WHITE PAPER

CNC Machinery 2.0.

Updated research on the strategic role of CNC machines in curtailing Russia's military capacity

by Olena Yurchenko (ed.),
Denys Hutyk, Olena Zhul, Bohdan Kovalenko &
Sofiya Maksymiv

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ECONOMIC SECURITY COUNCIL *of* UKRAINE

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Executive Summary

Being fully automatized industrial tools, which require almost no human intervention, Computer Numerical Control (CNC) machines have revolutionized manufacturing processes around the globe. Nowadays, CNC machines offer industrial manufacturers the highest precision, efficiency, and resilience, which makes them an indispensable and cost-effective method to produce sophisticated components regardless of the final product.

CNC machine tools are used in various industries, including aerospace, automotive, medical, electronics, woodworking, metalworking, and plastics manufacturing. They contribute to producing complex and high-precision components, from aircraft and ship parts to surgical instruments, to orthopaedic implants, etc.

Due to their unique features and accuracy, CNC machines are widely used in military production of different states, especially in the production of weapon hulls, aircraft parts, internal missiles components, UAVs components, critical microelectronics etc. To put it simply, it's hard or even impossible to find a type of modern weaponry that does not require the employment of CNC machines to be produced.

Given that fact, certain types of CNC machines, depending on the level of their precision or specific features, are classified as dual-use goods. Since 1996, CNC machines have been included in the Wassenaar Arrangement – an international arms control regime aimed at stopping the proliferation of equipment with both civilian and military uses.

Yet, such limitations are not comprehensive. Lots of types of CNCs are still not under export controls. Existing national and international regulations and restrictions continue to target high-accuracy specifications while excluding less precise CNC machines often used for military purposes. Combined with constant evasion efforts, those loopholes leave the CNC sector insufficiently controlled.

Yet, the opportunity and tools for such a control still remain. The geographical concentration of the machine tool industry is striking, with most global exports originating from just a few advanced nations in Western Europe and East Asia, notably Switzerland, Italy, Germany, and Japan, with the last two standing as the world's unequivocal industry leaders. The United Kingdom and the United States, though have witnessed declines in their industrial production capacities, maintain their positions among the biggest CNC producers and consumers globally. Taiwan and South Korea are successfully narrowing the technology gap with the biggest players on the market.

Such relative monopoly of Western and Western-allied states on the CNC machinery market makes other countries and their industries dependent on the imported equipment. One of those countries is the Russian Federation.

Russia's dependency on foreign CNC machine tools (70%) and their components (80-95%) has developed and deepened for years. Its sources lie in the absence of a domestic CNC machine-building industry and other factors such as market size, economic changes in the 1990s, and a lack of qualified personnel. Despite several attempts of import substitution, the overall dependence of Russian industry on the western CNC machinery remains to this day, being the most striking within the military-industrial complex.

Weapons producers are the key consumer of CNC machines in the Russian Federation. Between 70% and 80% of all machines in Russia are used by the military complex. Such a dependency presents a unique opportunity for Western and Western-allied states to use the strategic vulnerability of the aggressor to curb its military capacity.

Equally or even more important in the long run, is the fact that the Russian Federation is not the only rogue state for which the "monopoly" of Western and Western-allied countries on the CNC market is a vulnerability. Iran, North Korea, and China have a similar dependence to varying degrees.

The full-scale Russian invasion of Ukraine exposed the weak points of Russia's (as well as other rogue states') reliance on Western and Western-allied CNC machines, components, and software. However, despite sanctions and export controls, Russia's CNC machine market remained stable in 2022, raising concerns about the effectiveness of these measures. Consequently, the Russian military complex retained access to the critical equipment. The situation with Iranian, Chinese, and North-Korean weapons producers may be the same.

The key factors contributing to Russia's ongoing access to foreign CNC machines and technology include export control deficiencies, gray import and sanctions evasion schemes, as well as lenient and outdated compliance by CNC producers.

Even more crucial factor is the lack of capacity of the enforcement bodies as well as the lack of their focus on leveraging Russia's dependence on Western machinery. Being a crucial and weak point of the Russian military industry as well as being used in the production of all kinds of modern weaponry, CNC machine tools along with their global supply chains still remain only one of the numerous targets on the list of the relevant national enforcement authorities.

To address all these challenges, a set of specific measures should be taken by governments and market representatives. In particular, states should enhance their national export regulations, review collectively the international export control regime in the CNC machinery sector, increase liability for the manufacturers not in control of their supply chains, launch a full-fledged technological decoupling from violators of international law, as well target regularly and systematically the intermediaries and procurement companies responsible for the illicit supply of CNC machines and their components.

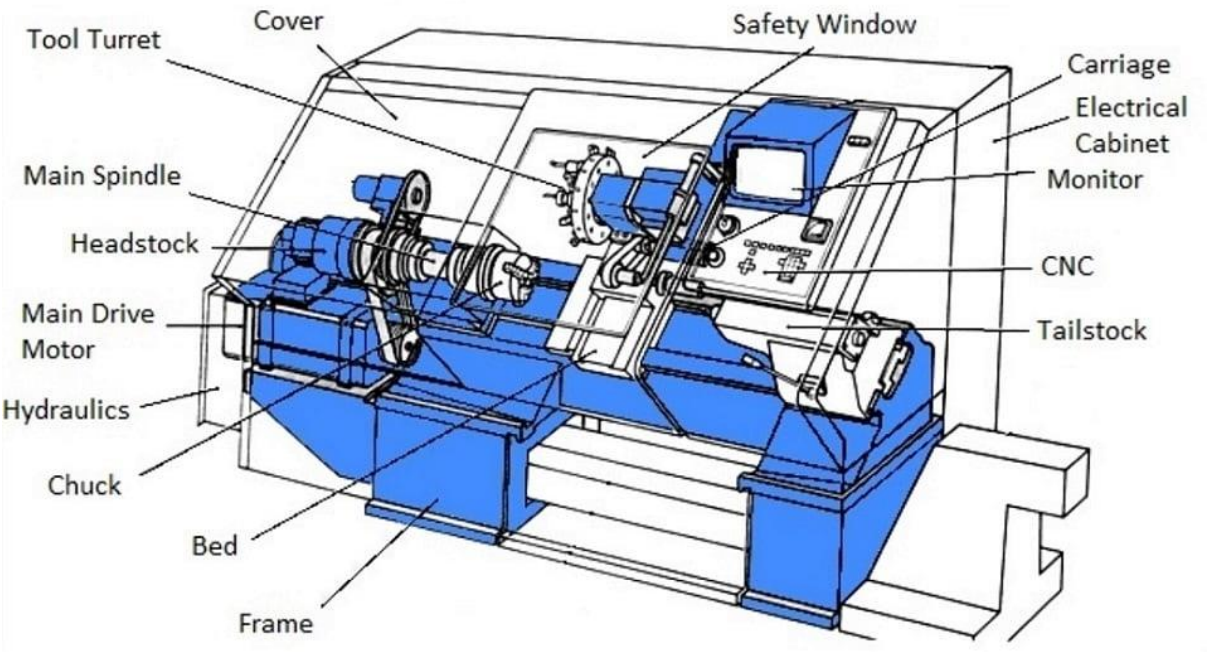
Recommendations for CNC manufacturers mainly focus on changing their approach to the due diligence, compliance and KYC practices, which includes implementing mandatory remote control systems for CNC machinery, controlling gray imports of their products and reporting on the unauthorized and irresponsible resellers, shifting to a risk-based approach, conducting trade exclusively with authorized partners, ensuring clear compliance rules, withdrawing from sanctioned markets, and implementing sanctions circumvention markers.

These recommendations aim to enhance the effectiveness of export controls, reduce vulnerabilities to sanctions evasion, and create a more responsible and secure environment for the international trade of dual-use technologies, particularly CNC machines and the relevant components. These recommendations are universal and aimed at preventing the acquisition of CNC machines and technologies by states that violate international law, terrorist groups, and illegal armed groups.

1. CNC machines – principles, application, regulation, market

1.1. CNC machines – basic principles of operation and structure

CNC (computer numerical control) machines are automated tools designed to manufacture products from various materials according to a set program without direct human intervention[1]. In addition to automating the machining process and enhancing precision, CNC-based machining eliminates manual tasks and frees machinists to oversee multiple machines running simultaneously. In addition, once a tool path has been designed and a machine is programmed, it can run a part any number of times. This provides a high level of accuracy and repeatability, which in turn makes the process highly cost-effective and scalable[2].



Picture 1. A turning CNC machine (usual appearance). Source[3]

A typical CNC machine is composed of the following elements[4][5]:

1. **Input Device** used to load CNC programs into the machine. This input device could be the keyboard (to input G-code commands directly), a USB flash drive (to transport a completed program from another computer), or wireless communication (if the program is to be downloaded from another computer using the local network).

2. **Display Unit** is a screen that displays essential information to the operator. The display unit shows how the operator interacts with the various CNC machine functions, such as inputting G-code or changing machine settings. The display unit also shows the current machine operating status.

[1] https://www.xometry.com/resources/machining/parts-of-a-cnc-machine/
[2] https://metalcutting.com/knowledge-center/precision-cnc-machining/#general-industry-applications
[3] https://all3dp.com/2/what-is-cnc-turning-simply-explained/
[4] https://www.tramarindustries.com/2021/10/25/what-are-the-components-used-in-a-cnc-machine/
[5] https://www.xometry.com/resources/machining/parts-of-a-cnc-machine/

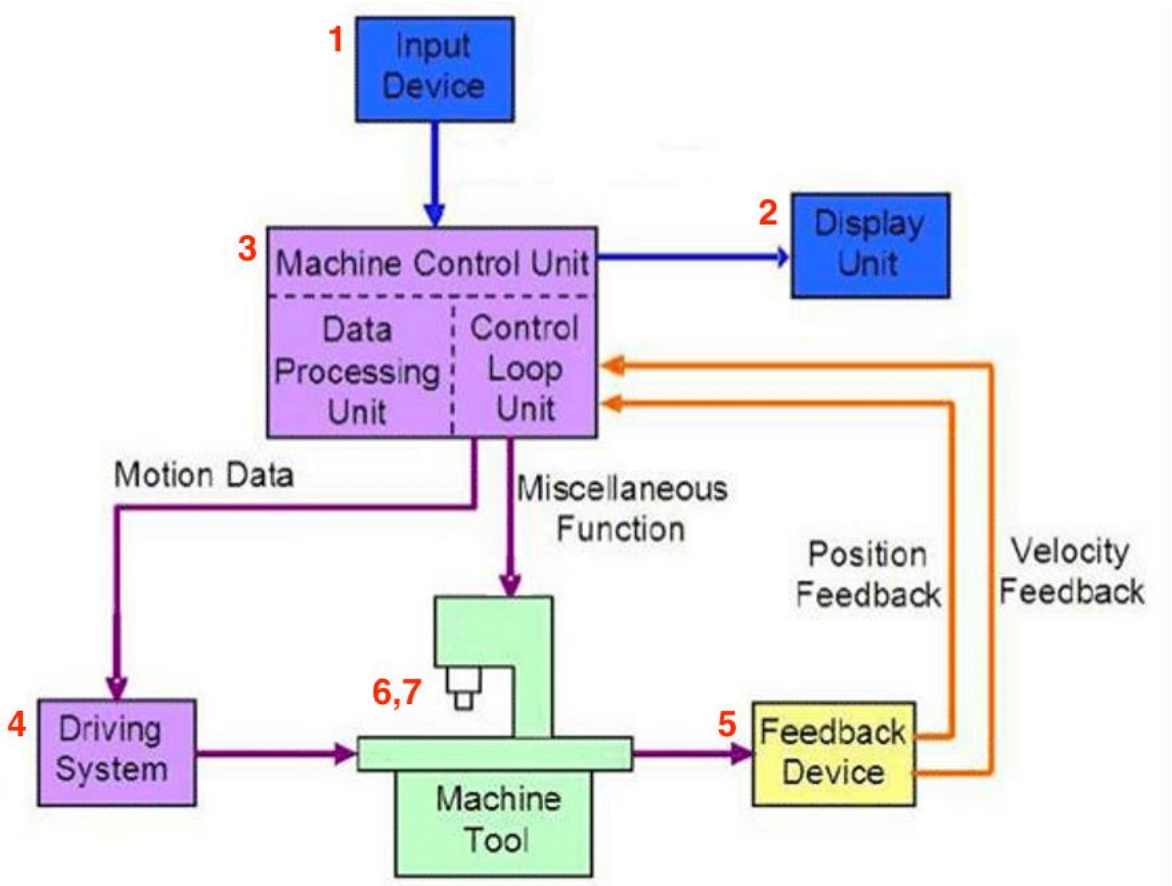
3. **Machine Control Unit (MCU)** is the electronic hardware and software set that reads the input device's G-code and translates it into instructions that the tool drivers can execute to perform the desired machining actions. The MCU interprets the G-code and coordinates into movements carried out by servo motors along the various machine axes. It also analyzes information from feedback sensors to ensure the tool is in the expected position after the movement.

4. **Driving System** is the motors that move the tool along the various machine axes. Usually, Driving System consists of servo motors, ball screws, and linear guides. Servos can precisely move the ball screw nut to position the various mechanical components, such as the bed and the spindle. Linear guides ensure the bed and spindle movement is precise, with as little play as possible.

5. **Feedback System** is a set of sensors ensuring that after the machine moves a mechanical component to a specific position, this position is verified and, if necessary, adjusted. The position can be measured using a linear or rotary encoder attached to the servo motor. Special probing tools are also used to zero the machine and measure the actual part during machining to adjust machining parameters to meet dimensional requirements potentially.

6. **Bed** is where the raw material is mounted. Various work-holding jigs are used to secure the workpiece in place. The bed often has t-slots or holes to which the jigs can be attached. Conventional CNC machine beds only along the horizontal x- and y-axes, but more advanced 5-axis machines can include rotational motions along the x- and y-axes.

7. **Machine tools** is the general term for any instrument that may perform a process on a workpiece, usually cutting tools. Machine tools take on many forms depending on the type of CNC machine. CNC lathes use stationary tools and move the spinning raw material into the tool to make cuts. CNC mills move spinning tools into stationary material. However, more complex 5-axis machines can move both the tool and the workpiece, which makes it possible to create more sophisticated features in the finished part. Machine tools are often kept in “tool libraries,” which are machine racks to store all the tools that may be required to machine a part. A tool changer automatically removes a tool from the spindle, places it in the tool library, and installs the next tool.



Picture 2. A generic scheme of a CNC machine structure (annotated by the author). Source[6]

Thus, the typical manufacturing process using the CNC machine tools will proceed in the following way (please refer to Picture 2 for visualization of the explanation below):

1. First, taking a computer-aided design (CAD) model of a product, a machinist (CNC machine operator) uses computer-aided manufacturing software (CAM) to create the instructions for machining a part[7]. These instructions are written in the particular language - G-code. This G-code contains the coordinates of the specific part features, the required tool to use, the optimal speeds and feeds, and commands for when to turn the coolant on or off;

2. After creating the instructions, the machinist uses the input device (1) to insert the instructions into the machine;

3. On the receiving end, the machine control unit (3) converts this G-code into instructions for the driving system (4) (various servo motors and spindles) to produce the desired part;

4. The driving system (4) puts in motion the machine tools (7), which start to process the material on the bed (6);

[6] https://www.researchgate.net/figure/1-Elements-of-CNC-System-14_fig1_308266254
[7] https://sprutcam.com/whats-cad-cam/

5. During the manufacturing process, feedback sensors and probing devices (5) monitor a part's accuracy and precision and report it back to the machine control unit (3);

6. The current machining operation status can be observed on the Display unit (2).

7. This is the general description of a CNC machine operation. Naturally, depending on the manufacturing process (milling, turning, grinding) or the number of axes (two, three, four, five), some additional components (e.g., tailstock, headstock, footswitches, chucks) are also included in the machine[8]. There is also notable variation in the tools (instruments) used to process materials, including laser beams, waterjets, drills, lathes, and plasma cutters.

1.2. Advantages of CNC machines over the other types of processing machinery

Precision CNC machining is often plays critical role in the production of small metal parts and precision metal components used in various industries. As is true of virtually all cutting and small pieces machining methods, different materials behave differently, and the size and shape of a component also significantly impact the process. However, in general, the process of precision CNC machining offers the following advantages over other machining methods[9] [10]:

- **Precision.** CNC machines can achieve very high levels of accuracy and repeatability in the parts they produce[11]. It is achieved through high-precision sensors and actuators, allowing the machine to control the cutting tool's movement precisely. The accuracy (tolerance) can range from ±0.0127 mm to ±0.00508 mm and higher;

- **High speed.** Using high-speed spindles and cutting tools, CNC machines can achieve faster cutting speeds and higher material removal rates. This allows manufacturers to produce parts more quickly and efficiently, reducing production times and costs.

- **Multi-Axis Processing.** CNC machines can perform multi-axis machining operations, which involve moving the cutting tool along multiple axes simultaneously. This allows manufacturers to create complex, three-dimensional shapes and features that would be difficult or impossible to create using traditional machining methods.

