The prospect of development of robotics in Russia

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Abstract. The article considers the position of the Russian robotics market in relation to the matrix of approaches to the development of national programs. At this stage, Russian robotics is based more on foreign basic research with a focus on the external market, since the capacity of the domestic Russian market is still insignificant and for the sustainable development of domestic developers and manufacturers of robotic systems it is necessary to focus on foreign markets. Robotics is traditionally divided by the international robotics Federation (IFR) into service and industrial robotics. Currently, the first type of robotics prevails in Russia, which can be seen by the number of companies belonging to these types: 80 companies developing service robots against 10 industrial ones. Thanks to the SWOT analysis of the robotics market in Russia conducted in the second part of the article, the main competitive advantages of the country were identified, among which, for example, one can note the huge territories and small population. Due to this situation, the use of unmanned transport (air, land, sea and river) in our country can be justified and cost-effective. As a result, driverless transport on our routes can be used for commercial purposes a little earlier than in countries with higher population density. It is also worth noting the threats that arise in the way of the development of domestic robotics. In the first place among the main ones are geopolitical barriers: the current sanctions regime against the Russian Federation puts barriers on scientific and technical cooperation with foreign specialists, prevents the import of technologies and blocks access to international investment. It is also worth noting the increase in the trend

1 The Global Robotics Market

1.1 What Is a Robot?

Smart machines, similar to people, were born in the imagination of writers and created by the hands of masters or engineers for centuries. However, the appearance of the term “robot” in 1921, when the Czech writer Karel Čapek first used this word in his play “R.U.R.” (“Rossum universal robots”), did not make the essence of this technology more

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understandable. A humanoid mechanism, a toy, an automaton, an electronic double copying certain body movements, an assistant for people with disabilities, an effective worker. We can agree with all of the above.

It is also a "long fist" in military applications, and a super-precise scalpel of a surgeon, and a safe mobile tool for working in extreme or uncomfortable conditions. We understand this listing is very limited. A robot is a functional extension of a person. From simple physical "organoprojection" - tools as an extension of the human body - we move on to robots - tools that have self-learning artificial intelligence. That is, tools with the potential for self-reflection. We assume that this trend will only intensify in the near future.

According to Paul Krugman, Nobel Laureate in Economics, from an economic point of view, any object that uses technology to do the work that people have previously done can be considered a robot.

But let's pay attention, almost 100 years have passed, and until now there is no universally accepted definition of a robot. This was difficult to do in the first place because the understanding of the robot changed with the development of technology, gaining new meanings. The robot, which was considered highly developed 50 years ago, is today an everyday solution. A compromise can be considered the current definition of the International Federation of Robotics (International Federation of Robotics, hereinafter - IFR): "A robot is a working mechanism that can be programmed along several axes with a certain degree of autonomy and capable of moving within a certain environment, fulfilling its tasks." This definition takes into account the features of robots that distinguish them from other mechanical devices - autonomy and independent execution of the task. The robot is able to independently move in the environment and adapt to the tasks. For example, a robotic arm picking up boxes from a conveyor belt. And the device that distributes the boxes between the two conveyor belts is not a robot. A dishwasher that does the dishes is not a robot. But if it can automatically load and / or unload dishes, then it can already be considered a robot.

According to renowned robotics scientist Rodney Brooks, robotics has not yet passed the childhood phase. He formulates four major technological problems of modern robotics that must be overcome in order for robots to become more widespread in our economy. Rodney Brooks expresses these barriers through anthropomorphism:

- robots must learn to recognize any objects of the world at least at the level of a two-year-old child;
- robots must learn to recognize natural language at least at the level of a four-year-old child;
- robots must have sleight of hand and fine motor skills at the level of a six-year-old child;
- robots must have social communication skills with people at least at the level of an eight-year-old child.

However, in our opinion, such a description lacks one component that is characteristic of new generation robots - the ability to recognize a changing situation, reflect on the observed changes, and actively influence the environment surrounding the robot and objects of its activity. For example, a robot must not only take all objects in a row from the conveyor, but also distinguish them by size and shape and sort them into different baskets. The rapid change in technology leads to the rapid obsolescence of standards and definitions. Terminological uncertainty prompted Sberbank Robotics Laboratory to introduce a functional definition of the robot - STA-definition - from the words Sense, Think, Act. A device can be called a robot provided that the following conditions are met at the same time.

1. Sense: the robot has the ability to perceive the world using sensors. Such sensors can be microphones, cameras, various electromechanical sensors, and more.

2. Think: the robot has the ability to understand the signals that it receives from sensors observing the physical world, build and adapt behaviors, and make decisions depending on the selected behaviors. This ability can be realized in different ways: the on-board computer of the robot, the "intelligent" cloud or the person who controls the robot using telecontrol or a tactile interface.
3. Act: the robot has the ability to affect the physical world in any effective way.

Fig. 1. Robotics classification. Source: IFR.

The accelerated development of robotics is also reflected in the evolution of standards and technologies. IFR's traditional approach to dividing robots into industrial and service robots (Figure 1) often does not reflect the mutual penetration of technologies: service robots are increasingly being used in industrial environments, and industrial robots are used a lot in typical service organizations. This trend can be described as "the convergence of industrial and service robotics technologies". Experts predict that over the next three to five years, the division of robots in an explicit form into industrial and service (professional) will lose all sense from the point of view of categories: the same robot will be able to work both in the workshop and in a typical service environment.

