev — Vice-president, Industrial Cooperation & Governmental Programs at the Skolkovo Institute of Science and Technology (Skoltech), Professor at the National Research University – Higher School of Economics. Address: 100 Novaya str., Skolkovo, Odintsovsky District, Moscow Region 143025, Russia. E-mail: ponomarev@skolkovotech.ru

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The concept of Advanced Manufacturing

The development of advanced manufacturing technologies (sometimes called "breakthrough" technologies, to emphasize their revolutionizing effect on the production pattern) has been widely discussed in developed and newly industrialized economies over the last few years. Such attention is well-deserved as advanced technologies create new markets and industries, promote operational efficiency, competitive growth in certain industries and national economies in general. With their potential to drastically upgrade the workflow, facility management methods and the skills of the workforce, these technologies often drive changes in the economic setup. Advanced manufacturing technologies may trigger, for example, the closing of large-scale production facilities as a result of shifting to product customization and reducing the reliance on a cheap workforce. Digital technologies make the workflow more coherent. Technologically, advanced manufacturing technologies are primarily associated with 3D-printing, the Internet of things, innovative materials and robototronics [MIT, 2013].

Russia lags behind developed and some developing nations in terms of advanced manufacturing practice. However, Russia still has a chance of catching up with the global leaders: the critical task is to identify the economic and technological areas to be developed for the breakthrough technologies to emerge in the country. This paper investigates the experience of foreign countries where advanced manufacturing is promoted by the government. Our methodology consisted of reviewing scientific publications and government policy documents from the USA and UK and conducting interviews in the USA with officials in charge of development and implementation of advanced manufacturing technologies.

Many studies devoted to different dissemination aspects of advanced manufacturing technologies have been undertaken for several decades. However, such aspects as customization and localization, i.e. different forms of aligning manufacturing facilities to customer needs, have only recently become priorities. In the mid-1980s and early 1990s, studies to assess the impact of some technologies on productivity and efficiency of enterprises and companies became popular [*Beaton, Bull,* 1987; *Son, Park,* 1987; *Gertler*, 1993; *Lei et al.*, 1996].

The early 2010s saw a new surge in interest for advanced manufacturing technologies, when both researchers and governments focused on the new manufacturing related to localization and customization [*Tassy*, 2010; *Gibson et al.*, 2010] and the respective changes in the requirements to personnel qualifications [*Davis et al.,* 2012]. One of the recent significant papers on the subject discusses the changing approaches to localization of production facilities in the USA [*Berger,* 2013]. European researchers pay great attention to assessing the government-supported manufacturing technology programs, in particular, the relevant aspects of Framework Programs [*Arvanitis et al.*, 2002], and the recent study on the potential of technological platforms in assessing advanced technologies and their promotion policy [ManuFuture-EU, 2011].

Characteristically, researchers have not yet agreed on a single definition of promising (advanced) manufacturing technologies. Nonetheless, the wording of the definitions have something in common, including, in particular, using innovative technologies to improve products and/or workflows as well as the innovative business methods. The definition of advanced manufacturing proposed by Paul Fowler, Research Director of the US National Council for Advanced Manufacturing (NACFAM) [STPI, 2010], is the best known:

> 'Makes extensive use of computer, high precision, and information technologies integrated with a high performance work force in a production system capable of furnishing a heterogeneous mix of products in small or large volumes with both the efficiency of mass production and the flexibility of custom manufacturing in order to respond rapidly to customer demands.'

Later, the Institute for Defense Analyses (IDA) introduced a wider notion of advanced manufacturing into public use. This notion was elaborated based on surveys among the scientific community, public administration and industry. Advanced manufacturing means both conventional and high-tech industries where existing materials are improved and/or new materials, products and processes are created by implementing the achievements of science and technology, high-precision and information and communications technologies (ICT). These achievements are integrated with a high-performance workforce, the innovative business or organizational models [*Shipp et al.*, 2012].

Professionals have become increasingly interested in the large-scale customization feature of advanced technologies [*Piller, Tseng*, 2010; *Boër et al.*, 2013], meaning large-scale manufacturing of customized (consumer and capital) goods. That is comparable with high-volume manufacturing in terms of efficiency and differentiation and this creates economic advantages of advanced manufacturing for potential users. Customization envisages transferring certain functions related to a finished product technological design to suppliers, and therefore it becomes essential to obtain suppliers' constant feedback which can be taken into account in subsequent manufacturing. Hence, customization has both service and production dimensions.

