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Original Article

Strategic Implications in Product-Service System in the Welding Industry

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Abstract: The Product-Service System (PSS) integrates products and services to meet customer requirements. This concept enables the application of security and protection support. This article explores the potential of PSS in the fight against various threats. Currently, this sector and the welding plants operating within it face several threats related to digitalization, labor shortages, energy costs, and specialized equipment. We used a database of literature and technical data, including industry reports, price trend analyses, company reports, professional association statistics, and information from welding company websites and publications, to explore the application of PSS. SWOT and PESTEL analyses were used in the analysis. The results revealed that the strengths of PSS, including innovation, include device unavailability, device overuse, and the shutdown of digital devices and electricity. These include technological complexity, high IT security requirements, and the need for organizational and cultural change. The main threats include economic uncertainty, the rapid deployment of cybersecurity threats, and increasingly stringent environmental and data protection regulations. These analyses are available because PSS can challenge the welding sector and provide comprehensive solutions, long-term development, and strategic application.

Keywords: Product-Service System (PSS); Product-Service System Development; Welding Industry; Welding Equipment

Introduction

Recent years have seen dynamic industrial development [1,2]. This focus is not only on technological issues but also on innovative business models that meet evolving customer requirements and align with sustainable development strategies [3,4]. Furthermore, changing market conditions, increasingly stringent environmental standards, and digitalization are forcing industrial companies to constantly seek new solutions [5,6]. All of this means that the operations of industrial companies are no longer determined solely by the production of tangible products, but also by the provision of closely related services [7,8]. This combination of products and services has led to the development of the Product-Service System (PSS) concept. It provides customers with access to products and services and aims to meet their requirements while efficiently utilizing resources. Furthermore, it supports environmental protection and aligns with sustainable development efforts [9,10].

The use of PSS in the welding industry could prove particularly important [11,12]. This sector is a fundamental sector of modern industry, and the welding processes it implements are essential for other industries [13,14]. The changes taking place in this sector have a direct impact on other sectors of the economy [15,16]. Currently, this sector is grappling with a wide range of challenges, including labor shortages, rising energy prices, tightening environmental regulations, the development of digitalization, and technological change [14,17]. Furthermore, the high costs associated with purchasing and operating welding equipment, as well as the long payback period for this investment, pose a significant challenge for welding shops. All these factors indicate that the traditional sales model for welding equipment is insufficient, and that this sector requires new business solutions [18,19].

This paper aims to examine the prospects for using PSS in the welding industry. It highlights the opportunities PSS can offer the welding industry. It also identifies and assesses the political, economic, social, technological, environmental, and legal factors that may influence the use of PSS in this sector. The study utilizes SWOT and PESTEL analyses. This study aims to help understand the opportunities and threats in the market environment and support the development of effective PSS for the welding industry.

This article goes beyond the general introduction to the PSS concept and presents a structured analysis focused on the welding industry. The main contribution of this research is focused on three points. First, it is new to the welding industry. This research is the first to systematize the possibilities for implementing PSS in the welding industry from strategic (SWOT) and macro-environmental (PESTEL) perspectives, identifying sector-specific strengths and weaknesses, as well as key external risks and opportunities. Second, it is the methodology and database used. The analysis is based on literature sources and market data (industry reports, price trends, company information, and industry statistics), and on an integrated SWOT and PESTEL analysis framework to evaluate PSS implementation. Third, it is the potential for practical application. Based on the obtained results, the article provides specific guidelines for welding industry players (selection of recommended PSS application options (product-oriented, use-oriented, performance-oriented)), decision criteria for financing and digitalization, and a risk checklist (technological complexity, IT security, regulatory compliance, economic uncertainty). Thus, the study not only provides a theoretical framework but also offers a decision-support tool for welding companies and equipment manufacturers, enabling them to implement PSS-based business models.

The paper is structured as follows: The first chapter is an introduction. The second chapter presents the concept of PSS. The third chapter describes the development of PSS. The fourth chapter describes the need for new solutions in the welding industry. The fifth chapter presents case studies of PSS use in welding. The sixth chapter presents strategic analyses of PSS for the welding industry. The final section contains conclusions.