For this reason, there is now a serious discussion between experts from the ISO international standardization organization on how to change the above definition of the robot. In the new version, which is still being discussed within the working group of the corresponding ISO technical committee, the definition of the robot is not limited to a given environment, therefore the robot is considered as a program-based mechanism that has a certain autonomy and performs the movement, manipulation or positioning of itself or other objects in space.

The increase in the pace of robotization and automation of industry and the service sector leads to the fact that society begins to think about the social consequences of such changes. Despite the fact that so far robots seize power only in science fiction books and Hollywood movies, public institutions are already trying to provide ways to control robotization. An example of such a defensive reaction of public institutions is domestic and international legislative and public initiatives to develop a legislative framework and a legal definition of robots.

Public organizations, politicians and the academic community raise questions about whether a robot can potentially be considered the subject of legal relations, which requires a clear definition of the concept of "robot" from a legal point of view. So, according to experts of the law firm Dentons Europe, the right approach to defining the concept of "robot" is to highlight its key characteristics [1]:

- mechanism;

- physical beginning;
- artificiality;
- a sufficient degree of autonomy of actions, a key characteristic that allows you to determine the difference between a robot and any other mechanism.

By autonomy, company experts mean programmability, the robot performing tasks "for its intended purpose" for it; the possibility of perceiving the environment, which can be provided by a system of sensors; interaction with the environment, including the user; the presence of a drive that provides physical functioning. It is easy to see that the proposed legal definition largely overlaps with the current version of the definition of ISO.

1.2 Industrial robotics is growing for the sixth year in a row

The technological vector of a post-industrial society is determined by the transition to fully automated digital production using self-organizing cyberphysical systems. An important part of such systems is autonomous industrial robots, which have already become a cost-effective alternative to human labor in an expanding range of industries.

According to the McKinsey Global Institute (MGI), overall operational cost savings from automation can range from 15% to 90%, depending on the industry. In most industries of economically developed countries, robots have already proven their effectiveness, which has led to an increase in global demand for them. According to IFR estimates, in 2017, sales of industrial robots increased by 31% compared to 2016. In total, 381,335 robots were sold (Figure 2).

Fig. 2. Dynamics of sales of industrial robots in the world in 2009–2017 and forecast for 2018–2021, thousand units. Source: IFR World Robotics 2018.

Fig. 3. Annual growth in the global market for industrial robots in value terms for 2012-2017, \$ billion. Source: IFR World Robotics 2018.

Fig. 4. Average cost per unit of industrial robot, \$. Source: IFR World Robotics 2018.

The total market volume of industrial robots in 2017 amounted to \$ 16.7 billion, excluding the cost of software (Figure 3). Based on the software, the market estimate is even higher and amounts to more than \$ 48 billion [6]. Although the final data for 2018 has not yet been presented, but according to preliminary information we received from IFR, the growth in robot sales in 2018 ranged from 1% to 10% compared to 2017. Thus, the estimate of the number of industrial robots sold in 2018 is up to 421 000. Despite the fact that the total number of robots installed in the world barely exceeds 2 million units, actively running robots have left a noticeable mark on the global economy. The World Economic Forum (WEF) estimates at 29% the share of world production that is already robotic to some extent. Distribution of robots will continue. It is expected that by 2021, the total number of installed industrial robots will double compared to today. The growth in demand for robots is accompanied by a decrease in the cost of them: the average price for one industrial robot decreased from \$ 45,500 in 2016 to less than \$ 44,000 in 2017. At the same time, the share of “inexpensive” robots in the total volume of installations in 2017 increased by compared to previous years.

Such a dramatic growth in the industrial robotics market is caused by a number of factors. The main one is the ongoing large-scale modernization of Chinese industry: about a third of all global sales of industrial robots are in China. Another factor contributing to robotization is the use of 3D printing with composite materials and other new technologies for the production of robots, which make them cheaper, more affordable and better. No other important factor is the significant increase in investment in this industry. According to The Robot Report (TRR), investment in robotics continues to grow rapidly. The total funding for the ten largest transactions in 2018 exceeded \$ 11.5 billion. For comparison, the ten largest transactions in 2017 totaled \$ 700.6 million (an increase of more than 16 times). Along with investments, the number of patents for robotic developments is increasing. According to IFI Claims, a patent monitoring and research company, the number of applications related to robots has tripled over the past decade. China leads the patent race – it accounts for 35% of applications filed, which is double the second place in Japan [2].

According to the earlier IFR data, from 2019 to 2021. Almost 1.7 million units will be sold. Sales may grow by an average of 14% annually. Another research organization, IDC, gives a more optimistic forecast. IDC analysts see the market volume of industrial robotics by 2022 in excess of \$ 210 billion, taking into account software.

In our opinion, this is not without reason, since the main factors in the dynamics will be a gradual decrease in prices for robotics, high demand for products and a continued increase in investment. There are no prerequisites for the influence of these factors to decrease. Almost two-thirds of all industrial robots manufactured in the world consume the automotive and electronics industries. As in the previous year, these sectors account for 33% and 32% of all sales, respectively (Figure 5).

Fig. 5. Distribution of supplies of robots by manufacturing industries in 2017. Source: IFR World Robotics 2018.