- **Tool Changing.** CNC machines are capable of changing cutting tools automatically without the need for operator intervention. This allows manufacturers to use multiple cutting tools in a single machining operation, reducing the need for manual tool changes and increasing efficiency.

- **Program Storage and Retrieval.** CNC machines can store and retrieve machining programs electronically. This allows manufacturers to easily recall and reuse machining programs for future production runs, reducing setup times and increasing productivity.

[8] https://mdaltd.ca/cnc-machine-tools-types-functionalities/
[9] https://metalcutting.com/knowledge-center/precision-cnc-machining/#general-industry-applications
[10] https://mdaltd.ca/cnc-machine-tools-types-functionalities/
[11] It is crucially important to differentiate between accuracy and repeatability. The CNC machine's accuracy is defined as its closeness to the intended value. In other words, accuracy is the degree to which the system's reported measurements match up with reality. Repeatability is the degree to which the outcome differs when repeated attempts are made to achieve the same goal, such as visiting the same spot, measuring the same quantity, or bonding the same number of wafers in succession under the same conditions.

It also allows for easy modifications to existing programs, making it easy to update part designs or make other changes.

These features make precision CNC machining a cost-effective and versatile manufacturing process for small metal parts and precision components.

1.3. Applications of CNC machine tools

Various industries heavily rely on CNC machine tools to manufacture a broad range of components. These machines are instrumental in producing complex and high-precision parts for applications in the aerospace, automotive, medical, electronics, and military sectors[12].

Aerospace and Shipbuilding Industry: The aerospace and shipbuilding industries rely heavily on CNC machine tools to produce aircraft and ship components. CNC machines produce complex, high-precision parts such as turbine blades, engine components, and landing gear. Moreover, such parts as aerodynamic profiles, manifolds, bushings, RF suppression materials, electrical connectors, engine and wing parts, gearbox and connector components, deck and hull structures, trim, and titanium cladding are also produced on CNC machines[13][14].

Automotive Industry: The automotive industry uses CNC machine tools extensively to produce vehicle components. CNC machines produce engine blocks, drive axles, gearboxes, transmission components, and suspension parts. CNC machines also produce molds and dies in automotive manufacturing[15].

Medical Industry: The medical industry uses CNC machine tools to produce medical devices and implants. CNC machines produce surgical instruments, orthopaedic implants, and dental components. CNC machines also produce custom prosthetics and other patient-specific medical devices[16].

Electronic Industry: The electronic industry relies heavily on CNC machine tools to produce electronic components such as printed circuit boards (PCBs), semiconductors, and consumer electronics[17]. CNC machines are used to make PCBs and microchips with high precision and accuracy, ensuring that components fit together correctly and function properly.

Military industry: The applications of CNC systems in this area are vast, from complex, customized weapons hulls to the internal components of missiles. Some parts manufactured using the CNC production process are main rotor hubs, couplings, seat frames for ground and air transportation, flanges, transmission parts, missile components, helicopter components, retaining rings, and ammunition lifting components[18]. The production of guided missiles, anti-missile defense systems, radio-electronic equipment, navigation equipment, armored vehicles, and submarines is impossible without CNC machines[19]. De facto, every modern weapon requires a CNC machine tool to produce its components[20]. The extensive military application

[12] https://www.rapiddirect.com/knowledge-base/applications-of-cnc-machining/
[13] https://www.scmgroup.com/en/scmwood/news-events/news/cnc-machine-applications-in-the-marine-industry.n68595.html
[14] https://waykenrm.com/blogs/cnc-machining-for-aerospace-industry/
[15] https://autoprotoway.com/cnc-machining-in-the-automotive-industry/
[16] https://at-machining.com/medical-cnc-machining/
[17] https://www.3erp.com/blog/how-cnc-machining-is-used-in-the-electronics-industry/
[18] https://at-machining.com/cnc-machining-in-defense-industry/
[19] https://www.3erp.com/blog/cnc-machining-use-cases-in-the-military-and-defense-industries/
[20] https://www.china-machining.com/blog/cnc-defense/

of CNC machines makes them dual-use goods, subject to export control regulations at the international level.

Other Industries: CNC machine tools are also used in various other industries. For example, the woodworking industry uses CNC machines to produce furniture, cabinetry, and other wooden components. The metalworking industry uses CNC machines to produce various metal components, from small precision parts to large structural components for buildings and bridges. CNC machines are also used to produce plastic components for multiple applications.

1.4. International export control regime for CNC machines

As mentioned above, CNC machines are used to produce all weapons in modern warfare. These include aircraft (seat frames, couplers, retainer rings, jet engines), ships (rotor hubs, armor, retainer rings, naval engines, propellers), missiles and munitions (hoist components, internal guidance systems, other components), small arms, armored vehicles, and nuclear weapons[21]. Some examples of CNC machines' military application compared to civilian use, as summarized in the Cox Report of 1999, are presented in the table below[22].

Table 1. Application of CNC machine tools in military, civilian, and nuclear sectors[23]

Machine Tool Type	Conventional Military Applications	Nuclear Applications	Civilian Applications
Precision lathes	Inertial guidance system parts; high performance fuel-pump parts; tank transmissions.	Parts for uranium enrichment centrifuges and laser isotope separation.	Automotive transmissions; VCRs; CDs, computer components.
Diamond turning lathes	Reflecting mirrors for laser gyros; harpoon missile advanced optical system.	Hemishells.	Molds for contact lenses; prisms for optical equipment; computer hard drives.
Large centre-drive lathes	Gun barrels for 120- and 150-mm cannon (external cuts).	(No critical application).	Turbine shafts; large motor shafts; propeller shafts.
Mills	Stabilization and aiming systems for M1A1 Tanks; airframe and missile parts.	Enrichment Components.	Instrument brackets; large computer frames; airframe parts.
Large five-axis mills	Aircraft parts; propellers for Navy ships and submarines.	(No critical application).	Aircraft parts; propellers for commercial ships.

[21] https://www.bdeinc.com/industries/military-cnc-machining/
[22] https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf
[23] https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf

Small five-axis mills	Jet engine impellers.	Enrichment components.	Compressor pumps for fluids.
Grinders	Radar systems for aircraft; inertial guidance system parts; helicopter main shaft bearings; gas turbine blades; high performance fuel pumps.	Enrichment components, tooling and fixturing.	High speed motor shafts and bearings; automotive injector valves; dies, molds, pumps.

Given that CNC machine tools are used to produce all kinds of military equipment, they are considered dual-use goods and have been subject to export control regimes for several decades. During the Cold War, the Coordinating Committee for Multilateral Export Controls (CoCom)[24] established multilateral controls on exports to the Warsaw Pact allies and Communist China of machine tools that restricted linear positioning accuracy below 10 micrometers[25].

The issue of export controls on CNC machines became especially prominent in 1987 during the so-called Toshiba-Kongsberg scandal.[26] Japanese company Toshiba, in cooperation with Norwegian company Kongsberg and several front companies, between 1982 and 1984 sold machine tools to the then USSR in violation of an agreement between the members of the CoCom. The Soviet Union used the respective equipment in the nuclear and heavy industries as well as the production of very high-precision screws for submarines. According to the position of the United States that case significantly improved the ability of Soviet submarines to evade detection. Congress moved to sanction Toshiba and ban imports of its products into the United States[27].

However, the consensus for relatively strict export controls dissolved after the Soviet Union's collapse. CoCom aimed to control and limit technology transfers to Communist countries considering global security threats and had a multilateral consent mechanism for export approvals. In contrast, its successor, the Wassenaar Arrangement of 1996, was coined in the spirit of the liberal consensus, where the technical standards for dual-use goods were set high (e.g., only the most precise and novice goods with many exceptions) and export licensing (as well as many other aspects) was left to national discretion[28]. Currently, different multilateral export control regimes exist, e.g., the Nuclear Suppliers Group[29] and Missile Technology Control Regime[30], but the CNC machine tools are still mainly controlled under the generic Wassenaar Arrangement.

In the early Wassenaar era of export controls, the issue of CNC machines export regulations was also a part of the so-called Cox Report (Report of the Select Committee on U.S. National Security and Military/Commercial Concerns with the People's Republic of China) on China's covert operations within the United States during the 1980s and 1990s[31]. The Cox report concentrated mainly on the Chinese nuclear weapons development and US technologies found

[24] https://www.stimson.org/wp-content/files/file-attachments/Report7_1.pdf
[25] https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf
[26] https://apnews.com/article/905ab91cce3e82bff2853cf713e6eaf9
[27] https://www.kcl.ac.uk/news/the-toshiba-kongsberg-case
[28] https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf
[29] https://www.nuclearsuppliersgroup.org/en/
[30] https://www.mtcr.info/en
[31] https://www.govinfo.gov/content/pkg/GPO-CRPT-105hrpt851/pdf/GPO-CRPT-105hrpt851.pdf

in Chinese weaponry. A separate chapter (McDonnell Douglas case) of the report was dedicated to the issue of CNC machine tools.

The Wassenaar designations of dual-use CNC machines are a bedrock of current national export control regulations of numerous states. Namely, in the USA, those regualtions are included in the Commerce Control List, Category 2, controlled and maintained by the Bureau of Industry and Security[32].

In the EU, the CNC machines belong to Part IV-Category 2 of Annex 1 of Regulation 2021/821 of the European Parliament and of the Council dated May 20, 2021, setting up a Union regime for the control of exports, brokering, technical assistance, transit, and transfer of dual-use items[33]. In the EU case, the situation is complicated because no central EU authority is issuing licenses – this is left to the individual Member States, which also have separate, more detailed export control lists[34].

In Japan, the export control system emerged after the Toshiba scandal[35] and now is based on all multilateral export control regimes such as Australia Group, Missile Technology Control Regime, Nuclear Suppliers Group, and Wassenaar Arrangement – CNC are also included under category 2-(12) in the Japanese Export Trade Control Order [36][37][38]. In all cases, the specifics of license requirements, countries of concern, and exemptions from the export control are left to the national discretion.

Overall, the international framework for controlling CNC machine tools reflects the political conjuncture of the Wassenaar Arrangement emergence. Namely, Wassenaar Arrangement along with corresponding national export regulations[39] currently control for the following segments of CNC machinery sector:

- **CNC machines** (with specifications below) (Section 2.B.1.);
    - Multi-axis turning machines (lathes) that are accurate to 1.1. micrometers (Section 2.B.1.a.);
    - Five-axis milling machines accurate to 6 micrometers; three-axis milling machines with rotary axis accurate to 0.9 micrometers (Section 2.B.1.b);
    - Five-axis grinding machines accurate to 6 micrometers; multi-axis grinding machines are accurate to 1.1 micrometers Section 2.B.1.c).
    - Multi-axis cutting tools accurate to 0.003 degrees that use lasers, electron beams, or fluid jets (Section 2.B.1.e.);
    - Two-axis electrical discharge machines that do not use wires for shaping (Section 2.B.1.d);

[32] https://www.bis.doc.gov/index.php/documents/federal-register-notices-1/3316-ccl2-5/file
[33] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R0821
[34] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:C_202300441
[35] https://www.cistec.or.jp/english/export/Overview4th.pdf
[36] https://www.cas.go.jp/jp/seisaku/hourei/data/ETCO.pdf.
[37] https://www.meti.go.jp/policy/anpo/seminer/shiryo/guidance_english.pdf
[38] https://www.bis.doc.gov/index.php/enforcement/oea?id=1156
[39] https://www.wassenaar.org/app/uploads/2022/12/List-of-Dual-Use-Goods-and-Technologies-Munitions-List-Dec-2022.pdf

- Numerically controlled optical finishing machine tools accurate to 1 micrometer that use lasers, electron beams, or fluid jets (Section 2.B.2.);

- Numerically controlled gear cutters that can cut hardened steel gears larger than 1.25 meters in diameter (Section 2.B.3.).

- **CNC software** used for the production or operation of the equipment described above (2.D.); CNC software simultaneously coordinates more than four axes (Section 2.D.2.);

- **CNC machine components and tools**, which are used in the equipment described above (robots, compound rotary tables, coordinate measuring machines, feedback units, laser and plasma cutting equipment, and tilting spindles) (Section 2.B.5 – B.9.).

Thus, these export control norms cover only the most precise equipment. The export control does not include the CNC machines with an accuracy of less than 6 micrometers (in some cases – 1 micrometer, depending on the type of processing technology – e.g., milling, turning). However, the standard levels of machining tolerance (accuracy) for CNC machine tools for the standard processes range between 130 micrometers (0.13 millimeters) and 762 micrometers (0.762 millimeters)[40]. Despite lower accuracy, even the less precise CNC machine tools for standard processes are widely used for military purposes.

CNC machines can also be modified so export control norms are not applied (e.g., a machine may be designed with four-axis capability). However, if an end-user application is only for two-dimensional parts, the device can be built with motion in only two axes. Therefore, controls that apply to machines with three or more axes do not come into play)[41]. Another way is to obtain a non-controlled CNC and use it for military purposes at high precision – for instance, a user who is prohibited from buying a machine with 4-micrometer accuracy can legally purchase a numerically controlled three-axis machine with 7-micrometer accuracy that is set up to run high-speed feed rates, slow it down, and obtain 4-micrometer accuracy[42].

The CNC export controls also have many exceptions. For instance, if a metalworking machine has a CNC system but is limited to the manufacture of gears, an export license is not required. The same is true for machine tools to produce crankshafts or camshafts, tools or cutters, extruder worms, etc (see Section 2.B.1., Notes 1 and 2). The grinding machines are also exempt from export licensing if they are limited to cylindrical or surface grinding (Section 2.B.1. c. Note)[43].

Thus, it is obvious that the existing export controls regime for CNC machinery sector is not comprehensive and includes numerous loopholes, which combined with the constant efforts of the rogue states to evade even the introduced restrictions leaves this critically important for military production sector uncontrolled. Given the advantages of CNC machines and technologies, they often become subject of industrial espionage and are of particular interest to states that violate international law. There are numerous cases where the CNC machines or components appeared in the so-called "jurisdictions of concern" in violation of export regulations, among them:

[40] https://www.3erp.com/blog/cnc-machining-tolerances/
[41] https://apps.dtic.mil/sti/pdfs/ADA490280.pdf
[42] https://apps.dtic.mil/sti/pdfs/ADA490280.pdf
[43] https://www.wassenaar.org/app/uploads/2022/12/List-of-Dual-Use-Goods-and-Technologies-Munitions-List-Dec-2022.pdf

- **McDonnell Douglas Scandal** - On November 14, 2001, the US Department of Commerce imposed a USD 2.12 million civil penalty against McDonnell Douglas Corporation of St. Louis, Missouri, as part of a settlement of charges that the company violated federal export control laws. The Order imposing the penalty concluded a six-year investigation into exports of machine tools to China between 1994 and 1995. The Department alleged that McDonnell Douglas submitted license applications containing false and misleading statements about the end-use and end-user of the machine tools. The Department also alleged that the exports violated the conditions of U.S. export licenses issued to the company. In addition to the civil penalty, the Order and settlement agreement require that McDonnell Douglas' parent company, The Boeing Company, assume responsibility and liability for all exports under the Commerce Department's jurisdiction made or to be made by McDonnell Douglas. In a related case concluded in May 2001, the Department had imposed a USD 1.32 million civil penalty and a denial of export privileges on a group of Chinese government-owned companies and their U.S. affiliates that had received the machine tools from McDonnell Douglas[44].

- **Mitutoyo Scandal** – Japanese Mitutoyo Corporation, a leading precision measuring device manufacturer, was charged with the illegal transfer of five precision measuring devices to a subsidiary in Malaysia via Singapore between 2001 and 2005. These devices ended up in a facility that had been a part of Libya's now-defunct nuclear weapons program. Mitutoyo equipment was also easily acquired by Japanese brokers working with companies in Iran. In June 2007, two important final judgments in the case were handed down: on June 25, a Japanese court gave four former executives multi-year jail sentences and fined the company ¥45 million (about USD 350,000); the next day, the Japanese government imposed a two-phased export ban on the company with a total duration of three years[45].

- **Horkos Scandal** – Horkos is a Hiroshima-based machine tool manufacturer that produces a variety of different types of machine tools. Between 2000 and 2008, Horkos is believed to have exported around 650 'Machining Centres' and other machine tools without an export license. Horkos staff labeled the goods falsely as lower specification machine tools to reduce the risk that national authorities would snag them. Horkos was fined ¥47,000,000 (approximately £350,000). METI, the Japanese national export authority, also suspended Horkos' right to export to any location for five months from 21 August 2009 to 21 January 2010[46].

- **Hashem-Khan Iranian Case** – In 2019, U.S. enforcement action uncovered a scheme to procure export-controlled U.S. and Canadian equipment, many of which had nuclear applications, for an end user in Iran. The case exhibited characteristics common in illicit Iranian procurement, involving Iranian nationals based overseas, using various freight forwarders to obscure Iran as the end user, relying on Dubai as a transshipment point, and submitting falsified shipping documents. The conspiracy spanned from 2015 to 2018, underscoring Iran's persistent efforts to acquire Western technology despite the Joint Comprehensive Plan of Action (JCPOA) implemented in January 2016. The technologies in question were various computer numerical control (CNC) vertical machining and turning centers controlled by the United States for nuclear non-

[44] https://web.mit.edu/1.265/www/Export%20Penalty%20Cases.pdf
[45] https://www.nti.org/analysis/articles/will-japan-learn-its-mistakes/
[46] https://www.kcl.ac.uk/news/export-control-violation-by-japanese-machine-tool-manufacturer

nonproliferation reasons. Charges were filed against Mehdi Hashemi and Feroz Khan, accusing them of illegal exports and attempted exports of machine tools and related parts, with Hashemi operating from the U.S. and Khan in the UAE[47].