For several decades, attempts to set up large-scale customized production facilities have been underway. The additive technologies that emerged have prompted this process, although forging an efficient teamwork along the entire value chain, including integrating into the supply system, is the fundamental difficulty.

In Russia, the term "advanced manufacturing" is used in statistical accounting, where it means "flow processes including microelectronics or computer controlled machinery, accessories, equipment and devices that are used in designing, manufacturing or processing" [HSE, 2014, page 398]. Obviously, this definition does not reflect particular features of the modern developmental stage in manufacturing technologies, such as large-scale customization.

Thus, the new understanding of advanced manufacturing covers the following dimensions:

1. Technological substitution that leads to major improvement of existing products or to the creation of entirely new ones;
2. Computer-aided manufacturing that imposes new requirements on professional qualifications;
3. Customization of production facilities i.e. their flexible adaptation to customer needs;
4. Localization: cutting down costs by procurement savings and ensuring proximity to the consumer (customer);
5. Economic efficiency related either to cost cutting compared with large-scale manufacturing or to resource conservation, higher productivity, investment appeal and competitiveness.

In this article, we try to limit the range of key technologies (in the technical sense of the term) to the development of production facilities with certain economic features (low-cost customized products and manufacturing that can be decentralized). The following definition is proposed for the purpose:

> 'Promising (advanced) manufacturing technologies is a set of processes intended for high tech designing and manufacturing of customized items (goods) of different complexity, with the value comparable to the value of mass-produced commodities, in particular, in low-wage countries.'

This group of flow processes makes it possible to decentralize development and manufacturing, while ensuring significant logistic advantages in the creation and promotion of goods to the market, reduction in their cost, and the cost of their delivery to the end consumer. On the one hand, these processes depend on efficient information dissemination, and the level of automation and computerization. On the other hand, they depend on new materials, and research and development (R&D) in physics, biology, and related fields.

Advanced manufacturing may be technically described using the five key areas of the transdisciplinary research group focus. To work in the areas, participants should be able to use meta languages of each appropriate field. Based on different approaches to defining the top priority areas of the advanced manufacturing technologies [MIT, 2013; ARTEMIS, 2013; NIST, 2013, p. 3], we highlight the following:

1. Flow process control systems, including sensors to monitor equipment, material flow parameters and the state (size, composition et al.) of created (processed, grown) items;
2. Multi-dimensional modeling of complex products that enables you to improve their different parameters (durability, service life and, possibly, the manufacturing flow). Such modeling systems allow an item to be customized through modification for customized or small-scale manufacturing;
3. Intellectual production management systems (improvement of external and internal procurement, process flow modes), in particular, in robototronics and the so-called 'Internet of things';
4. Material item creation and transformation (growing) system, in particular, 3D-printing; the infusion technologies that become of greater significance; promising surface processing methods and thermoplastic polymer handling methods. Growth technologies in their broad meaning are critical for this area;
5. Materials efficient in the creation of promising actuation devices (first of all, growth technologies) — composition materials, as well as the materials demonstrating their properties in subtle structures.

The progress in these fields may create some visible cost advantages in addressing the multiple production problems. The production infrastructures based on these technologies are regulated by industrial, innovation, scientific and educational policies. Educational policy is becoming increasingly intertwined with the new industrial policy, due to changes in manufacturers' needs, exhaustion of the conventional regulation mechanisms, as well as some disappointment in expert forecasting through the academic community's efforts. The leading universities and research centres provide the research and educational components, and private enterprises carry out the innovation component on a different scale [CSST, 2013].

Expectations about the potential of advanced manufacturing technologies for the global economy and for the transfer of promising production facilities to countries with highly developed technologies and educational systems, a positive business environment, and a high level of demand for new technologies are a significant incentive for governments of more developed countries to pay more attention to advanced manufacturing.

Encouraging New Industrialization

The notion of localization, i.e. the placement of new industrial infrastructure near the development and design centres, research and design units, is closely linked with advanced manufacturing. Localization is common in US companies, as the US government is concerned about repatriation of production facilities. The country has lost a third of its industrial output as a result of moving production facilities overseas in the last decade. Meanwhile, just 35% of qualified engineers, 60% of R&D professionals and just 9% of workers are employed in the USA [CSST, 2013]. The drain of diverse highly qualified staff as a result of international relocation of the production facilities is regarded, in particular, as a threat to national security, one response to which is localization. At the same time, the government has stepped up its support to new institutions (regional 'hubs') engaged in development and prototyping of technologies and has quickly

Box 1. US Government Policy in Advanced Manufacturing

June 2011. President Barack Obama announced the Advanced Manufacturing Partnership (AMP), a multi-agency initiative with the participation of the US Departments of Defense, Energy, and Education as well as NASA, the National Science Foundation and the National Institute of Standards and Technology (NIST). AMP Steering Committee includes the heads of the top engineering universities, such as the Massachusetts Institute of Technology (MIT), University of California, Stanford University, University of Michigan and others, and the top management of major US companies (Caterpillar, Corning, Dow Chemicals, Ford, Honeywell, Intel, Johnson&Johnson, Northtrop Grumman, Procter&Gamble, United Technologies).