The automotive industry is undergoing major changes and therefore requires new, more advanced robots. In connection with the European Union’s emission reduction program, European automakers are planning to increase production of cars with low carbon emissions by 2030 and are gradually switching to fully electric transport. All this against the background of high consumer requirements for quality and product customization. As a result, sales of robots in the automotive industry grew in 2017 by 22%. An important consequence of the “mass customization” of the automotive industry was the practice when a person works “side by side” with robots in collaboration mode. That is why the growth of collaborative manipulators for safe and productive work in the factory is the most noticeable growth factor for industrial robots. For example, at a Ford plant in Germany, Kuka robots are working with people to install shock absorbers in Ford Fiesta cars. Similar examples are found at the factories of Mercedes, BMW and other leading automakers. The direct interaction of the robot and man has become a sign of a successful and modern organization of production processes. Over the years, the demand for robots in the automotive industry has largely determined the overall flow of investment in installing robots in the world. However, in recent years, the status of the main robotics market has moved to another industry. In the leading countries of the robotics industry – Japan, China, South Korea – the main driver of demand for robotics was the production of electronics. It is the electronics industry that accounts for 32% of all global shipments of robots. Demand for robots in this industry is growing rapidly: in 2017, sales increased by 33% compared to 2016. In our opinion, it is precisely the growing demand for consumer electronics and the need to automate the entire production, including the production of batteries, chips and displays, in the production of household goods that will continue to remain the main factor in the global growth in sales of industrial robots, despite the fact that in absolute terms, growth may slow down. Thus, according to preliminary IFR data, the number of deliveries to this industry decreased in 2018 by 8% compared to 2017 [3].

The metalworking industry has yielded to quantitative leadership, but still demonstrates the strong growth rate of installed robots. According to IFR, in 2017, sales of robots in this industry increased by 55% compared to 2016 and reached more than 44,000 units in all subcategories: in the production of metals, metal products, industrial equipment. The least-robotized industries include the nuclear industry, shipbuilding, aircraft manufacturing, mining, and agriculture. According to IFR, in 2017, only 6055 robots for agriculture and about 300 robots for mining were sold worldwide. Sales data for robots for the nuclear industry, shipbuilding and aircraft manufacturing are not disclosed at all, but, according to a rough estimate of the IFR, do not exceed 1000 units. The reason for this is that the robotization of these industries is still complicated and expensive at the current level of technology. That is why we expect breakthrough technologies to be created in these

industries, and the next big thing in robotics will appear. It is noteworthy that these five sectors are traditionally strong in Russia. Therefore, the growth of domestic robotics can be expected precisely in them.

1.3 The geographical aspect of the robot market

Asia is still the fastest growing robotics market in the world: in 2017, sales of industrial robots in the region increased by 37% compared to 2016. Market growth in 2018, according to IFR, increased by 14% compared to 2017 d. This result is primarily ensured by the rapid development of the Chinese economy. The European market is the next largest - sales of industrial robots in 2017 increased by 18%. The market of America (North and South) grows most slowly - by 12% compared to 2016. More than 70% of global sales are in 5 countries: China, Japan, the Republic of Korea, the USA and Germany (Figure 7).

Fig. 6. Dynamics of sales of industrial robots by region in 2016–2017 and forecast for 2018–2021, thousand units. Source: IFR World Robotics 2018.

Fig. 7. Top 15 countries of the world in sales of industrial robots in 2017, thousand units. Source: IFR World Robotics 2018.

Fig. 8. Dynamics of sales of industrial robots in China, thousand units. Source: IFR World Robotics 2018.

China is the undisputed market leader, and the following facts indicate this:

- every third industrial robot in the world is sold in China;
- sales in 2017 compared to the previous year increased by almost 60% (Figure 8);
- Since 2013, China has been a leader in the number of installed robots. In 2017, more than 473,000 robots were already working in the country (+ 39% by 2016);
- over the past 8 years, the density of robots has increased by almost 10 times - from 11 robots per 10,000 people employed in industry in 2009 to 97 robots per 10,000 people employed in industry in 2017. This year, China exceeded the world average robot density.

The reason for such a rapid growth in China's robotics is the rapid growth of the economy, especially the automotive and electronic industries. It is the development of these two industries (one is the traditional leader in demand for robots, and the other is the new leader) that provides high demand for robotic products. This becomes clearer if for comparison we look at the neighboring industrialized state - South Korea - in this country, robotics has reached saturation. Robot sales in Korea in 2017 decreased by 4%. The key reason was the decline in demand from the electronics industry, as saturation was achieved there. Robot sales in Korea in 2017 decreased by 4%. The key reason was the decline in demand from the electronics industry, as saturation was achieved there. The rapid growth of electronics production is causing the growth of robotics in other Asian countries. In 2017, there was a significant increase in sales of industrial robots in Vietnam from 1,600 devices in 2016 to 8,300 devices in 2017. This allowed Vietnam to enter the top 10 countries for sales of industrial robots in the world. It is the electronic industry that has become the main driver of such an upswing. According to experts, one of the important features of the Chinese market is the focus of entrepreneurs on the developer community. Everyone who is interested in quickly capturing markets creates development kits for developers of various solutions (both software and hardware). Sparing no money, Chinese technology companies at their own expense promote products and services, attracting developers to them. For example, the company iFlyTek, one of the titans of the artificial intelligence industry in China, thanks to the active promotion of its own SDK, has grown the developer community to 825,000 people who have already made 500,000 applications. State support also has a positive effect on the development of the robotics industry. In 2015, the Made in China - 2025 initiative was announced, which defines robotics as a strategic industrial direction. Then, in 2016, the Chinese government presented an ambitious development plan for

robotics, which defines specific technologies and types of robots that need to be developed [4].

Despite China's national successes, local manufacturers of industrial robotics have weaker positions than foreigners localizing production in China. In 2017, the share of Chinese companies in the domestic market decreased to 25%, compared to a year earlier - 31%. Such international giants as ABB, Yaskawa, Epson, KUKA, Comau localized their production, in 2015 they were joined by Kawasaki and Nachi, in 2016 - Rethink Robotics. The Swedish-Swiss ABB plans to build a new plant in Shanghai by 2020.