1.5. Main producers of CNC machines in the world (countries and companies)

The global machine tools market size was estimated at USD 87.94 billion in 2022 and is anticipated to expand at a compound annual growth rate (CAGR) of 5.7% in the coming decades[48]. At the same time, the CNC segment accounted for 85.8% of the global machine tools machines revenue share in 2022[49].

At the same time, the geographical concentration of the machine tool industry is striking, with most global exports originating from just a few advanced nations in Western Europe and East Asia, notably Switzerland, Italy, Taiwan, South Korea, Germany, and Japan, with the last two standing as the world's unequivocal industry leaders[50]. Given that the machine tool sector serves as the cornerstone for manufacturing across various industries, including the military, the significant regional variations in quantity and quality of machine tool production carry profound strategic implications.

Namely, the continuous reliance of many states, including Russia, China, Iran, and North Korea, on metal-cutting machines, machine components, and essential supplies from abovementioned developed countries, many of which are allies of the United States, creates a strategic vulnerability of the key rogue states that the Western and Western-allied countries can exploit and leverage to secure the global order.

Machine tool production is knowledge-intensive, surpassing most manufacturing industries' technological and skilled labor demands. Its foundation lies in innovative digital control technology, well-developed mechanical engineering, and an enduring tradition of craftsmanship. Consequently, the historic industrial giants that effectively embraced technological development play a disproportionately significant role in this industry[51].

Within the sector, dominance is enjoyed by long-established producers who successfully navigated the transition from manual to computer-based controls. While emerging producers are making strides in narrowing the quantitative gap, the disparities in quality and technology prove more challenging to bridge. Notably, these disparities are most pronounced in producing strategically vital high-end equipment, emphasizing the contrast between the old industrial powers and the new entrants[52].

Western European and Japanese leaders. In 2023, Western European (Germany, Switzerland) and Japanese producers control the supply of quality CNC machine tools. According to the World Machine Tool Survey conducted by Gardner Business Media in 2022, Germany produced machine tools (of all kinds, including CNC machines) for USD 10.3 billion, and Japan – for USD 10.5 billion. Among other leading producers of the group are Italy (USD

[47] https://www.wisconsinproject.org/u-s-targets-procurement-network-supplying-machine-tools-to-iran/
[48] https://www.grandviewresearch.com/industry-analysis/machine-tools-market
[49] https://www.grandviewresearch.com/industry-analysis/machine-tools-market
[50] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[51] https://kamilkazani.substack.com/p/who-produces-machine-tools
[52] https://kamilkazani.substack.com/p/who-produces-machine-tools

6.9 billion) and Switzerland (USD 2.6 billion)[53]. Japan and Germany are also the world's largest exporters of machine tools[54].

Combining technological superiority with the difficult-to-emulate tradition of craftsmanship, they have effectively monopolized a range of strategically important sub-sectors of the machine tool industry, especially at the high end. Their dominance is particularly pronounced in producing critical components, mechanical or electronic[55].

According to the CCID Consulting ranking, among the 2022 top-10 CNC machine producers in the world, eight companies originate from the group of countries described above – 4 from Japan (Yamazaki Mazak, AMADA, OKUMA, Makino), and four from Germany (DMG Mori, Trumpf, GROB, EMAG)[56]. MAZAK from Japan secured the first position with USD 5.28 billion in produced machinery, followed by German company TRUMPF in the second position with USD 4.24 billion, and DMG MORI in the third position with USD 3.82 billion[57].

Declining industrial powers. The United Kingdom and the United States are waning industrial powers in the CNC machines market. As former industrial powerhouses, the US and UK lost much of their production capacities, especially at the low end. Still, they have high capabilities, retaining sophisticated production and even the leading edge in specific sub-sectors of the machine tool industry[58]. In addition, the British and American companies are mainly domestic market-oriented[59].

Still, as of 2022, the United States produced machining equipment worth USD 5.9 B[60].The USA remains the world's second-largest consumer of CNC machine tools, having consumed machines for USD 10.1 billion last year[61]. One of the largest CNC machine producers in the world is the US-based company Haas Automation Inc[62]. Another American CNC machine tools producer is Hardinge[63].

Catching-up countries. Another group of countries producing CNC machines are Eastern Asian nations following the Flying Geese industrial development model[64]. These countries have started their progress only recently and from a shallow base. Consequently, their capabilities are limited, albeit to various degrees.

As Taiwan and South Korea are in the very advanced stages of their learning process, the quality and technology gap dividing them from the old industrial powers is narrower. Both countries demonstrated impressive results in production in 2022 – USD 4.5 billion for South Korea and USD 3.9 billion for Taiwan [65]. Taiwan is also one of the world's leading exporters of machine tools. Still, even these advanced catching development producers often cannot provide an alternative to the import from the old industrial powers.

[53] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[54] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[55] https://www.gtai.de/en/invest/industries/industrial-production/machinery-equipment
[56] https://www.machinemfg.com/top-10-cnc-machine-tool-companies/
[57] https://www.machinemfg.com/top-10-cnc-machine-tool-companies/
[58] https://apps.dtic.mil/sti/pdfs/ADA490280.pdf
[59] https://apps.dtic.mil/sti/pdfs/ADA490280.pdf
[60] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[61] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[62] https://www.machinemfg.com/top-10-cnc-machine-tool-companies/
[63] https://www.stylecnc.com/blog/top-10-best-cnc-machine-manufacturers-brands.html
[64] https://www.grips.ac.jp/forum/module/prsp/FGeese.htm
[65] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022

Among the big companies of Taiwanese and South Korean origin, one may name Doosan Machine Tools Co., Ltd. (South Korea), Hyundai WIA (South Korea), Tongtai Machine and Tool (Taiwan), Kao Fong Machinery (Taiwan), Litz Hitech (Taiwan), Victor Taichung Machinery Works (Taiwan)[66].

Mass market producer. As a newcomer in the industry, China remains a producer of tertiary importance while being the largest consumer of machine tools globally (USD 27.4 billion in 2022)[67]. Going through an earlier stage of its learning process, its production capabilities are minimal, and the catching development associated problems are particularly pronounced. Having a heavily lopsided production structure with the prevalence of low-end equipment, China has limited capacity to satisfy the needs for high-end equipment produced by Western and Japanese manufacturers[68].

However, emphasizing low-quality machining equipment, including CNC, compensates for quality with quantity – in 2022, China was the leading producer of machining equipment in the world with USD 27.1 billion worth of products[69]. Although the localization of Western and Japanese producers is facilitating the learning progress of China, Chinese machines remain the last resort option for CNC consumers looking for high-tech equipment. DMTG, SMTCL, and JIER [50] are well-known Chinese brands.

Conclusion. *CNC (computer numerical control) machines are the automated industrial machinery operating on the programmed instructions. CNC machines are crucial in modern manufacturing, offering a set of advantages, namely high precision, fast speeds, multi-axis capabilities, automatic tool changes, and program storage, which makes them cost-effective and versatile for manufacturing sophisticated precision metal parts.*

The operation of a typical CNC machine depends on the vast range of critical elements like input devices, display units, machine control units (MCUs), driving systems, feedback sensors, and the machine bed, lathes and mills, etc.

CNC machine tools are critical for manufacturing complex and high-precision components in various industries, namely aerospace and shipbuilding, automotive industry, medical field, electronic prpduction, woodworking, metalworking, and plastics manufacturing. In the military, CNC systems are used to manufacture various components for all kinds of existing weaponry, including guided missiles, defense systems, armoured vehicles, navy vessels, etc.

CNC machines are categorized as "dual use" goods, serving both civilian and military purposes, leading to their regulation under international export control regimes. CNC machine exports faced rigorous controls during the Cold War. Yet, the consensus for stringent regulation weakened after the Soviet Union's dissolution. The Wassenaar Arrangement, initiated in 1996, introduced a more permissive approach, allowing individual nations greater discretion in export licensing decisions.

Current controls target only the most accurate equipment (typically below 6 micrometers), while less precise CNC machines, widely used for military purposes, are not subject to the

[66] https://www.cncbul.com/which-are-the-top-10-taiwanese-cnc-machine-tools-manufacturers/
[67] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[68] https://proleantech.com/the-ultimate-guide-to-china-cnc-machining-services/
[69] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022

same export restrictions. Export controls have many exceptions applying to specific tasks like gear manufacturing, crankshafts, and other non-proliferation-sensitive uses, where export licenses may not be required. CNC machines can also be adapted to evade export controls, such as limiting the machine's capabilities or obtaining non-controlled versions and configuring them for military precision. CNC machines are highly sought after for their capabilities and have become targets of industrial espionage and illicit procurement activities by rogue states.

The global machine tools market, with a 2022 estimated size of USD 87.94 billion, is experiencing substantial growth, driven primarily by the CNC segment, which accounted for a significant 85.8% of the total machine tools revenue. Leading the industry are Western and Western-allied countries like Germany and Japan, which are known for their rich tradition of craftsmanship and technological expertise. They dominate various sectors, especially in the production of critical components. In contrast, the United Kingdom and the United States have seen a decline in their industrial production capacities, particularly at the lower end of the CNC machines market. Nonetheless, they maintain capabilities in sophisticated production and specific sub-sectors. Eastern Asian nations like Taiwan and South Korea have been making impressive strides in closing the technology gap with older industrial powers. While the world's largest consumer of machine tools, China remains a significant producer, albeit primarily in low-quality machining equipment. China compensates for quality with quantity, producing a substantial amount of machining equipment and establishing itself as the leading global producer.

2. Russia's dependence on imported CNC machine tools

2.1. Sources of Russian import dependency on foreign CNC machines

While import dependency characterizes almost all Russian industries (e.g., radio electronics[70], civil aircraft building[71], shipbuilding[72], oil and gas servicing equipment[73], etc.), it is especially acute in importing CNC machine tools and their components. This stems from the critical value of CNC machine tools for the Russian military industry and the limited potential for swift and comprehensive localization or import substitution.

According to the annual World Machine Tool Survey conducted by Gardner Business Media, Russia was one of the top 10 importers of machine tools in 2022, it imported machine tools for USD 2.1 billion in value[74]. As estimated by the Russian Ministry of Industry and Trade, in 2021, the share of imported CNC machine tools in the Russian market was 70% [75].

The critical dependency of Russia on the import of CNC machines and their components stems from the absence of an internal CNC machine-building industry. Although the Russian Ministry of Industry and Trade claims that 30% of internal demand for machine tools is satisfied by local producers – namely, STAN Group (Moscow), StankoMashComplex (Tver), Sasta (Sasovo), Stankomashstroy (Penza) [76], there are serious grounds to distrust this assessment.

For instance, many breakthroughs in the Russian machine-building industry were fake. For example, in May 2019, V. Putin visited the Kazan Aviation Plant named after S.P. Gorbunov, where he was shown a new CNC machine tool made by domestic industry leader STAN Group in Kolomna.[77] Specialists noted that the Russian machine precisely resembled an Italian CNC machine tool by Camozzi.[78]

In addition, information has also been found pointing to Chinese machines being presented as Russian[79], along with corruption scandals in the industry. For example, at the end of 2021, the head of Baltic Industrial Company, Diana Kaledina, was detained in Moscow on suspicion of supplying a foreign machine tool under the guise of a Russian one.[80] These are the most emblematic cases widely covered by the Russian media. Thus, even 30% of Russian-made CNC machine tools in the total consumption rate seems overstated, especially given the state of the Russian machine-building industry.

Overall, there are numerous causes behind the missing Russian machine building. The first factor impeding the development of the Russian machine-building industry is the **small size of the Russian machine tool market**. According to Russian producers, as of 2022, the Russian machine tool industry market is estimated at USD 1.5-2 billion[81]. To compare, the world

[70] https://bod.frprf.ru/public/documents/plan-po-importozameshheniyu-v-radioehlektronnojj-promyshlennosti
[71] https://bod.frprf.ru/public/documents/plan-importozameshheniya-v-otrasli-grazhdanskogo-aviastroeniya
[72] https://bod.frprf.ru/public/documents/plan-po-importozameshheniyu-v-sudostroitelnojj-promyshlennosti
[73] https://bod.frprf.ru/public/documents/plan-po-importozameshheniyu-v-neftegazovom-mashinostroenii
[74] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[75] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[76] https://xn--80adjnjrzbj.xn--p1ai/news/51/
[77] https://ndn.info/publikatsii/52760-pokupajte-nashe-otechestvennoe-kak-rossiya-pytalas-modernizirovat-ekonomiku-i-chto-iz-etogo-vyshlo/
[78] https://www.kp.ru/daily/26982/4041505/
[79] https://news.ru/business/kak-minpromtorg-spasaet-stankostroenie/
[80] https://www.bbc.com/russian/news-59784138
[81] https://madeinrussia.ru/ru/news/24989

machine tools market in 2022 was USD 82.6 billion in production and USD 79.5 billion in consumption[82]. Another market development indicator is the number of machine tools (expressed in terms of value) per capita. By this indicator, Russia currently ranks only 33rd in the world[83].

The market's small size is one of the key characteristics, as it creates specific conditions under which national machine tool production development is irrational cost-wise, as the total cost of such a project is extremely high and has a long payback cycle. The real profits and results of the machine tool industry development will be realized only after decades. In addition, the funds invested in this process are disproportionate to the potential profits from meeting domestic demand, which, given its low level due to the size of the market and the availability of Western analogs that are of high quality and relatively affordable, makes any plan for complete autarky in the industry unprofitable.

In the 1990s, the Russian leadership's stance was that without domestic precision machine tool-building capabilities, no funds should be allocated to its development. Instead, the necessary machine tools should be purchased abroad.[84] As shown above, given the specifics of the operational environment and market size, this policy was not without market logic. But in retrospect, the radical interpretation of the free market led to the Russian market for engineering services and machine tool building occupied by foreign companies that maintained almost unshakable leadership until the 2000s.

The second factor for Russian import dependency is the **lack of continuity**. In the early 1990s, the Russian machine tool industry rapidly lost the world positions it had gained. This was attributable to the general economic crisis and stagnation of the planned system, chaotic attempts to transition to a market economy quickly, the loss of a leading position in the national economy by the military-industrial complex and heavy industry, an unprofitable production base, as well as the economic inexpediency of creating a technologically complex and financially costly CNC machine tool industry in the face of open markets and vast import opportunities. While in 1990, 16,700 thousand CNC machines were produced in the Russian Soviet Federative Socialist Republic (RSFSR), their annual output dropped by 167 to 100 in 1996-1999.[85] Although the Soviet Union never had a high-end CNC machine production sector, it produced many mechanical CNC tools – therefore, it had the respective infrastructure, industrial base, and human resources. All this potential was lost in 1990-2000s. By the time the issues of the machine building industry came to the governmental attention, the window of opportunity was lost.

The third factor is the **lack of scientific and production facilities and element base**. CNC machining includes the production of CNC software, CNC components (machine control units, spindles, ball screws, precision bearings, linear guideways, feedback units), and instruments (mills, lathes, water jet units, laser beam units, cutters). All these critical components may be called an element base. Unsurprisingly, one would require CNC machines of a precision level higher than the desired product to produce the CNC components and instruments[86].

[82] https://www.mmsonline.com/articles/world-machine-tool-production-and-consumption-modestly-down-in-2022
[83] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[84] https://volynko.livejournal.com/529187.html
[85] https://volynko.livejournal.com/529187.html
[86] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf

Therefore, to properly develop the CNC machine-building industry, one must invest trillions of dollars in machine tool procurement, construction, and government subsidies. In addition, to produce the whole range of element base products, one must develop the metalworking, controlling, and measuring devices, engine-building, and electronic industries. In the Russian case, all these industries are either undeveloped (e.g., only crude materials production) or import-dependent.

Thus, the level of import dependency on CNC machine components is between 80% and 95%, according to the 2020 Russian governmental strategy for developing the machine tool-building industry[87].

The fourth factor is the low **level of innovation activity**. The main reasons for the low level of innovation activity include the low volume of investments in research and development, caused by the acute shortage of own financial resources for the implementation of breakthrough innovative projects, lack of regulation to incentivize investment in R&D, and deficit of highly qualified personnel[88].

The **deficit of personnel** is a problem caused by weak continuity of generations in research and development, reduction in the number of graduates of specialized departments, and cessation of the inflow of well-trained young specialists to science and production, including due to the uncompetitive low-level of salaries, lack of links between research centers and production centers[89].

Financial factors are also influential. The development of a full-fledged CNC machine-building industry would require trillions of governmental subsidies to sustain manufacturers during the payback cycle and funds for research and development, technological modernization, personnel training, preferential loans, etc[90].