July 2012. The President received a report on increasing the domestic competitive advantages in manufacturing technologies. It includes 16 recommendations divided into 3 groups: 1) promotion of innovations (including creation of new R&D consortiums); 2) personnel support (new educational programs and internships); 3) business environment improvements (tax reform, change in the technical regulation rules, enhancement of the trade and power engineering policy).

August 2012. The first specialized National Additive Manufacturing Innovation Institute (NAMII)[1] was set up. It is a consortium amalgamation of more than 80 manufacturing companies, 9 research universities, 6 four-year colleges and 18 nonprofit organizations included into the Technological Belt of Ohio — Pennsylvania — West Virginia. USD 40m of financing comes from the industry and USD 30m from the government.

January 2013. The main parameters of the future National Network for Manufacturing Innovation (NNMI) were defined. It is intended to consolidate 15 institutes created as part of AMP.[2] The President requested USD 1 billion for funding of the network from the federal budget.

May 2013. The President announced the tender to set up three institutions of the following profile:

- Digital manufacturing and innovations in design;
- Manufacturing of light and modern metals;
- New generation in power electronics.

October 2013. Pooling the first experience, revision of 16 recommendations, their adjustment and detailed elaboration as part of AMP 2.0.

January 2014. The preferred bidders were approved for USD 1.5m to be allocated to each of them from the federal budget annually over 4 years. The tender to be held within a year to additionally set up four institutions – two to be supervised by the Department of Energy, and two by the Department of Defense — was announced.

Sources: [EOP, NSTC, AMNPO, 2013; White House, 2012, 2013a, 2013b].

implemented efforts to integrate them into the single network. The key facts and dates given in Box 1 demonstrate how promptly some particular decisions have been agreed upon and made, and also how rapidly the decisions have been incorporated into the operations of these institutions.

'The Advanced Manufacturing Partnership (AMP) is not the first in a series of US governmental initiatives aimed at supporting 'new industrialization'. Some technologies recognized as advanced now were federally supported in the past, but without major breakthroughs. For instance, the cyber physical systems and the Internet of things have been developed since 2006 but have not given rise to new manufacturing platforms. Out of the 108 projects supported by funding of between USD 500,000 to USD 1 million from the US National Science Foundation (NSF) since 2008, just one concerns industrial cyber physical systems [Forschungsunion, Acatech, 2013].

The new governmental initiative met with a mixed expert response. Some of them note, in particular, that repatriation of the manufacturing facilities to the USA is likely to boost labour efficiency but does not guarantee cost savings to major companies and growth in their securities quotations [*Ratnikov*, 2013].

The reasons why governments in many countries proceed to develop support efforts for advanced manufacturing are different. For instance, Germany thinks it is a global leader in plant engineering and construction, and its development is driven by growing competition on the part of the US, India, and China. Accordingly, government support focuses on enhancement of tools (procedural standardization, work algorithm improvement, trainings) and the regulatory environment, rather than on establishment of new en-

[1] Available at: http://www.manufacturing.gov/nnmi_pilot_institute.html, accessed 20.02.2014.

[2] Late in 2013, the possibility of expanding the network to include 45 institutions was discussed. Source: interview with MIT Vice Principal Martin Schmidt, taken by Irina Dezhina (Boston, 02.12.2013).

tities [Forschungsunion, Acatech, 2013]. Maintenance of global leadership in manufacturing equipment and expansion to new markets are chosen as strategic priorities. The idea is to use two global integration approaches for this purpose:

- Horizontal, via networks;
- Vertical, via related manufacturing systems.

Horizontal integration consists of linking IT systems used at different stages of the process flow and business planning. It implies the exchange of materials, energy and information, both within a company and between several companies (networks) [Forschungsunion, Acatech, 2013].

Vertical integration consists of connecting IT-systems from different hierarchy levels — process launch, monitoring, management, manufacturing, implementation, and corporate planning.