Product-Service System

Servitization involves a shift from treating a product as a physical form to one where the tangible product is inseparable from a set of accompanying services, thus creating a Product-Service System (PSS). Productization, on the other hand, involves a shift from treating services as a non-physical form to one where services are inseparable from the associated tangible product [20,21]. The interpenetration of these trends focuses on a common understanding of the product and services as a whole [22,23]. This represents a completely new solution that provides customers with entirely new usability options. Such a PSS can be considered a market innovation that expands the classic functionality of a product by offering additional services along with it [24,25]. It is a technical and organizational system that defines how a physical product and services are interconnected and delivered to customers. Typically, a PSS guarantees functionality for the customer and reduces environmental impact. The fundamental elements of a PSS include [26,27]:

- physical product: a product manufactured for sale, meeting customer requirements,
- service: an activity that generates added value for the customer, implemented based on commercial principles.
- system: a set of relationships and elements between a physical product and a service(s).

PSS can also be defined as a system composed of physical products and services. In this system, the main components are designed and interconnected to meet specific customer requirements. Currently, PSS are perceived as an excellent instrument that simultaneously increases competitiveness and supports sustainable development. A business model based on PSS gives companies access to entirely new sources of added value because [28,29]:

- it meets customer requirements in a personalized and integrated manner, thus allowing customers to focus on their core business,
- it enables the establishment of unique relationships with customers, simultaneously maximizing their loyalty,
- it enables even more innovation by meeting customer requirements even more comprehensively.

PSS is also a business model that ensures sustainable development in consumption and production. It will be used by companies offering a combination of a product and related services. Scientific literature most often suggests a three-level classification of PSSs (product-oriented, use-oriented, and outcome-oriented). Each of these differs fundamentally in the meaning assigned to the product (physical part) and the principles of ownership. Product-oriented PSSs are characterized by the transfer of ownership of the physical product to the customer, while additional services are provided by the manufacturer. Usage-oriented PSSs are characterized by the retention of ownership of the physical product by the manufacturer. They provide the customer with the functions of the physical product through optimized distribution and payment systems. Outcome-oriented PSSs are characterized by the replacement of the physical product with services [21,30].

Product-Service System Development

The scientific literature provides a range of PSS development methods. A significant element is the diversity in how PSS is integrated into an enterprise's management system. Some methods implement PSS as a functional component of the production process or at the business model level – meaning that PSS is a strategic premise that determines a company's operations. Others discuss PSS as a component of a company's marketing strategy. Furthermore, researchers use various tools to develop PSS, including:

- the Deming cycle [31],
- the product life cycle [32],
- the QFD house of quality [33],
- the sustainable development concept [34,35],
- the SADT model (Structured Analysis and Design Technique) [36],
- the PMI approach (Project Management Institute) [37],
- IT tools and solutions such as CAD [38],
- the unified modeling language UNML 2.0 [39].

The common thread among available PSS design methods is the design phase. Authors typically distinguish phases such as planning, design, and implementation. Moreover, when developing new solutions, the most common steps include identifying customer needs and requirements, concept development, preliminary design, prototype testing, and implementation. The wide range of PSS development options described in the scientific literature, including design methods and supporting tools, underscores the enormous interest of researchers worldwide in this topic. Furthermore, the literature lacks information on the implementation of PSS in enterprises, its evaluation, and its performance outcomes [37,40].

The Need to Develop New Solutions in the Welding Industry

Due to technological changes, digitalization, and tightening environmental regulations, the welding industry is undergoing a revolution [41,42]. This revolution focuses on the modernization and development of welding equipment, which will maximize the welding capabilities of companies. Modernizing traditional welding processes, digitizing them, and combining them with new technological solutions is key. Furthermore, this sector demonstrates a number of needs related to defect reduction, improved weld quality, process automation, maximized production efficiency, and cost optimization [43,44].

