PRODUCT-SERVICE SYSTEM: A NEW OPPORTUNITY FOR THE WELDING INDUSTRY

Mariusz SALWIN[a)], Tomasz CHMIELEWSKI[b)], Andrzej KRASLAWSKI[c)]

[a), b)] Warsaw University of Technology, Warsaw, POLAND
[c)] Lappeenranta University of Technology, Lappeenranta, FINLAND
[a)] e-mail: mariusz.salwin@pw.edu.pl, ORCID: 0000-0001-9325-8796
[b)] e-mail: tomasz.chmielewski@pw.edu.pl, ORCID: 0000-0003-0002-8751
[c)] e-mail: andrzej.kraslawski@lut.fi, ORCID: 0000-0002-8393-1526

Abstract: A Product–Service System (PSS) is defined as an innovative concept that integrates products and services into solutions that meet specific customer requirements. This idea allows enterprises to build a competitive advantage, generate environmentally friendly solutions, and support sustainable development. There are many potential applications in PSS industrial practice and PSS design, but examples of the concept's use in welding are relatively rare. This research work focuses on proposing a conceptual PSS aimed at welding. This model was developed based on research in a welding company specializing in producing a wide range of high-quality steel structures, elements for machines and devices, and specialized components on individual customer orders using welding machines from renowned companies. During the research, real production problems and the needs and expectations of the welding company regarding services were analyzed. The PSS developed in this paper provides the welding company with a comprehensive offer, combining a welding machine and related services that eliminate or significantly reduce production problems while increasing operational efficiency.

Keywords: Product–Service System, Product–Service System Design, Welding, Welding Industry, Welding Machines.

JEL Classification: L60, L80, L84, L90, O14.

1 Introduction

There is an increasingly visible evolution in the economy's structure, with traditionally manufacturing-oriented companies changing their business model to combine products with services (Domański, 2012; Ding, Liu and Yang, 2019). This change in how they operate allows companies to use resources more efficiently, especially by integrating services with lower resource consumption, generating higher margins and increasing profitability (Charro and Schaefer, 2018; Sarancic, Pigosso and McAloone, 2021). Integrating services with products fosters innovation, as it forces them to improve their offerings continuously and, at the same time, develop innovative solutions, which can contribute to achieving a competitive advantage (Domański, 2016; Liu, et al., 2019). Combining products with services enables companies to gain a deeper understanding and better tailor their offerings to their customers' needs (Salwin, Lipiak and Przęczka, 2018; Salwin, Lipiak and Kulesza, 2019). This translates into increased customer loyalty and a stronger market position for the company (Ardolino, Adrodegari and Saccani, 2017; Cong, Chen and Zheng, 2020). Combining products with services fosters innovation, forcing them to continuously improve their offerings and develop innovative solutions, which can contribute to a competitive advantage (Abramovici, et al., 2014; Adler, et al., 2024). The change in approach also benefits sustainable economic development, enabling more efficient use of natural resources and reducing the negative impact on the environment (Domański, 2011; Abou-foul, Ruiz-Alba and Soares, 2020). Such a change in the way it works also favors the development of the economy by promoting the growth of the service sector and increasing employment in it (Annarelli, Battistella and Nonino, 2017). These points underline the need for businesses to adapt to a new economic structure increasingly focused on customers and services (Mordecai and Dori, 2016; Chen, et al., 2019).

The answer to the structural evolution of the economy is the Product–Service System (PSS) (Belkadi, et al., 2020; Baines, Ziaee Bigdeli and Kapoor, 2024). This model offers companies an innovative business

strategy that combines products and services into coherent solutions (Kloock-Schreiber, et al., 2020; Baines, Ziaee Bigdeli and Kapoor, 2024). PSS enables companies to transform their traditional products into integrated products and services. This promotes a deeper analysis and understanding of individual customer needs, translating into better-personalized services (Domanński, 2012; Boucher, Coba and Lamy, 2024). Under a PSS, the customer purchases a product and benefits from related services such as training, servicing, or consultancy (Chen, et al., 2019; Belkadi, et al., 2020). This solution increases the value of the offer to the customer and positively impacts the sustainable use of resources (Heisler, Gick and Franke, 2018; Vezzoli, et al., 2018). The systematic servicing and monitoring of products within a PSS can significantly extend their lifespan and is compatible with sustainability and minimizing environmental impact (Centenera and Hasan, 2014; Alamerew, et al., 2020). PSS additionally enables companies to generate profits while reducing operating costs by increasing the share of service revenues in the company's financial balance sheet (Azarenko, et al., 2009; Domański, Kotarba and Krupa, 2014). A PSS's financial advantage results from a more stable yet predictable service revenue stream compared to one-off product sales (Sarancic, Pigosso and McAloone, 2021).

The issues discussed are of particular importance in the context of welding (Technology Cluster Manager [TCM] et al., 2020). The sector faces numerous challenges related to implementing sustainable business practices (Chaturvedi and Arungalai Vendan, 2021). Welding is constantly challenged to reduce greenhouse gas emissions and energy consumption, as well as to reduce waste generation and develop recycling systems. Furthermore, the sector has the potential to influence a change in consumer habits by spreading greener business practices. The implementation of end-to-end solutions integrating products and services instead of traditional product sales models indicates an opportunity to revise the approach to consumption (Davim, 2021). Such an approach can effectively contribute to a more environmentally conscious society, which is a priority for the long-term sustainability of the sector (Skowrońska, et al., 2022).

The welding sector is a distinctive branch of industrial production (Pereira and Silva, 2021). This industry is not limited to joining materials (usually metals or thermoplastics) by heating and melting them at the point of joining with or without adding a filler metal (Bohnart, 2017). It also includes using specialized welding machines and robots necessary for production. This sector has played a fundamental role in promoting technological progress and innovation, significantly influencing the rapid development of various industries. Over the past decades, welding has undergone significant transformations (Bowditch, et al., 2024). The dynamic development of technology in this industry has contributed to the continuous expansion of the range of products available and the improvement of their quality. This demonstrates the great importance of welding in the context of global economy (Technology Cluster Manager [TCM], et al., 2020).

Welding organizations, businesses, professionals, and managers see PSSs as a beneficial solution that contributes to the welding industry's efficiency, reliability, quality, and sustainability. According to experts, PSS has the potential to become the sector's future while responding to complex market expectations, consumer needs, and stringent environmental standards and fostering the development of environmentally friendly innovations (Technology Cluster Manager [TCM], et al., 2020).

