

**SCIENTIFIC AND TECHNICAL PROGRESS AND ITS IMPACT ON INDUSTRIES,
ECONOMIC GROWTH, AND INNOVATIVE DEVELOPMENT**

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Technological sovereignty in machine-tool industry: statistics, uncertainty, and specifics of development measurement

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Abstract. The article considers the features of formation and provision of technological sovereignty both at the general methodological level and its application to the machine-tool industry. The analysis of the development of the machine-tool industry and its economic indicators of the state and development is given. The analysis of the content and essence of obtaining and forming statistical data, their reliability and objectivity, as well as the conditions for the manifestation of their degree of uncertainty in assessing technological independence is given. The purpose of this study is a methodological review and justification, based on existing and accessible sources of statistical data, their sufficiency to ensure the objectivity and reliability of the system of indicators for assessing the level of technological independence using the example of the machine-tool industry. The methodology of system analysis makes it possible to justify and measure the parameters under consideration, and the methods of structural analysis to identify the connections between them and give an assessment. All this made it possible to give reasonable conclusions and proposals on the methodology for considering technological sovereignty

Key words: technological structure, technological sovereignty, technological independence, technical level, machine tools

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**НАУЧНО-ТЕХНИЧЕСКИЙ ПРОГРЕСС И ЕГО ВЛИЯНИЕ НА ОТРАСЛИ
ЭКОНОМИКИ, ЭКОНОМИЧЕСКИЙ РОСТ И ИННОВАЦИОННОЕ РАЗВИТИЕ**

ОРИГИНАЛЬНАЯ ИССЛЕДОВАТЕЛЬСКАЯ СТАТЬЯ
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Технологический суверенитет в станкостроении: статистика, неопределенность, особенность измерения развития

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Аннотация. В статье рассматриваются особенности формирования и обеспечение технологического суверенитета как на общеметодологическом уровне, так применительно к станкостроительной отрасли. Проведен анализ развития отрасли и её экономических показателей производства за период с 1900 г. по настоящее время. Приведён анализ содержания, сути и формирования статистических данных, их достоверности и объективности, а также условий проявления степени их неопределённости при оценке технологической независимости. Методология системного анализа позволяет проводить обоснование и измерение рассматриваемых параметров, а методы структурного анализа выявляют связи между ними и дают возможность их оценить. Целью настоящего исследования является методологическое рассмотрение и обоснование достаточности и определённости параметров для обеспечения объективности и достоверности оценок уровня технологической независимости. В выводах предложен комплекс направлений снижения степени неопределённости при оценке показателей технологического суверенитета.

Ключевые слова: технологический уклад, технологический суверенитет, технологическая независимость, технический уровень, металлорежущие станки

Информация о финансировании: Данное исследование выполнено без внешнего финансирования.

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INTRODUCTION

The concept of innovation waves (Glazyev et al., 1992; Glazyev et al., 2019), as well as the essence of economic and technological factors and characteristics that shape and determine them, are considered as processes of their change and development based on stably homogeneous dominant technologies over a certain period of time. The study (Glazyev & Kosakyan, 2024) notes that the change of innovation waves can be represented by sets of technologically related industries, i.e., technological sets.

The publications on the economics of scientific and technological development (Sukharev, 2024a, Sukharev, 2025) emphasise that “technological dynamics can be considered as an independent object of study, since production methods or ways of influencing any objects making up various technologies develop according to their own life cycle with inherent properties and patterns”; the technological dynamics forms a new direction of research – economics of technology.

The contemporary economy and its success in the socio-economic development of states directly depend on the content, type and forms of their scientific and technological development, which has determined the significant role of technological sovereignty and its dominant significance at the present stage. Many countries have adopted this thesis both as a basic principle for the formation of technological

foundations in material production and well-being and as a crucial part of state policy. Thus, ensuring technological sovereignty becomes increasingly important for states.

Taking into account the historical retrospective of the first mentions about the concept of technological sovereignty in the 1970–1980s, relevant scientific publications, both in our country and abroad, discuss various aspects, formulations and definitions of the essence and boundaries of content and application throughout this time. Let me note some recent publications reflecting the research directions of a number of scientists, given that they contain references to the works of other authors:

- general issues of the content and concept of technological sovereignty (Kovalev, 2020; Afanasyev, 2022; Afanasyev, 2023b; Potaptseva et al., 2024; Kapoguzov & Sheresheva, 2024; Stepanov et al., 2024);
- indicators, assessment and measurement of technological sovereignty (Eremchenko & Kurakova, 2023; Chichkanov & Sukharev, 2024; Glazunova, 2024; Sukharev, 2024b; Kuznetsov, 2024a; Sukharev, 2024c; Medvedeva, 2024);
- state issues of technological sovereignty in industries, including machine tool manufacturing (Gareev, 2023; Demytyev, 2023; Afanasyev, 2024; Kuznetsov, 2024a; Kuznetsov, 2024b).

Russian publications fail to provide the substantive meaning of technological sovereignty: both similar and closely related concepts are used. A.A. Afanasyev in his article (Afanasyev, 2025) attempts to systematise the most capacious and general concepts, mainly over the past 5 years. The author points out the diversity of practical, theoretical and scientific-methodological approaches and judgments, as well as their application in various fields of activity. The study of (Kuznetsov, 2024a) used the above works to formulate the technological sovereignty as aimed at ensuring technological independence and security: the level of technological sovereignty directly affects the probability of success in achieving this.

Thus, for example, S. Yu. Glazyev, in relation to the importance of set elements in the concept of innovation waves and the basic initial data, indicates: "It should be acknowledged that the classifications of goods and activities in official statistics have no unambiguous identification of their sets precisely corresponding to certain technical specifications. Moreover, different product positions may hide the same technologies in different proportions and conditions of application, which makes it difficult to measure technologies by product positions, due to both incomplete and repeated accounting" (Glazyev, 2024, p. 15).

The "Means of Production and Automation" National Project consists of the "Development of the Machine-Tool Industry" Federal Project, which includes such an indicator as the "Increase in the volume of machine tool production for various industries of the Russian Federation in relation to 2022". In 2024, the share of Russian machine-tool products in the domestic market was 31%; by 2030, it is planned to increase to 60%, i.e., 103% of production volume. Although the measurement units are not indicated, the production volume and share of Russian products are relatively measured quantities. At the same time, the level of technological independence (the project specifies its value as 65% at the beginning of 2025 with an increase to 95% by 2030) requires methodological justification and development of an assessment methodology, including the

determination of initial data, methods for obtaining them and other parameters.