Digital transformation, fueled by the dynamic development of Artificial Intelligence (AI), forces welding companies to implement modern IT solutions [45,46]. These solutions support welding by monitoring and predicting welding parameters, as well as process control. Modern digital solutions optimize welding processes, leading to error reduction, waste minimization, and a reduction in harmful environmental impact. Additionally, they increase productivity and enable compliance with stringent standards (e.g., EN ISO 3834, EN 15085, and ISO/IEC 62264) related to quality and safety [47,48].

Scientific literature and business practice indicate that the welding industry requires the implementation of new solutions [17,19]. However, such solutions require high initial investments related to the purchase and maintenance of welding equipment, digital infrastructure, and the development of employee competencies [49,50]. This fact means that a significant number of welding shops cannot afford such solutions. Such large investments are unattainable for many companies with limited budgets. Furthermore, the long payback period is discouraging [18,19].

These facts demonstrate a strong need to develop flexible, efficient, and innovative business models for the welding industry. The existing business models are no longer sufficient, and customers themselves are seeking comprehensive solutions [42,51]. In this context, business models based on PSS are gaining in importance. The introduction of new business solutions is particularly important here, not only from the perspective of product and service integration, but also due to labor shortages and rising energy prices [52,53]. Manufacturers operating in other industries are already implementing these types of solutions, while those operating in the welding industry have not yet recognized their potential. Business practice and research indicate that the use of PSS-based solutions improves equipment utilization, reduces maintenance risks, and supports the implementation of a circular economy [54,55]. Furthermore, this opens new revenue streams for welding equipment manufacturers and provides users with affordable access to equipment [56,57].

Product-Service System in the Welding Industry – Literature Cases

One of the few studies on PSS in the welding sector was conducted by Dambietz and colleagues. They point out that traditional welding solutions operate based on a product-based sales model, while services are merely an additional function. From a business perspective, this study has both theoretical and strategic significance. The authors used model-based systems engineering (MBSE) to develop PSS using a mobile laser welding system as an example. This solution combines product (hardware) and service elements in a single, integrated, modular architecture. Dambietz and colleagues demonstrate that PSS, in this case, enables the development of flexible solutions. The modular design and digital elements integrate the concept of digital servitization.

Dambietz and colleagues point out that welding equipment requires significant financial outlays, and many welding shops prefer to use it as a service or rent it rather than purchase it. Furthermore, operating it requires specialized knowledge that can be acquired through operator training, which is provided as a separate service module by the manufacturer. Moreover, the needs and requirements of welding shops are changing dynamically, intensifying the dynamics of service components and increasing the need for flexible, scalable solutions.

Dambietz and colleagues point to the welding process itself and the need to configure process parameters and related software. Furthermore, using MBSE for PSS development enables integrated modeling of service and product elements within a single data network. An example of this is the addition of a new optical unit to the system, which will be automatically visible in all service modules (logistics, training). The authors point out that during PSS design, modular PSS elements can be divided into three groups: product modules (including, among others, the optical system and the control system), service modules (including, among others, training and logistics), and mixed modules (containing both – these should be minimized to reduce complexity).

Using MBSE in PSS development is intended to ensure vertical consistency (data consistency across lifecycle stages) and horizontal continuity (tracking changes throughout the development schedule) in the PSS architecture. Moreover, MBSE's consistency checks and iterative support have led to an 80% reduction in errors. The mere use of PSS in the welding sector provides a strategic advantage by enabling quick adaptation to changing customer needs and requirements, optimizing costs through service scaling, increasing competitiveness, and building long-term customer relationships [58].

The authors of another study related to this topic proposed a solution based on PSS for Intelligent Welding Systems (IWS). They pointed out that this represents a new approach in welding. The developed solution offers intelligent technology-as-a-service, creating a complex ecosystem that combines physical, digital, and service-related elements. The authors focused on integrating physical elements (welding robots, sensors, support devices, network infrastructure) with services (maintenance, fault diagnosis, raw material supply, training, waste management) and digital elements (predictive maintenance, cloud data processing, a digital platform, and a mobile application), creating a complex PSS ecosystem for modern welding. The proposed solution guarantees access to the IWS for welding shops of all sizes without requiring investment. The manufacturer remains the owner of the IWS, while the welding shop operates it under flexible financing terms.