In addition, the **strategic approach to the industry is missing**. The Russian government adopted three programs to develop machine tool building in Russia (the latest one in 2020[91]). It twice took on an action plan for import substitution in the machine tool industry[92] (the second was adopted in 2021). The goals of strategies were ambitious - to increase the production of machine tool products at an average annual rate of 5.7% to RUB79.5 billion by 2035, localize the production of components up to 70% by developing domestic production, and increase exports to RUB16.5 billion [93].

In addition, state funds were allocated to the industry: in 2016, the amount of state support for the industry was about RUB2.7 billion; in January-October 2017, more than RUB1.5 billion was subsidized for the industry through the Federal Regional Development Fund alone [94].

However, as the experts claimed, all these documents and measures were cosmetic. They provided subsidies for research and development and preferential treatment for machine tool

[87] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[88] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[89] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[90] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[91] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[92] https://bod.frprf.ru/public/documents/plan-po-importozameshheniyu-v-stankoinstrumentalnojj-promyshlennosti
[93] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[94] https://www.kommersant.ru/doc/3482601

plants while ignoring that the development of an entire industry is a more profound phenomenon by its very nature[95].

Finally, there is **no significant domestic demand for Russian-made CNC machine tools**. The government tried to create artificial barriers for the consumers and force them to buy Russian goods. For instance, in 2011, Resolution No. 56 [96] was adopted by the Russian government, which prohibited defense enterprises from purchasing imported machine tools if their analogs were produced in Russia.

However, Russian companies still prefer to purchase foreign equipment and find ways to circumvent the ban. For example, according to the Russian Federal Anti-Monopoly Service (FAS), Russian companies purchase foreign equipment and paste Russian labels without significant modifications. Another method used to circumvent the ban on foreign purchases is crafting technical specifications for open tenders in a way that favors imported equipment, even when the task can be carried out using Russian machines that do not differ significantly in their characteristics.[97]

Even more, Russian customers are suing the Russian CNC producers. For example, United Engine Corporation (UEC) employees sent a letter to the State Duma describing the current problems of Russian machine tool building.[98] The letter's authors cite delays in STAN Group's product deliveries under contracts that have been paid for by 90% of the country's largest manufacturing enterprises. They call for accountability from the group's owners and the officials who instructed them to continue placing large orders and participating in programs to support the domestic industry.

2.2. Level of Russian import dependency on foreign CNC machines

Thus, given the distressing state of the internal machine-building industry, one may convincingly state that Russia has depended critically on Western and Western-allied CNC machine tools and components for decades. Since the first round of international sanctions after the annexation of Crimea and the war in Donbas in 2014, the Russian government has adopted several governmental import substitution plans to tackle industrial vulnerability in the machine tools sector[99].

Namely, in 2014, the Russian Ministry for Industry and Trade adopted the first Plan for import substitution in the machine-building industry with a contemporary level of dependency and projected 2020 levels [100]. Later, in 2015, the Ministry of Industry and Trade of the Republic of Tatarstan published memo[101] on the federal support for the industry, machine building included. The memo contains data on the import dependency in critical sectors, the key foreign producers, and the potential for import substitution.

[95] https://stimul.online/articles/sreda/trudnaya-zhizn-stankov/
[96] https://base.garant.ru/12182710/
[97] https://marketing.rbc.ru/articles/13577/
[98] https://versia.ru/rabotniki-odk-obratili-vnimanie-gosdumy-na-problemy-stankostroeniya-i-gruppy-stan
[99] https://www.garant.ru/news/1581704/
[100] http://investkostroma.ru/uploads/file/650_stankostroenie.pdf
[101] https://mert.tatarstan.ru/file/old/html/MinProm2015_17_sm.pdf

These two documents present the most comprehensive government assessment of the level of Russian import dependency in critical spheres, particularly – in the machine tools sector. The adapted version of the data from both documents is presented in the table below[102]:

Table 2. 2014-2015 data on the Russian CNC machine import dependency.

Type of goods	Share of imported goods in consumption (2014)	Projected share of imported goods in consumption (in 2020)	Names of the foreign producers (from countries which imposed or are likely to impose sanctions)
CNC machines			
1. CNC lathes	90% (60%)[103]	60%	DMG (Germany), Yamazaki Mazak (Japan), Okuma (Japan), Kitamura (Japan), Kovosvit (Czech Republic)
2. Turning and milling machining centres	95%	80%	DMG (Germany), Yamazaki Mazak (Japan), Okuma (Japan), Kitamura (Japan), MAG (Germany), Niles-Simmons (Germany)
3. Carousel lathes	85% (93%)	57%	Toshulin (Czech Republic), MAG (Germany), Danobat (Spain)
4. Ultra-precision lathes and milling machines with CNC with machining accuracy not lower than class A according to GOST 8-82	100%	53%	Kugler (Germany), Spinner (Germany), Moore (USA), Presitech (USA), Hembrug (Netherlands), FANUC (Japan).
5. Horizontal boring machines	80% (99%)	61%	Tos (Czech Republic), Toshiba (Japan)
6. Coordinate boring machines	99%	84%	Dixi (Switzerland)
7. Vertical milling 5-axis machining centres	90% (97%)	69%	DMG (Germany), Yamazaki Mazak (Japan), Okuma (Japan), Mori Seiki (Japan), MAG (Germany)
8. CNC vertical milling machines	90% (80%)	59%	DMG (Germany), Yamazaki Mazak (Japan), Mori Seiki (Japan), Matsuura (Japan)

[102] Related only to the processing machine tools, the forging and pressing equipment, as well as additive equipment is not included.

[103] In case of discrepancies in data between the two sources, both versions are included. The first figure is retrieved from the 2014 import substitution plan, second (in brackets) – is from the 2015 memo.

9. CNC horizontal milling machines	80% (85%)	59%	DMG (Germany), Doosan (South Korea), Trens (Czech Republic), Kitamura (Japan)
10. Portal and overhead milling machining centres	100% (90%)	63%	TOS (Czech Republic), Skoda (Czech Republic), SNK (Japan)
11. Coordinate grinding machines	97%	85%	Heinrich Hauser (Germany), Mitsui Seiki (Japan), Moore Tool (USA)
12. Ultra-precision surface grinding machines with machining accuracy not lower than class A according to GOST 8-82	98% (100%)	84%	Blohm Jung (Germany), Wasino (Japan), Elb-Schliff (Germany)
13. Ultra-precision cylindrical grinding machines with machining accuracy not lower than class A according to GOST 8-82	98% (97%)	83%	Junker (Germany), Studer (Germany)
14. Thread grinding machines	97%	73%	Matrix (UK), Matsuura (Japan), Mitsui Seiki (Japan)
15. Ultra-precision grinding machines	100%	73%	Ewag (Switzerland), Anca (Germany), Weiler (Germany)
16. Gear hobbing machines	99%	71%	Emag Koepfer (Germany), Hamai (Japan), Gleason (USA)
17. Gear grinding machines	99%	67%	Liebherr (Germany), Gear Spect (Czech Republic), Gleason (USA)
18. Gear drilling machines	99%	75%	Reishauer (Germany), Gear Spect (Czech Republic), Gleason (USA)
19. Wire-cutting machines	88% (95%)	61%	ONA (Spain), Sodick (Japan), Mitsubishi (Japan)
20. Broaching machines	88% (97%)	61%	ONA (Spain), Sarix (Switzerland), Sodick (Japan)
CNC software			
21. CNC systems for controlling 5 or more axes	100%	25%	Fanuc (Japan), Siemens (Germany), Heidenhein (Germany)

22. CNC systems for controlling 2-3 axes	85%	N/A	Fanuc (Japan), Siemens (Germany), Heidenhein (Germany)
CNC components			
23. Electric drives for CNC machines, including linear drives	100%	78%	Fanuc (Japan), Siemens (Germany)
24. Sensors, rulers, transmitters	90% (98%)	90%	Heidenhein (Germany), Siemens (Germany), Renishaw (UK)
25. Motor spindles, electric spindles	97% (93%)	81%	Kessler (Germany), Fischer (Switzerland), Ibag (Switzerland)
26. Ball screws	95% (98%)	82%	THK (Japan), NSK (Japan), Hiwin (South Korea)
27. Bearings	90%	86%	SKF (Sweden)
28. Electric motors	100% (88%)	86%	Siemens (Germany), FANUC (Japan)
29. Hydraulic equipment	100% (95%)	61%	Bosch-Rexroth (Germany)
30. Revolving heads	98%	87%	Duplomatic (Italy), Sauter (Germany), Baruffaldi (Italy)
31. Rotary tables	100%	96%	Nikken (Japan), Haas (USA)
32. High-pressure coolant supply stations	97%	90%	N/A
33. Extendable precision units for milling and boring machines	95%	92%	N/A
34. Tool storage for machining centres with automatic tool change mechanism	93%	90%	N/A

As the table shows, Russia has imported all the required CNC machines, software, and components from Western and Western-allied countries. The products from the German and Japanese producers, particularly those with a global presence, loom large in the overall picture. In addition, the 2015 document by the Ministry of Industry and Trade of the Republic of Tatarstan[104] explicitly highlights that most suppliers of the said goods and technologies originate from countries that had already imposed sanctions or were likely to. A separate column was designed to include the import substitution options from the 'friendly' countries. However, 95% of the said goods could not be substituted with Chinese analogs according to the document[105].

[104] https://mert.tatarstan.ru/file/old/html/MinProm2015_17_sm.pdf
[105] https://mert.tatarstan.ru/file/old/html/MinProm2015_17_sm.pdf

The only issue with these data analytically is that it dates to 2014-2015 and does not account for the Russian import substitution efforts taken before the full-scale invasion of Ukraine[106]. However, with almost universal recognition from experts and Russian authorities, none of the import substitution programs was correctly implemented. As stated by Andrey Klishas, chairman of the Federation Council Committee on Constitutional Legislation and State Building:

> *"The import substitution program has failed completely. There is nothing but bravura reports from sectoral departments. Our people see this in consumer goods and many other areas."*[107]

However, one cannot dismiss these efforts in their entirety. Even if they did not strategically change the situation with machine building, these efforts would indicate an acute understanding of the strategic vulnerability of such import dependency.

The most detailed breakdown of the Russian dependency on the imported goods of the CNC machines before the 2022 invasion is provided in the 2021 Plan on Import Substitution in the machine tool building industry by the Russian Ministry of Industry and Trade[108]. The adapted version of data[109] in the table (presented as import levels) is below:

Table 3. 2021 data on the Russian CNC machine import dependency.

Type of equipment	Share of imported goods in 2021	Share of imported goods in 2024 (forecast)
1. Machines for laser metal working and machines of similar type; machining centers and machines of a similar type	68%	58%
2. Turning machines, boring and milling metal-cutting machines	75%	67%
3. Components for machine tools (overall)	85%	65%
4. Computer numerical control devices	90%	78%
5. Spindles	85%	77%
6. Ball screws	88%	80%
7. Bed frames	70%	62%
8. Linear guideways	90%	84%
9. Tool heads	90%	84%
10. Tool storage devices	90%	78%

The comparison of the two tables immediately reveals a more strategic approach to the information disclosure – the 2021 import substitution plan does not provide technical details

[106] https://www.garant.ru/news/1581704/
[107] https://ria.ru/20220519/importozameschenie-1789395009.html
[108] https://bod.frprf.ru/public/documents/plan-po-importozameshheniyu-v-stankoinstrumentalnojj-promyshlennosti
[109] Related only to the processing machine tools, the forging and pressing equipment, as well as additive equipment, is not included.

for CNC machines, its software, or all components. The declared levels of dependency are lower compared to 2014-2015 data: the imports of CNC machines contracted by 15-20%, the imports of CNC software – by 10%, and of the CNC components – by 10-15%. Nevertheless, given the questionable validity of the Russian governmental statistics and the persistence of critical dependency in the sector between 70 and 90% overall, the issue of Russian import dependency in the CNC machine tools sector remained relevant and pressing shortly before the full-scale invasion of 2022.

2.3. Russian military complex as the primary user of the imported CNC machine tools

According to the Russian governmental strategy on the development of the machine tool-building industry, adopted in 2020[110], military industry enterprises are the primary consumers of machine tools in the Russian Federation - namely, the defense industry segment accounts for 70% of the total consumption of machine tools in Russia[111]. According to Russian CNC manufacturers, companies in the Russian military-industrial complex account for at least 80% of their orders[112]. Therefore, it shall suffice to say that the military and industrial complex consume around 70-80% of all machine tools in Russia (both imported and produced locally). Consequently, given the level of Russian import dependency in the respective sector, we may assume that almost all CNC machine tools employed by the Russian military complex are imported from Western and Western-allied countries.

Apart from the governmental strategy on the development of the machine-building industry and assessment by the Russian CNC machine producers, there are two kinds of evidence supporting the notion of the military and industrial complex as the leading consumer of CNC machine tools in general and of the Western ones – in particular. These are Russian TV videos from the Russian military plants and the data from open governmental procurement registries.

While the public availability of state defense procurement may appear controversial, given the sensitivity of such information and security risks, these phenomena are essential to the Russian political regime's survival. As the analysts from Rhodus Intelligence explain, such evidence is publicly available for the following reasons[113]:

- **Propaganda needs:** A significant aspect of maintaining the regime's legitimacy is emphasizing military expansion, which instils national pride. Consequently, there is immense pressure on authorities to present a compelling image of a modern, well-equipped military-industrial complex to a broad audience. Federal and regional television channels serve as the primary source for visually showcasing military products, thus fulfilling this need.

- **Market needs:** Since the dissolution of the USSR, the military industry has been actively engaged in the competitive marketplace, acting as both a seller and a buyer. While classified facilities may have some control over the information they disclose, they cannot always censor the content published by their counterparts, including employees, suppliers, or contractors.

[110] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[111] http://static.government.ru/media/files/NyeLKqLhrJrydnGRBm39nHl0hJNOzHzQ.pdf
[112] https://topwar.ru/169114-mnogostanochniki-kakovo-mesto-rossii-v-mirovom-stankostroenii.html
[113] https://texty.org.ua/fragments/110752/osint-analityky-pronykly-vseredynu-rosijskoho-zavodu-z-vyrobnyctva-stratehichnyh-raket-sho-vony-tam-znajshly-foto/

- **Accountability needs:** The increased involvement of military plants in market transactions has intensified the principal-agent problem between the state and state-owned military enterprises. To combat managerial corruption, the state has developed an extensive and transparent system for public procurement. This system has become a valuable tool for state controllers and investigative efforts.

However, such sources have been gradually closing down. For instance, in April 2020, the State Duma of Russia passed a law eliminating the obligation of state defense contractors to make information on procurement publicly available in the unified information system for state procurement.

"State contracts, as a rule, contain technical specifications, which have a classification," the explanatory note says. Placing a set of such information in open sources, including in the unified information system, taking into account the assignment of state contract identifiers, makes it possible to collect and reproduce the terms of reference by constituent elements, which may cause damage to the interests of national security and defense, the authors of the initiative point out.

In addition, procurement in the defense industry is complicated by the introduction of international sanctions. Disclosure of information on such procurements means disclosure in the public domain of data on the interaction between suppliers and a person included in the sanctions lists, which entails negative consequences for suppliers (discrediting, inclusion in the sanctions lists, cancellation of export licenses) and for defense industry enterprises (inability to purchase products of sanctioned origin, failure to receive products under concluded contracts, refusal of suppliers to interact with defense industry enterprises)[114].

Therefore, state procurement in the defense industry currently contains a limited amount of data; in some cases – since 2021, all the data about contracts is missing.

As for the TV videos, some of them are being deleted from public platforms such as YouTube. A relatively new phenomenon is the propagandist videos that are shot in military plants, but the tape is manually corrected to blur the names and logos of the foreign equipment used in the production.

Nevertheless, based on available information, one can still make meaningful inferences regarding the Russian military complex as the primary user of imported CNC machine tools in Russia. For instance, the Russian **Uralvagonzavod**, the only producer of tanks in the Russian Federation that manufactures Armata T-14 tanks, T-90 tanks, modernized T-72 tanks, and many armored vehicles, is extensively equipped with CNC machines[115]. Namely, according to the Russian state procurement database, the enterprise concluded 57 contracts[116] worth RUB 3,472 billion, for the procurement of CNC machines and components.

Another primary user of CNC machines is **Kalashnikov Concern**, which produces about 95% of all small arms in Russia and supplies to more than 27 countries worldwide[117]. According to publicly available videos, various enterprises of Kalashnikov Concern, including Izhevsk Mechanical Plant and Mytishchi Engineering Plant, are equipped with CNC machine tools

[114] http://duma.gov.ru/news/48305/
[115] https://www.globalsecurity.org/military/world/russia/uralvagonzavod.htm
[116] https://bit.ly/3SxVNFx
[117] https://en.kalashnikovgroup.ru/

from Boehringer[118] (Germany, Taiwan), Index Traub[119] (Germany), Sodick[120] (Japan), and Okuma[121] (Japan).

Overall, computer numerical control machines are indispensable in several sectors of the Russian military-industrial complex. These include producing missile and missile systems, aircraft, spacecraft, shipbuilding, engine building, and nuclear weapons.