The density of robotics in the world is growing year by year. For more than a decade, the world of robotics has been using a very useful indicator of market growth - the density of robots. It is measured as the number of robots per 10,000 workers employed in industry. This indicator is in good correlation with both the state of economic development and growth rates. According to IFR, in 2017 there were an average of 85 robots per 10,000 people employed in industry around the world (74 robots in 2016, 66 robots in 2015).

Europe, as a region that began to actively develop robotics in the automotive industry decades ago, has the highest robot density in general - 106 robots per 10,000 people employed in the industry. Whereas in the USA - 91 robots, in Asia - 75 robots. Europe's leadership in robotic density is explained by the fact that automation of production is the best way to reduce costs due to the high cost of labor in the region. However, if we consider the growth rate of the density of robotization, then leadership passes to the countries of the Asian region - 12% annually, from 2012 to 2017. In North and South America, this growth was only 9%, in Europe - 5%. True, in many respects the indicators of the European region worsen the countries lagging behind in robotics, such as Russia with its four robots per 10,000 people employed in industry.

At the same time, in the country context, South Korea remains the world leader in robotic density, which increased the rate from 631 to 710 robots per 10,000 employed in the industry, bringing this indicator to saturation; it is followed by Singapore with 658 robots, Germany with 322 robots and Japan with 308 robots (Figure 11). Korea leads with advanced electronics and automotive industries. The high position of Singapore is explained not only by the fast pace of economic development, but also by the relatively small volumes of production capacity in the country. Also in Singapore, the small number of people employed in the manufacturing industry is about 240,000 workers (according to the International Labor Organization).

Fig. 9. Comparison of the cost of an hour of human and robot labor (on average, the whole world), Euro / hour. Source: Financial Times, 2017.

Fig. 10. Dynamics of the average world density of robotization in 2010–2017, the number of robots per 10,000 employed in industry. Source: IFR World Robotics 2018.

Fig. 11. The density of robotization by country at the end of 2017, the number of robots per 10,000 employed in industry. Source: IFR World Robotics 2018.

1.4 Major manufacturers of industrial robots

The industry of industrial robotics has long been formed, but, despite this, data on the number of robots remain difficult to access by manufacturers. In 2018, Sberbank Robotics Laboratory published statistics on leading companies by the number of robots produced. Manufacturing companies of industrial robots are strictly distributed in three large regions: Northern and Western Europe, USA, Southeast Asia. The list of market leaders does not change from year to year: the Japanese companies FANUC, Yaskawa, Kawasaki, Nachi, Denso, Mitsubishi, Epson, Omron dominate. The Swedish five company ABB is in the top five (Figure 12).

However, in the last decade, a monolithic landscape formed by major players in the industrial robot market has cracked. New companies enter the scene (Figure 15), designated as “others”. In our opinion, this is a natural process, since the demand for robots is growing, and their production is becoming more affordable due to the cheapening of materials and components. Therefore, more and more start-ups and small companies are beginning to engage in a direction that seemed previously unpromising for venture entrepreneurship - industrial robotics. For example, one of the most famous robotics companies in the world -

Universal Robotics - began its activities in 2005 as a small university startup with the idea of creating a compact robot that is easy to install and program. And, in our opinion, there will be more and more such companies, although not all of them will be successful.

Fig. 12. World leaders - companies (year of foundation) and the number of industrial robots installed by them for the entire time (according to mid-2018), units. Source: Robotics and Automation News.

Fig. 13. Geography of distribution of manufacturers of industrial robots in 2018. Source: The Robot Report 2018.

Fig. 14. Distribution of proceeds from sales of industrial robots by companies in 2015–2017%. The share of new players is growing. Source: ABI Research 2018.

1.5 Service robotics leads in growth rate

We often call our created society post-industrial, due to the fact that the modern economy is primarily a service economy: the share of services in global GDP is about 63%, and industry is about 30% (the rest is agriculture) [5]. Over the past decades, the growth of industrial robotics has been achieved primarily due to the fact that it is easier to make robots for industry - it is relatively easy to adapt the industrial environment for a robot rather than a robot for an industrial environment. However, industry, as a point of growth, has its own limitation. The service economy as a whole is larger than industry. Therefore, further growth of robotics will occur due to service robotics.

Here are just a few examples. The success of Intuitive Surgical, whose revenue in 2018 increased by 20% and approached \$ 4 billion, is visible. The daVinci robot-surgeon recently received another official approval for a new type of operation. The company's sales are growing, and, according to the end of 2018, almost 5,000 robotic surgeons worldwide performed more than a million operations of various types [6].

According to IFR, the growth rate of professional service robotics in 2017 amounted to 85%, which is several times higher than the growth rates of industrial robotics (31%) and

world GDP (3.7%). As a result, in 2017, 109,500 professional service robots were sold worldwide. According to experts, 50% more robots were sold in 2018 than in 2017. As a result, the market volume reached \$ 8.7 billion by 2018. According to experts, from 2019 to 2021, sales of professional service robots annually will increase by an average of 21% (Figure 15). Today, sales of logistics robots, power exoskeletons, demanded by both workers at the factory and older people with limited mobility, are growing rapidly. Demand for such robots is expected to continue to grow at an accelerating pace (Figure 16).

Fig. 15. Dynamics of sales of professional service robotics in 2014–2017 and forecast for 2018–2021, thousand units. Source: IFR World Robotics 2018.