The present study aims to methodologically assess and justify the sufficiency of these indicators for ensuring the objectivity and reliability of the system of technological independence indicators as applied to the machine-tool industry and its most significant distinctive features.

Thus, the main available sources of initial data, features of their measurement, reliability and objectivity, as well as methods for assessing indicators should be analysed to propose a scientific and methodological solution to identified problems.

Methodology: statistics for assessing technological sovereignty of machine-tool industry

Let us use statistical data and historical information on the development of the Russian machine-tool industry as one of the main sources for assessing its technological sovereignty to trace the evolution of its production potential.

The number of machine-tool factories in Russia (Kuznetsov, 2025) was 8, 21, 34 and 40 in 1870, 1896, 1910 and 1912–1914, respectively, at a 25% share of domestic machine tools. In the USSR, 37, 136 and 398 specialised machine-tool factories were operated in 1940, 1960 and 1980, respectively. The Russian Federation operated 428 enterprises and organisations of the USSR Ministry of Machine-Tool Industry in 1991; about 42 machine tool factories remained by 2020–2024.

Table 1 presents the production of metal-cutting machines, including those with numerical control (CNC), based on the data of (Shailieva & Sergeeva, 2023; Afanasyev, 2023) and state statistics. It can be assumed that until 1992, the production of machine tools in the RSFSR amounted to 60–65% of the total USSR production volume; further *Table 1* indicates statistical data on production only in the Russian Federation.

The report of 1915 by professor N.N. Savvin "About duties on metalworking machines" (Savvin & Semenov, 1915, pp. 1–2) notes: "The import of metalworking machines to Russia increased,

Table 1. Machine tool production* in the USSR and the Russian Federation by year**Таблица 1.** Выпуск станков* в СССР и РФ по годам

Year	1913	1922	1928	1932	1937	1940	1941	1942	1944	1945	1950	1960	1970	1978	1980	1985
Machine tools, thousand units/CNC	1.8/-	0.2	2.2/-	19.7/-	48.5/-	60.0/-	44.5/-	22.9/-	34.0/-	38.4/-	70.6/-	156.0/0.016	202.0/1.6	238.0/7.2	216.0/8.9	182.0/18.0
Year	1990	1995	2000	2010	2015	2020	2021	2022	2023	2024						
Machine tools, thousand units/CNC	157.0/25.0	18.0/0.1	8.9/0.2	2.8/0.28	3.4/0.32	4.7/0.71	7.2/0.73	8.2/0.6	9.3/0.89	11.3/0.87						

* including CNC

Source: Russian Statistical Yearbook for 1993–2024; National Economy of the USSR, 1922–1991; I.G. Kalabekov, USSR and Countries of the World in Figures, 2025; I.G. Kalabekov, Russian Reforms in Figures and Facts, 2024; Stankoinstrument Association, 1992–2025.

Источник: Российский статистический ежегодник за 1993–2024 гг.; Народное хозяйство СССР, 1922–1991 гг.; Калабеков И.Г. СССР и страны мира в цифрах, 2025; Калабеков И.Г. Российские реформы в цифрах и фактах, 2024; Ассоциации «Станкоинструмент», 1992–2025 гг.

starting in 1906, in the following manner. During the five-year period 1906–1910, an average of 3 million roubles worth of them were annually imported; in 1911, 1912 and 1913, this value was 7.4, 8, 12.7 million roubles, respectively.

Domestic production is concentrated in a small number of factories: Gerlyakh and Pulst in Warsaw, Felzer in Riga, Phoenix in Petrograd, Kramatorovka and Bromley in Moscow and several small factories. According to private information, the production of these factories rose from 3.4 million roubles in 1910 to 5^{1/2} million roubles in 1913. Thus, the market capacity for metalworking machines and tools reached 17–18 million roubles in 1913 with domestic production accounting for no more than 1/3 of the total machine tool consumption. Machine-tool industry has made little progress over the past decade.

The reasons for this unfortunate phenomenon include the variety of machine types, limitations of the domestic market filled with the products of numerous foreign (German, UK and US) factories operating on the global market and mass-producing a very limited number of models." It is absolutely necessary to protect Russian machine tool manufacturers from competition with foreign factories" (Savvin & Semenov, 1915).

The above analysis of the state, proposals and direction of changes in the machine-tool industry closely resembles present realities,

reflecting the essential aspects in the current development of the machine-tool industry. Both the methodological approach itself and the generalised indicator for assessing the machine tool production, i.e., the cost per unit of its weight, are of interest.

The above report of professor N.N. Savvin, who provides a well-reasoned analysis of problems in the machine-tool industry during the specified period, indicates a significant similarity between the described situation and today, considering that the policy of import substitution (technological sovereignty) was extremely successful during the years of industrialisation in the USSR.

In 1930, only 34% of installed machine tools were domestic; then, this value had increased to 91% by 1937. By the 1970s, large machine tool manufacturing centres had been constructed, including factories, numerous design bureaus and research organisations both in Russia and in union republics. The share of imported metal-cutting machine tools has decreased: since the 1960s, it has been steadily at up to 10% (e.g. about 3% in 1966).

Table 2 presents data on the share of domestic machine tools in total consumption, calculated by the number of units for the period from 1900 to the present. The reliability of these values can generally be estimated at 90%, which corresponds to the uncertainty of initial data

in different periods, both in quantitative and structural terms.

In the summarised data of *Table 2*, without respect to periods of time, government purchases of imported equipment and domestic production constitute the absolute majority at a lower uncertainty of indicators (for example, in the periods 1928–1933, 1933–1938 and further, according to the five-year plans). Mass-produced machine tools prevailed, while relatively precise and structurally complex domestic machines or kinematic units accounted for no more than 40–50% of consumption and therefore continued to be imported for many years, as evidenced by the data of *Table 2*. The advent of a scientifically based classifier in 1937–1939 entail the necessity and opportunity for targeted improvement and change in the structure of manufacturing machine tools, as well as their product ranges.