The ARTEMIS technological platform covering the eight areas of manufacturing technologies was established to promote R&D projects in the European Union. As part of this initiative, the Vision for Manufacturing 2.0 discussion document was drafted to define the investment priorities for the EU's new comprehensive program Horizon 2020 (2014/2020) [ARTEMIS, 2013].

China faces the challenge of rising labour costs; the development of advanced manufacturing is regarded as an instrument to address that challenge. Thus, the Chinese government's policy focuses on the technologies to decrease reliance on labour resources. In addition, the 12th five-year plan (for 2011–2015) aims to reduce foreign technology imports. The plan includes the use of subsidies, tax cuts and other financial instruments. In 2010, the first Chinese Internet of Things Centre was created, with a USD 117m budget to finance R&D, and the Area of the Internet of Things with 300 companies employing more than 70,000 persons was opened [*Voigt*, 2012].

Development Priorities

Advanced manufacturing can be seen as a set of R&D fields identified with some particular precision (Table 1). For instance, US experts initially identified 11 key areas subdivided into 135 technologies based on crowd sourcing with the participation of the private sector only [NIST, 2013].

Despite a noticeable growth in the government's interest in new industrialization, Russia does not even have an indicative, agreed upon list of priorities in the field, let alone crowd sourcing of industrial companies [*Gorbatova*, 2014b]. The list of priorities is still adjusted within an ordinary budget cycle.[3] Some forecasts prove that the country has advanced manufacturing development potential; in particular, there have been significant advances in mathematical simulation and development of new materials. Several experts point to biomedicine and ICT as potential winners. According to the best-case scenario drafted by the Centre for Macroeconomic Analysis and Short-Term Forecasting (CMASF), the country's development prospects coincide with global trends in the core advanced manufacturing development areas, except for flexible manufacturing lines (where there is a 10-year lag behind global trends) and android robots (where Russia is not shown on the flow chart before 2030) (see Table 2).

New Support Policy: US and UK Experience

Development of advanced manufacturing in foreign countries is largely integrated into their scientific and innovative policy. The most important points of emphasis are:

[3] According to the recent assignment given by the Russian President (assignment 8, Section 2), it is necessary to change the top priority areas of science, technology and equipment development in the Russian Federation and the list of critical technologies approved by Order of the Russian Federation President no 899 of July 7, 2011. Source: Russian President, List of Assignments to Implement the Message to the Federal Assembly, 27.12.2013. Available at: http://www.kremlin.ru/assignments/20004, accessed 14.02.2014.

Table 1. **Indicative advanced manufacturing priorities**

European Union	USA	China
• advanced manufacturing • adaptive and smart manufacturing systems • digital, virtual and resource efficient manufacturing • mobile and cooperating enterprises (network manufacturing and agile production chains) • employee-centered manufacturing • consumer focused manufacturing	• sensors, measurement and flow control • modern materials design, synthesis and processing technologies • visualization, informatics and digital manufacturing technologies • sustainable manufacturing • industrial nano technologies • flexible electronics manufacturing • industrial biotechnologies and bioinformatics • 3D-printing • advanced manufacturing and test (quality assurance) equipment • industrial robotronics • advanced forming and connection technologies	• ICT –new generation industry • biological engineering • high-performance technologies and equipment • advanced materials • sensors • smart technologies

Sources: [Factories of the Future PPP, 2012; White House, 2012; *Knyaginin*, 2013].

Table 2. **Manufacturing Technologies Development Prospects: Russia and the World**

Technology development horizon	Before 2015	Before 2020	Before 2030
Composite materials	World, Russia		
Manufacturing line flexibility improvement		World	Russia
3D-designing		World, Russia	
Internet of things			World, Russia
Industrial manufacturing of carbon nano tubes			World, Russia
Android robots			World

Source: [CMASF, 2013].

1) Use of technological priority directions as the benchmark that does not envisage mandatory financing of the outlined areas (technologies). The priorities are shaped not only through special appraisal or forecast studies but through crowd sourcing and serve rather to monitor subsequent development than to be the structural basis of future programs or created centres;

2) Creation of consortiums as one of the most common forms of advanced manufacturing support. These comprise companies, universities, regional authorities, service and consulting firms. Financial costs are partially covered by the federal budget, but the principal burden lies on the industry — co-financing by companies normally accounts for more than a half of the aggregate consortium budget. Consortiums have the following particular features:

- Prototyping and output expansion as the top priority lines of business;
- Network type of relationship;
- Mandatory partnership with small businesses, science and educational institutions (in the USA, up to two-year colleges), links with the vocational colleges that meet the industry demand for personnel with new competences;
- Ongoing concern for an autonomous existence and transition to self-financing after budget financing comes to an end.