The authors' goal was to develop a theoretical model and a practical solution that precisely address the specific needs, requirements, and challenges of welding shops. This overcomes the financial barriers associated with high initial costs that hindered the modernization of welding equipment. This study fills a market niche and creates an opportunity to modernize the slowly digitizing welding sector. The study was conducted as part of research and training, as well as educational and design workshops, at a welding plant. The involvement of welding plant employees in developing the PSS through these workshops enhances the practical significance of the proposed solution.

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In another study, the authors proposed a PSS for the welding sector that combines welding machines and related services, grouped into categories. This solution utilizes flexible financing options that are significantly more affordable for welding shops than traditional purchasing methods. In this PSS, the welding machine remains in the manufacturer's hands, while the welding shop bears the costs of its operation and maintenance.

The researchers conducted a thorough analysis to identify welding process issues, as well as the company's expectations and requirements for welding machines and related services. The presented flexible financing options are more affordable for welding shops than traditional purchasing methods.

This study indicates that welding is not just a technological process but a complex ecosystem in which equipment and services play a fundamental role. Furthermore, the digitalization of welding is becoming increasingly important, offering a range of new development opportunities.

In the solution proposed by the authors, responsibility for the entire lifecycle of the machine is transferred to the manufacturer. The solution proposed by the authors aims to: eliminate or significantly reduce welding process problems, increase operational efficiency, and meet sustainable development goals [12].

SWOT and PESTEL Analysis

SWOT Analysis of Product-Service System in the Welding Industry

The welding industry is a fundamental sector of the economy, whose operation is essential for many other industries. As mentioned earlier, economic transformation and growing environmental requirements require the implementation of new business solutions. PSS seems to be a particularly promising solution. In the welding industry, it can lead to better utilization of raw materials and welding equipment, optimize costs, contribute to reducing the sector's environmental impact, and generate greater value for welding shops.

Implementing this type of solution is associated with a number of challenges. Therefore, a comprehensive analysis is necessary to reveal the internal and external criteria influencing the use of PSS. A SWOT analysis was used in the research process. This analysis is the most appropriate tool, allowing for simultaneous examination of the strengths and weaknesses, as well as the opportunities and threats of this project. Furthermore, its use is recommended because PSS represents a new business solution for the welding industry. From a strategic decision-making perspective, it is crucial for stakeholders (machine manufacturers and welding shops) to precisely define the benefits and internal limitations of this solution. Based on literature and market data, a SWOT analysis was conducted (Table I).

Table I SWOT analysis

No.	Strengths	No.	Weaknesses
1.	An opportunity for innovation	1.	Technological Complexity
2.	Extending the lifespan of welding equipment	2.	Logistical Challenges
3.	Sustainable development	3.	Data Security Threats
4.	Flexible financing	4.	Complex Contracts
5.	Digitalization of the welding sector	5.	Need for Cultural Change
6.	Strengthening customer relationships	6.	Difficulties with System Integration
7.	Fast error response	7.	Lack of Skilled Employees
8.	Increased energy efficiency	8.	High IT Security Requirements
No.	**Opportunities**	**No.**	**Threats**
1.	Strengthening sustainable development trends	1.	Economic uncertainty
2.	Digitalization expansion	2.	Rapid technological change
3.	Development of new business models	3.	Cybersecurity threats
4.	Access to modern technologies for smaller companies	4.	Rapid shifts in customer expectations

5.	Connecting and accelerating robotization and welding automation	5.	Intense market competition
6.	Supporting the circular economy	6.	Stronger data protection regulations
7.	Optimization based on modern technological solutions	7.	Stronger environmental requirements
8.	Research collaboration	8.	Disruptions in the global supply chain

PSS offers a range of benefits to the welding sector, primarily in critical areas. Strengths include innovation, environmental protection, and digitalization. Weaknesses stem from technological complexity and high initial costs. Opportunities, on the other hand, are strongly linked to global trends that are expected to ensure long-term growth. Threats, however, primarily come from external factors such as economic instability, supply chain disruptions, and cybersecurity. The analysis indicates that PSS has significant potential in the welding sector, but it is complex, requiring digital infrastructure and a robust service network to achieve sustainable market success.