As applied to the domestic machine-tool industry, many authors typically provide information or comparative data on the production of metal-cutting machines, either in physical or cost terms, to emphasise the complexity and depth of the considered problem. These relatively independent figures without commentary can indeed potentially be misleading. In the paradigm of considering technological sovereignty, digital indicators are conditional without explanation and analysis in relation to other components of the needs, goals and capabilities of society.

For example, the production of metalworking machines in the USSR and the Russian Federation was the highest in the 1980–1990s

(see *Table 1*) followed by a decline to 1774 thousand units in 2009. At the same time, the import of metal-cutting machines in all these years amounted to about 12 and 11.6 thousand units (in 1975 and 1980, respectively) or about 2 billion USD in monetary terms, which is the second place in import after the USA. By 2010, the import amounted to 15.0 thousand units, which is 7–11 thousand units annually in 2015–2020 or ~1–1.5 billion USD; in 2023 and 2024, these were ~35 and 27 thousand units or ~2.3 and ~2.3 billion USD, respectively. Without going into details, let us note that in statistics, the given figures have a fairly large fluctuation of up to 10 times both in physical and monetary terms. In particular, Rosstat indicates that import of metal-cutting machine tools amounted to 739, ~1000 and 681 thousand units in 2021, 2023 and 2024, respectively. This directly depends on the classification criteria used for assignment and accounting. However, this issue is the subject of a separate study. Thus, given the aim of present research, let me only note a significant range of discrepancies between the data of Rosstat and Stankoinstrument Association, as well as statistical analysis of the machine tool market by Tebiz group and other sources.

It is also important to note that in the 1980s, the USSR was second only to Japan for the number of produced CNC machine tools, ranking third in the world in terms of total machine tool production. Thus, the volume of machine tool production in the USSR in 1980 amounted to 5 billion USD or 7.8% of the world output.

Table 2. Share of consumption for domestic metal-cutting machine tools

Таблица 2. Доля потребления отечественных металлорежущих станков

Year	1900	1910	1917	1925	1930	1935	1937	1945	1960	1980	1990	2000	2010	2020	2024
%	28	24	20	24	34	70	91	56	91	95	89	18	22	26	28

Source: Russian Statistical Yearbook for 1993–2024; National Economy of the USSR, 1922–1991; I.G. Kalabekov, USSR and Countries of the World in Figures, 2025; I.G. Kalabekov, Russian Reforms in Facts and Figures, 2024; Stankoinstrument Association, 1992–2025; D.M. Kazakevich, A.P. Goryunov, National Economic Significance of Technological Modernisation and Production Improvements at Operating Enterprises, 1959; <https://yarovan.ru/otechestvennoe-stankostroenie/>

Источник: Российский статистический ежегодник за 1993–2024 гг.; Народное хозяйство СССР, 1922–1991 гг.; Калабеков И.Г. СССР и страны мира в цифрах, 2025; Калабеков И.Г. Российские реформы в цифрах и фактах, 2024; Ассоциации «Станкоинструмент», 1992–2025 гг., Казакевич Д.М., Горюнов А.П. Народнохозяйственное значение обновления техники и совершенствования производства на действующих предприятиях, 1959; <https://yarovan.ru/otechestvennoe-stankostroenie/>

For comparison, the 1980 global production volume of metalworking machines (the volume of metal-cutting machines is estimated at 65–70%) was about 65 billion USD; the current value is 93–94 billion USD. Therefore, the phenomenon of technical and technological policy of the state in the 1990s is difficult to explain from the standpoint of rational arguments or a new development ideology. This can rather be seen as a madness or challenge in the form of a voluntary renunciation of one's own, even rather noneffective, production.

For example, at the time of the USSR collapse in 1991, approximately 36 thousand Soviet machine tools were operated in Germany alone (excluding the GDR). Approximately the same number of machines were in operation in Switzerland, France and Japan. At the Paris Machine Tool Exhibition in 1991, the USSR presented 49 units of equipment, and all of them was sold directly from the stands.

A rather high level of technological sovereignty is also evidenced by the fact that 1990 fleet of metal-cutting machines installed in the country (*Table 3*) in all sectors of the national economy amounted to about 6 million units; as of 2020, it can be estimated at 290 thousand units (e.g. data on the metal-cutting fleet are provided only for 1940–1955 in (Afanasyev, 2023a)).

Relative technological independence requires up to 20 thousand machine tools only to replace

the loss without assessing the structure of equipment demand at an annual average machine tool loss of at least 5% (7% according to some data; see above for the correspondence with import data).

The CECIMO European Association of Manufacturing Technologies predicts that by 2035, the global production volume of metal-cutting machines will increase by 2–2.2 times to 180–190 billion USD. In other words, the rate of global growth in production will also be approximately 7% per year, which is almost the same as the share of decline, provided that the technological structure, socio-economic and political situation, as well as development trends remain at the current level.

The greatest growth will be in the production of CNC machines: according to CECIMO expert estimates, after reaching approximately 800 thousand units in 2023, global sales of CNC machines will increase to 2.5–3 million units by 2035.

A similar trend is observed in the structure of machine types, which is due to the tendency for a greater concentration of types and processing methods in the designs of new models, as well as due to an increase in technological functions able to change the structural proportions in needs and production. The most probable structure includes multifunctional machining centres and systems, as well as CNC, grinding, specialised and other types of

Table 3. Fleet of metal-cutting machine tools*

Таблица 3. Оценка парка металлорежущих станков*

Year	1910	1932	1940	1945	1950	1960	1970	1980	1990	2000	2010	2020
thousand units	75	163	551	930	1500	2200	4100	5400	6000	1450	780	290

*The machine tool fleet of the national economy is indicated; in mechanical engineering and metalworking, the machine tool fleet accounts for approximately 60% of the total in the national economy.

Source: Russian Statistical Yearbook for 1993–2024; National Economy of the USSR, 1922–1991; I.G. Kalabekov, USSR and Countries of the World in Figures, 2025; I.G. Kalabekov, Russian Reforms in Facts and Figures, 2024; Stankoinstrument Association, 1992–2025, A.A. Afanasyev, Comparative Analysis of the Importance of Domestic Machine-Tool Industry for the Modernisation of Production in the USSR and Post-Soviet Period, as well as at the Current Stage of Russia's Development, 2023, <https://yarovan.ru/otechestvennoe-stankostroenie/>

Источник: Российский статистический ежегодник за 1993–2024 гг.; Народное хозяйство СССР, 1922–1991 гг.; Калабеков И.Г. СССР и страны мира в цифрах, 2025; Калабеков И.Г. Российские реформы в цифрах и фактах, 2024; Ассоциации «Станкоинструмент», 1992–2025 гг., Афанасьев, А.А. Сравнительный анализ значения отечественного станкостроения в модернизации производств СССР, постсоветского периода и на современном этапе развития России, 2023, <https://yarovan.ru/otechestvennoe-stankostroenie/>

machines making up to 35, 25, 12, 10 and 15%, respectively.