The institutions created as part of the US National Manufacturing Innovations Chain, the Plants of the Future funded by EU through a public-private partnership [MIT, 2013] and the British Catapult Centres are examples of such consortiums;[4]

3) Combination of different instruments by insisting on flexibility and diversity in managerial decisions, giving up rigid arrangements and algorithms;

[4] Available at: https://www.innovateuk.org/-/catapult-centres, accessed 14.02.2014.

4) Permanent progress monitoring — diagnostic monitoring[5] — of the initiatives to detect any hurdles and to elaborate on possible improvements. The problems may be brought about by both the wrong choice of development tools and contractor errors. Diagnostic monitoring is different from more popular methods of effort efficiency measurement in that it assesses the degree of achievement of goals set earlier.

Structural features of US. consortiums

Each institution in the established US National Network for Manufacturing Innovation is tasked with transformation into a regional 'hub' — the platform where fundamental research 'melts' into new products, and companies, universities, colleges and federal departments jointly invest into advanced manufacturing development. Such infrastructure also constitutes the unique 'education factory' — the foundation for training students and employees of all levels — as well as the chain of centres for collective use of equipment for small manufacturers that create, test and manufacture prototypes of new products and carry out pilot launches of process flows.

Operations of the institutions that are part of the described chain include, but are not limited to, the following kinds of activities:

- Applied research;
- Demonstration projects that reduce the costs and mitigate the risks related to commercialization of advanced technologies or that enable the problems industrial enterprises face to be resolved;
- Educational and training activities at all levels;
- Development of innovative methods and practices for integration of sales systems;
- Cooperation with small and medium industrial enterprises.

The last item is critical because the institutions are intended to assist in small business development in various forms, in particular, by ensuring access to the centres for collective equipment use, technical advice and assistance to the firms which may lack staff possessing the necessary competencies, and by providing information on advanced technologies. Finally, the institutions may deal with commercialization of their own startups.

The operations of all institutions are regional by nature, while the entire network of production innovations remains national in scale and significance. The idea is that essential technologies should be identified locally and should serve regional interests.[6] The possibility of using well-established tools (such as challenge grants provided by the State or funds on a tender basis) is discussed by experts in advanced manufacturing. This grant envisages that the money is not remitted until the set goals have been achieved, thus encouraging the recipients to achieve a particular result and look for new solutions. The innovation vouchers first tested in the Netherlands have proved to be efficient. They entitle the bearer to a certain sum of money for R&D, business plan development, et al. Small innovation companies, which often lack funds, may apply for vouchers to the appropriate department or fund. Then the firms that receive the vouchers turn to universities or centres capable of performing the required research, development or designing. The deliverable is paid for by the voucher, the value of which is made up for by the issuing agency later [*Kiselev, Yakovleva*, 2013].

In addition to the fundamental consortium operation principles, their *organizational setup* was subjected to thorough elaboration. Each consortium should have significant autonomy with respect to partner companies and an

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[5] This term is borrowed from corporate managerial practices. It is the method of involved observation widely used in sociological surveys and which enables difficulties experienced by all process participants to be identified and ways to rectify the the problems found.

[6] Source: Mr. M. Schmidt, MIT Vice Principal, interviewed by I. Dezhina (Boston, USA, 02.12.2013).

Box 2. SEMATECH Consortium Development Stages

SEMATECH nonprofit consortium initially included 14 major companies — semiconductor manufacturers (AMD, Freescale Semiconductor, Hewlett-Packard, IBM, Infineon Technologies, Intel, Panasonic, Philips, Samsung, Spansion, TSMC, Texas Instruments, and others) and was set up in 1986. It received funding on a parity basis from, on the one hand, the US Department of Energy (DOE) and DARPA Program for 5 years, and on the other hand, from industrial companies. The annual contribution of each of the parties came to USD 100m.

The consortium was tasked with studying advanced development trends in the semiconductor industry, development of the next-generation technologies, improvement of the expertise used in manufacturing of various products in this field, as well as enhancing competitiveness of the US industry to match the successes of Japanese manufacturers [SEMATECH, 1988]. SEMATECH uses not only its own laboratories transferred to it by the government but also participating companies' equipment.