2.3.1. Missiles and missile systems production

CNC machines are crucial in producing missiles and missile systems by providing precise and automated manufacturing capabilities. CNC machines can fabricate intricate components with high tolerances, such as missile bodies, propulsion systems, guidance components, and warhead casings. CNC machining allows for consistent and efficient production of these critical parts, ensuring they meet strict quality and performance standards.

In the Russian context, this is confirmed by the governmental procurement of **JSC Tactical Missiles Corporation[122] (KTRV) (**Russian: Корпорация Тактическое ракетное вооружение**)**. This holding is the biggest producer and supplier of anti-ship, anti-radar, and multi-purpose missiles designed to equip aviation, shipboard, and coastal tactical missile systems. JSC Tactical Missiles Corporation (KTRV) concluded 30 contracts[123] worth RUB 661 million, for the supply of CNC machines and components by Okuma (Japan), Hardinge (USA), Sodick (Japan), Kitamura (Japan).

One of the biggest consumers of Western CNC machines is Kolomna-based **Machine-Building Design Bureau[124]** (Russian: Конструкторское Бюро Машиностроения), a leading developer and manufacturer of portable anti-aircraft missile systems ("Igla," "Strela"), anti-tank missile systems ("Shmel," "Malyutka," "Shturm"), operational-tactical missile systems (Oka, Tochka-U, Iskander). The Bureau concluded 44 contracts[125] worth RUB 1 billion to acquire CNC machines by DMG Mori (Japan, Germany), Haas (USA), and Kososvit MAS (Czech Republic).

Another sizeable user of Western CNC machines is **NPO Splav[126]** (Russian: Научно-Производственное Объединение "Сплав" имени А.Н. Ганичева), one of the world's leading developers and manufacturers of multiple rocket launchers (RCMS), as well as one of the critical companies supplying Russian weapons to the world market in this field. This is the only enterprise in Russia that designs and develops multiple rocket launchers and cartridges. The company concluded 44 contracts[127] worth RUB 515 million, for the supply of CNC machines and their components.

JSC Central Research Institute Of Automation And Hydraulics[128] (Russian: Центральный Научно-Исследовательский Институт Автоматики и Гидравлики), a research institute for

[118] https://youtu.be/r9NLenvuzfU?t=178
[119] https://youtu.be/r9NLenvuzfU?t=168
[120] https://youtu.be/feJhxUHFQ6o?t=30
[121] https://youtu.be/feJhxUHFQ6o?t=38
[122] https://sanctions.nazk.gov.ua/en/sanction-company/25/
[123] https://bit.ly/3QSC7v7
[124] https://dfnc.ru/predpriyatiya/kbm-npk-kolomna/
[125] https://bit.ly/3ugbjf6
[126] https://xn--80aegj1b5e.xn--p1ai/factory/npo-splav
[127] https://bit.ly/3QM3lmV
[128] http://gim-group.ru/about/partners/OAO_TsNIIAG/

the creation of high-precision control systems, also uses CNC machines actively. The Institute of Automation and Hydraulics is developing high-precision control systems used in the Iskander, Topol-M, and Bulava missile systems. Devices developed at the institute are part of the Tochka-U and Oka high-precision missile systems, Aerofon ballistic missiles, unmanned aerial vehicles, etc. The company concluded eight contracts[129] on CNC machines by Fehlmann (Germany), Walter (Germany), etc., worth RUB 215 million.

Another sizeable user of foreign CNC machines is the **JSC Machine-building plant named after Kalinyn[130] (Ekaterinburg)**. This enterprise is a part of Almaz-Antey Concern, a producer of missiles for MLRS S-300B and surface-to-air missile complex BUK-M1. The plant is equipped with CNC machine tools produced by DMG Mori[131] (Germany, Japan), Hedelius[132] (Germany), Kososvit MAS[133] (Czech Republic), Dr.Johannes Heidenhain GmbH[134] (Germany). According to the Russian state procurement database[135] - since 2011, the plant has concluded 118 contracts for the supply of CNC machines and their components worth RUB 84 million.

2.3.2. Aircraft, spacecraft, and shipbuilding

CNC machines are widely employed in producing aircraft, spacecraft, and shipbuilding products due to their precision and versatility. In aircraft manufacturing, CNC machines fabricate components, including wing sections, fuselage parts, and engine components. In spacecraft production, CNC machines are instrumental in crafting complex and lightweight structures, such as satellite components, using materials like aluminum and composites. CNC machines manufacture ship components like hull sections, propellers, and steering systems in shipbuilding.

Among the leading users of CNC machines from the aircraft industry is **Ilyushin Aviation Complex[136]** (Russian: Авиационный Комплекс Им. С.В. Ильюшина) is a Russian aircraft manufacturer and design bureau. The company concluded two contracts[137] worth RUB 647 million, to purchase CNC machines.

Another big consumer is JSC **123 Aviation Repair Plant[138]** (Russian: 123 Авиационный Ремонтный Завод) carries out repairs and maintenance of IL-76, IL-78, L-410 UVP-E3 aircraft and their components; repair of D-30KP/KP2, AI-20 engines, repair of auxiliary power units TG-16 and TG-16M and propellers AV-68I, AV-72T; re-equipment of IL-76 aircraft for civil aviation purposes etc. The company concluded eight contracts[139] worth RUB 234 million for the supply of CNC machines and their components by Siemens (Germany), Aristech (Taiwan), etc.

[129] https://bit.ly/475qRRJ
[130] https://www.zik.ru/
[131] https://www.youtube.com/watch?v=xw_6-DXPPpU
[132] https://youtu.be/QiayyNICM0g?t=1130
[133] https://youtu.be/xw_6-DXPPpU?t=72
[134] https://youtu.be/r42TtgnC3-w?t=180
[135] https://bit.ly/3sg5tdq
[136] https://ilyushin.org/
[137] https://bit.ly/3SxBXuk
[138] https://novgorodinvest.ru/companies/123-avia.php
[139] https://bit.ly/40tfaS6

In the spacecraft industry, the **Khrunichev State Research and Production Space Center**[140] (Russian: Государственный Космический Научно-Производственный Центр Имени М.В. Хруничева) is probably the largest consumer of CNC machine tools in this industry. It is a leading enterprise in the Russian rocket and space industry; one of the world leaders in the development and serial production of space launch vehicles (heavy-class launch vehicles, upper stages, and their systems), as well as large-sized orbital modules; developer and serial manufacturer of the Proton-M heavy-class launch vehicles with the Briz-M upper stage, the Angara family of launch vehicles of various payloads, and the Rokot light-class launch vehicle. It concluded 22 contracts worth RUB 6, 593 billion to purchase CNC machines. [141]

In the shipbuilding industry, **JSC Admiralty Shipyards**[142] (Russian: Адмиралтейские верфи) stands out as a CNC machine user. Its military products include warships such as non-nuclear (diesel) submarines and large support ships and vessels. The construction of the fourth-generation submarines of Project 677 ("Lada"), "Kronstadt" and "Velikye Luky" has been resumed recently. The company actively uses CNC machines and concluded 30 contracts[143] for RUB 1,542 billion to purchase CNC machines, components, and software.

Another enterprise of the Russian shipbuilding industry actively using CNC machines is **Concern Sea Underwater Weapon Gidropribor JSC** (Russian: Морское Подводное Оружие - Гидроприбор[144]), one of the oldest enterprises in Russia developing weapons for the Navy. About 95% of naval underwater weapons currently in service with the Russian Navy were created by the Concern or with its direct participation[145]. The Concern concluded four contracts[146], worth RUB 496 million, to purchase CNC machines of such brands as Okuma (Japan), etc.

2.3.3. Engine building

CNC machines are essential in the production of engines for various applications. They play a critical role in precision machining, allowing for the creation of engine components like cylinder heads, blocks, crankshafts, and pistons with tight tolerances and high-quality finishes. CNC machines are ideal for prototyping, customization, and mass production of engine parts, enabling engineers to test and optimize designs, meet specific requirements, and ensure consistent quality in large quantities. They excel in crafting complex geometries, working with various materials, achieving precise surface finishes, and maintaining tight tolerances vital for engine efficiency. Additionally, automation capabilities streamline production processes, making CNC machines indispensable for engine manufacturing across automotive, aerospace, marine, and industrial sectors.

The leading Russian enterprise of the sphere is the **United Engine Building Corporation**[147] (Russian: Объединенная Двигателестроительная Корпорация - ОДК), which produces engines for aviation, space programs, oil and gas energy. According to publicly available videos, the leading enterprises of the United Engine Building Corporation, ODK-Star, ODK-Saturn, ODK-Perm Engines, ODK-Rybinsk, ODK-UMPO, are equipped with CNC machine

[140] https://www.khrunichev.ru/
[141] https://bit.ly/3u8Fqp3
[142] http://admship.ru/
[143] https://bit.ly/3GaBOWp
[144] https://www.gidropribor.ru/
[145] https://www.gidropribor.ru/
[146] https://bit.ly/3ugaT8w
[147] https://www.uecrus.com/

tools produced by DMG Mori[148] AG (Japan, Germany), GF Machining Solutions[149] (Switzerland), Hermle[150] (Germany), Nakamura Tome[151] (Japan), Kososvit MAS[152] (Czech Republic).

One of the United Engine Building Corporation's enterprises, **ODK-Kuznetsov PJSC**[153] (Russian: Публичное Акционерное Общество "ОДК-Кузнецов"), is a prominent use of CNC machines. This plant is charged with the development, production, and service maintenance of engines for strategic and military transport aviation, liquid rocket engines, industrial gas turbine units, etc. ODK-Kuznetsov has concluded 32 contracts[154] worth RUB 2,640 billion, to purchase CNC machines and their components.

Another plant of United Engine Building Corporation, **ODK-Ufa Motor Manufacturing Association PJSC**[155] (Russian: ОДК-Уфимское Моторостроительное Производственное Объединение), is involved in the development, manufacturing, servicing and repair of turbojet aircraft engines and gas pumping units, manufacturing and repair of helicopter components. Serially produces turbojet engines for aircraft of the Su-27 family (AL-31F engine), Su-30 (AL-31F and AL-31FP engines), Su-35S (AL-41F-1S), Su-57 (AL-41F- 1), Su-25 (R-95Sh and R-195), assemblies and units for helicopters "Ka" and "Mi."[156] The company concluded 69 contracts[157] worth RUB 1,886 billion, to purchase CNC machines and their components.

2.3.4. Nuclear weapons production

CNC machines are also widely used to produce nuclear weapons, including in Russia. For instance, the Russian **Votkinskiy Plant**[158] (Russian: Воткинский завод), which produces long-range solid-fuel ballistic missiles (Yars intercontinental ballistic missiles, Bulava submarine-launched ballistic missiles, Iskander short-range ballistic missiles), has been analyzed by the OSINT investigators from Rhodus Intelligence in September 2023[159]. Having analyzed publicly available videos shot by Russian TV stations in 2016-2022, the analysts from Rhodus identified CNC machine tools produced by Kovosvit MAS (Czech Republic), TOS Varnsdorf (Czech Republic), Index Traub (Germany), Extron (Taiwan), JINN FA (Taiwan), ABB (Switzerland, Sweden), Walter (Germany), MAZAK (Japan), DMG Mori AG (Japan, Germany)[160]. Overall, Votkinsk Plant is equipped with 525 CNC machine tools[161].

[148] https://youtu.be/VoSQ_n1tcwQ?t=43
https://youtu.be/5fYoMkdG7Cw?t=85
https://www.youtube.com/watch?v=yo_DkjMhpno&ab_channel=KorabelRu
[149] https://youtu.be/mL-XxjfvTaM?t=1437
[150] https://youtu.be/jnVY4ax4kh0?t=75
https://bit.ly/3FOFz3q
[151] https://bit.ly/46740Uk
[152] https://youtu.be/00yssYgj6pU?t=125
[153] https://www.uecrus.com/about/structure/pao-odk-kuznetsov/
[154] https://www.uecrus.com/about/structure/pao-odk-kuznetsov/
[155] https://www.umpo.ru/
[156] https://www.umpo.ru/
[157] https://bit.ly/3FQN89N
[158] https://vzavod.ru/
[159] https://texty.org.ua/fragments/110752/osint-analityky-pronykly-vseredynu-rosijskoho-zavodu-z-vyrobnyctva-stratehichnyh-raket-sho-vony-tam-znajshly-foto/
[160] https://rhodus.substack.com/p/how-to-make-an-iskander
[161] https://texty.org.ua/fragments/110752/osint-analityky-pronykly-vseredynu-rosijskoho-zavodu-z-vyrobnyctva-stratehichnyh-raket-sho-vony-tam-znajshly-foto/

Another prominent Russian nuclear enterprise which uses CNC machines extensively is **Titan-Barrikady**[162] (Федеральный Научно-Производственный Центр "Титан-Баррикады"). It produces launchers and other ground-based units of strategic missile systems. The enterprise concluded 16 contracts[163] worth RUB 1,187 billion for the supply of CNC machines and components by Sunnen (USA), etc.

Russian Federal Nuclear Center - All-Russian Scientific Research Institute of Technical Physics named after Academician E. I. Zababakhin (RFNC-RSRITP)[164] (Russian: Федеральное Государственное Унитарное Предприятие "Российский Федеральный Ядерный Центр - Всероссийский Научно-Исследовательский Институт Технической Физики Имени Академика Е.И. Забабахина), which produces nuclear weapons in several areas — strategic complexes of the Navy, cruise missiles, aerial bombs, nuclear missiles – is a significant consumer of imported CNC machines as well. The company concluded 40 contracts[165] worth RUB 114 million, to purchase CNC machines of such brands as ALMAC, Schaublin, etc.

Conclusion: *Russia's import dependency on CNC machine tools and their components is critical, mainly due to their significance in the Russian military industry and the limited potential for local production or import substitution. Russia ranks among the top 10 importers of machine tools globally, importing around USD 2.1 billion in 2022, with imported CNC machine tools making up approximately 70% of the market. This import dependency results from the absence of a domestic CNC machine-building industry, despite claims that Russian producers meet 30% of local demand.*

Several factors contribute to Russia's import dependency. The first is the small size of the Russian machine tool market, making developing a domestic industry costly and less profitable. Second, the lack of continuity and the rapid loss of market position in the early 1990s has further hindered domestic production. Third, Russia's insufficient scientific and production facilities and element base, with low innovation activity and a shortage of highly qualified personnel, add to the challenges. Finally, the absence of a significant domestic demand for Russian-made CNC machine tools has led to limited adoption of locally produced machinery despite government efforts to create artificial barriers favoring domestic equipment.

Russia has long been critically dependent on Western and Western-allied sources for CNC machines, software, and components, as revealed in government documents and reports. In the period leading up to the 2022 invasion, these documents provided insights into the extent of this import dependency. In 2014-2015, CNC machines and components saw high import shares, ranging from 80% to 100%, with Germany and Japan as major suppliers. Despite these figures, the 2014-2015 data did not account for Russia's import substitution efforts.

However, the import substitution programs initiated by the Russian government were not effectively implemented. Russian authorities and experts acknowledged the failure of these programs to reduce import dependency, illustrating the challenging nature of the issue. Still, these efforts demonstrate a deep understanding of the strategic vulnerability posed by import dependency, especially in the CNC machine tool sector.

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[162] https://cdbtitan.ru/
[163] https://bit.ly/3Quj5d0
[164] http://vniitf.ru/
[165] https://bit.ly/3QtUc11

In a 2021 import substitution plan, lower levels of dependency were projected for 2021-2024 compared to 2014-2015 data. While the reported decreases are notable, viewing these statistics cautiously is essential due to concerns about their validity. Despite some progress in reducing dependency, the CNC machine tools sector remained a relevant and pressing issue for Russia just before its 2022 invasion.

According to the Russian government's strategy for machine tool-building industry development in 2020, military industry enterprises are the primary consumers of CNC machines in Russia, accounting for 70% of the total consumption. Russian CNC manufacturers state that at least 80% of their orders come from the military-industrial complex. This suggests that the military-industrial complex consumes around 70-80% of all machine tools in Russia, both imported and domestically produced. Given Russia's import dependency in this sector, it's likely that most CNC machine tools used by the Russian military complex are imported from Western and Western-allied countries.

Evidence supporting this includes publicly available videos from Russian military plants and government procurement data. However, these sources have become less accessible due to closures and restrictions. Despite this, it's still evident that various Russian military enterprises use CNC machines extensively. These include missile and missile systems production, aircraft, spacecraft, and shipbuilding, engine building, and even nuclear weapons production.

CNC machines are pivotal in producing various crucial components in military and defense applications. These machines enable precise, automated manufacturing capabilities, making them indispensable for military purposes. In building missiles and missile systems, CNC machines fabricate intricate components like missile bodies, propulsion systems, guidance components, and warhead casings with high tolerances and quality. The Russian JSC Tactical Missiles Corporation (KTRV), the largest producer of anti-ship, anti-radar, and multi-purpose missiles for aviation, shipboard, and coastal tactical missile systems, has been actively procuring CNC machines and components, including those from foreign sources such as Okuma (Japan) and Sodick (Japan).