This work aims to develop a PSS adapted to the welding industry. PSS presented in this paper is based on research carried out at a welding company specializing in producing a wide range of high-quality steel structures, components for machinery and equipment, and specialized components for individual customer orders, where welding machines from renowned companies are used. With PSS, several innovations will be introduced to the welding industry. The welding machine manufacturer offers comprehensive solutions that include the supply of materials, services, and technical support. As a result, customers no longer have to worry about purchasing, storing, or disposing of raw materials, allowing them to concentrate on their core business. PSS for welding proposed in this work introduces a revolution in this sector through flexibility in financing, a comprehensive solution, and a concern for sustainability. The benefits of the developed PSS can be seen for the transaction stakeholders and the environment.

The paper is structured as follows: the first part is the introduction. The next part presents the research methodology. The third part contains the literature analysis. The next part presents the analysis of the welding company. The fifth part contains the PSS model for welding industry. The last part is the conclusions.

2 Research methodology

The paper aimed to develop a PSS for welding. The following questions were posed in this research work:

- What is the potential for the application of PSS in the welding industry?
- What benefits can PSS bring to welding machine manufacturers, their customers, and the environment?

The analyses carried out in this article cite suggestions that are applicable to the development of PSS for the welding sector.

The research methodology used in this article includes the following steps (Figure 1):

1. Literature analysis: A specific type of literature review was used in this step, namely a systematic literature review. A double literature review was performed here. The first was a review of industrial PSS cases, while the second focused on PSS design methods. The leading scientific databases (Web of Science, Scopus and Science Direct, among others) were used for the literature review. The article authors searched the databases above for the keyword "Product–Service System in the industry," as well as its synonyms. The search criteria included publications edited in English from 2000 to 2022. One hundred and fifty papers on PSS in different industry sectors were identified.

A survey of PSS design methods was then conducted using the same scientific databases and time range. The authors searched for the phrase "Product–Service System design" and also its synonyms. This analysis identified 70 PSS design methods described in 74 publications.

2. Analysis of a welding sector: This research stage focused on analyzing welding machine manufacturers and users of these machines. Statistical yearbooks, analyses, and reports on the welding sector were used here.
3. Analysis of a welding company: In a welding company specializing in the production of a wide range of high-quality steel structures, components for machinery and equipment, as well as specialized components for individual customer orders, a study was carried out focusing on the problems and needs related to the operation of welding machines and the demand for specialized additional services directed at the welding machines in the company in question. A Pareto–Lorentz analysis was implemented in the welding company under study to identify problems generating significant losses and costs. Subsidiarily, the most critical service needs of the analyzed company were diagnosed using a brainstorming technique. On this basis, a questionnaire form was drawn up, which included service proposals to address the identified problems and needs of the enterprise. The services in the questionnaire were classified as follows:

- related to the welding machine,
- welding process related,
- health and safety related,
- quality management,
- environmental,
- additional.

From each group, the welding company employees selected the most relevant services to their work.

4. Constructing a PSS for the welding industry: This phase focused on constructing a PSS for the welding industry. It utilized knowledge gained from a literature review, industry analysis, and research carried out in a welding company. This enabled the design of a PSS in which the physical component of the PSS, that is, the welding machine, stood enriched with an additional intangible component in the form of services of most significant interest to the company's employees. Subsequently, the developed PSS was evaluated in a group discussion, enabling further refinement. The interdisciplinary approach and the involvement of the company's employees from different levels contributed to creating innovative PSS solutions for welding machines and related services.

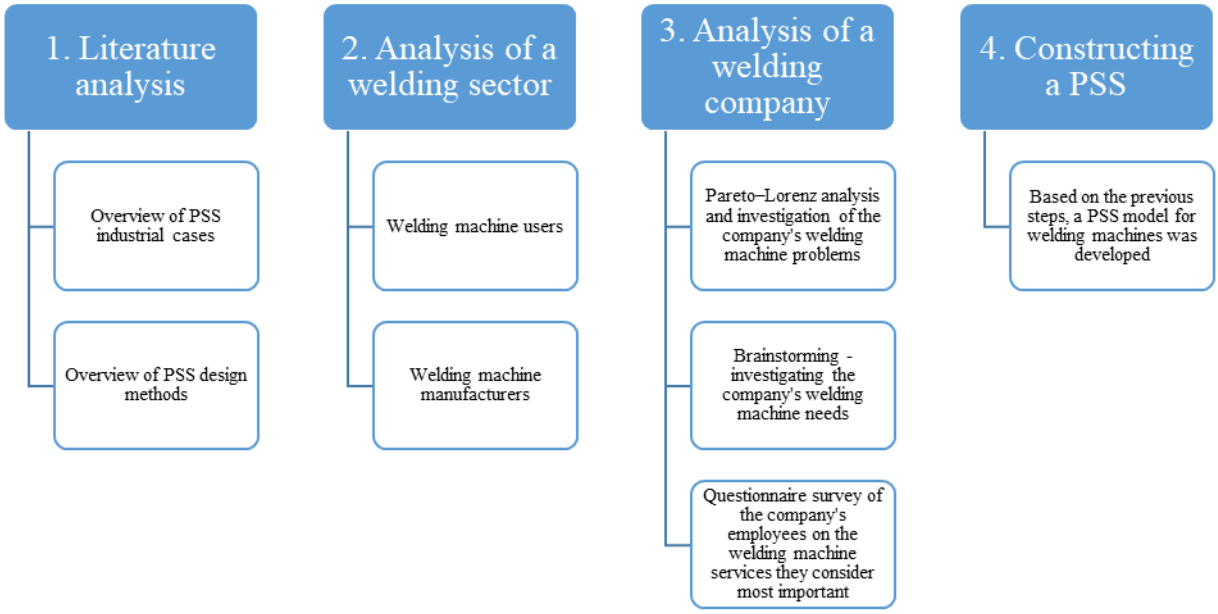

Figure 1. The research methodology adopted in this article
(*Source:* Authors' own research)

3 Systematic literature review

3.1 Product-Service System in industrial practice

In industrial practice, PSS represents an innovative approach to creating added customer value by integrating products and services. The idea behind this business model is to move from traditional product sales to offering comprehensive solutions that meet specific customer needs. In addition to increasing customer satisfaction, PSS aims to promote sustainability and operational efficiency. Critical aspects of applying PSS to industrial practice include:

- Innovation: PSS opens up new opportunities for innovation development, enabling companies to differentiate themselves in the market through unique combinations of products and services. This enables them to better respond to complex and evolving market needs, offering complicated solutions for competitors to imitate (Annarelli, Battistella and Nonino, 2017; Adler, et al., 2024).
- Strengthening customer relationships: PSS enables companies to build deeper and longer-term relationships with their customers through continuous value delivery and support. Models such as leasing, maintenance, or the delivery of results (e.g., guaranteed availability of machines) allow a better understanding of customer needs and a rapid response to changing requirements (Ding, Liu and Yang, 2019; Baines, Ziaee Bigdeli and Kapoor, 2024).
- Sustainability: By integrating products and services, PSS promotes better use of raw materials and materials, reduced waste, and a reduced carbon footprint. Companies have greater control over the entire product life cycle, from design to use to recycling or, reusing or disposal, which encourages environmentally friendly practices (Abramovici, et al., 2014; Vezzoli, et al., 2018).
- Operational efficiency: Relying on PSS can help optimize production and operational processes, reduce costs, and increase productivity. Companies can focus on their core competencies while outsourcing other aspects of the business, which contributes to better resource management (Mordecai and Dori, 2016; Ding, Liu and Yang, 2019).
- Using data and technology: Data and technology are very important for PSS as they play a vital function in monitoring the status of products, analyzing customer behavior, and delivering and improving services. Technologies such as the Internet of Things (IoT) and cloud computing enable companies to deliver personalized and intelligent services, increasing value for customers (Charro and Schaefer, 2018; Liu, et al., 2019).

Implementing PSS in industrial practice can involve significant changes to business strategy, organizational

culture, and operational processes. However, addressing this challenge must uncover new growth potential, build customer loyalty, and achieve sustainable success in increasingly competitive markets (Salwin, et al., 2021; 2022).

The literature shows that PSS is applicable across industries, offering innovative approaches to business. Out of 150 cases, five flagship PSS examples were selected for detailed analysis: Caterpillar Fleet Management Solutions, Komatsu Smart Construction, Philips Lighting as a Service, Rolls-Royce "Power by the Hour," and Xerox Managed Print Services (Table 1). These PSS models represent a manifestation of product and service integration, aiming to provide customers with added value through innovative billing and improved asset management.

Table 1. Analysis of five Product-Service System cases in industry
(*Source:* Authors' own research)

Company	Model	Product	PSS type	Industry	Innovation	Customer benefits	Environmental impact	Challenges
Caterpillar	Fleet Management Solutions	Construction, mining, and other machinery	Result-oriented PSS	Construction/heavy equipment	Digital heavy equipment fleet management	Optimize machine utilization, manage operating costs	Increased machine efficiency, reduced emissions and waste	Integration with heterogeneous hardware and operating systems
Komatsu	Smart Construction	Automatic construction machines	Platform-oriented PSS	Construction	Digital site management	Increase project efficiency, improve site safety	Optimization of construction processes, reduction of waste	Ensuring data security and integration with existing systems
Philips	Lighting as a Service	Lighting	Result-oriented PSS	Miscellaneous	Subscription-based lighting services	Access to modern lighting solutions without large upfront investment	Energy efficiency, reduced consumption of raw materials	Maintaining quality of service and technological innovation
Rolls-Royce	Power by the Hour	Jet engines	Result-oriented PSS	Aviation	Hours-based maintenance of aircraft engines	Reduction in maintenance costs, increased fleet availability	Optimization of resource use, less waste	Ensuring continuous availability of parts and rapid response to failures
Xerox	Managed Print Services	Copiers	Result-oriented PSS	Miscellaneous	Comprehensive print management	Reduction in operating costs, more efficient office processes	Reduction of paper and energy consumption, better waste management	Personalizing services to specific business needs

One of the leading examples of the application of the PSS concept in industrial practice is Caterpillar. The company has developed Fleet Management Solutions, an advanced fleet management system for heavy machinery. The solution goes beyond traditional equipment sales, offering comprehensive support services, performance monitoring, servicing, fleet optimization recommendations, access to detailed reports and analysis, and equipment life cycle management. Caterpillar Fleet Management Solutions uses telematics technology to monitor the condition and performance of machines in real time. The system collects operating

hours, fuel consumption, location, and diagnostics data. Then, to optimize equipment utilization, schedule preventive maintenance, and minimize downtime, this data is analyzed. The solution allows customers to increase operational efficiency, reduce operating costs, and improve machine life cycle management. Developed by Caterpillar, it helps customers make critical business and strategic fleet management decisions (Caterpillar, 2024).

Komatsu offers a Smart Construction or construction site management solution using advanced technologies such as IoT, data analytics, and drones to optimize construction processes. Key elements of the solution include:

- the collection of field data using drones and survey equipment;
- the creation of detailed 3D models using Building Information Modeling (BIM) software; and
- the planning and optimization of construction work based on analysis of the collected data.

The model is characterized by automatic construction machines guided by Global Positioning System (GPS) data and 3D models, which guarantees high precision and efficiency of the work. Ongoing monitoring of the progress of the works using drones allows for quick correction of deviations from the plan. Smart Construction allows for effective communication and cooperation between all project participants. The benefits of this solution primarily include increased accuracy and efficiency, a higher level of risk management, improved safety on site, and cost reductions through faster project delivery and more efficient use of resources (Komatsu, 2024).

The Philips Lighting as a Service model is an innovative use of PSS for lighting that changes the traditional model of purchasing and using lighting systems. Philips offers its customers lighting equipment and, more importantly, a comprehensive service covering design, installation, maintenance, and lighting management. It gives customers access to lighting management tools to optimize energy consumption. The development of this solution starts with an audit and design of a customized lighting system, followed by the installation of modern light-emitting diode (LED) solutions and intelligent control systems. Customers do not buy the lighting products directly; instead, they pay for the lighting service, allowing them to benefit from state-of-the-art solutions without incurring significant capital expenditures (Philips, 2019).

The Rolls-Royce Power by the Hour model is an innovative solution in which the airline pays a fixed fee for each hour the engine runs. The fee also covers maintenance, repairs, and spare parts. A telemetry system monitors engines in real time, enabling performance optimization and proactive maintenance, reducing the risk of failure and the likelihood of aircraft downtime. The service support that Rolls-Royce guarantees ensures a rapid response to problems of all kinds.The main benefits of Power by the Hour for airlines include reduced operational risk, cost predictability, increased operational efficiency, and fleet availability through engine optimization (Rolls-Royce, 2019).

Xerox has developed Managed Print Services (MPS), a PSS model focusing on print management that optimizes the entire enterprise print environment. The process starts with an analysis and audit of the existing system. Based on this, Xerox developed an optimization strategy that consolidates print devices and implements central print management. In the next stage, the company installs new printing devices and dedicated software for them and takes over day-to-day management, including monitoring, servicing, and supply of consumables. The Xerox solution guarantees optimization, automatic adaptation to changing customer needs, reduced costs, increased productivity, improved security, and support for sustainability (Xerox, 2024).