It should be noted that the data summarised in the present paper from CECIMO and associations of machine tool manufacturers from various countries indicate that machine tool manufacturing is actually a relatively small industry in terms of the output in the economies of countries, accounting for less than 1% of GDP in most developed countries. In 2023, the contribution of machine-tool industry to the Russian GDP can be estimated at approximately 0.045%, which is several times lower than the figures for the main leading machine tool manufacturing countries: 0.25, 0.33 and 0.41% for China, Japan and Germany, respectively. Despite the insignificant share of machine-tool industry in the GDP of all countries, machine tool manufacturing is much more than the category of economy, representing its system-forming industry. Machine-tool industry largely determines the technological level of the country's economy and the state of its technological independence, security and sovereignty.

Over time, it became clear that machine tools and technological equipment are not only a key competitive feature, but an advantage for the domestic industry and economy, as well as for the country possessing this technological tool. This is precisely why the improvement and development of machine tools and technologies, their defining parameters and characteristics, such as precision, productivity, speed and development of advanced technologies based on other physical principles form the dominant factor of technological sovereignty. Today, these are additive technologies, which are predicted to reach 30–40% of the entire materials processing market in terms of development and increase in use by 2035.

This trend has been observed for almost the last 30 years as the widespread use of a modular construction principle in machine designs based on the expansion of mechatronic elements and units. Moreover, their development has been outlined in the direction of adaptronic modular systems, which embody control functions in addition to the mechatronic principle. The miniaturisation of such systems,

units, devices and elements has also intensified. Practice shows the above reducing the number of simple parts (gear wheels, shafts, worms, etc.) and units, as well as original components by 5 times or more. The need for their total quantity has decreased from thousands to hundreds of units. Thus, the technology for producing the machines themselves and associated processes, both organisational and technological, as well as economic and production management, have changed.

The qualitative change in the technological capabilities of metalworking machines was accompanied by a sharp increase in the complexity of their elements, which led to a change in the entire production structure of this equipment. Machine tool factories have been transformed from full-cycle enterprises into relatively compact firms, primarily focused on assembly production with divisions for finishing machining and processing of critical and knowledge-intensive components, parts and units. At the same time, the volume of production increased; the types and directions of scientific research and development expanded, including at the interdisciplinary level.

According to the development of the machine-tool industry as a branch of the national economy, the following groups of countries can be distinguished:

1. Countries with a poorly developed machine-tool industry, characterised by a weakly developed domestic machine-tool industry and an almost complete dependence on imported equipment.

2. Countries with a nascent machine-tool industry, characterised by a small production volume, poorly developed machine-tool industry and high dependence on imported equipment; however, they:

- a) import high-tech equipment;
- b) carry out the transfer of imported technologies;
- c) localise the manufacture of machine tool products, including through the creation of joint ventures with technological leaders in machine tool manufacturing.

3. Countries with a developed machine-tool industry, characterised by a sufficient volume

of domestic production, range of types and kinds of machine tools, as well as their technical level at a relative dependence on imported equipment; however, they:

- a) strive to most fully meet the needs of the country's economy with domestic machine tools and other resources for technological support with a sufficiently large share of cooperation in production between countries;
- b) develop and improve their own technologies and conduct research, development and experimental work;
- c) carry out work to develop advanced, promising, unique, competitive, as well as technically, organisationally and economically efficient technologies and equipment, as well as to develop technological innovations through broad cooperation and joint work with enterprises and organisations both domestically and internationally;
- d) maintain a high share of exports (more than 50%);
- d) create and develop scientific foundations for various areas of science on processing technology and machine tool manufacturing;
- e) establish international and interstate associations to address complex labour- and knowledge-intensive areas of development, including in related fields of technology.

4. Countries with a highly developed machine-tool industry, characterised by significant domestic production, high technical level of manufactured machines and their range with almost complete independence from imported high-tech and highly efficient equipment; however, they:

- a) have all characteristic features of countries with developed machine-tool industry at a higher share of expenditures, both their own and state, on extensive fundamental and research work and realise projects for the development of machine tools and technologies with the provision of physically achievable limit values of parameters and characteristics,

as well as with the use of new materials and physical effects;

- b) represent the sole developers and manufacturers of certain types of high-tech machines and equipment.

A change of the innovation wave, i.e., qualitative transformations of products and goods, lead to the transformation of the machines themselves, their design-technological and functional-economic properties and characteristics, as well as the required volume, time and structure of production.

An example of this is the change in the type and essence of the vehicle component base, as well as its structural transformation into an electric vehicle: this currently determines fundamental changes in the types and volumes of required technologies, as well as technological and production machines and systems.

Methodological feature of uncertainty in assessing the state of technological sovereignty

A number of works (Kuznetsov, 2016; Kuznetsov, 2024a; Kuznetsov & Sukharev, 2025) define the technological sovereignty, as well as a number of related or derivative concepts: technological independence, technological security, technological breakthrough, competitiveness, localisation, etc. *Figure 1* graphically illustrates their formation and interdependencies.

Unfortunately, the terms given in the above-mentioned works fail to cover the concepts enshrined in the official regulatory documents of the Russian Federation. Let us supplement this omission with only three key and essential, from the standpoint of the present study, concepts:

- Technological leadership of the Russian Federation represents its technological independence expressed in the development of domestic technologies and manufacture of products using these technologies under the national control over critical and end-to-end technologies based on domestic lines of technology development for the purpose of

exporting competitive high-tech products and (or) replacing them on the domestic market with products manufactured by obsolete and (or) foreign technologies, as well as the for the superiority of such technologies and products over foreign analogues¹;

- The sovereignty of the Russian Federation in the technological sphere (technological sovereignty) is the ability of the state to develop and apply science-intensive technologies critically important for ensuring independence and competitiveness, as well as to use them for organizing the production of goods (performance of work and provision of services) in strategically important areas of activity of society and the state²;
- Localisation of production assumes the development of production in the Russian Federation based on foreign technologies: further development of technologies, including competence, technical documentation and production of key components, to one degree or another is managed outside the Russian Federation³.