Fig. 16. Sales volume of professional service robots by type of robots in the largest market segments, number of units in 2017. Source: IFR World Robotics 2018.

In our opinion, the most promising area of professional service robotics are logistics robots. In 2017, sales of such robots increased by 162% compared to 2016 (Figure 17). The market volume then reached \$ 2.4 billion. As a result, 63% of the market for professional service robots falls on logistics (Figure 16). Figuratively speaking, in the market of professional service robots there are only two types of robots - logistics and all others. However, this is only the beginning. According to IFR estimates, in 2018 sales of logistics robots increased by another 66%, and the market volume reached \$ 3.9 billion. Next from 2019 to 2021. sales will increase annually by no less than 18%. High demand for mobile logistics robots will be supported by the development of all types of trade, including electronic. In particular, experts estimate that e-commerce has created more jobs in logistics than it has declined in offline stores. For example, economist Michael Mandel reports that in the United States from 2007 to 2016. 355,000 jobs in electronic commerce were created - seven times more than the number of reduced positions in the retail sector over the same period [7].

Gradually, robots of types AGV / AMR (Automated Guided Vehicles / Autonomous Mobile Robots) become an important new tool for the production environment, as the replacement of workers with such devices increases productivity and reduces costs. Warehouse robots allowed Amazon to reduce the operating costs of each warehouse by about 20% (about \$ 22 million in annual savings). That is, operations that a person spent 60–75 minutes on, these robots perform in 15. There is great potential for AGV / AMR also in non-production areas, such as hospitals, where typical tasks (dispensing the same drugs on schedule) and the deterministic environment of departments and wards creates opportunities for automation.

Ease of automation in logistics can be ensured due to the fact that many devices that previously needed a driver can be finalized and brought to complete autonomy. For example, this is the case with forklifts. Improving technologies such as machine vision and gripper design will expand the range of applications for logistics robots. An example of a universal platform for automating logistics operations is the robot courier Jeeves from the German company Robotise. The robotic platform, equipped with three-dimensional optical vision and a set of sensors, is capable of autonomous navigation in multi-storey buildings, including the use of elevators via a wireless interface. This platform serves as the basis for the modular design of the courier robot: various modules can be installed on it, including containers for moving packaged products, cooled or heated containers, and special containers. Now this approach allows the use of a single Jeeves platform for assembling robots for hotel services, but in the near future the company plans to offer its robot for work in hospitals and in industrial environments.

The market for personal service robots is also growing rapidly. People are constantly in need of entertainment, training, cleaning, or security services. Robotization of such services already has a significant impact on the development of this market. So, in 2017, about 2.4 million edutainment robots were sold (12% more than in 2016) and 6.1 million household robots (31% more than in 2016) Despite significant quantitative indicators of sales, the market for personal robots is inferior in money terms to the market for professional robots. In 2017, it was estimated at \$ 2.1 billion compared to \$ 6.6 billion for professional ones. However, it can increase significantly, according to IFR estimates (Figure 18).

Fig. 17. Dynamics of sales of logistics robots in cash and in kind in 2015–2017 and forecast for 2018–2021. Source: IFR World Robotics 2018.

Fig. 18. Dynamics of sales of personal service robots, thousand units. Source: IFR World Robotics 2018.

Fig. 19. Dynamics of sales of professional service robotics by region, thousand units. Source: IFR World Robotics 2018.

The best indicators for the period from 2016 to 2018. demonstrated a segment of household robots, experts expect that in the future, by 2021, this segment will retain its leadership. A large proportion of it will be occupied by cleaning robots: vacuum cleaners, window washers and others. Robots for education and entertainment will be actively developed. The volume of this market may increase from \$ 0.5 billion in 2018 to \$ 2 billion in 2021.

North America dominates the service robot market. Europe is following it - thanks to the growing demand for service robots in the defense, medical, and construction sectors. The main player in the service robotics market is the United States - 45% of service robots are manufactured in America. However, Asian manufacturers are actively catching up with the leader: in recent years, they have increased their share from 30% to 43%. At the same time, Europe accounts for only 12% of all manufactured robots. According to IFR, there are 719 key manufacturing robot service companies in the world, of which 155 are startups (in 2017 there were 699 and 202). Despite the leadership in the number of service robots sold, America is still inferior to Europe in the number of manufacturers.

Fig. 20. Dynamics of sales of personal service robotics by region, thousand units. Source: IFR World Robotics 2018.

Fig. 21. The number of manufacturers of service robotics of all types by region in 2017. Source: IFR World Robotics 2018.

The European region accounts for 42% of all companies, North America - 35%, and Asia - 18%. At the same time, the number of Asian companies decreased by 2% compared to 2016. In the country context, the USA is still the leader in the number of companies producing service robotics. Favorable conditions for conducting the technology business have led to the fact that 222 companies in the field of service robotics work in the territory of this country, of which 43 are startups. In Russia, the opposite situation is currently observed - the share of startups exceeds the share of mature companies (60% and 40%, respectively). According to estimates, about 150 startups operate in Russia. For its part, The Robot Report on an interactive map of world robotics provides an alternative estimate of the number of service robot manufacturers, more than 1,500 service robot manufacturers with segmentation by field of application (professional or personal). The number of startups marked on the same map exceeds 1400. The TRR data for Russia is 18 manufacturers of service robots and 27 start-ups. However, it should be noted that this card is compiled mainly at the request of the companies themselves, that is, companies that have not reported about themselves may not be on the card.

2 Robotics in Russia

2.1 Market Overview in Russia

Russia has the potential to become a significant player in the service robotics market. Unfortunately, this potential remains unrealized. The individual successes of some domestic startups in niche markets do not change the overall picture. But, despite the lack of significant success, new names continue to appear on the map of Russian robotics.