An analysis of the available case studies on using PSSs in industry indicates their use in various industries. PSSs are developed by companies with significant corporate scale. They are complex solutions combining product and service elements aimed mainly at the business-to-business (B2B) market. PSSs develop products characterized by design complexity that find application in the day-to-day operations of their users. Despite the wide range of PSSs available in the industry, more implementation in the welding area is needed.

3.2 Product-Service System design

A review of the scientific literature identified 70 PSS design methods, which were classified in detail based on a verification criterion. This classification includes methods validated in an industrial context, applied in

research projects, and proposals formulated by the academic community (as shown in Table 2).

When considering the available PSS design methods, not all were directly linked to specific economic industries (as shown in Table 3). Of the 70 methods examined, 14 were not assigned to specific economic industries. The most significant number, 13 methods, was identified in the area of domestic appliances, consumer electronics, and other equipment sectors. Furthermore, the literature analysis must indicate the presence of PSS design methods dedicated to the welding sector (Salwin, et al., 2024).

Table 2. Product-Service System design methods – classification by verification
(*Source:* Authors' own research)

Verification criterion	Number of methods
Verified in industrial practice	19
Verified in scientific projects	22
Proposed by scientists	29

Table 3. Product-Service System design methods – classification by industry
(*Source:* Authors' own research)

Industry	Number of methods
No reference – potentially arbitrary	14
Domestic appliances, consumer electronics, and other equipment sector	13
Mechanical engineering	12
Production sector	11
Logistics and transport	10
Construction and environmental engineering	6
Other sectors	4
Energy sector	4
Electronics sector	3
IT sector	3
Food sector	3
Training sector	2
Telecommunications sector	2

The next stage of the analysis focused on the types of PSS that can be designed using the PSS design methods available in the literature. The available scientific literature distinguishes five types of PSS, namely integration-oriented PSS, product-oriented PSS, service-oriented PSS, user-oriented PSS, and results-oriented PSS. Table 4 shows the complete classification of available methods. The analysis shows that one design method is often directed to several PSS types. Among the available methods, as many as 20 can be used to design all PSS types.

Table 4. Product-Service System design methods – classification by Product-Service System types that can be designed
(*Source:* Authors' own research)

PSS design method type	Number of methods
Integration-oriented PSS	37
Product-oriented PSS	49
Service-oriented PSS	64
Use-oriented PSS	48
Results-oriented PSS	40

4 Welding industry and welding machines

4.1 Welding industry

The welding sector is indispensable for many industries ranging from construction and industrial production to energy, automotive, and shipbuilding. It provides the required parts and structures for various industrial applications (Bowditch, et al., 2024). A characteristic feature of welding products is their flexibility to create complex shapes and the precision of their manufacture (Bohnart, 2017). As a result, they can be tailored to customers' specific requirements (Skowrońska, Chmielewski and Zasada, 2022). The welding process makes creating durable and high-strength connections between metals or thermoplastics possible. Welding makes it possible to create joints that often have a strength equal to or even exceeding the materials they are joining (Bohnart, 2017). Welding offers unique strength, durability, and versatility, making it indispensable in manufacturing, construction, and repair processes in many sectors of the economy (Chaturvedi and Arungalai Vendan, 2021).

In 2022, the global welding market was valued at $23.75 billion. The most important welding markets are the USA, China, Japan, South Korea, India, and countries belonging to the European Union. The welding sector in Europe is an important job generator with a long history. In addition, it is closely linked to other industries (Grand View Research, 2023).

4.2 Welding machines

The welding machinery industry underpins the manufacturing sector, providing the specialized equipment and technology needed to create durable and strong metal and thermoplastic joints (Chaturvedi and Arungalai Vendan, 2021). The sector encompasses a wide range of machinery, from portable equipment to advanced automatic systems (Bowditch, et al., 2024). Hand-held welding machines, automatic and semi-automatic welding systems, cutting equipment, and accessories are among the equipment used. The equipment is characterized by its versatility, long service life, and adaptability to new technological developments. This is a dynamic area of the economy that is evolving with technological advances, responding to the industry's increasing demands for quality, efficiency, and occupational safety (Davim, 2021). Aspects such as worker safety and environmental protection are fundamental here. Manufacturers of this equipment pay particular attention to implementing solutions that increase welding efficiency and precision, provide a high level of safety for operators, and minimize the negative impact of welding processes on the environment (Pereira and Silva, 2021).

In 2018, the global welding machines market was valued at $11.58 billion. The most important welding machine markets are China, Germany, the USA, Japan, South Korea, India, and Italy.

Currently, leading manufacturers, including Lincoln Electric, Miller Electric, ESAB, Fronius International, and Kemppi, present the market with a wide range of machines used in welding, available in a variety of equipment options, which are offered as a package with standard services such as training, installation, and maintenance (Grand View Research, 2023).

5 Company analysis

5.1 Characteristics of the Analyzed Company

The surveyed welding company has extensive experience and a long tradition. It specializes in producing a wide range of high-quality steel structures, machinery and equipment components, and specialized components for individual customer orders. The company has a wide range of machinery and employs a team of specialists with experience. Using these resources, the company can perform various tasks, including graphic design, cutting, welding, painting, and delivering the finished product to the customer. In addition, the surveyed company adheres to international quality and safety standards, including ISO 9001 and welding-related standards such as EN 1090 and ISO 3834. This assures customers that all products are made to the highest industry standards in terms of workmanship, durability, and safety. Over the years, the company has gained the trust of a wide range of customers from different industry sectors (construction, automotive, and energy).

The company mainly uses MIG Metal Inert Gas, MAG (Metal Active Gas), and TIG (Tungsten Inert Gas) welding methods, which ensure high-quality and esthetic welds. MIG and MAG methods are used to weld steel structures and components of greater thickness,

ensuring high production efficiency. Due to the precision and cleanliness of the weld, TIG welding is mainly used in producing delicate components and for materials requiring special care, such as aluminum and stainless alloys.

The company surveyed uses welders from reputable companies such as Lincoln Electric, Miller, and ESAB. The choice of these brands results from the company's desire to ensure the highest weld quality, reliability, and energy efficiency. For several years, the company has also started to invest in modern technologies, such as robotic workstations, which enable the automation of welding processes for the serial production of components.

5.2 Company problems and needs

In this stage of research, an identification of the problems and requirements of the company that uses welding machines was made. The analysis was carried out in a workshop held at the company under study.