The authors of (Kuznetsov & Sukharev, 2025) propose to consider the content of definitions of concepts and phrases with the word “technological” as a certain coordinate vector space built on a set of values. The position and orientation of their vector on the selected basis depend on the parameters, either initial or specified from a certain point in time, their connections and characteristics, while the assessment measures are determined by operations on their sets. Then, the very assessment of the level or direction of their change functions (area of states and behaviour) determines both the type of the function itself and its magnitude in the specified coordinate space.

From a methodological point of view, the content of a term or concept, as well as its fullness with necessary and sufficient sets of distinctive features and characteristics, should provide a clear and sufficiently defined opportunity of solving a set of problems in finding quantitative indicators of technological sovereignty that reflect the properties of the concept as a system. Otherwise, the resulting uncertainties blur boundaries, content, subordination, conditions of application, compatibility, interconnection and interdependence of certain elements in sets of distinctive features and characteristics, which sometimes violates even common sense, making the obtained results go far beyond the scope of the required solutions.

Since the technological sovereignty primarily represents a technical and technological component (organisational and production, financial and other parts are considered as complementary, see *Figure 1*), the indicators of sovereignty and independence should be primarily assessed taking into account the technical and technological parameters, i.e., as an “economics of technology” model. At the same time, the general model of achievement evaluates the ability of organisational and economic support for decisions and methods forming the technological sovereignty.

Uncertainty I

The above and a number of other features impose rather strict requirements and necessitate the formation and application of principles for data classification, objectivity and internal reliability, as well as their essence. Thus, the classification of metalworking machines adopted in the Russian Federation in accordance with OKPD⁴ establishes only the boundaries for the generated sets of initial data. However, their content is the most significant component of objectivity, which can be taken into account from the 7th to the 10th characters with the possibility of additional explanations about national characteristics.

¹ Federal Law No. 523 of December 28, 2024. On Technological Policy in the Russian Federation. Section 3, p. 15.

² Decree of the President of the Russian Federation No. 145 of February 28, 2024. On the Strategy for Scientific and Technological Development of the Russian Federation. Section I, p. 4i.

³ Order of the Government of the Russian Federation No. 1315-r of May 20, 2023. Concept of Technological Development for the Period up to 2030. Section II, p.4.

⁴ OKPD – All-Russian classifier of products by type of economic activity, harmonised with the Statistical Classification of Products by Activity in the European Economic Community (CPA 2008).

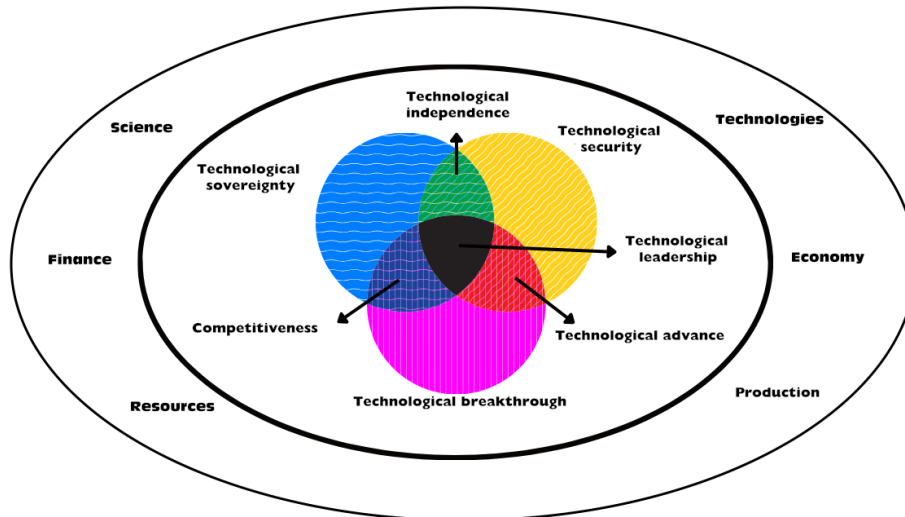


Figure 1. Diagram for the formation and measures of the technological leadership and sovereignty as a general probability of completed events

Рисунок 1. Схема формирования и меры состояния уровня технологического лидерства, суверенитета как общая вероятность свершившихся событий

Source: The figure was prepared by the author

Источник: разработано автором

Due to the uncertainty of element sets named in the formulated concepts (see above and (Kuznetsov, 2016; Kuznetsov, 2024a; Kuznetsov & Sukharev, 2025)), the indicators of technological independence will be uncertain to the same or greater extent as the components forming these indicators and constituting the dependencies for their determination. It is already clear that the OKPD2 classifier, like a number of others (TNVED, industry-specific ENIMS, etc.), structurally lags significantly behind the current level of development of technology and engineering. Although such a discrepancy between uncertainties can be circumvented by including the machines in a more or less suitable group, the principle of sovereignty and independence can be observed only relatively. In accordance with the established reporting forms of Rosstat, all machine tools produced by the enterprise are included in them without their level as Russian (sovereign) products in accordance with the Decree of the Government of the Russian Federation No. 719 (PP No. 719) of July 17, 2015 and subsequent additions and amendments.

As applied to the Decree, the following measurement uncertainties can be additionally noted:

1. From 2015 to 2021, machine tools in terms of Russian products were defined as the percentage of their localisation, i.e., manufacture in the Russian Federation, at a level from 30% to 70% and higher by 2021.
2. The share of foreign components for the production of goods is set at 70% in the specified years and no more than 30% from 2020, respectively; the number of technological operations is set at no less than 4 and 6 operations in 2016 and from 2020, respectively.
3. In 2022 (with amendments in subsequent years and in accordance with the amendments of March 27, 2025), a point assessment system with uncertainty as a measurable value was introduced for achieving a total number of points for the performance of the specified operations (conditions) by each component unit of production on the territory of the Russian Federation; the number

of points is established for each period of 2022–2023; in 2024–2026, the number is in accordance with the groups of machines and/or components specified in the Decree⁵.