Since industrial development inevitably entails robotization, Russia has good potential for introducing the latest generation robots into production operation. Now we see that this potential is not being realized. The growth of industrial production in Russia in 2018 amounted to about 3%, while the growth in manufacturing industries was slightly higher, 3.2% (data from the Ministry of Economic Development). However, given the low density of robotization in the country, it is impossible to draw conclusions about the correlative growth of investment in production and the introduction of industrial robotic solutions. At the same time, we see that large domestic state and private companies are growing interest in robotics. The state itself takes certain efforts aimed at the development of technology, specialized education and state regulation.

Large companies are interested in robotics:

- Ozon - one of the largest online stores in Russia - intends to robotize order processing.
- Gazprom Neft entered into an agreement with Central Research Institute of RTK on cooperation in the development of robotics and unmanned control systems. And she has already shown a prototype of a robot for loading oil products into an airfield tanker.
- Severstal invested in the Chrysalix RoboValley fund, which invests in the development of robots and artificial intelligence.
- Alrosa Group of Companies and OMZ (United Machine-Building Plant), together with the Skolkovo Fund, launched the Technostart-2019 contest, in which they are looking for projects including robotics.
- SIBUR Holding launched a corporate accelerator, in the framework of which it is looking for projects in robotics.
- A National Competence Center for Robotics and Mechatronics has appeared on the basis of Innopolis University. The center was formed by a consortium of several universities and large companies - industrial partners.
- The national program "Digital Economy" has appeared. The course of this program is the responsibility of the autonomous non-profit organization of the same name, in which Sberbank was one of the co-founders. The objectives of the program include the development of digital end-to-end technologies, among which are components of robotics and sensors.
- The National Association of Russian Robotics Market Participants (NAURR) with the support of the Ministry of Industry and Trade announced the start of work on a development strategy for robotics in Russia.

To date, the world has developed several approaches to the development of national robotic programs, the characteristics of which can be described by the following signs:

- focusing on basic scientific research in the field of robotics or vice versa, on the engineering embodiment of research results;
- focusing on sales in the domestic market or vice versa, expansion into foreign markets;
- in such a coordinate system, it can be determined that, for example, US robotics is characterized by a significant amount of fundamental scientific research, and local manufacturers are focused on the capacious domestic North American market.

Fig. 22. The matrix of approaches to the development of national programs. Source: Sberbank Robotics Laboratory.

At the same time, the robotics of the countries of the European Union also relies on a strong fundamental science, but the EU’s domestic market is much less capacious, therefore European manufacturers are focused on consumers in the foreign market. If we look at the development path of China's robotics, it becomes obvious that local manufacturers work mainly to satisfy domestic demand and are currently consumers of the results of foreign basic research, that is, there are more engineers in the country who study foreign scientific materials and implement “metal” developments.

As for the position of Russian robotics, the situation is partly similar to the Chinese one: now we are more consuming the results of foreign basic research than we are doing our own. At the same time, the capacity of the domestic Russian market is still insignificant and for the sustainable development of domestic developers and manufacturers of robotic systems it is necessary to focus efforts on foreign markets. Naturally, such a matrix is not black and white, and the interests of domestic consumers are indispensable for satisfaction, and the development of Russian fundamental science is a factor in ensuring national security. However, it is this approach that makes it possible to determine the direction that will ensure a more energetic start and sustainable development of robotics in Russia.

2.2 SWOT analysis of the Russian robotics industry

The past year has confirmed the correctness of the choice of the SWOT method for analyzing the situation in the Russian robotics industry. Other researchers came to similar conclusions, including during the development of the DC SC “Components of Robotics and Sensors”. In the framework of the Digital Economy project, in our opinion, the factors we mentioned that affect Russian robotics and are presented in the SWOT analysis of last year’s review have not lost their relevance. However, we revised the wording of some of them, and also expanded and updated all four categories in connection with the changing economic, technological and geopolitical situation.

Table 1. SWOT analysis of the Russian robotics industry.

Strengths	Weaknesses
Domestic Engineering School: Design and Programming The popularity of engineering education is growing	Low speed and high cost prototyping It is difficult to create a prototype of a robot in a university or startup
Ability to solve complex and unique technical problems Domestic inventions have the advantage	Shortage of domestic advanced production capacities Product scaling is a barrier to lower product costs.
Technocratic population Ease of adaptation of the population to new technologies	Lack of young qualified teaching staff and obsolescence of university educational programs Lack of a complete national strategy for the development of educational programs in the field of robotics
	Low culture of industrial design It is difficult to create an attractive product for the consumer
	Migration policy and low social protection of workers Robotization is disadvantageous due to the fact that there is always cheap labor that does not have adequate social protection
	Weak penetration of the world's best robotization practices into the national economy Decision makers do not have the necessary knowledge to make informed decisions about technological modernization and robotization
Capabilities	Threats
Reducing the cost of an “entrance ticket” to robotics for startups Increasing the number of startups, increasing competition	Geopolitical barriers to fundamental science Economic sanctions and difficulties in international scientific cooperation
Lack of established leaders in the global service robotics market Race losers clear niche for new applicants	Speeding up brain drain Emigration of skilled professionals
Opportunities for a radical increase in labor productivity Low labor productivity creates great potential for modernization of production	“Robotics Winter” - the decline in interest of private investors Deficit of “smart and patient” money in private investors
Affordable electricity and metals Ability to manufacture and implement lower cost robotic solutions	Rapid breakthrough technology development / technology race acceleration Acceleration of the startup life cycle of a product
Expanding the scope of robotics New robotic solutions automate new market niches	
The coincidence of growth points of the global robotics and traditionally competitive industries in Russia Significant potential for the development, implementation and	

export of robotic solutions for the mining industry, agriculture, nuclear energy, aircraft and shipbuilding	
Huge territory and a small population The use of unmanned vehicles is justified and effective	
Strong service sector of the economy A capacious niche for retail and service robots	

Strengths. Domestic Engineering School: Design and Programming.