Likewise, CNC machines are vital for producing precision components in the aircraft, spacecraft, and shipbuilding sectors. In aircraft manufacturing, they fabricate wing sections, fuselage parts, and engine components. For spacecraft, CNC machines craft lightweight structures, such as satellite components, while shipbuilding relies on these machines for manufacturing hull sections, propellers, and steering systems. Furthermore, companies like the Khrunichev State Research and Production Space Center, a leading Russian rocket and space industry player, have procured CNC machines for their production processes.

CNC machines are critical for creating engine components with tight tolerances, high-quality finishes, and precision machining in engine building. The United Engine Building Corporation, a significant producer of engines for aviation, space programs, and more, has equipped its facilities with CNC machines from various sources, including DMG Mori (Japan, Germany) and Hermle (Germany). The role of CNC machines in the military-industrial complex extends even to nuclear weapons production. Facilities like the Russian Votkinskiy Plant, responsible for producing long-range solid-fuel ballistic missiles, have been identified as users of CNC machine tools made by various international brands.

These examples underscore the extensive military applications of CNC machines in Russia, which are instrumental in producing vital defense systems and components, ranging from missiles to engines and nuclear weaponry.

3. The Russian continued access to the CNC machines and components after the beginning of the full-scale invasion of Ukraine

3.1. Russian imports and production of CNC machines after February 24, 2022

Immediately upon the beginning of the full-scale Russian invasion of Ukraine and ensuing international sanctions and export control strengthening, the Russian media were replete with articles describing the abysmal state of the Russian machine-building industry and its dependency on the Western and Western-allied CNC machines, components, and software[166].

Russian machine tool building also became a public topic as a strategic industry. For example, in March 2022, Russian Minister of Industry and Trade Denis Manturov emphasized the critical importance of state support for machine tool building:

> *"It is important to unify components for machine tool products and to actualize cooperation ties between Russian companies. We already have all the necessary competencies, and now we must emphasize the production of unified, high-volume products."*[167]

The international isolation also brought back the old anxieties of the industry specialists. Quoting Pavel Shatskikh, general director of the Kazan plant Elektropribor OJSC:

> *"There are things that can stop the Russian industry altogether. For example, everything related to metalworking equipment is imported: spare parts, spindles, and tools (although this point has been improved a bit). If you don't do maintenance once, the machine won't work until you replace the original component: the program includes identification by originality and expiration date. That's why a country cannot be called a superpower or even a developed industrial country unless it produces its own equipment. And we don't make full-fledged CNCs, we just make tags for Chinese equipment. In short, it's no exaggeration to say that equipment can stop functioning at any minute."*[168]

However, the Russian governmental statistics for the 2022 CNC machine market demonstrate that the general dynamics remained stable[169]. According to Rosstat, the total consumption of machine tools in Russia in 2022 consists of two components: domestic production – 6 706 units and imports – 9 074 units, including forging and pressing equipment, in total – 13 965 units[170]. In comparison, Russian domestic output in 2021 totaled 4,877 units, and imports 9,146 units for 14,023 units[171].

Therefore, the market for metal cutting machine tools consumption in Russia in 2022 was RUB 82.4 billion, and in 2021 - RUB 79.9 billion. Based on these figures, the consumption market in Russia in 2022, relative to 2021, grew (82.4 -79.9) by RUB 2.5 billion despite the increased export controls and sanctions regime[172].

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[166] https://stanki-expo.ru/novosti/tpost/5u4cril2j1-situatsiya-v-stankostroenii-vesnoi-2022
[167] https://plastinfo.ru/information/news/49216_28.03.2022/
[168] https://www.business-gazeta.ru/article/448724
[169] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023
[170] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023
[171] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023
[172] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023

Looking closely at the imports, according to Russian customs statistics, imports of metalworking equipment in 2022 totalled USD 574 million, or 9074 machine tools in units. In 2021, imports were 11 433 units and USD 816,8 million[173]. The drop in money was 29.7 % and in units 20.63 %[174].

Still, critical import dependency persists, as Russia in 2022 produced machine tools worth RUB 9.7 billion (1298 machines) and imported machine tools worth RUB 40.1 billion (9074 machines)[175].

The most notable changes, however, happened in the structure of imports. Thus, in 2021, Germany was in first place in the supply of equipment (24.84% of total imports), followed by Italy (18.17%), China (10.93%), Taiwan (9.75%), South Korea (9.49%), Finland (7.1%), and Japan (5.91%)[176]. As a result of the imposed restrictions, the share of supplies from Western countries in total imports of metalworking equipment decreased almost 1.8 times to 38.6 % in 2022[177]. In contrast, in 2022, China's share of imports increased to 43.25%, and Taiwan's to 15.45%[178].

According to other sources, the share of imports of metalworking equipment from Taiwan increased almost 1.5 times (the increase in value in terms of supplies from this country amounted to over 17% or more than USD 18 million). As for South Korea, in 2022, it increased its share in total shipments by more than 1.4 times (in value terms, the increase was more than 14% or by more than USD 6 million). The share of equipment supplied from Turkey increased more than 2.7 times to 9.9% in 2022 from 3.6% in 2021. In value terms, the increase in the volume of supplies from this country was more than 2.2 times or more than USD 55 million [179].

Various factors may explain the increase in Chinese machine tools import. First, Russian industrialists' capacity was insufficient to quickly replace the Western suppliers who had left and will remain such for the coming decades. On the other hand, domestic machine tool builders cannot compete on price with China. For example, the average cost of a Russian-made machine tool was RUB 7.5 million in 2022, while the average price of an imported machine tool was RUB 4.4 million[180]. Therefore, the import dependency persists; however, the Western producers were partially replaced by the Chinese ones. In this respect, it is worth noting that the substantial market share of Chinese imports in the Russian machine tool industry is already beginning to alarm many industrialists. Vladimir Serebrenny, the rector of the Stankin Moscow State Technical University, has warned:

> *"The determination to buy machine tools massively from China is fraught with great danger. At this stage, it is important not to fall into one dependency, and it will be even more difficult to get out of it, as a monopoly is always dangerous."*[181]

[173] https://dzen.ru/a/ZG4Zw-Pg13HyP4K1?utm_referer=www.google.com
[174] https://dzen.ru/a/ZG4Zw-Pg13HyP4K1?utm_referer=www.google.com
[175] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023
[176] https://dzen.ru/a/ZG4Zw-Pg13HyP4K1?utm_referer=www.google.com
[177] https://1economic.ru/lib/118955
[178] https://dzen.ru/a/ZG4Zw-Pg13HyP4K1?utm_referer=www.google.com
[179] https://1economic.ru/lib/118955
[180] https://stanki-expo.ru/novosti/tpost/87ydvamjj1-situatsiya-v-stankostroenii-na-mart-2023
[181] https://business-magazine.online/fn_1168932.html

At the same time, one should not forget that China is a global leader in producing low- and medium-precision CNC machines but lags in the high-precision machine tool industry. In addition, many components of Chinese CNC machines are also imported from Western and Western-allied countries, especially CNC software. Finally, the increased Chinese imports may hide many Western-made CNC machines from companies with production sites in China.

While the increase of Chinese machine tools import may be considered somewhat 'expected,' given the political conjuncture and Turkish imports increased given sanctions evasion schemes, the rise of Taiwanese and South Korean imports to Russia is especially concerning. As Russian analysts note, more lenient sanctions regimes from Taiwan and South Korea tightened only in 2023, making it possible to increase 2022 supplies of machine-tool products from them[182]. Such a phenomenon is increasingly concerning given the strategic relations between Taiwan and South Korea, on the one hand, and the US, on the other hand.

The Taiwanese case is especially explicable, given the country's existential threats from the PRC. According to data and analytical summaries from the analyst of the Ukrainian Kruk UAV Centre provided to the Economic Security Council of Ukraine, in January-July 2023, Russia bought 932 units of CNC machines worth 50,4 million USD from Taiwanese manufacturers. Among the leading Taiwanese manufacturers and suppliers of CNC machines were L.K. Machinery Corp. (96 units), Victor Taichung Machinery Works Co., Ltd (81 units), Ray Feng Machine Co., Ltd (58 units), Akira Seiki Co., Ltd (51 units), Litz Hitech Corp (50 units), etc. Noteworthy, this analytical summary includes only the CNC machines themselves, while combined with CNC software units, CNC components, and instruments, the sum may be much higher.

Finally, the share of the 'unfriendly' (Western and Western-allied) countries' supplies of CNC machine tools still ranges between 38[183]-42[184]%. This number includes the direct supplies and the origin countries of CNC machine tools supplied via third countries. Given the sanctions regime and export control restrictions, this figure is deeply concerning and raises questions regarding the reasons behind such a phenomenon.

3.2. Reasons for the continued Russian access to the Western and Western-allied CNC machines and technology

Three leading causes for the continued Russian access to the Western and Western-allied CNC machines and technology are export controls, gray import schemes, and CNC producers' lenient compliance.

3.2.1. Deficiencies of export control

The problems of the existing export control regime for CNC machinery sector may be divided into two primary groups – substance issues and enforcement issues. Substance issues include challenges related to definitions of dual-use CNC technologies, differing national standards, and exemptions. Enforcement issues involve evasion tactics employed by regulated entities, transshipment through third countries, and procedures to ensure export control compliance.

[182] https://1economic.ru/lib/118955
[183] https://1economic.ru/lib/118955
[184] https://dzen.ru/a/ZG4Zw-Pg13HyP4K1?utm_referer=www.google.com

Substance issues. Export control norms for CNC machines cover only the most precise equipment. As mentioned above, the export control does not include the CNC machines with an accuracy of less than 6 micrometers (in some cases – 1 micrometer, depending on the type of processing technology – e.g., milling, turning). However, the standard levels of machining tolerance (accuracy) for CNC machine tools for the standard processes range between 130 micrometers (0.13 millimeters) and 762 micrometers (0.762 millimeters)[185]. Moreover, despite lower accuracy, even the less precise CNC machine tools for standard processes can still be used for military purposes.

The CNC export controls also have many exceptions. For instance, if a metalworking machine has a CNC system but is limited to the manufacture of gears, an export license is not required. The same is true for machine tools to produce crankshafts or camshafts, tools or cutters, extruder worms, etc. The grinding machines are also exempt from export licensing if they are limited to cylindrical or surface grinding.

Enforcement issues. Even those CNC machine tools included in the export control regulations still reach the Russian Federation. For example, according to the ESCU findings, between February 24, 2022, and July 31, 2023, Russian companies imported German dual-use CNC machines and components controlled by the EU Regulation 833/2014[186] for 242,8 million USD. Many of the Russian importing companies have direct connections to the military and industrial complex of the Russian Federation.

This is possible not only because of the evasion schemes or increased number of intermediaries in the supply chain but also because of the inefficient export control practices, which create broad room for forgery of end-user certificates, lenient pre-transactional and post-transactional due diligence, etc. An equally important factor that significantly weakens export control of the CNC machine tools sector is the lack of capacity of the enforcement bodies as well as the lack of their focus on leveraging Russia's (as well as of other rogue states) dependence on Western machinery. Being a crucial and weak point of the Russian military industry as well as being used in the production of all kinds of modern weaponry, CNC machine tools along with their global supply chains still remain only one of the numerous targets on the list of the relevant national enforcement authorities.

3.2.2. Gray import schemes and procurement companies

With the full-scale invasion of Ukraine, the number of Russian shell companies aimed at sanctions evasion increased dramatically. For example, in 2022, Russians opened more than 1,300 companies in Turkey - 670% more than in 2021[187]. In Kazakhstan, the number of companies with Russian capital increased by 70% over the year[188]. In Georgia and Armenia, 2022 also saw a surging wave of Russian businesses - 21,000[189] and 6,500[190], respectively. Judging by the financial activities between China, the UAE, other Central Asian countries, and Russia, the overall number of front companies may exceed 30 thousand entities.

[185] https://www.3erp.com/blog/cnc-machining-tolerances/
[186] https://lexparency.org/eu/32014R0833/ANX_XXIII/
[187] https://www.bloomberg.com/news/articles/2023-03-20/russia-inc-booms-in-turkey-with-surge-in-newly-opened-firms?sref=l3J6d079
[188] https://www.forbes.ru/biznes/495329-cislo-kompanij-v-kazahstane-s-rossijskim-kapitalom-vyroslo-za-god-na-70
[189] https://rus.err.ee/1609043669/posle-24-fevralja-2022-goda-rossijane-otkryli-v-gruzii-bolee-21-000-kompani
[190] https://www.forbes.ru/rubriki-kanaly/video/490322-kak-relokanty-iz-rossii-vliaut-na-ekonomiku-armenii

The trade statistics also uphold the claim about the continued Russian import of critical components via intermediaries. The post-Soviet neighbouring countries and other "friendly" states drastically increased exports to Russia in 2022, especially China, which added USD 8,57 billion (13%) in 2022, the highest result in absolute terms. Apart from China, the top 5 are Turkey (3,568 billion, +62%), Kazakhstan (1,762 billion, +25%), Armenia (1,571 billion, +298%), Uzbekistan (896 million, +53%) and Kyrgyzstan (571 million, 246%)[191]. At the same time, in 2022, all these countries dramatically increased the import of technical products from Western countries, which imposed sanctions against Russia. The most impressive figures are demonstrated by Turkey, which increased its imports from Switzerland by 454%, and Armenia, whose imports from Germany and the USA increased by 234% and 434% accordingly[192]. The abovementioned states became buoyant sanctions evasion hubs, debilitating the existing restrictions.

Soon after the full-scale invasion, specific patterns of CNC machine supply chains emerged. For instance, Japanese precision Tsugami units are imported through China. Okuma units with the specified serial numbers are imported with hidden information about the exporter. Fanuc products go through Hong Kong, and Kitamura is imported through the Russian hub in Turkey (Akhmedov's Group). Fanuc's CNC modules are available to Russian machine manufacturers as part of assemblies from China, Taiwan, and South Korea[193].

Via Turkey, the Russians are also supplied with units by German brands Hermle, Stadler Keppler, Deckel, and DMG Mori. The products From the Czech Republic are transported by Inter Style Plus from Kyrgyzstan, the official representative of the world's leading manufacturers of machine tools and components. The company cooperates with Phiffner, Mori-Say, Fermat, Kovosvit Mas, Tajmac-ZPS, and other leaders in machine tool technology[194].

The exact figure of CNC machines and technologies supplied via procurement companies in third countries is unknown. However, the most common pattern for Russian procurement companies is concentrating on one sector (e.g., CNC machines or microelectronic equipment) rather than dispersing the efforts to import all groups of critical components or supplying one specific military producer. Among the biggest Russian importers of CNC machines and components, according to the ESCU analysis, one finds JSC Baltic Industrial Company, Kami Group LLC, Pumori Engineering Invest LLC, Art Mechanics LLC, System Technik LLC[195], etc.

3.2.3. Continued operation of Western CNC machine producers in the Russian market and lenient compliance practices

Foreign CNC machine producers have continued their operations in the Russian market, demonstrating resilience despite international sanctions and export controls. Their ongoing presence in Russia indicates their commitment to sustaining business relationships and highlights the challenges of enforcing the existing sanctions. Additionally, foreign producers have sometimes employed lenient compliance practices, potentially allowing them to navigate restrictions and continue exporting CNC machines and components to Russia.

[191] https://forbes.ua/ru/money/proboini-u-sanktsiyakh-forbes-viyaviv-shcho-kraini-es-ta-ssha-anomalno-zbilshili-eksport-do-susidiv-rosii-yak-ukraina-boretsya-z-reeksportom-do-rf-16082023-15437
[192] https://forbes.ua/ru/money/proboini-u-sanktsiyakh-forbes-viyaviv-shcho-kraini-es-ta-ssha-anomalno-zbilshili-eksport-do-susidiv-rosii-yak-ukraina-boretsya-z-reeksportom-do-rf-16082023-15437
[193] https://zn.ua/ukr/macroeconomics/jak-rf-obkhodit-sanktsiji-dlja-virobnitstva-visokotekhnolohichnoji-zbroji.html
[194] https://zn.ua/ukr/macroeconomics/jak-rf-obkhodit-sanktsiji-dlja-virobnitstva-visokotekhnolohichnoji-zbroji.html
[195] ESCU findings

DMG Mori case[196]. DMG Mori is a German-Japanese company, the third-largest CNC manufacturer in the world. Before the full-scale Russian invasion, DMG Mori was one of the largest suppliers of CNC machine tools. Over 30 Russian military enterprises have used DMG Mori machines to produce their weapons systems, which makes DMG Mori one of the most popular brands among the Russian MIC. About 8 of those enterprises produce missile systems currently used in Ukraine[197]. At the end of February 2022, DMG Mori announced that it had ceased all sales and service activities in Russia and all production at its factory in Ulyanovsk. Russian media even reported on the negative impact of such a decision on the economy of the whole Ulyanovsk region. On the other hand, during more than a year and a half of the full-scale invasion, DMG Mori has not sold its assets in Russia. The company explains this for several reasons:

1) Given that DMG Mori is a critical manufacturer for Russia, the company cannot obtain permission from the Russian government to sell its assets.

2) The company does not want to sell its assets and production sites because it does not want all its equipment and know-how in Russia to fall into the hands of the Russian military-industrial complex.