After 9 years of operations (in 1996), the consortium actually abandoned the initial objectives and refocused on the global semiconductor industry. By resolution of the board of directors, the participating companies rejected budget financing, in particular, due to problems with the rights to intellectual deliverables [NRC, 2003].

SEMATECH performance was most actively assessed in the early 1990s, spurred by the interest in efficiency of such public-private partnerships. No consensus was reached on SEMATECH performance. Negative feedback was received, in particular, from medium and small businesses, for which the consortium was a closed club of big chip manufacturers that had monopolized the technology developed within the club [*Hoft,* 2011]. The business community also indicated that SEMATECH did not have any breakthroughs that would have been impossible outside the consortium. However, the academic community gave positive feedback to the partnership touting it as a successful model of public-private cooperation [OECD, 2011]. It was calculated that, since SEMATECH's establishment, R&D costs for the new generation chips dropped by 30%.

The model was further disseminated in other sectors such as car making, construction, artificial intelligence based test-and-measurement systems, and environment-friendly industrial technologies.

independent board of directors comprising mostly of *representatives of companies.* To the extent possible, consortia should cooperate with each other, by exchanging resources, advanced experience and R&D deliverables. Financial models, the findings of forecast research and consortium membership tools should be discussed openly. Such transparency is necessitated by the fact that while consortia are not direct competitors and pursue different goals, they share a common mission to promote greater competitiveness of industrial manufacturing in the country.

Federal funding of USD 70–120m is allocated to each centre for 5 to 7 years. At the end of 2013, the possibility of extending this term to 10 years was discussed. At least half of each centre's budget is private investors' money. While federal funding is expected to be more significant in the first 2 to 3 years of operation, the share of private funding sources is planned to increase gradually in the future. In 7 to 10 years, all consortia must be *self-financed* through membership fees, income from intellectual property licensing, contractual research and other paid services.

The idea of the consortium network develops the model used to create SEMATECH, a consortium of semi-conductor companies (see Box 2). SEMATECH is usually viewed by politicians as a successful experience of 'steady' public-private partnership. The projects have different missions and goals, although their structure is generally the same. The question of whether the model is worth replicating under new conditions to develop advanced manufacturing is still open. The comparison of financial indicators only suggests that President Obama's current initiative, with a USD 70m budget of the pilot institution (see Box 1), is almost three times cheaper than SEMATECH's initial budget of the late 1980s, when the US dollar 'weight' was much bigger. One can hardly expect any breakthroughs, given such budget hurdles, unless the established centres are partially virtual and use first of all, the capacities of participating companies' and universities' laboratories.

With monitoring playing a key part in assessing efficiency of the consortia, the criteria by which one can judge the advantages and drawbacks of the new

Table 3. **USA: Key Indicators for Diagnostic Monitoring of Centre Development within AMP**

Positive impact on industrial development	Performance and efficiency of the centres	Network management efficiency	Stability of centres
Number of new jobs	*Number of new jobs*	Quantity and quality of relations between institutions	*Number of new jobs*
Number of created startups	*Number of created startups*	Income generated by institutions from the industry participation	Increment in the number of the industry participants, in particular, small companies
Intra-institution partnerships	*Intra-institution partnerships*	Number of patents/ intellectual property items in all the network institutions	Income from licensing intellectual property items
Number of new technologies on the market	*Number of new technologies on the market*	Learning lessons and dissemination of innovative approaches	New products and processes
Application of the methods developed by the industry in the institution	Participation of small businesses in institution operations		Number of repeated project co-investors
	Funding received from the industry and the federal budget		Income/cost ratio
	Number of projects brought from the study stage to the prototype		New export
	Number of students and industry personnel in the institution		
	Intellectual property portfolio		
	Number of licenses		
	Trade balance		
	Number of promotion efforts		

Source: [NIST, 2013].

entities become more important. The criteria currently discussed in the USA, in the course of elaboration of the created consortium network, are shown in Table 3. They are to be used within AMP to: (1) confirm or deny a favorable impact of the established centres on industrial development; (2) to assess their performance; (3) to evaluate the entity's efficiency in network management; and (4) to evaluate the centres' degree of stability [NIST, 2013]. Obviously, the proposed criteria partially overlap (we italicized these items in Table 3) and do not contain entirely new indicators. However, their mix, combined with quantitative and expert estimates, gives an idea of the nature of the existing problems and achievements.