The popularity of engineering education is growing. At the same time, a strong engineering school remains in Russia [7]. This is especially true for programming and design. In the mechatronics and robotics specialty alone, approximately 800 young people annually receive engineering degrees from 60 Russian universities.

Ability to solve complex and unique technical problems.

There are many examples in the history of our country when our engineers solved the most difficult tasks: pioneering work in the fields of radio, electricity, aerodynamics, nuclear physics and space exploration. This feature is repeatedly noted by foreign researchers in the history of science and technology in Russia.

Technocratic population.

The population of Russia demonstrates the speed of adaptation to new technologies. This is illustrated by the penetration of both smartphones and electronic forms of interaction between the population and the state and business. This provides an opportunity for quick adaptation of the population to new products and services that are based on robots and artificial intelligence.

Positive attitude towards robots.

The cultural code of the Soviet Union twenty-odd years ago formed the attitude towards robots as human assistants, helping people not only explore the world around them, but also help people to understand themselves [8]. Since the cultural code of the USSR was largely transposed into the culture of modern Russia, a positive attitude towards robotics as a whole contributes to the popularization of this area of technology as an activity among the population.

Weaknesses. Low speed and high cost prototyping.

Difficulties in creating prototypes of robots are due to both the low speed of their creation using specialized prototyping centers and the high cost of work, compared to similar projects in Asian technology clusters such as Shenzhen. Many successful robotic companies create their own centers for rapid prototyping (development) right next to large electronics shopping malls - this helps to perform work much faster than competitors farther from suppliers.

Shortage of domestic advanced production capacities.

Advanced manufacturing technologies are a key tool for scaling a product. Their absence in Russia is a barrier to reducing the cost of the product and, as a result, prevents their competitiveness in the international market. A successful prototype creates opportunities for enterprises. But these opportunities can be quickly missed if there is no production that can cheaply, efficiently and quickly ensure the production of the required quantity of product on time.

Lack of young qualified teaching staff and obsolescence of university educational programs.

The lack of a clear and complete national strategy for the development of educational programs in the field of robotics leads to the fact that the previously mentioned domestic engineering school is experiencing a huge shortage of qualified teachers, as well as the

rapid obsolescence of educational programs. Young talented engineers find application in the private sector and have no desire to share their experience with a new generation of engineers. Educational programs are rapidly becoming obsolete due to the acceleration of the technology life cycle, on the one hand. On the other hand, the current generation of teachers is not interested in switching to new training programs, as this will lead to rewriting of already created programs. For example, in Russia there is nothing like strategic plans for scientific, technological, engineering and mathematical education (STEM Education, USA). In particular, only two domestic universities have training programs in collaborative robotics: Skoltech and Innopolis.

Low culture of industrial design.

For service robotics, that is, the industry that provides services to humans, industrial design issues are a priority. However, in Russia it is still extremely difficult to create an attractive product for the consumer. This is due to both the large shortage of qualified designers and the low quality and high cost of the work of existing specialized industrial design centers in Russia. Such a situation hinders the launch of attractive solutions for consumers on the market. Domestic companies wishing to enter the international market and create competitive solutions are forced to resort to the services of foreign designers.

Poor migration policies and low social protection for workers.

The investment attractiveness of industrial robotics depends primarily on the cost of manual labor and the social protection of workers. If human labor is paid well, and the mechanisms of social protection of workers from harmful conditions are built adequately, then robotization is beneficial. But if workers are paid little, and the employer does not care about working conditions, then robotization is disadvantageous because there is always cheap labor that does not have adequate social protection. Migration policy also contributes to the low investment attractiveness of robotics in Russia - if it is more profitable to hire a labor migrant to implement low-skilled routine work than to introduce technology, then there is little chance of developing high-tech industries. Recalling the "economic" definition of the robot of Nobel laureate Paul Krugman, we can say that the robot can do everything except one thing - to replace a labor migrant, especially when employers are not interested in such a replacement.

Weak penetration of the world's best robotization practices into the national economy.

Decision makers do not have the necessary knowledge to make informed decisions about technological modernization and robotization. Weak penetration of world best practices into modernization processes in various industries and the low level of readiness of decision makers for their use impede the mass implementation of robotic solutions and require immediate action, both of a popularizing and administrative nature. Most decisions of domestic leaders are based on short-term financial benefits. Long-term economic and social consequences are rarely taken into account.

Capabilities. Reducing the cost of an "entry ticket" to startup robotics.

Under the influence of Moore's law, there is a constant decrease in the cost of hardware necessary for the development of robotics. The creation of new sensors (such as Microsoft Kinect) has led to the emergence of a large number of projects that use new features in the field of computer vision, voice recognition, gestures, people and objects. Low entry cost leads to the rapid entry of non-traditional players into the market. For example, Google Waymo is a completely unconventional player in the transport mobility market. Another example - the creators of the "cameras with wings" (for example, DJI) brought to life a whole industry of drones. Previously, this industry was mainly the patrimony of large defense holdings. At the same time, there is a corresponding increase in the "degree" of competition.