Uncertainty II

As applied to the design, technological and layout solutions of contemporary metal-cutting machines, taking into account the principles of their design and production, let us touch upon the issue discussed in more detail in previous research (Kuznetsov, 2016, 2024a). The quantitative volume of components that form and provide the machines with the basic and main functions of their technological purpose (products for *general machine tool applications* (Kuznetsov, 2016)) reaches 50–70% for many types of machines. The labour intensity of assembly operations and machine tool testing fluctuates on average within $10 \pm 2\%$ of the total labour costs for production. The higher the requirements for the functional complexity and science intensity of components, the higher the share of imported components, which can amount to 90% in value terms. Thus, the cost expressions of production volume should be determined based on their actual labour intensity, excluding the costs of components.

This feature creates another uncertainty in assessing the technological sovereignty and independence based on statistical data.

It can be stated that domestic production of goods for *general machine tool applications* in the Russian Federation is practically absent or negligibly small relative to the required volumes in terms of scope, quality and quantity. *Table 4* summarises data illustrating this situation in the machine-tool industry and lists the groups of critically important products for general machine tool applications. Numbers indicate the criticality level of each group: 0 – high criticality level, 1 – important criticality level, 2 – relative criticality level.

⁵ Detailed information on the methodology of the specified principles for classifying products as Russian ones, their essence and features, as well as problems and solutions can be found in the author's publications in the *Stankoinstrument* journal for 2016, 2018, 2019, 2022 and 2025.

Thus, the statement about machine tools produced in the Russian Federation or about sufficient technological independence and sovereignty is only conditional.

The previous works of 2016, 2018, 2019, 2022 and 2025 also substantiate that, in accordance with the requirements of PP No. 719, it is possible to manufacture a machine tool that will be recognised as a Russian-made one to become the initial statistical accounting unit for determining the technological independence.

Thus, such an indicator can be called “structural technological independence,” which characterises the share of types of Russian-made machines related to the number of all classification types of machines. For example, the ENIMS classifier contains 90 (9410) types of machine tools at only 75 produced ones. In this case, the level of structural independence will be $(75/90) \cdot 100 = 83\%$. Thus, for 50 types recognised according to PP No. 719, the level of structural independence is 53%. If the weighted average share of the localisation degree is equal to 70%, then the level of structural independence is $53 \cdot 0.7 = 37.1\%$, and not 70% (Kuznetsov, 2025).

As noted, the machine-tool industry itself has undergone a qualitative change. Until the 1970s, 1980s and the turn of the 1990s, enterprises were primarily full-cycle production based on homogeneous technologies with machine tools produced almost entirely at a single enterprise. The change in design and technological solutions, driven by the proposed new science-intensive functional modules and systems, required corresponding technological solutions for production. The increasing complexity of science-intensive parts, components, systems and products entails additional features of ensuring independence and sovereignty, appropriate measurement methods and objective assessment methodologies.

Given the above, the methods of statistical analysis and formation of initial data making up the set of statistical elements, as well as the principles of classification should also change. The system and methods for statistical analysis and accounting should be adapted to adequately understand the changes.

Table 4. Groups of critically important products for general machine tool applications***Таблица 4.** Группы критических значимых изделий общестанкостроительного применения*

Type	Level of criticality	Provision of machines with the main technological function(s)	RF manufactured/ Imported, %
0. Materials	1	+	95/5
1. Basic and body parts and products	0	+	90/10
2. Units and mechanisms for general machine tool applications: – <i>main drive units and mechanisms: motors, spindles, bearings, pulleys, couplings, etc.</i> – <i>units, parts, systems of drives and linear and circular movement</i>	0	+	15/85
3. Machine tool components, mechanisms and systems	2	±	75/25
4. Devices and systems of technological support	1	-	60/40
5. Information and control systems and devices	0	+	15/85
6. Standard products and norms: – <i>rolling bearings (precision, hybrid), sliding, aero- and hydrostatic, dynamic, magnetic</i> – <i>process fluids, lubricants, coatings and films</i>	1	±	50/50
7. Auxiliary, specialised, original and supporting elements, units, mechanisms and systems: protective, safety, chip crushing, etc.	2	±	70/30

*For a more detailed classification of components, see (Kuznetsov A.P., 2024a)

Source: The table was prepared by the author
Источник: разработано автором

Uncertainty III

The long-term absence of systematic research into domestic machine tools and some other features of existing R&D work on machine tool development result in the industrial lag and actual return of the technical level of manufactured machine tools to many years behind relevant achievements of equipment and production technologies. This leads to negative phenomena, including the following development directions that are not always evidence-based. As a structural and technical system, technical level indicators of metal-cutting machine tools with production based on the forced use of lower-cost components (and, thus, lower quality characteristics and parameters) cannot basically correspond to a high or required level due to considerations of ensuring greater economic efficiency of production, as well as the repetition or reengineering of solutions, simplification of technological production processes, duplication of analogous design solutions of foreign manufacturers or

their forced partial adaptation to real production capabilities.

In addition to two uncertainties mentioned above, another methodological feature of considering technological sovereignty is that technical characteristics and properties of products are the main and most important components of their usefulness and, thus, competitiveness. The price of a product fails to uniquely determine its competitiveness, influencing it indirectly through the total cost of ownership, which takes into account both the economic effect and operating costs determining the payback period.

The requirements for achieving high levels of ideality (precision) by products and their constant growth are particularly evident in astronomical and medical instrument making, as well as aviation, space, nuclear, electronic, biological and some other industries. It is no coincidence that restrictions on the equipment supply have been introduced for these industries and those in accordance with the Wassenaar

Arrangement, an international agreement in the field of control over the export of conventional arms, signed in 1995 by representatives of 28 (currently 42) states to develop a mode for control over dual-use goods.

This agreement for metal-cutting machine tools (Category 2. Material processing. 2.1. Systems, Equipment and Components: Turning, Milling and Grinding Machine Tools, as well as Five-Axis and More Machine Tools) in each category of p. 2.1 sets criteria for the technical level, primarily for accuracy, taken as indicators established by the international standard ISO 230-2-2014 or its national equivalent (for Germany VDI 3441), which determines the quality and value of the indicator for all machine tools produced at the manufacturer.