Despite its ongoing presence in the Russian market, DMG Mori claims that its representative office has six employees performing only administrative functions, with the plant in Ulyanovsk being closed and guarded by a specially hired security company. Newly received evidence shows that DMG Mori's representative office and the factory in Russia have been continuing suspicious business activities despite all the statements of the parent company.

According to the Russian tax records, DMG Mori Rus LLC sold USD 16 million worth of products/services in the Russian Federation in Q3 and Q4 2022 alone. In 2023, DMG Mori Rus continued its sales in the Russian market. Most of the products/services in question were sold to a limited number of clients. They include DM Technologies LLC, Service Pro LLC, Service Plus LLC, and Ulyanovsk Machine Building Plant. All four entities mentioned above have clear connections to the DMG Mori brand and are linked with each other and DMG Mori Rus LLC through common individuals, trade transactions, manufacturing facilities, and/or foreign suppliers. Moreover, in Q3 and Q4 of 2022, the three entities mentioned above (Servis Pro LLC, Servis Plus LLC, DM Technologies LLC) each supplied Russian enterprises connected to the Russian military-industrial complex[198].

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[196] https://www.zeit.de/2023/41/dmg-mori-russlandgeschaeft-werkzeugmaschinen-ukraine-krieg-sanktionen

[197] **ODK-Saturn PJSC** (producing engines for Kh-31,Kh-35, 3M14 Kalibr missiles), **Kazan Plant Electric Device OJSC** (producing components for Kh-101 missiles), **Kirovskoe Machine-Building Enterprise JSC** (9M334 anti-aircraft missile modules for TOR complexes, K-36 and K catapult seats -Z6D-3.5, target missiles, cargo lifting mechanisms for aviation, beam holders for helicopters), **Scientific And Production Association "Iskra" PJSC** (manufacturer of solid-fuel rocket engines and their elements for missile complexes of various purposes), **Moscow Machine-Building Plant Avangard JSC** (main supplier of missiles for the S- 300 and S-400 complexes), **Machine-Building Plant named after M.I. Kalinin, Yekaterinburg PJSC** (produces combat equipment of the S-300B anti-aircraft missile system; combat equipment of the BUK-M1 anti- aircraft missile complex), **JSC Obukhovsky Plant** (part of Almaz-Antey Concern producing command posts for the Strategic Missile Forces: 15V52 for the RT-2 missile complex), **Design Bureau Of Instrument-Making, Named After Academic A. G. Shipunov** (manufactures guided weapons for ground forces, aviation and air defence),etc.

[198] **JSC 'SPE 'Zavod Iskra'** (one of the leading manufacturers and suppliers of the element base for manufacturers of radio-electronic equipment, computer equipment, communications equipment and special-purpose equipment), **JSC UEC-Perm Motors** (engineering company with a focus on the production of aircraft engines), **JSC Russian Institute Of Radio Navigation And Time** (develops radio **JSC Integral Experimental Plant** (defence-industrial complex of Russia, a part of the Concern of Radio Engineering 'VEGA' of Rostec Corporation, engaged in the production, modernization and repair of

Apart from that, in July 2022, three CNC machines produced by the Ulyanovsk plant of DMG Mori from DMG Mori Rus came under the control of the internationally sanctioned Russian enterprise Promtech Dubna JSC. Promtech Dubna has been designated as a 'military end user' under US, UK, EU, and Swiss sanctions. Promtech-Dubna and its affiliates advertise themselves as manufacturers in the civil aviation industry. However, government contract databases indicate that Promtech-Dubna has been contracted by major military producers like MKB Raduga (tactical missile production), MIG, and Sukhoy (jet fighters) for at least up to 2018.

Given all of the above, it is evident that DMG Mori is not fulfilling its duties and is not taking due and full responsibility as a manufacturer of critical dual-use technologies. DMG Mori's subsidiaries continue to operate in Russia, while the parent company publicly states the opposite.

If DMG Mori knew and approved the activities of its Russian office, the company itself and its management should be held legally responsible for facilitating the circumvention of international sanctions. If DMG Mori's management was unaware of or disregarded its subsidiary's continued business in Russia, then this is an unprecedented manifestation of negligence and disrespect for the sanctions regime and the sacrifices made by Ukraine in its fight for freedom.

Haas case[199] [200]. Haas Automation Inc. is an American manufacturer of machine tools and rotary products. The company is headquartered in Oxnard, California, and has facilities in the US cities of Auburn, Washington; Fremont, Sacramento; and Union City, California.[201] Haas Automation sells its products internationally through a network of distributors in various jurisdictions. Since 2015, the distributor of Haas Automation in Russia has been a Russian-based company called Abamet, as well as the network of its regional subsidiaries. Between 2015 and 2022, Haas Automation shipped more than 4,500 batches of its products to Abamet.

Until March 2023, Abamet's website listed (currently, the access to the website is closed) a variety of Haas products for sale in Russia, including CNC machining centers, CNC lathes and rotary products and parts, as well as related services.[202] According to Russia's public procurement records, since 2015 Abamet has repeatedly provided Haas equipment, parts, and after-sales services to Russian defense entities, most of the companies being part of the Almaz-Antey, Rostec, Roscocmos, Sozvezdie, and United Aircraft Corporation holdings, being sanctioned by the US government and producing critical weapons systems, including jet fighters, artillery systems, control systems for ship anti-aircraft missiles, military radio equipment[203].

According to the open customs databases, between March and October 2022, during Russia's full-scale invasion of Ukraine, Abamet received directly from Haas's headquarters in Oxnard,

special purpose radio-electronic means), **PJSC Proletarsky Plant** (part of the United Shipbuilding Corporation, under US and Ukrainian sanctions), **JSC's 'Siberian Instruments and Systems'** (producing electric drives and control units for spacecraft for communication, navigation and geodesy in the interests of government and commercial customers, part of Roscomsoc).

[199] https://www.pbs.org/video/russian-invasion-1678827073/

[200] https://www.pbs.org/video/on-strike-1691174803/

[201] https://www.zippia.com/haas-automation-careers-25465/locations/

[202] https://web.archive.org/web/20230317151333/https://www.abamet.ru/catalog/metallorezhushhie/tokarnye-chpu/bu_haas-st-20y/

[203] https://www.rusprofile.ru/search?query=абамет&search_inactive=0

California, about 40 shipments of equipment, the most recent of which arrived in Russia in October 2022, nine months after the outbreak of the invasion. According to the open customs databases, since November 2022, no entities in the Russian Federation territory received direct shipments from Haas Automation Inc.

Nevertheless, customs data shows that the Abamet group of companies, at least until July 2023, maintained its access to Haas equipment and spare parts through independent suppliers. Between August 2022 and July 2023, Abamet received 330 shipments of Haas products, totaling USD 1.1 million. During the period mentioned above, the only supplier of Haas products for the needs of Abamet, a long-time contractor of the Russian military-industrial complex, was a Chinese company named Suzhou Sup Bestech Machine Tools Co., LTD[204].

Thus, Haas Automation is or certainly should be aware that its products are used for military purposes. Based on the open-source analysis, it is evident that Haas Automation had numerous opportunities to learn that the final customers of its products in Russia are listed military enterprises using US machines to produce weapons systems and military equipment but chose to ignore them. Moreover, it is evident that even after Haas Automation announced the complete termination of its business activities in Russia, the Russian military-industrial complex maintained its access to the critical equipment designed and produced in the territory of the United States, with the procurement scheme developed around Russian based Abamet Group making it possible.

Conclusion: *The full-scale Russian invasion of Ukraine led to international sanctions and a strengthening of export controls, which exposed Russia's heavy reliance on Western and Western-allied CNC machines, components, and software. Industry experts warned of potential breakdowns due to imported spare parts and a lack of self-sufficiency. Despite export controls and sanctions, Russia's CNC machine market remained relatively stable in 2022. Imports decreased, mainly from Western countries, while Chinese imports increased significantly. The rise in imports from Taiwan and South Korea, known for their strategic ties with the US, raised concerns, especially considering Taiwan's precarious relationship with the People's Republic of China. The share of "unfriendly" countries' supplies of CNC machine tools in Russia remained significant, highlighting potential issues with export controls and sanctions enforcement.*

Three key factors contribute to Russia's ongoing access to Western and Western-allied CNC machines and technology: export control deficiencies, gray import schemes, and lenient compliance by CNC producers.

Export control issues encompass substance and enforcement concerns. Substance problems include limitations in the definition of dual-use CNC technologies, disparities in national standards, and exceptions. Enforcement issues involve regulated entities employing evasion tactics, utilizing third-country transshipment, and manipulating export control compliance procedures.

Gray import schemes and procurement companies have multiplied, with an upsurge in Russian shell companies established to evade sanctions. These companies often exploit trade routes through countries considered "friendly" to Russia, inflating the problem of circumventing sanctions.

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The continued presence of foreign CNC machine producers in the Russian market, such as DMG Mori and Haas Automation, and lenient compliance practices on their part allow Russia to access CNC machines and components despite international sanctions. These producers either continue operations or maintain connections through intermediaries and lax enforcement of sanctions.

4. Recommendations

The information presented in the sections above clearly demonstrates the significant dependence of Russian industry on the constant supply of Western-made CNC technologies. Especially important in the context of global opposition to Russia's full-scale invasion of Ukraine is the critical dependence of the Russian military-industrial complex on foreign CNC equipment. According to the present research by the Economic Security Council of Ukraine, the production of almost all types of weapons currently employed by Russia in Ukraine requires the use of the above-mentioned equipment.

Equally important, or even more important in the long run, is the fact that the Russian Federation is not the only rogue state for which the "monopoly" of Western and Western-allied countries on the CNC equipment market is a vulnerability. Iran, North Korea, and China have a similar dependence to varying degrees.

Despite all the above facts, the CNC machine tool sector remains insufficiently controlled at the international and national level. The so-called "jurisdictions of concern" still retain access to Western CNC technology. Some of these jurisdictions (namely China), realizing their dependence, are trying to develop their own CNC industry and fill the markets of their "allies" (including the Russian market). Thus, while the critical instrument of influence in the hands of Western and Western-allied states remains unused, the window of opportunity for its use is narrowing over time.

The following recommendations aim to address the complex challenges associated with the circumvention of international sanctions through the acquisition of dual-use technologies, particularly CNC machines and their components, described above. These recommendations target government authorities and CNC manufacturers to enhance export controls, improve oversight, and ensure responsible corporate practices in this critical sector.

4.1. Recommendations for the government

a) Strengthen export controls on dual-use goods in terms of content, enforcement and prevention of export control violations.

- The state members of the sanctions coalition should expand the range of CNC machines and components (relevant HS codes) subject to their national export controls. For CNC machine tools, this measure calls for the extension of export control rules to main components for CNC machines, software for CNC machines, tools of CNC machines regardless of the level of precision or dual use as the main criteria.

- The CNC machines, their components, software and instruments (as respective HS codes) should be included in Common High Priority Items List administered by BIS, respective competent authorities in the countries of Export Enforcement Five partnership (US, UK, Australia, Canada, New Zealand), and broader sanctions coalition. CNC machines and related technologies should also be included in the Disruptive Technology Strike Force by BIS and Department of Justice as priority items.

- The states of the sanctions coalition should strengthen their practices of controlling and preventing violations of export control rules by introducing and improving new mechanisms. In particular, enhance practice of end-user certificates (export licenses requirement should be extended to the reconsidered and updated list of dual-use goods), regular inspections of exporting companies' transactions (also based on the updated list of CNC tools and technologies considered dual-use).

- To promote the effectiveness of national export control regimes and simplify the independent enforcement by non-governmental actors, it is essential to digitize, automate, and simplify the identification of goods and technologies subject to export controls through the establishment of the relevant tools (e.g. open digital sources/registers, simplified digital databases, hotlines). This measure is necessary for media, civil society, and business representatives to actively monitor export control violations and correctly investigate such cases on their own.

- In their instructions and guidance for business representatives, the authorities should focus not only on describing red flags (characteristics that may indicate a violator of the sanctions regime or a shell company), but also on clear independent tools, databases, methods, approaches that businesses can use to identify such irresponsible companies. A special focus should be placed on providing different types of tools and approaches, both complex and expensive, and simpler and lower-priced ones. It is very important to offer cost-effective approaches to businesses interested in complying with the sanctions and export regimes.

- The signatories to the Wassenaar Arrangement should launch a global process to review export control regulations at the international level, especially within the framework of the sanctions coalition. Export control norms at the level of content, form, implementation, monitoring, and penalties for violations should be strengthened, and best practices of national legislation of individual states should be disseminated internationally. For example, specific provisions of Japanese legislation on the export of dual-use goods (including CNC machine tools) (e.g., regular inspections and visits by representatives of the manufacturer to establish the location and use of the product for non-military purposes), which are enshrined at the international level, may be effective in ensuring compliance with export control regulations in the future.

b) Establish, at the legislative level, new standards for General Compliance, Know Your Customer, Pre- and Post-Transactional Due Diligence to be conducted by manufacturers of dual-use goods (specifically CNC machinery)

The new norms and regulations should be applied to all companies that produce and export dual-use goods, as well as should include the following obligations:

- Take due diligence to verify the identity of the buyer company, its owners and beneficiaries, its activities and links to the military-industrial complex, sources of funding and experience of cooperation with other manufacturers, country of registration and political connections, etc. Companies should also incorporate all markers and guidances published by the competent sanctions authorities in connection to all existing sanctions and export controls regulations into their customer due diligence procedures.

- Apply a risk-based approach when trading with sanctioned jurisdictions and jurisdictions identified as sanctions evaders. When entering a sale and purchase agreement, a company should refuse to evaluate each delivery from the perspective of "not prohibited by sanctions, therefore permitted." Instead, the company should assess the risks that the products may end up in a sanctioned country or with a sanctioned counterparty, taking into account the specifics of the particular jurisdiction and the information available in open sources on how third countries circumvent sanctions restrictions.

- Continuously reassess and monitor current risks in trade in dual-use goods with sanctioned jurisdictions or jurisdictions identified as circumventing sanctions. Manufacturing companies should regularly review and assess the risks of working with their customers, update information about them, and monitor the customer's use of the purchased products their (re)export to third parties or sanctioned jurisdictions (post-transactional due diligence).

- Regularly report publicly as well as to the competent authorities on implementing and updating internal compliance and Know Your Customer standards. Companies should formulate a clear code of internal compliance that serves as a basis for regular reporting to competent authorities on its compliance. In addition, the competent authorities should conduct regular independent audits of companies' compliance with the abovementioned procedures.

- Monitor any supply of goods under their own brand on the global market. Using modern supply chain monitoring tools, the companies should regularly identify unlicensed and unauthorized suppliers and resellers of their own products who are involved in the supply of such products primarily for the needs of the Russian military-industrial complex, as well as to any sanctioned persons and jurisdictions. All identified companies should be brought to the attention of the competent authorities of the relevant country of the manufacturer. As a last resort, producers should publicly report the presence of specific unauthorized non-responsible suppliers, thus alerting the market. Such reporting should become a full-fledged law-enshrines obligation of the company. In case of failure or insufficient fulfilment of this obligation, which has led to the transfer of dual-use goods (new or used) to sanctioned persons or persons producing weapons for aggressive purposes, the manufacturer should be held legally liable.

- The liability for violations of all the abovementioned regulations and standards by companies should be strengthened. In particular, as with AML, senior executives, compliance officers, and those involved should be held criminally liable for knowingly submitting false reports and for deliberate violations or negligence in implementing export controls, sanctions restrictions, or compliance practices.

c. Introduce a more focused, systemic, regular, and coordinated approach to targeting intermediaries and procurement companies in Russia and third jurisdictions (China, Hong Kong, Turkey, etc), facilitating Russia's continued access to CNC machine tools and their critical components.

Due to the crucial role that CNC machine tools play for the Russian military capacity as well as the significant projected impact of suggested policy changes in the sector, including that on the battlefield, CNC machine tools should become a leading priority for the competent authorities of all countries of the sanctions coalition.

Focusing efforts on targeting Russia's dependence on Western and Western-allied CNC machines will enable the members of the sanctions coalition to identify and efficiently block the critical supply chains of CNC machines used by the Russian military-industrial complex.

Apart from focused, systemic, and regular sanctioning of illicit CNC machine suppliers on the national level, the countries of the sanctions coalition should take all measures to synchronize the restrictions already in place and act in sync in imposing the sanctions in question. Among other things, the following measures could speed up the process.

4.2. Recommendations for CNC machine manufacturers

a. Ensure that all customers are required to install a remote control/management system.

Installing the set of hardware and software solutions enabling the full remote control over the machine by the producer (remote control system) should be mandatory for all customers, regardless of when the machine was purchased. It should be included in all machine models produced in the future.

In addition, companies must publicly report on their progress in implementing the remote monitoring system rule for machines already sold and in production.

The remote control system must be triggered not only by physical movement of the machine or mechanical damage but also by an attempt by the user to change the machine's design characteristics (e.g., remove the gyroscope), install unlicensed spare parts, or refuse to perform a critical software update. The remote control system should also make it impossible to use the machine and its regular operation in case the user attempts to disable or modify it.

b. Improve control over grey/parallel imports of products under the specific brand of the company.