U.K. technical and innovative centres

The program to develop a network of technical/innovative Catapult centres in the UK was launched as early as 2010. Initiated by the government-created Technology Strategy Board, it envisages seven areas of focus for the new Catapult centres: high value manufacturing, cell-based treatment, offshore renewable energy, satellite software, integrated digital economy, cities of the future, and transportation systems.[7] The High Value Manufacturing Catapult was the first to be launched in October 2011. That Catapult centre was engaged in testing new technologies and systems before a decision on further investments into innovative projects was made. The Catapult included seven centres from different regions of the UK, specializing in different areas — from composite materials to 'process flow innovations'.[8] The organizational principles of the centres resemble those adopted in the USA, as part of AMP, namely:

- Multiple financing sources (national budget, industry, universities), with the planned total budget of GBP 140m for 6 years, provided that industry contributes half of the aggregate financing;

[7] Available at: https://hvm.catapult.org.uk/history;jsessionid=A8D3A67DEB0ADB9955D8CE96E99A972B.2, accessed 17.03.2014.

[8] Available at: https://www.catapult.org.uk/high-value-manufacturing-catapult;jsessionid=1D85531FC73C5B43AE08089FE0587537.3, accessed 05.04.2014.

- Prototyping and manufacturing of advanced products and services as business priorities.

The first deliverables of the High Value Manufacturing Catapult are already visible. It has created 700 new jobs and cooperated with almost 2,000 small and medium innovative companies involved in R&D.[9]

Advanced Manufacturing Development Potential in Russia

The advanced manufacturing leaders regard Russia simply as a growing market for their new products in their strategic documents. Actually, since 2010, Russia has increased purchases of manufacturing equipment and is likely to maintain its status as one of the major importers in the near future. The aggregate demand of China, India and Russia for IT technologies accounts for 14% of global demand [Forschungsunion, Acatech, 2013].

In contemporary Russia, advanced manufacturing development is still governed as part of the country's industrial policy or local initiatives. For instance, the bulk of engineering projects that enjoy great attention [*Labykin,* 2014] are related to the creation of specialized centres at universities.[10] This approach is hardly justified as universities lack sufficient competencies to market manufactured products. Neither are the arrangements for implementing scientific developments discussed in Russia. At the same time, domestic companies have gained a certain amount of experience in creating advanced manufacturing consortia.

It is worth remembering that 2002 saw the launch of the program of innovative nationwide mega projects. Teams of scientists and industrialists were involved in these large-scale initiatives, which were jointly tasked with overcoming the biggest hurdles to greater competitiveness, in particular, reduction in production costs through resource savings. The mega projects were mostly selected based on a consensus between scientists and businessmen, and their non-budgetary financing was supposed to amount to at least 60%. Their work did not produce any systemic results; however, formal indicators recognized the mega projects as efficient in terms of use of the budget. Nevertheless, specialists of the National Research University — Higher School of Economics estimated the supported companies' efficiency to be lower than those participating in similar Western programs [*Gokhberg et al.,* 2011, p. 54].

This experience, in particular in project monitoring, may be useful for the development of advanced manufacturing. In addition, there are some examples of when diagnostic monitoring was successfully used to assess the effects of government incentives for corporate-academic cooperation [*Dezhina, Simachev,* 2013].

Technological platforms are a second potential tool. They help mobilize companies to discover the critical areas required to develop advanced manufacturing. In addition, as European practice suggests, technological platforms may lay the groundwork for setting up the consortia where major companies play the leading part.

Unfortunately, there are still more problems than achievements in the area under review for both science and innovations. First, according to the Thomson Reuters overview published in 2013, Russia is not included among the countries leading in the 100 most advanced research and development fields [*King, Pendlebury*, 2013]. Second, while developed nations have already shifted to multi-disciplinary research underlying many advanced manufacturing tech-

[9] Available at: http://www.insidegovernment.co.uk/event-details/catapult-centres/202, accessed 12.03.2014.

[10] This situation is partially explained by the data provided by the Ministry of Industry and Trade, according to which just 2% of Russian companies make use of engineering skills [*Gorbatova*, 2014a]. Based on the tender held in 2013, 11 winning universities were designated as engineering centre sites (11 projects were selected for implementation of the pilot projects aimed at creation and development of the engineering centres based on the leading technical universities). Available at: http://минобрнауки.рф/новости/3719, accessed 18.10.2013.

nologies [*Balcerak*, 2012], the importance of trans-disciplinarity is still at the discussion stage in Russia. That notion means blurring of distinctions between individual disciplines, combining different methodologies, the emergence of hybrid research areas, in particular, those areas helping to address complex technical and technological objectives.