Lack of established leaders in the global service robotics market.

High competition in the market of service robotics only contributes to the constant opening of new markets for new players. Many start-up companies go bankrupt and close, but this frees up space for new, stronger teams that continue the work they have started, taking into account the experience accumulated by their predecessors. In the end, the engineers themselves remain and can use their experience, often negative, in other projects. And they provide their invaluable negative experience for analyzing the correctness of decisions to competing teams.

The emergence of new software and hardware robotic solutions.

This makes it possible to automate what was previously difficult or impossible to automate. For example, if earlier industrial manipulators were mainly used in the shops of enterprises, then collaborative robotics, mobile autonomous robots are more and more used in various service industries - from the hotel business to finance and retail.

The coincidence of growth points of world robotics and traditionally competitive industries in Russia.

In developed countries, robots are already widely implemented in many industries - from the automotive industry to the chemical industry. In some industries, especially in advanced countries, such as the automotive industry, robotics are close to saturation. However, some industries have not yet received the massive introduction of robots due to technological difficulties or due to the fact that the demand for services in these industries has just appeared. For example, the use of robotics in crop production is not yet high due to the fact that robots do not have the manipulative capabilities to collect the fruits of crops that a person has. Manual labor so far prevails in the assembly of aircraft and ships because it is necessary to show the highest accuracy of operations in confined spaces. The technological paradigm has just begun in the nuclear industry, which has necessitated the dismantling of obsolete nuclear power plants, giving rise to a multi-billion dollar market for services for the dismantling of energy blocks of nuclear power plants. In our opinion, this creates significant potential for the development, implementation and export of robotic solutions for the mining industry, agriculture, nuclear energy, aircraft and shipbuilding. It is these sectors that are also the most competitive sectors of the national economy of Russia. This opens a window of opportunity for the development of robotic solutions both to satisfy domestic demand and to bring the developed solutions to international markets with guaranteed demand.

Vast territory and a small population.

The use of unmanned vehicles (air, land, sea and river) in our country can be justified and cost-effective due to the vast territories and small population. As a result, unmanned vehicles on our routes can be used for commercial purposes a little earlier than in countries with a higher population density. For example, in only one Sberbank, collection teams transport thousands of tons of valuable goods for tens of thousands of kilometers due to the fact that there is no direct road connection between settlements located only a few tens of kilometers from each other.

Strong service sector of the economy.

A strong service economy in Russia creates opportunities for the widespread use of robotic solutions. Together, trade and finance account for about 20% of Russia's GDP. Retail and logistics are among the main applications of robotics. In Russia, the share of trade in GDP is one of the highest in the world, even in comparison with other countries focused on the service economy. From the point of view of the development of robotics, this is a competitive advantage, as it gives a chance to use a significant "home" market to create solutions that are competitive in the international market.

Threats. Geopolitical barriers to fundamental science.

In the current reality, domestic fundamental research in the field of robotics and sensorics is experiencing serious opposition, as in other industries. The current regime of

sanctions against the Russian Federation puts barriers on scientific and technical cooperation with foreign experts, prevents the import of technologies and blocks access to international investment.

Speeding up brain drain.

Emigration of skilled professionals tends to increase. According to the Gallup research agency, [9] the share of Russian citizens willing to emigrate has tripled since 2014 and reached a record 20%. At the same time, the results of a study by Stratfor agency [10] show that among those who want to emigrate, 23% are people with higher education, doctors, engineers, scientists and teachers. The main reason for this dangerous trend is the lack of opportunity for young scientists to engage in science at home [11].

“Robotics Winter” - a fall in the interest of private investors.

Following the extreme demand for robotic ideas and companies, inevitably comes a weakening interest in the topic from most private investors. This thesis is confirmed by a series of bankruptcies of once-growing startups that, for one reason or another, were unable to enter the next round of investments. This problem is global, but, given the unfavorable investment climate in Russia, it will have a braking effect on the domestic market. In our opinion, the “winter of robotics” has already arrived. The time for easy decisions has passed, and long-term investors have largely left the market. We observe a shortage of “smart and patient” money from private investors. The response of technology companies that need solutions to their problems is the creation of their own laboratories aimed at creating breakthrough solutions.

Rapid breakthrough technology development / technology race acceleration.

Speeding up the startup or product life cycle in developed countries is a significant threat to research and development in more technologically backward countries. This has a strong negative impact on Russian developers, who are finding it increasingly difficult to maintain a technological race for industry leaders and force them to abandon ambitious tasks in favor of niche solutions. To paraphrase the words from an interview with Stephen Elop, we can say that during the time that Russia is making a presentation about the product, the product itself is being made in Shenzhen.

The prospects for the development of the Russian robotics market are monitored not only by domestic players, but also by international experts. According to the general expert opinion, the Russian market is promising, with professional engineering personnel and a low robotization base in the vast majority of industries [12].

According to Andra Keay, managing director of Silicon Valley Robotics, many of the Russian startups stop doing business a couple of years later. Even if the robotics industry as a whole is really starting to grow, startups are paying too much attention to entering the global market from the very beginning. This leads to the fact that Russian robots are not suitable for any market.

The potential for introducing robots in Russia is huge. The country has a large and still growing domestic market for consumer goods. There is a high demand for updating production capacities, as well as for investments in new production capacities. The density of robots in production in Russia is only three robots per 10,000 people employed in production. The government promotes automation and modernization of production. The Russian Ministry of Industry launched a program for industrial digitalization in 2017. Thanks to the Industrial Development Fund, the introduction of industrial robots in production will be supported.

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