PESTEL Analysis of Product-Service System in the Welding Industry

PESTEL (political, economic, social, technological, environmental, and legal) assesses macro-environmental factors, reflecting the model's impact on society and vice versa (Table II).

Table II PESTEL Analysis

No.	Political	No.	Economic
1.	National and international welding development strategies	1.	Growing demand for welding services
2.	Regulations promote environmentally friendly solutions	2.	Inflation
3.	Subsidies for welding robotics and automation	3.	Rising interest rates
4.	Innovation policy	4.	High energy prices
5.	Increasing requirements for meeting safety and quality standards in welding	5.	Demand for flexible financing
6.	Tax incentives	6.	Investment in digitalization is growing
7.	Harmonization of welding regulations	7.	Competition in the welding market
8.	Job creation policy	8.	Fluctuations in raw material prices
No.	**Social**	**No.**	**Technological**
1.	Labor shortage, including skilled welders	1.	Development of automated and robotic welding processes
2.	Growing environmental awareness among customers	2.	Development of remote diagnostics and service technologies
3.	Social pressure for sustainable development	3.	Use of artificial intelligence in welding
4.	Employee openness to digital technologies	4.	Cybersecurity
5.	Growing employee expectations regarding ergonomics and occupational safety	5.	Modularity, interoperability, interoperability, and hybridity of welding solutions
6.	Demand for customer-oriented solutions	6.	Technological scalability
7.	Generational change in the labor market	7.	Digitalization of welding machine functions
8.	Training needs	8.	Development of autonomy in welding stations
No.	**Environmental**	**No.**	**Legal**
1.	Development of energy-efficient welding technologies.	1.	Application of quality standards in welding
2.	Regulations for reducing carbon dioxide emissions	2.	Changes in requirements for welding rooms and stations
3.	Requirements for improving energy efficiency	3.	Tax changes
4.	Requirements for recycling and reducing welding waste	4.	Strengthening environmental regulations
5.	Requirements for hazardous waste management	5.	Strengthening cybersecurity regulations

6.	Support for solutions based on the circular economy	6.	Strengthening occupational health and safety regulations
7.	Development of sustainable raw materials and welding consumables	7.	Changes in foreign trade regulations
8.	Environmental audits and certifications	8.	Protection of intellectual property rights

The PESTEL analysis highlights a number of fundamental factors influencing the development of PSS for welding. The political category highlights factors related to innovation, development strategies, the promotion of environmentally friendly solutions, and systemic incentives that can foster the development of PSS for the welding industry. These factors indicate that there is a demand for such solutions and could accelerate their widespread adoption.

In the economic sphere, demand for welding services will support this solution. Factors such as fluctuating raw material prices, energy prices, and inflation exacerbate the cost sensitivity of welding shops. Furthermore, these factors pose challenges for welding shops that can further stimulate the use of PSS. Flexible financing options available in PSS-based solutions will lead to predictable cost distribution and reduced investment risk for welding shops. All this, supported by investments in digitalization, will significantly increase the attractiveness of PSS for welding.

At the societal level, a noteworthy fact that poses an urgent challenge is the generational shift and the shortage of specialists, especially welders. This is increasing demand from welding companies for automated, digitally assisted welding stations. PSS can contribute to improving the quality of training, knowledge transfer, and the management of the work environment and its ergonomics, meeting the needs of service welding shops in this area and increasing their attractiveness as a workplace. Furthermore, the constantly growing environmental awareness of employees is increasing the demand for environmentally friendly industrial solutions.