To prevent CNC manufacturers' products from appearing on the markets of countries that are subject to international sanctions or are involved in activities aimed at circumventing international restrictions on third parties, companies should take thorough measures to control so-called grey imports. These measures include:

- **Shift from a general permissive approach to a risk-based approach to trade with sanctioned states and countries known to circumvent sanctions.**

When entering a sales contract, the company should refuse to evaluate each delivery from the perspective of "not prohibited by sanctions, therefore permitted." Instead, the company should regularly and thoroughly assess the risks that its products may end up in a sanctioned state, with a sanctioned counterparty, or that its products will be used to manufacture

weapons for states that violate international law, taking into account the specifics of a particular jurisdiction and the information available in open sources on how third countries circumvent sanctions restrictions.

- **Apply the presumption of refusal to trade with sanctioned countries and countries known to be involved in sanctions circumvention.**

The company should refuse to sell goods to companies from sanctioned countries and countries identified as circumventing sanctions until the company proves that the product in question will not be (re)exported, transferred to an authorized individual or entity, used for military purposes, or in an industry that is vital to the country's military potential.

- **Conduct trade relations worldwide exclusively with authorized partners and distributors from jurisdictions criminalizing parallel imports.**

The company should trade its goods only with authorized distributors, with whom relations are based on an explicit license agreement that outlines mutual rights and obligations. Among other things, one of the obligations of this distributor should be to agree on the list of end users and customers with the company and to apply strict compliance in the domestic market, which reflects the company's fundamental compliance principles (in an updated format). In addition, the company should refrain from doing business in jurisdictions where parallel or grey imports are legalized or not prosecuted.

- **Require distributors and foreign representative offices of the manufacturing company to take all measures to track the place and agent of arrival of goods on the export control list (post-transactional due diligence).**

Companies that sell products under the brand name of the respective company (official representative offices and distributors) must document that the end user specified in the relevant certificate has received and put into operation the branded product and that it will not be transferred to a third party on the secondary market.

Such a requirement should be clearly stated in any agreements entered into between the company and its distributors/foreign representative offices, and violation of such a requirement should entail clear and fixed legal consequences, including severance of any business ties with the violator and legal liability under the laws of the relevant jurisdiction.

- **Monitor any supply of goods under their own brand on the global market.**

Using modern supply chain monitoring tools, companies should identify unlicensed and unauthorized suppliers and resellers of their own products who are involved in the supply of such products primarily for the needs of the Russian military-industrial complex and any sanctioned persons and jurisdictions.

All identified companies should be brought to the attention of the competent authorities of the relevant country of origin of the manufacturer. As a last resort, producers should publicly report the presence of specific unauthorized non-responsible suppliers, thus alerting the market.

- **As part of the implementation of the updated internal compliance of the companies, it is necessary to significantly expand the range of tools for monitoring the performance of this compliance by licensed suppliers and other legal entities and individuals that may be involved in the supply of the company's products to the territory of the Russian Federation and other states that violate international law, namely:**

  – Actively use the analysis of open customs databases to track all international supply chains of the company's products and monitor the emergence and implementation of new open and commercial tools, registers, and databases that can strengthen the company's internal compliance performance.

  – Based on open and commercial customs databases and other digital tools, registers, and information services, closely monitor any exports of the company's products to the Russian Federation and independently identify legal entities and individuals involved in the unauthorized supply of such products.

  – Take all measures necessary and available to the company to stop illegal international trade in the company's products by third parties.

  – Publicly report the measures taken and regularly notify licensed distributors of actual and potential violators of the company's compliance and trade rules to avoid cooperation with such legal entities and individuals.

  – On a systematic and regular basis, inform the competent authorities of the relevant state (including the states in which the company is registered or operates) about the identified violators above.

- **Completely withdraw from the Russian market as a manufacturer and distributor of CNC machines, which includes the following steps:**

– Completely close down the manufacturer's official representative offices, industrial facilities, and service centers in Russia, meaning that they would not operate at all, with only adequate security for the premises and equipment.

– To dismiss all personnel, including administrative and service employees, in all companies (official representative offices, industrial sites, service centers, etc.) working for the manufacturer in the Russian Federation.

– Terminate any relationships (direct and indirect) with any customers registered or operating in Russia, including providing service and technical support, supply of spare parts, and provision of unlock codes for machines in the event of an emergency system.

– Take all necessary measures to completely block access to its own equipment, which remains in Russia in warehouses and on the balance sheet of the company's Russian representative office and plant.

– Report publicly on the measures taken to withdraw from the Russian market entirely.

- Regularly report on the current state of affairs and the progress of asset sales, closure of legal entities, and exit from the market.

- **Implement into the company's internal compliance the markers of sanctions circumvention intermediaries proposed by the Bureau of Industry and Security (BIS), the US Department of Justice (DOJ), and OFAC as the most relevant to the current sanctions challenges of international trade. Companies that fall under the above criteria should be classified as persons that cannot be counterparties of the relevant international manufacturing company:**

  - Use of corporate structures to conceal (i) ownership, (ii) source of funds, or (iii) countries involved especially sanctioned jurisdictions;

  - Purchases under a letter of credit are consigned to the issuing bank, not to the actual end user. In addition, supporting documents, such as a commercial invoice, do not list the actual end-user.

  - Parties to transactions listed as ultimate consignees or listed in the "consign to" field appear to be mail centers, trading companies, or logistics companies.

  - Use of shell companies to make international wire transfers, often involving financial institutions in jurisdictions other than the company's registered office;

  - A payment originating from a third country or company not specified in the End User Statement or other applicable end user form;

  - A customer lacks or refuses to provide details to banks, shippers, or third parties, including details about end-users, intended end-use(s), or company ownership.

  - Changes to standard commitment letters that conceal the end customer;

  - Transactions involving changes in shipments or payments previously planned for Russia or Belarus;

  - Transactions involve a purported civil end-user, but basic research indicates the address is a military facility or co-located with military facilities in a country of concern.

  - Transactions involving companies that are physically co-located or have shared ownership with an entity on the Entity List or the SDN List.

  - Routing goods through specific locations is commonly used to divert prohibited goods to Russia or Belarus illegally. Such locations may include China (including Hong Kong and Macau) and jurisdictions close to Russia, including Armenia, Turkey, and Uzbekistan.

  - Transactions involving organizations with little or no online presence;

  - IP addresses that do not correspond to the customer's reported location;

  - Transactions involving customers with phone numbers with country codes that do not match the destination country.

- Use of personal email accounts instead of company email addresses;
- Managing complex and/or international businesses using shared residential addresses or addresses for multiple legal entities;
- Last-minute changes to shipping instructions that are contrary to customer history or business practices;
- The customer is significantly overpaying for an item based on known market prices.
- The item (commodity, software or technology) does not fit the purchaser's line of business;
- Failure to provide standard installation, training, or maintenance of the purchased item(s).

5. Conclusions

CNC (computer numerical control) machines automate manufacturing processes based on programmed instructions, improving precision and efficiency. A typical CNC machine comprises key elements like input devices, display units, machine control units (MCUs), driving systems, feedback sensors, and the machine bed. These machines employ various tools, including lathes and mills, to produce parts accurately. CNC operations begin with G-code instructions generated from a CAD model, loaded into the machine via input devices, and executed by the MCUs, ensuring precision while feedback sensors monitor progress. CNC machines are crucial in modern manufacturing, offering automation and high accuracy. Precision CNC machining is preferred for small metal parts and precision components due to its advantages. CNC machines provide high precision, fast speeds, multi-axis capabilities, automatic tool changes, and program storage, making them cost-effective and versatile for manufacturing small metal parts and precision components.

CNC machine tools are critical for manufacturing complex and high-precision components in various industries. In aerospace and shipbuilding, they produce aircraft and ship parts like turbine blades, landing gear, and electrical connectors. The automotive industry uses CNC machines for engine blocks, gearboxes, and molds. In the medical field, CNC machines create surgical instruments, orthopedic implants, and dental components. The electronic sector benefits from CNC technology for producing PCBs and microchips with precision. In the military, CNC systems manufacture various components for weapons, guided missiles, defense systems, and more. These machines are also used in woodworking, metalworking, and plastics manufacturing industries.

CNC machines are categorized as "dual-use" goods, serving both civilian and military purposes, leading to their regulation under international export control regimes. Historically, CNC machine exports faced rigorous controls during the Cold War, emphasizing linear positioning accuracy. However, the consensus for stringent regulation weakened after the Soviet Union's dissolution. The Wassenaar Arrangement, initiated in 1996, introduced a more permissive approach, allowing individual nations greater discretion in export licensing decisions. In the United States, CNC machines fall under Category 2 of the Commerce Control List, and the Bureau of Industry and Security supervises them. The European Union and Japan have their own export control systems. These controls cover CNC machines with high accuracy specifications, multi-axis turning and milling machines, cutting tools with precise orientation, and related software and components. While these controls target the most accurate equipment (typically below 6 micrometers), less precise CNC machines, widely used for military purposes, are not subject to the same export restrictions. CNC machines can also be adapted to evade export controls, such as limiting the machine's capabilities or obtaining non-controlled versions and configuring them for military precision. Exceptions apply to specific tasks like gear manufacturing, crankshafts, and other non-proliferation-sensitive uses, where export licenses may not be required. CNC machines are highly sought after for their capabilities and have become targets of industrial espionage and illicit procurement activities. Several cases highlight the illegal transfer of CNC machines or components, violating export regulations.

The global machine tools market, with a 2022 estimated size of USD 87.94 billion, is experiencing substantial growth, driven primarily by the CNC segment, which accounted for a significant 85.8% of the total machine tools revenue. Leading the industry are Western European countries like Germany and Japan, which are known for their rich tradition of craftsmanship and technological expertise. They dominate various sectors, especially in the

production of critical components. In contrast, the United Kingdom and the United States have seen a decline in their industrial production capacities, particularly at the lower end of the CNC machines market. Nonetheless, they maintain capabilities in sophisticated production and specific sub-sectors. Eastern Asian nations like Taiwan and South Korea have been making impressive strides in closing the technology gap with older industrial powers. While the world's largest consumer of machine tools, China remains a significant producer, albeit primarily in low-quality machining equipment. China compensates for quality with quantity, producing a substantial amount of machining equipment and establishing itself as the leading global producer.

Russia's import dependency on CNC machine tools and their components is a critical issue, mainly due to their significance in the Russian military industry and the limited potential for local production or import substitution. Russia ranks among the top 10 importers of machine tools globally, importing around USD 2.1 billion in 2022, with imported CNC machine tools making up approximately 70% of the market. This import dependency results from the absence of a domestic CNC machine-building industry, despite claims that Russian producers meet 30% of local demand.

Several factors contribute to Russia's import dependency. The first is the small size of the Russian machine tool market, making developing a domestic industry costly and less profitable. Second, the lack of continuity and the rapid loss of market position in the early 1990s has further hindered domestic production. Third, Russia's insufficient scientific and production facilities and element base, with low innovation activity and a shortage of highly qualified personnel, add to the challenges. Finally, the absence of a significant domestic demand for Russian-made CNC machine tools has led to limited adoption of locally produced machinery despite government efforts to create artificial barriers favoring domestic equipment.

Russia has long been critically dependent on Western and Western-allied sources for CNC machines, software, and components, as revealed in government documents and reports. In the period leading up to the 2022 invasion, these documents provided insights into the extent of this import dependency. In 2014-2015, CNC machines and components saw high import shares, ranging from 80% to 100%, with Germany and Japan as major suppliers. Despite these figures, the 2014-2015 data did not account for Russia's import substitution efforts.

However, the import substitution programs initiated by the Russian government were not effectively implemented. Russian authorities and experts acknowledged the failure of these programs to reduce import dependency, illustrating the challenging nature of the issue. Still, these efforts demonstrate a deep understanding of the strategic vulnerability posed by import dependency, especially in the CNC machine tool sector.

In a 2021 import substitution plan, lower levels of dependency were projected for 2021-2024 compared to 2014-2015 data. While the reported decreases are notable, viewing these statistics cautiously is essential due to concerns about their validity. Despite some progress in reducing dependency, the CNC machine tools sector remained a relevant and pressing issue for Russia just before its 2022 invasion.

According to the Russian government's strategy for machine tool-building industry development in 2020, military industry enterprises are the primary consumers of CNC machines in Russia, accounting for 70% of the total consumption. Russian CNC manufacturers state that at least 80% of their orders come from the military-industrial complex. This suggests

that the military-industrial complex consumes around 70-80% of all machine tools in Russia, both imported and domestically produced. Given Russia's import dependency in this sector, it's likely that most CNC machine tools used by the Russian military complex are imported from Western and Western-allied countries.

Evidence supporting this includes publicly available videos from Russian military plants and government procurement data. However, these sources have become less accessible due to closures and restrictions. Despite this, it's still evident that various Russian military enterprises use CNC machines extensively. These include missile and missile systems production, aircraft, spacecraft, and shipbuilding, engine building, and even nuclear weapons production.

CNC machines play a pivotal role in producing various crucial components in military and defense applications. These machines enable precise, automated manufacturing capabilities, making them indispensable for military purposes. In building missiles and missile systems, CNC machines fabricate intricate components like missile bodies, propulsion systems, guidance components, and warhead casings with high tolerances and quality. The Russian JSC Tactical Missiles Corporation (KTRV), the largest producer of anti-ship, anti-radar, and multi-purpose missiles for aviation, shipboard, and coastal tactical missile systems, has been actively procuring CNC machines and components, including those from foreign sources such as Okuma (Japan) and Sodick (Japan).

Likewise, CNC machines are vital for producing precision components in the aircraft, spacecraft, and shipbuilding sectors. In aircraft manufacturing, they fabricate wing sections, fuselage parts, and engine components. For spacecraft, CNC machines craft lightweight structures, such as satellite components, while shipbuilding relies on these machines for manufacturing hull sections, propellers, and steering systems. Furthermore, companies like the Khrunichev State Research and Production Space Center, a leading Russian rocket and space industry player, have procured CNC machines for their production processes.

CNC machines are critical for creating engine components with tight tolerances, high-quality finishes, and precision machining in engine building. The United Engine Building Corporation, a significant producer of engines for aviation, space programs, and more, has equipped its facilities with CNC machines from various sources, including DMG Mori (Japan, Germany) and Hermle (Germany). The role of CNC machines in the military-industrial complex extends even to nuclear weapons production. Facilities like the Russian Votkinskiy Plant, responsible for producing long-range solid-fuel ballistic missiles, have been identified as users of CNC machine tools made by various international brands.

These examples underscore the extensive military applications of CNC machines in Russia, which are instrumental in producing vital defense systems and components, ranging from missiles to engines and nuclear weaponry.

The full-scale Russian invasion of Ukraine led to international sanctions and a strengthening of export controls, which exposed Russia's heavy reliance on Western and Western-allied CNC machines, components, and software. Industry experts warned of potential breakdowns due to imported spare parts and a lack of self-sufficiency. Despite export controls and sanctions, Russia's CNC machine market remained relatively stable in 2022. Imports decreased, mainly from Western countries, while Chinese imports increased significantly. The rise in imports from Taiwan and South Korea, known for their strategic ties with the US, raised concerns, especially considering Taiwan's precarious relationship with the People's Republic of China.

The share of "unfriendly" countries' supplies of CNC machine tools in Russia remained significant, highlighting potential issues with export controls and sanctions enforcement.

Three key factors contributing to Russia's ongoing access to Western and Western-allied CNC machines and technology are export control deficiencies, gray import schemes, and lenient compliance by CNC producers.

Export control issues encompass substance and enforcement concerns. Substance problems include limitations in the definition of dual-use CNC technologies, disparities in national standards, and exceptions. Enforcement issues involve regulated entities employing evasion tactics, utilizing third-country transshipment, and manipulating export control compliance procedures.

Gray import schemes and procurement companies have multiplied, with an upsurge in Russian shell companies established to evade sanctions. These companies often exploit trade routes through countries considered "friendly" to Russia, inflating the problem of circumventing sanctions.

The continued presence of foreign CNC machine producers in the Russian market, such as DMG Mori and Haas Automation, and lenient compliance practices on their part allow Russia to access CNC machines and components despite international sanctions. These producers either continue operations or maintain connections through intermediaries and lax enforcement of sanctions.

The following recommendations aim to address the complex challenges associated with the circumvention of international sanctions through the acquisition of dual-use technologies, particularly CNC machines and their components, described above.

Recommendations for the Governments:

a. Review and strengthen export controls on CNC machine tools on the national level in international level.
b. Establish new legislative standards for all compliance practices to be conducted by manufacturers of dual-use goods.
c. Regularly and systematically target intermediaries and procurement companies illicitly supplying CNC machine tools.

Recommendations for CNC Manufacturers:

a. Introduce mandatory remote control/management systems.
b. Better control grey imports of the specific products and report on all unauthorized and irresponsible resellers.
c. Shift to a risk-based approach with the compliance procedures.
d. Conduct trade exclusively with authorized partners.
e. Ensure clear compliance rules and their regular review and update.
f. Withdraw from sanctioned markets.
g. implement sanctions circumvention markers prepared by the competent authorities.