5.2.1 Company problems

Despite having a wealth of tradition and experience, the company under analysis faces several problems related to the production process. A Pareto–Lorenz analysis was used to identify these problems (Figure 2). The company systematically implements various types of improvements to reduce the problems encountered. However, they generate significant costs. The most significant production problems in 2023 included: equipment upgrades, downtime due to breakdowns, welder training, welding waste management, inefficient material consumption, personal protective equipment, welding tests and optimization of welding parameters, quality control and inspection, and ergonomic provision for welders.

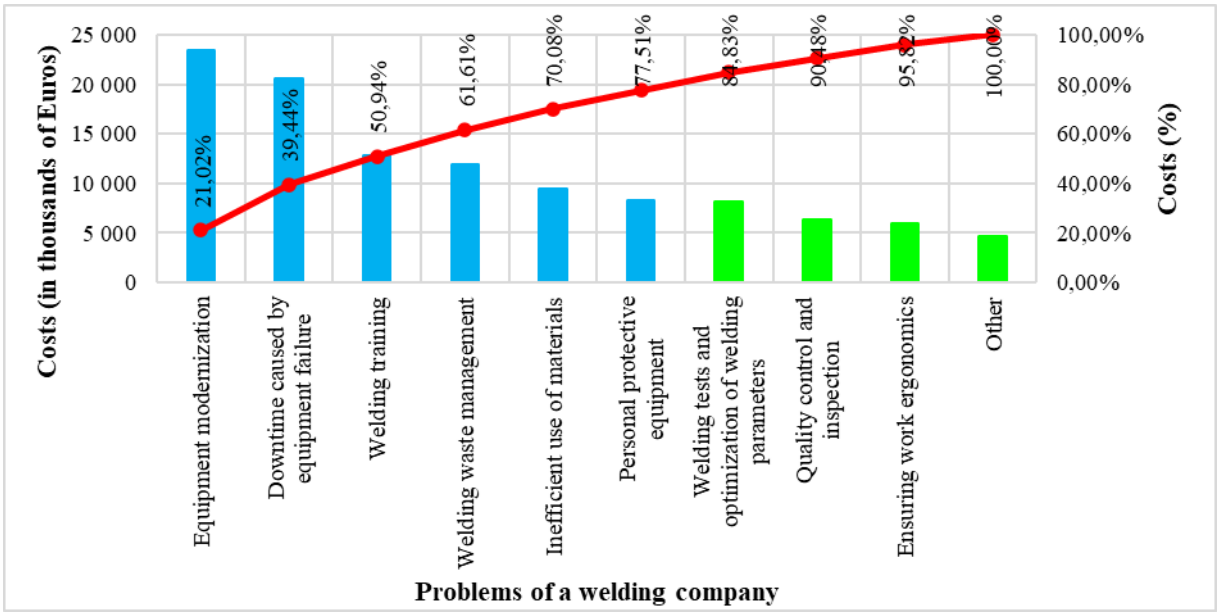

Figure 2. Losses in the investigated welding company – Pareto–Lorenz analysis
(*Source:* Authors' own research)

In the company surveyed, the most significant losses are due to the following problems: equipment upgrades, downtime due to breakdowns, welder training, welding waste management, and inefficient use of materials and PPE. Together, these account for 77.51%. The company should, therefore, focus on solving these problems. Their elimination can significantly increase productivity, reduce costs, and improve production quality.

The losses presented here are specific to the welding industry, characterized by high precision, repeatability, and a wide range of materials used. Even the smallest nonconformities prevent the product from being

shipped from the shop floor to the customer, resulting in additional costs.

In the company under review, an essential role in the entire welding process is played by welders who, based on their knowledge, independently select the appropriate welding technique and parameters for the type of material and structure, safety measures during work, and report any problems and defects related to equipment and material orders. Therefore, the training of welders to which the company dedicates its resources is essential. The costs associated with the management and disposal of welding waste are also worth noting.

5.2.2 Company needs

Realization of the industrial workshops made it possible to identify key service needs of the company related to the following:

- Service and maintenance of welding equipment: Lack of systematic maintenance and repairs or replacement of parts is postponed, so the company needs support for regular inspection, repair, and maintenance of welding equipment to ensure its reliability and performance. Continuous access to spare parts is necessary to carry out repairs and part replacements quickly.
- Training and development of workers: It is necessary to retrain workers and welders to improve their skills. Particular attention should be paid to training on new welding technologies, safety standards, and updating welding qualifications, as well as training programs on occupational safety and programming.
- Welding process: Advice on optimizing welding processes, selecting suitable welding consumables, and welding technologies for specific applications. A regular supply of welding wires, electrodes, technical gases (argon, argon mixtures for TIG, CO2 for MAG), and base materials. Access to laboratories and testing services, including non-destructive testing (NDT) and destructive testing, to assess weld quality and compliance with design requirements.
- Sustainability: Despite the company's pro-environmental activities, there is an apparent need for consultation and advice on best environmental practices in welding processes. Support for installing and maintaining advanced air filtration systems to minimize the emission of harmful welding fumes into the atmosphere. Implement solutions to optimize energy consumption and services related to the segregation, collection, and recycling of metal waste and other materials from the welding process.

The company's identified needs have a significant impact on its operational efficiency. Failure to act toward meeting them can have adverse financial consequences. In addition, they are associated with an additional burden on the environment, manifested by the excessive consumption of energy and water resources, as well as by the generation of waste that does not comply with quality standards and requires a disposal process.

5.3 The service needs of the company

The representatives of the analyzed company, including management, middle management, supervisors, welders, and employees in the welding and other departments, were then allowed to select services from the following six groups:

- welding-related services,
- services related to the welding process,
- health and safety at work services,
- quality management services,
- environment services, and
- additional services.

Each employee was able to select from each group the services that, from their point of view, were the most essential. The selection of services took place in the form of a survey. The results for the key services in each group are presented in Table 5.

Incorporating the selected services into the PSS model is an effective way of addressing the problems and requirements of the welding process, which contributes to improving the company's operational efficiency. Such a strategy allows the company to achieve a higher production quality standard, increase its market competitiveness, and improve customer satisfaction.