In addition to the above, productivity is another equally important and significant characteristic, which is assessed and determined by the speed parameters of the main functional units and devices of the machine (see Table 4). Over the period from the beginning of 1900 to the present day, the cutting speed indicator

(Figure 2), which is provided by both the characteristics of the tool and the speed parameters of the machine, has changed by a thousand or more times from 2–10 to $\sim 10^4$ m/min. During the same time, the complexity of products processed on machines also changed: it doubled every 20 years, while the speed of machine (productivity) grew at a slower rate and increased by almost 80–90%.

Figure 2 shows plots of changes in the achieved accuracy of four technology types, machine productivity (cutting speed for conventional processing methods) and compliance with the requirements of the Wassenaar Agreement. Moreover, if the requirements for achievable processing accuracy are ensured at a sufficiently high level, which is 92–95% of the ideal or physically achievable, then the issues of achieving the productivity level by contemporary machines are still insufficient amounting to about 12–15%. The leading machine-tool-manufacturing countries carry out their research for achieving technological advantages – sovereignty, independence and competitiveness – in the direction of

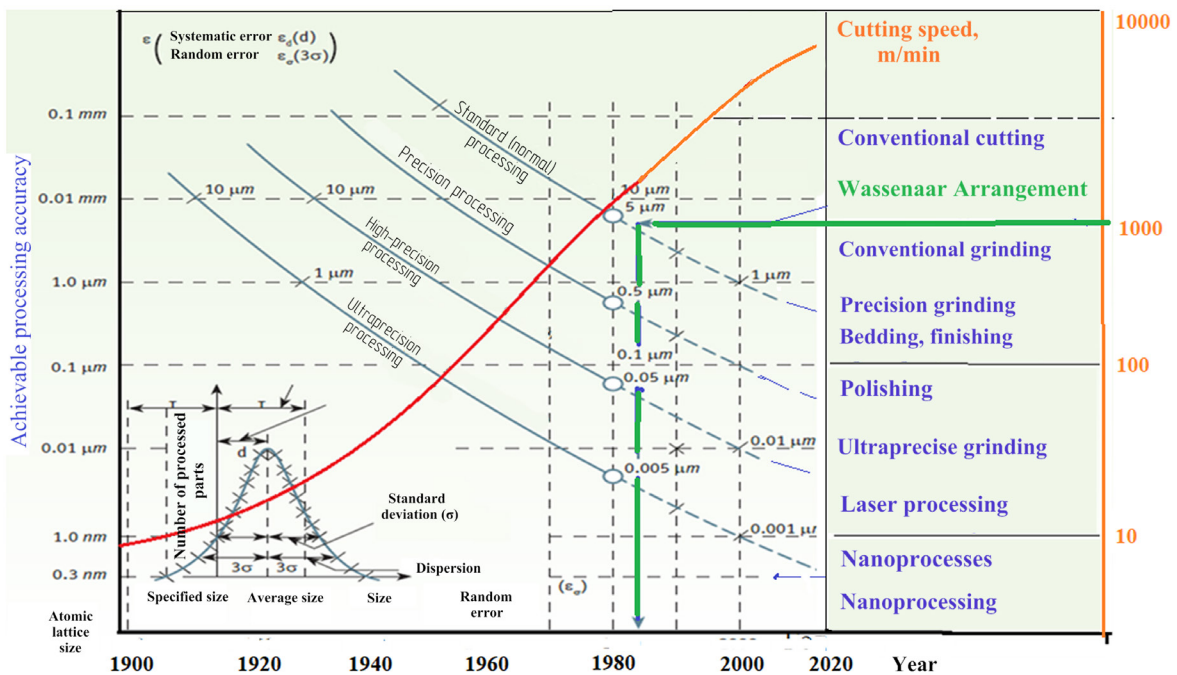


Figure 2. Change in the achievable machining accuracy and cutting speed

Рисунок 2. Изменение достижимой точности обработки и скорости резания

Source: The figure was prepared by the author

Источник: разработано автором

increasing speed (both cutting and technological time of use) and automation functions.

Although this position of statistical accounting and understanding of its importance is not considered, it is precisely accuracy and productivity that determine true independence and sovereignty. The Wassenaar Arrangement and BAFA requirements clearly demonstrate this component of independence and technological leadership.

Thus, the assessment of production volume and methodologies for assessing independence and sovereignty alone excluding the accuracy and/or productivity indicators appear insufficient: they cannot fully reflect their characteristics and level of significance, which is proved by the previously given share of machine tools in consumption and its significant change with the growth of accuracy and productivity characteristics over time.

Methodological feature of uncertainty in assessing the technological sovereignty

In the works (Kuznetsov, 2016–2025; Sukharev, 2024b, Eremchenko & Kurakova, 2023; Chichkanov & Sukharev, 2024; Glazunova, 2024), the authors propose methods for assessing the technological sovereignty, independence and localisation, which consist of finding the relative value of comparison between two sets or quantities, or the sum of grouped quantities, other relationships between sets, including the quotient from division or share(s) and rates of change, as well as probability of set intersection as the occurrence of an event. In all cases of instrumental application for such relationships, the most important role is played

by the values of elements in the sets, adopted by their physical essence, which significantly affects the assessed value, taking into account the noted uncertainties.

Example. Let us assume that the production of a machine requires N parts and assemblies, including imported and N_p Russian-produced. The production of the i -th part requires units of time at the C_i cost of their production. For simplicity of calculations, the machine consists of $N = 5$ parts and assemblies, including imported ones. The production of i -th parts and assemblies requires, respectively: $t_1 = 2$, $t_2 = 5$, $t_3 = 8$, $t_4 = 1$, $t_5 = 4$ units of time; $t_a = 6$ units of time are required to assemble the machine. Their cost will be $C_1 = 4$, $C_2 = 4$, $C_3 = 8$, $C_4 = 3$, $C_5 = 5$ and $C_a = 10$, respectively. Let the machines consist of parts and assemblies containing the following elements:

Option I: $i = 1, 2, 3$; $N_p = 3$; Option II: $i = 1, 4, 5$; $N_p = 3$; Option III: $i = 2, 4, 5$; $N_p = 3$.