From a technological perspective, PSS guarantees access to innovative welding solutions and technologies. Furthermore, this solution provides flexibility, scalability, and the ability to be customized for a specific welding shop.

Environmental factors point to the development of environmentally friendly solutions and simultaneously compel welding shops to implement them. This can, in a sense, drive the development of PSS for welding, which is based on a circular economy, innovative recyclable materials, and extended welding equipment lifespan. This aligns with new environmental regulations and brings environmental benefits.

In the legal category, cybersecurity, as well as occupational health and safety, pose challenges. The advantage of PSS is that the manufacturer who supplies welding machines and related services also takes responsibility for legal compliance. This minimizes risks for welding shops and ensures reliable and safe long-term cooperation.

The analysis indicates that PSS for the welding industry addresses a number of challenges facing this sector. It also guarantees a business model that provides a long-term competitive advantage for companies operating in this sector. Furthermore, it meets increasing legal and environmental requirements.

Conclusions

PSS focuses on integrating products and services into a single, coherent solution that delivers both physical assets and closely related services to the customer. Based on the literature review and analysis, it can be concluded that PSS is both a new business model and a strategic direction that enhances competitiveness and supports sustainable development. Implementing this solution in the welding industry, which is heavily influenced by automation, legal and environmental requirements, and human resources, is justified. Furthermore, it can be concluded that PSS offers a new perspective for this industry and has the potential to fundamentally change its operational logic.

The welding industry is currently facing various challenges. Among the most significant are the lack of skilled labor, high investment costs, and growing demands and increasingly stringent environmental and legal standards. PSS offers a way to address these challenges. In the well-known traditional model of purchasing welding equipment and its maintenance and upkeep, these represent a significant burden for welding companies, particularly those in the micro, small, and medium-sized enterprise sector. PSS minimizes financial risk and eliminates high entry barriers by enabling welding shops to use welding equipment as a service with predictable costs.

The global expansion of digitalization also means the development of digital solutions for the welding industry. Innovative data-driven welding solutions enable the development of new services related to welding equipment. Predictive maintenance, real-time monitoring, data analysis, and online employee training are becoming an integral part of this solution. Providing welding shops with such equipment-related services increases welding efficiency and quality, supports the rapid detection of errors and faults, and reduces defects.

The generational shifts and welder shortages evident in the welding industry are additional factors justifying the need for PSS development in this industry. PSS supports minimizing the shortage of experienced workers through knowledge transfer and education provided through training courses. New employees in the labor market, despite being very open to digital solutions, are also clearly indicating their need for an ergonomic and safe work environment. Legal and environmental issues also play a significant role in the welding industry. Increasingly stringent regulations regarding waste recycling, carbon dioxide emission minimization, cybersecurity standards, and occupational health and safety regulations are driving the need to develop new, yet flexible solutions that comply with these regulations. PSS allows the welding equipment manufacturer to assume responsibility for certain issues, freeing the welding facility from this responsibility, significantly improving its safety.

The cited literature confirms a number of benefits resulting from the use of PSS in the welding industry. They indicate that PSS can ensure transparency, iterative development, and minimize defects. They emphasize that PSS can accelerate the modernization and use of new digital tools and technologies in the slowly digitizing welding industry.

In summary, in the long term, PSS can simultaneously provide an alternative to traditional machinery purchases and a competitive business model for the welding industry. Combining welding machines and related services allows for increased flexibility, cost optimization, and reduced environmental impact. The aim of further work is to conduct survey research and develop a PSS for the welding industry.

This work suggests that Product–Service Systems (PSS) are an alternative sales model for welding and could support sustainability and better cost efficiency of welding. Welding equipment makers should create modular PSS architecture in order to allows digital services to be implemented. For welding shops, PSS could be used optimally when decisions will be based on life-cycle costs. The staff training should be focused on intelligent welding systems. This work is based exclusively on the secondary data. Therefore, it is strongly recommended for the future research to use various type surveys as well as case studies. The objective would be to develop indicators for measurement of PSS effects on costs, productivity, and sustainability.

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