Table 5. Services selected by welding company employees from each area
(*Source:* Authors' own research)

Service areas	Management	Middle management and supervisors	Welders and employees	Other workers
Welding-related services	Service and maintenance of welding machines	Service and maintenance of welding machines	Tool and equipment maintenance	Service and maintenance of welding machines
	Spare parts and consumables	Analysis of the causes of failure	Machine operation training	Spare parts and consumables
	Installation and commissioning	Monitoring and diagnostics of welding machines	Cause analysis	Guarantee
	Rent	Spare parts and consumables	Consultation parts and consumables	Rent
Services related to the welding process	Modernization and automation of welding processes	Planning and coordination of welding orders	Advanced training for welders	Automation and digitalization support
	Diagnostics and analysis of welding processes	Optimization of welding processes	Supervision of the welding process	Technical and engineering consulting
	Optimization of the consumption of welding materials	Material analysis and consulting	Technical and engineering consulting	Risk management
	Technical consultancy	Welding project management	Delivery of materials and supplies	Supplies of binder and technical gases
Health and safety at work services	Occupational risk assessment of welders	Occupational health and safety training	Personal protection	Measurements of harmful factors in the work environment
	Consulting in the field of ergonomics of workstations	Workplace audit	Risk assessment of use	Risk management
	Inspection and research of the working environment	Ventilation and dust removal systems	Work clothes	Work clothes
	Personal protection	Consulting in the field of ergonomics of workstations	Consulting in the field of workplace ergonomics	Personal protection
Quality management services	Training and certification for welders	Quality testing, weld certification, and inspections	Product quality control	Customer complaint management
	Legal support and advice on standards and certification	Supplies of binder and technical gases	Binder and technical supplies	Benchmarking and competition analysis
	Quality management systems	Data analysis and reporting	Advice and consultations	Quick response to qualitative incidents
	Quality control of supplied raw materials	Complaints and non-compliance management	Workshops on quality control methods	Alignment with industry standards and regulations
Environment services	Recycling and waste management	Environmental audit	Ecological training for employees	Recycling and waste management
	Environmental certification	Take-back	Recycling and waste management	Energetic audit
	Development of corporate social responsibility programs	Life cycle analysis of welding products	Filtration and emission reduction systems	Optimization of energy consumption
	Optimization of energy consumption	Filtration and emission reduction systems	Monitoring of residue emissions	Take-back
Additional services	Financial and insurance services	Market analysis and competition research	Services related to employee health protection	Supplier management and supply chain audits
	Human resources development and talent management	Software updates	Adaptation to regulations and industry standards	Legal and regulatory support
	Maintenance of infrastructure and facilities	Access to welding parameter libraries	Planning responses to awareness	Technical and engineering consulting
	Legal services and intellectual property protection	Automation and digitalization support	Analysis of the cause of defects and non-conformities	Financial and insurance services

Table 6. Service packages within the Product–Service System tailored for the welding industry (*Source:* Authors' own research)

Services areas	Basic package	Standard package	Advanced package	Premium package
Welding-related services	Rent	Service and maintenance of welding machines	Analysis of the causes of failure	Automation and digitalization support
	Guarantee	Spare parts and consumables	Monitoring and diagnostics of welding machines	Emergency response plans
	Installation and commissioning	Maintenance of tools and ancillary equipment	Machine operation training	Financial and insurance services
Services related to the welding process	Supply of raw materials and materials	Advanced training for welders	Technical and engineering consulting	Diagnostics and analysis of welding processes
	Supplies of binder and technical gases	Supervision of the welding process	Optimization of welding processes	Modernization and automation of welding processes
	Material analysis and consulting	Planning and coordination of welding orders	Optimization of the consumption of welding materials	Automation and digitalization support
Health and safety at work services	Work clothes	Workplace audit	Consulting in the field of ergonomics of workstations	Ventilation and dust removal systems
	Personal protection	Inspection and research of the working environment	Measurements of harmful factors in the work environment	Risk management
	Occupational health and safety training	Occupational risk assessment of welders	Services related to employee health protection	Maintenance of infrastructure and facilities
Quality management services	Training and certification for welders	Quality control of supplied raw materials	Quick response to qualitative incidents	Data analysis and reporting
	Workshops on quality control methods	Product quality control	Legal support and advice on standards and certification	Alignment with industry standards and regulations
	Quality management systems	Advice and consultations	Complaints and non-compliance management	Quality testing, weld certification, and inspections
Environment services	Waste management	Life cycle analysis of welding products	Energetic audit	Filtration and emission reduction systems
	Recycling and reusing	Environmental certification	Environmental audit	Monitoring emissions of harmful substances
	Take-back	Ecological training for employees	Environmental consulting	Optimization of energy consumption
Additional services	Welding project management	Risk management	Benchmarking and competition analysis	Development of corporate social responsibility programs
	Market analysis and competition research	Legal services	Supplier management and supply chain audits	Analysis of the causes of defects and non-conformities
	Software updates	Human resources development and talent management	Intellectual property protection	Access to welding parameter libraries

At this stage, the company expressed an interest in renting a welding machine and services to improve its operation and the whole welding process. In addition, the company was more interested in a monthly subscription for using the welding machine than purchasing it.

6 Product-Service System for welding industry

Using a methodology based on the PSS philosophy and based on the knowledge gained on the problems and needs of the company analyzed, the next stage of the workshop involved the construction of a PSS model. In this system, the key players are the manufacturer of the welding machines and the company using them. At the center of the model will be the welding machine and the services that interest the company, as detailed in Table 6.

The welding machine company provides its customers with access to these machines, complemented by a comprehensive set of services (Table 7, Figure 3). The billing structure is based on an hourly rate for the use of the welding machine and a monthly subscription. It should be noted that ownership of the welders remains with the manufacturer and is not transferred to the end user. The priority for the customer is to use the welders to maximize the number of welded structures produced, rather than directly owning, managing, and maintaining these machines. At the end of the designated helpful life, it is possible to replace the welders with a newer model.

Table 7. Concept of Product–Service System for the welding industry
(*Source:* Authors' own research)

Ownership	Sale	Service packages	Benefits for the customer	Benefits for the manufacturer	Environmental benefits
The manufacturer is the owner	Subscription	Basic package	Focus on core business	Increased customer value	Reduction of harmful impact on the environment
-	Payment for working time	Standard package	Flexibility and scalability	Increased competitive advantage	Reducing waste
-	Payment for welds performed	Advanced package	Reducing your total cost of ownership	Development of long-term relationships with customers	Reducing energy consumption
-	-	Premium package	Technical and service support	New sources of revenue	Optimization of binder, technical gases, and other materials
-	-	-	Risk reduction	Increased brand awareness and company image	Extending the service life of the welding machine

Implementing a PSS offers numerous benefits to all participants in the transaction process. The service recipient can concentrate on the key aspects of its business, that is, the welding process and the expansion of its welding business, eliminating the need for involvement in maintenance, repairs, or the procurement of spare parts for welding machines. The exemption from training welders and other personnel and purchasing dedicated equipment is also a significant benefit, saving time and money. In addition, in the event of a breakdown, the welding machine manufacturer undertakes to repair the machine expressly because of its interest in maintaining the uninterrupted operability of the machine. This approach enables the customer not only to increase the volume of orders processed, but also to reduce the operating costs.