The principles of budgetary support to technological R&D also need revision. Russia should move from funds allocation to management of current and expected deliverables, and from support to manufacturing of new prototypes to systemic technological upgrading [*Knyaginin*, 2013]. Advanced technologies account for less than 1.5% of funds of federal special purpose programs in civil aviation, marine equipment, electronic component base and pharmaceuticals.[11] Finally, the current 'innovation enforcement' policy only has negative implications due to the lack of economic demand and enforcement. For instance, the development and implementation of innovative development programs by state-run companies often evolve into attempts to pass off marketing projects as innovations [Expert-RA, 2012]. Irrespective of economic interest, companies seek to report properly to the state, without their involvement in significant innovations. As participants of the Open Government's strategic session noted in March 2014 the typical features of state-run companies 'forced' to innovate, just like their supervisory authorities, remain their closed nature and lack of transparency. Enterprises prefer investments for production upgrading rather than for the development of advanced technologies, which means they therefore lag behind foreign competitors and have reduced overall efficiency.

In our opinion, one should not disregard the experience of borrowing from Western models of recent public policy as they can offer useful lessons. Localization of new forms of support to the last stages of the development and design of industrial technologies in Russia may be simplified through understanding the local specifics and knowledge of the 'sore spots' in the national economy. The above mentioned diagnostic monitoring, as part of the consortium creation strategy, may be an experience worth borrowing. The customization development potential may also be found in a feature of Russian innovations whereby unique products are manufactured more successfully than mass industrial products [*Auzan*, 2013].

Developed and several developing nations use a broad range of tools for promoting the emergence and dissemination of advanced manufacturing: from amendments to various economic regulations to supporting new science-and-industry forms of cooperation. In such a way it is possible to build up an integral support system, while in contrast Russia is only introducing isolated measures. We still have time and recent foreign experiences, together with the innovative entrepreneurship infrastructure taking shape in Russia, which may enable us to connect with the global context and find our niche globally. In such a connection, two organizational scenarios are possible: first, where we establish territorial and industrial consortia and second, where we implement end-to-end R&D programs to ensure leadership in particular areas.

Particular Features of Consortium Creation: Instead of a Conclusion

In our opinion, the new advanced manufacturing development tools should be coordinated above all with the infrastructure projects and development programs for certain technical fields that Russia has already implemented. They concern the government support system which covers many fields from fundamental research to manufacturing of developmental prototypes and industrial technological re-equipment.

The creation of an institutional core comprising of consortia of scientific organizations and companies is of critical importance for advanced manufacturing. Such consortia may be established as part of a specialized program of scien-

[11] Federal Special Purpose Programs: Development of Civil Aviation Equipment in Russia in 2002–2010 up to 2015; Development of Civil Marine Equipment in 2009–2016, Development of Electronic Component Base and Radioelectronics in 2008–2015, Development of Pharmaceutical and Medical Industry in Russia to 2020 and Beyond.

tific and educational support to advanced manufacturing development, which would cover the pre-competitive research stage. Its implementation may begin with pilot projects coordinated with the Ministry of Industry and Trade sub-programs to support competitiveness of technological fields such as composition materials, machine tool building and robotototronics. Engineering centres that re-equip manufacturing facilities with new generation technologies acquire increased significance here.

Consortia may be created in places with existing efficient research infrastructure, such as universities, shared equipment use centres, technological clusters, and territorial structures (clusters, industrial clusters et al.) that are managed jointly with industrial companies. As shown above, operations of consortia might cover analysis of the research base; corporate demand assessment; applied research and prototyping; participation in research projects on the basis of international cooperation; personnel training; and further training (such as short-term courses, master programs and post-graduate programs in promising areas).

The consortium may comprise of several laboratories that implement, together with industry, three- to five-year programs of applied research and personnel training and involve students and post-graduate students in research. Co-financing by companies, with a gradual shift to self-sufficiency, is an important pre-requisite for the laboratories' operations. Such an approach would help to coordinate the government personnel and technological policies, which the previous paradigm did not ensure. Naturally, this strategy is not the only one: other options exist.

We argue that a systemic strategy for developing new technologies is a critical part of Russian research and development policy because of the many economic incentives brought by advanced technologies. Their implementation leads to favorable conditions for manufacturing decentralization, reduction of market entry barriers to small industrial companies, outsourcing, stimulation of small and medium business activity, and the creation of high-tech jobs in the regions. This exerts even greater pressure on major industrial corporations, thus improving the competitive environment. F

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