The level of technological independence (see Table 5) for the specified options can be determined according to the following dependencies:

$$U_N = N_p / N; U_T = \sum_{i=1}^{N_p} t_i / \sum_{i=1}^N t_i;$$

$$U_{Ta} = \left(\sum_{i=1}^{N_p} t_i + t_a \right) / \left(\sum_{i=1}^N t_i + t_a \right) U_{Ca} =$$

$$= \left(\sum_{i=1}^{N_p} C_i + C_a \right) / \left(\sum_{i=1}^N C_i + C_a \right)$$

Without delving into the explanation of the differences in the obtained values, their significance, objectivity and reliability become quite clear as a type of initial data predetermined by:

Table 5. Options for assessing the technological independence

Таблица 5. Варианты оценок уровня независимости

Option	t_1/C_1	t_2/C_2	t_3/C_3	t_4/C_4	t_5/C_5	t_a/C_a	U_N	U_T	U_{Ta}	U_{Ca}
1 – N_p	2/4	5/4	8/8	-	-	6/10	0.6	0.75	0.8	0.76
2 – N_p	2/4	-	-	1/3	4/5	6/10	0.6	0.35	0.5	0.65
3 – N_p	-	5/4	-	1/3	4/5	6/10	0.6	0.5	0.62	0.65
4 – N_p	-	-	-	-	-	6/10	0	0	0.23	0.29

Source: The table was prepared by the author
Источник: разработано автором

- essence of the selection or justification of the assessment method, its structure and validity;
- objectivity, uncertainty (types of acceptable uncertainty) and validity of selected parameters and characteristics of their distinctive sets in the concepts of technological sovereignty, independence and localisation, which are accepted and indicated in their definitions, e.g. those given earlier.

The spread of the final values and their substantive properties are also unambiguous: characterises the degree (fullness) of coverage with domestically produced parts and assemblies or a relative fraction of machine elements subject to import substitution; characterises the level of technological import dependence (technological localisation) of production; and characterise the level of production-technological import dependence (production-technological localisation) of the full production cycle and ensures greater objectivity and reliability of technological independence level.

Although the number of parts is more defined, their formation is scarcely entirely strict in terms of accounting. Therefore, the acquisition of these parameters and method of their determination, like those described above, introduce their own uncertainties into the value of technological sovereignty and independence. In other words, the parameters should be measurable by direct methods.

The Order No. 193 of the Ministry of Economic Development of the Russian Federation dated March 27, 2025 approved the methodology for calculating the “Integrated Technological Independence Index of the Russian Federation” stipulating the calculation based on the following relationship:

$$\begin{aligned}
 II = & 0,4 \times \frac{\sum_{i=1}^n \left(\frac{a_i - g}{k - g} \times 100\% \right)_i}{n} + \\
 & + 0,3 \times \frac{\sum_{j=1}^m \left(\frac{b_j - z}{q - z} \times 100\% \right)_j}{m} + \\
 & + 0,3 \times \frac{\sum_{v=1}^e \left(\frac{c_v - s}{l - s} \times 100\% \right)_v}{e}
 \end{aligned}$$

which is determined as the weighted average of three groups of components in the quotient from dividing the differences of the current a_i , b_j , c_v and planned k , q , l from the basic g , z , s values of technological independence for all constituent named components i , j , v and their quantity n , m , e .

An initial uncertainty is represented by the lack of a description and justification of the model for the formation of basic technological independence values or a reference to it. With a high degree of probability, the level of technological independence can be assumed similar, as applied to the national project in terms of metal-cutting and high-tech machine tools.

In particular, one of the uncertainty components involves the basic value of technological independence for the capital goods production; the share and method of its determination lie within the framework of implementing:

- National Project “Means of Production and Automation” for ensuring technological leadership: approved by the Order of the Ministry of Industry and Trade of the Russian Federation No. 1571 dated April 1, 2025, “Methodology for calculating the “Achieved Technological Independence of Capital Goods Production”;
- Federal Project “Development of Machine-Tool Industry”: approved by Order of the Ministry of Economic Development of the Russian Federation No. 222 dated April 10, 2025, “Methodological recommendations for calculating the achieved technological independence for high-tech products,” which assumes this indicator calculated according to the dependence:

$$I_{TI} = \frac{\sum_{i=1}^n L_{TRI} + \sum_{j=1}^m L_{PRj}}{2} \times 100\%$$

which is determined as the average of readiness levels for the missing numbers of technologies n and the number of critical components identified within the framework of the national project at the end of the reporting period.

The work (Kuznetsov & Sukharev, 2025) examines the problematic issues of applying the specified methodology, which is the source of

initial data for calculating the Integrated Technological Independence Index of the Russian Federation and is the same source of uncertainty as the data for I_{IT} .

The features of obtaining initial data, as well as their reliability, objectivity and degree of uncertainty considered in this study make it possible to assess technological independence with a low degree of probability, both when justifying its basic value and when assessing current values. It can be assumed that the practice of applying the specified assessment methods and analysing the obtained results will serve as a foundation for making appropriate adjustments, taking into account the stated provisions, as well as the proposals that are given in the aforementioned publications and works of a number of authors.

Conclusion

As a result of the performed analysis, let us formulate the following conclusions:

1. In the absence of a verified system for federal accounting of technologies and technological development that serves as a coordinate system, the development and approval of methodologically unequal, cumbersome and uninformative assessment methods distorts the view of technological development and sovereignty.
2. The degree of uncertainty in the data and expert assessments of technology and production readiness levels fails to achieve the necessary objectivity and reliability of assessed values. For this purpose, methods of direct measurement and assessment, as well as a general algorithm, approach and justification are proposed to use in combination with point-based or expert sets of initial data.

3. The relevant classifications and OKPD2 system used for correlating and analysing products are significantly behind the current level of development of technologies and technological equipment. They require modernisation or harmonisation in accordance with the level of development of technology and engineering, taking into account the direction of further transformation and technological leaps.
4. The number and types of technological independence and sovereignty should be determined and expanded based on a general methodological approach that considers them as quality indicators of the properties and characteristics of the system and its integrity. This scientific and methodological approach assumes establishing other types of technological independence and sovereignty in addition to the current ambiguous definition, including their description as a system and its constituent elements with structure-determining connections, which can also be an assessment algorithm.

All this can be used to develop and define a range of quality indicators for technological independence, sovereignty and leadership, as well as to determine the methods of their formation, state and patterns of change, development forecasts, management methods and a number of other system-wide tasks.

Конкурирующие интересы

Автор заявляет об отсутствии конфликта интересов.

Competing Interests

The author declares no conflict of interest.

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