The developed PSS plays a vital role in the operation and reliability of welding machines, offering significant benefits to end users and manufacturers. The implementation of PSS in the context of welding machines allows the equipment to be integrated into a suite of services, greatly enhancing the reliability and operational efficiency of these machines. Regular service and condition monitoring allows potential failures to be detected and counteracted in advance. All this minimizes downtime and associated costs. This

solution allows the welding machines to be adapted to the specific needs of the users through continuous software updates and technical modifications, resulting in better adaptation to changing operating conditions and increased equipment life.

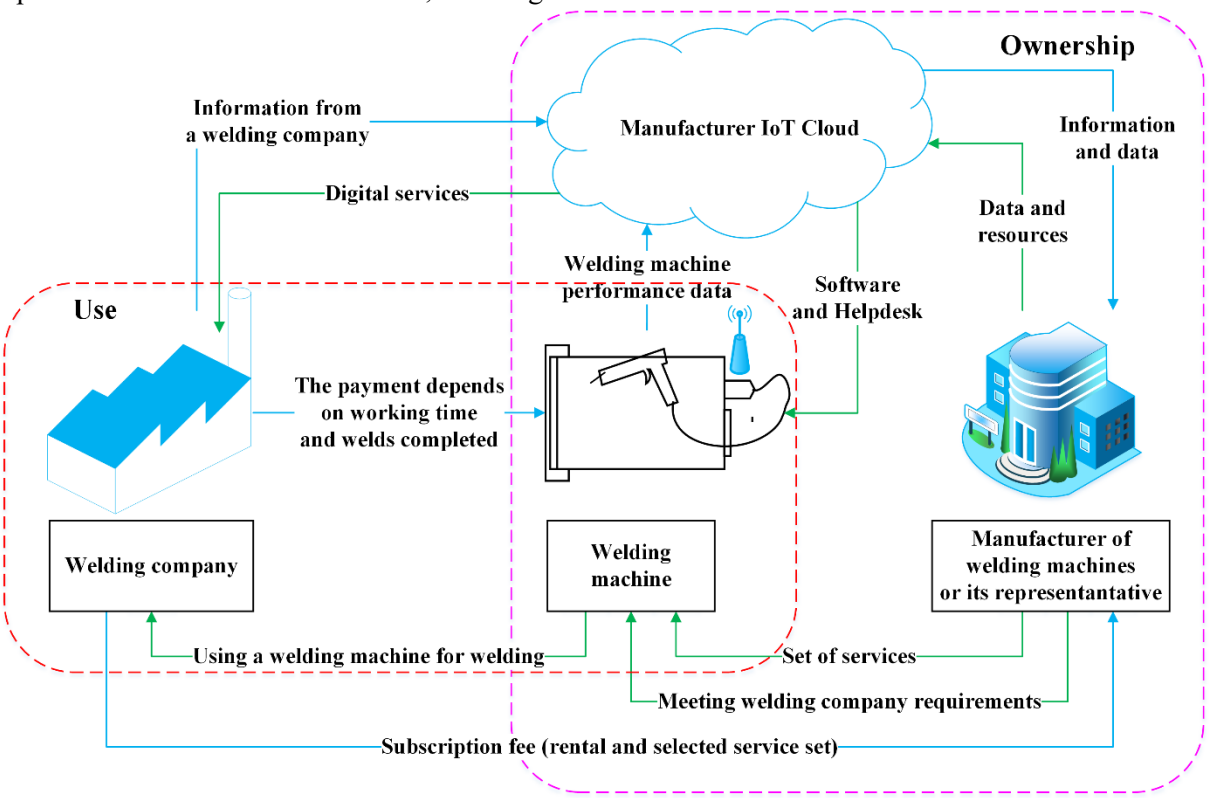

Figure 3. Concept of Product–Service System for the welding industry
(*Source:* Authors' own research)

The implementation of IoT and cloud computing within the PSS for welding machines are significantly transforming the management and monitoring of welding processes, offering a range of benefits to companies and their customers. IoT devices collect real-time data on the status of welding machines, enabling rapid response to failures and optimized maintenance, improving business efficiency. Customers benefit from personalized services such as remote problem diagnosis, contributing to business continuity and reduced risk of downtime. In addition, the IoT-based PSS model enables flexible financial solutions and promotes the development of new business models through integration with advanced data analytics algorithms.

IT tools will play a key role: IoT management platforms, analytical tools, enterprise management systems, data security systems, IoT device life cycle management systems, visualization dashboards, and mobile applications. They all provide the ability to collect, process, and analyze data generated by welding machines. IoT platforms (including AWS IoT Core, ThingWorx, Microsoft Azure IoT Hub, and Google Cloud IoT) allow the user to connect welding machines, send data to the cloud, and manage communication between machines and applications. Thanks to them, data generated by welding machines is collected, processed, and analyzed as part of the developed PSS. This data is later used to optimize the operation of welding machines, automate maintenance activities, and predict failures. These platforms support the integration of all machines, allowing for the development of a comprehensive IoT ecosystem within PSS. Analytical tools (including Azure Stream Analytics, Splunk, and Apache Kafka) are used to process data in real time. They enable the analysis of data streams generated by IoT devices. This enables the detection of patterns, monitoring of machine conditions, and very fast making of specific operational decisions. These tools, combined with machine learning algorithms, enable predictive data analysis, optimizing resource

utilization and failure prediction. However, integrating IoT devices with enterprise management systems (Customer Relationship Management, Enterprise Resource Planning) uses IoT middleware (including IBM Watson IoT and ThingWorx). These solutions guarantee fast data exchange between IoT devices and business applications. This enables the automation of tasks, improvement of process management, and personalization of customer services. In IoT, data security is ensured, thanks to Identity and Access Management tools (including AWS IoT Device Defender and Cisco IoT Security). They guarantee control of access to machines, data, and information and protection against unauthorized activities. Support in the field of data protection is also guaranteed by encryption and network monitoring systems (including Palo Alto Networks IoT Security). The following important element is the IoT device life cycle management systems (including SAP IoT, Bosch IoT Suite). Thanks to them, monitoring and managing devices in every operation phase is possible, from implementation to decommissioning. This allows for the continuity of devices' operation and reduces maintenance costs. Visualization of dashboards and mobile applications (including Power BI and Tableau) are critical. Thanks to them, customers can monitor IoT data and manage machines in an accessible and intuitive way. All the indicated tools make it possible to create a coherent PSS ecosystem.

Cloud computing will provide greater flexibility, scalability, and security, enabling access to data and services from anywhere. By using a cloud infrastructure, data is stored securely and the risk of data loss is minimized. Integrating different cloud services supports the creation of advanced analytics that help optimize processes and reduce operational costs. Cloud computing also allows the rapid deployment of new functionalities and services, such as remote training or software updates, thereby increasing the competitiveness of businesses. In addition, it enables better management of IT resources and ensures service continuity.

Advanced IT tools will play a key role here: cloud platforms, product life cycle and customer relationship management tools, cybersecurity systems, and IoT platforms, the role and use of which have already been discussed. They enable the integration, management, and analysis of real-time data. Cloud platforms (including Google Cloud Platform, Microsoft Azure, and Amazon Web Services) enable scalable environments for storing and processing large amounts of data generated by management systems, IoT devices, and applications. The platforms guarantee access to data analysis tools (including Google Cloud and Azure Machine Learning), enabling predictive and diagnostic analyses based on data from welding machines. Another important tool is cloud-based Product Life cycle Management systems (including Dassault Systèmes ENOVIA and Siemens Teamcenter). These tools enable full integration of design, welding, and service processes, while ensuring the availability of information and data for all stakeholders. In addition, they support real-time monitoring and identification of areas requiring optimization and analysis of the life cycle of welding machines. Another system integrated with cloud computing is Customer Relationship Management. It enables support in the scope of personalization of services and delivery of fast service solutions to customers. In turn, Enterprise Resource Planning class solutions (including Oracle NetSuite and SAP S/4HANA Cloud) enable effective management of logistics, warehouse, and financial processes within the developed PSS. As discussed earlier, IoT solutions are key in data integration and communication. In cybersecurity, tools from the scope (including IBM Security QRadar and Alto Networks Prisma Cloud) play a key role in protecting data transmitted in the cloud. They guarantee monitoring and protection against threats, which is extremely important in cloud-based systems. In turn, data visualization tools (including Microsoft Power BI and Tableau) will enable transparent presentation of information on system performance, their technical condition, and operational results. This will allow manufacturers and customers to make more informed operational decisions. All indicated IT tools will support the operation of the developed PSS, guaranteeing integration, optimization, and management of complex processes in a more effective and customer-oriented manner.

7 Conclusion

PSS is an innovation that integrates the offering of products with services to meet customer needs better and add value. It moves away from the traditional

approach focused solely on selling products, promoting a more sustainable and efficient use of resources by combining products and related services into a coherent and comprehensive solution. Global research considers the practical application of theoretical PSS concepts to industrial realities. In this article, a PSS-focused design workshop was conducted, focusing on the welding sector. The results of this workshop identified the main challenges and needs of a company using welding machines and developed a set of services that effectively address these needs. The welder and services, tailored to the company's actual needs, were integrated into a comprehensive PSS.

Based on the design workshop conducted, the following conclusions can be drawn:

- Understanding the customer's needs: The workshop reveals a deep understanding of welder customers' specific needs and expectations, which is essential for creating valuable PSS offerings.
- New technologies: Integrating IoT and cloud computing within the PSS for welders enables solutions that are more integrated and efficient and precisely tailored to individual customer needs. This synergy of technologies benefits both manufacturers and end users, opening new opportunities for optimizing and personalizing offerings.
- Welding process services create a new proposition for welding companies previously absent from the market.
- Ownership on the part of the manufacturer allows him to constantly control the welder's performance. This allows the manufacturer to detect its weaknesses and components that can be improved in future versions.
- The subscription option can be an interesting choice for customers, allowing them to use welders without making a large initial outlay. This can be particularly attractive during periods of high inflation and rising interest rates, which can prevent companies from being restricted in their new investments. In addition, it eliminates charges associated with machines' gradual wear and tear.
- By integrating welders and related services into PSS, it will be possible to manage their life cycle more efficiently, reducing the need for frequent equipment changes and reducing material consumption. The solution allows precise monitoring and adjustment of welding processes, minimizing the waste of energy and raw materials. The concept, developed at the workshop, motivates a more conscious use of resources, and thus supports sustainable development.
- Setting up a service network for PSS for welding machines can be challenging, mainly due to the logistical complexity and the requirement for a high level of technical expertise. A PSS system requires not only the supply of welders, but also the provision of comprehensive support, including maintenance, repairs, and upgrades. This, in turn, requires an extensive service network with well-trained staff capable of responding quickly to customer needs in different locations. In addition, it can be difficult to maintain a uniformly high standard of service across a wide service network, especially with ever-changing technologies and product specifications. As a result, developing such a network requires significant investment in training, knowledge management, and logistics, which is both organizationally and financially challenging.
- Grouping services into baskets and ensuring flexibility in their selection. This strategy allows customers to tailor the service package to their individual needs and expectations, which increases the value of the offer and customer satisfaction. Thanks to PSS's modular design, users can choose from various services, creating a solution that perfectly suits their operational and financial requirements. This flexibility allows for better cost management and more efficient use of welding machines, while facilitating adaptation to changing market and technological conditions, making PSS a more attractive and competitive solution.

The use of the proposed PSS may have some limitations. Effective management and protection of customer data is also necessary here. This may prove complicated and expensive. Integration of the customer's digital infrastructure with the equipment supplied by the manufacturer may prove fundamental. This may lead to a need for unified operational standards. This causes difficult communication and data exchange between the manufacturer and the customer, increases integration costs, and consequently slows development. In addition, the effective operation of PSS requires a wide range of customers, which may prove difficult to

achieve in the early implementation phase. From an organizational point of view, PSS is associated with changes in the scope of business processes. This may meet with resistance within the organization on the one hand and the need for training in the scope of PSS on the other. Culturally, welding plants (customers) may be skeptical about giving up owning welding equipment in favor of PSS, especially in the welding sector, where ownership of welding equipment is sometimes perceived as the basis for operational independence. Lack of trust in PSS, fear of dependence on the welding equipment manufacturer, and concerns about losing control over processes can be severe limitations.

Moreover, organized design workshops in a welding company specializing in producing a wide range of high-quality steel structures, elements for machines and devices, and specialized components tailored to individual customer orders constitute the necessary foundation for creating and implementing PSS for welding machines. They are crucial in identifying areas requiring special attention and elements that should be the subject of focus when adapting the PSS to the client's individual needs.

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