Smart Product-Service System for Intelligent Welding System

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Abstract. This paper aims to design a conceptual model of a Smart Product-Service System (SPSS) for Intelligent Welding System (IWS). To achieve this goal, a detailed literature review, analysis of the welding industry (WI), and a training-educational-design workshop on SPSS and IWS were conducted at a business partner, a welding plant. This allowed the researchers to develop an SPSS in which the tangible component is the IWS (welding robot, sensors, monitoring devices, supporting devices, network infrastructure), enriched with an intangible component, i.e., services and a digital component in the form of a platform and a mobile application. Focusing on specific problems, requirements, and needs of welding plant employees, the developed model aims to draw attention to important elements of the plant in the context of global digital transformation and environmental protection. Thanks to this solution, the WI receives several advanced innovations integrating digital technologies, services, and automation. Additionally, the approach to developing SPSS presented in the article emphasizes the need to combine theoretical knowledge with practical knowledge in welding. This contributes to developing innovative training, education, and design methods for innovative solutions in the digital era.

Keywords: Smart Product-Service System (SPSS), Smart Product-Service System (SPSS) Design, Intelligent Welding System (IWS), Welding Industry (WI).

1 Introduction

Modern manufacturing companies increasingly realize that providing traditional product-based solutions generates a tiny competitive advantage and value for the customer [1]. In addition, production and sales must be expanded to cover global trends related to environmental protection [2]. In addition, manufacturers must provide comprehensive solutions that include both products and services to meet market dynamics, growing technological innovations, and customer needs and requirements [3]. All this means that they are increasingly moving from traditional forms to combinations of products and services [4]. These combinations are commonly known as Product-Service System (PSS) [5]. They are defined as an integrated package of products and services that aims to create utility and functionality for the customer and generate new added value for him [6].

The rapid development of information and communication technologies (ICT) has enabled the global digital transformation (DT) of the economy [1]. Digital technologies have begun to be used to create and offer new values and generate revenues [7]. DT went hand in hand with developing digital servitization by integrating intelligent technologies with PSS [8]. This has become a fundamental element of the changing environment and has led to the emergence of the Smart Product-Service System (SPSS) [9]. SPSS is a business-oriented, customer-specific suite of digitalized and

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well-integrated artifacts in physical hardware, services, and software that deliver more excellent value than when used separately [7]. SPSS is characterized by an interactive and iterative problem-solving process in a customer-integrated value network spanning the entire customer life cycle [10]. This solution enables continuous adjustment of its components to changing buyer needs and supplier capabilities[11]. In this way, it opens a continuum that guarantees flexibility and adaptability in a long-term business relationship and supports the diffusion of new technologies (NT), and innovative solutions[8].

DT has a significant impact on industrial production [12, 13]. Revolutionary technologies implemented in industrial practice are used to automate processes, monitor in real-time, manage integrated systems that combine computational capabilities with material resources, and reduce environmental impact and costs [14]. Many traditional industrial processes have become obsolete, while digitally based industrial processes have become an indispensable element of intelligent production [15]. An intelligent production system is a combination of automated intelligent machines that can make precise decisions based on available data and information. In addition, such a system can more accurately and independently control production processes. In addition, it contributes to eliminating problems related to waste generation and disposal, emission of pollutants, and electricity consumption [16].

Welding is one of the important areas of industry, and the issues discussed are of particular importance [17]. The development and dissemination of the Intelligent Welding System (IWS) is a fundamental factor for modern welding [18, 19]. These advanced technological innovations allow the transformation of traditional welding processes into automated, intelligent, efficient, and precise production systems that respond to the requirements of today's industry sector [20]. The development of IWS focuses on the integration of modern technologies (Artificial Intelligence (AI), Machine Learning (ML), Intelligent Digital Twin (IDT), Cyber-Physical Systems (CPS), and the Internet of Things (IoT)) [18]. The fundamental goal of IWS is to maximize the flexibility, quality, and efficiency of welding processes while minimizing costs, reducing the negative impact on the environment, and adapting to the dynamically changing needs of the market [19].

This paper aims to develop a Smart Product-Service System (SPSS) for Intelligent Welding System (IWS). The solution was developed based on research and training-educational-design workshops in a welding shop (WS) focused on producing pressure vessels and steel elements for overhead cranes, hoists, and cranes. Thanks to SPSS for IWS, several advanced innovations integrating digital technologies, services, and automation will be introduced to the welding industry (WI). This aims to increase the flexibility, quality, and efficiency of welding processes. By enabling WSs to have easier access to IWS and advanced technologies without the need for high initial costs associated with the purchase. This solution will accelerate the digitalization process of the WI and the dissemination of innovative solutions, making them affordable for interested companies. The IWS manufacturer offers welding robots, AI-based software, sensors, and cloud services for process management and monitoring as part of SPSS. In addition, it is responsible for the supply of materials, technical support, and services. The WS, in turn, receives access to IWS, which increases welding efficiency, improves weld quality, and allows for cost optimization through real-time data analysis and predictive maintenance. Additionally, they do not have to worry about issues related to the purchase, storage, and disposal of raw materials, which allows them to focus on their core business. Thanks to its flexible financing, SPSS has introduced a revolutionary and comprehensive solution to the WI, available to every WS. This allows for implementing low-emission and energy-intensive solutions based on NT, thus supporting the protection of the natural environment.

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The paper is structured as follows: the first part is the introduction. The next part presents the research methodology. The third part contains the systematic literature review (SLR). The fourth part presents the analysis of the WS. The fifth part contains Smart Product-Service System for Intelligent Welding System. The last part are the conclusions.

2 Research Methodology

The paper aims to develop a Smart Product-Service System (SPSS) for Intelligent Welding System (IWS). The paper addresses the following research questions:

- What is the potential of using SPSS for IWS in the WI?
- Will SPSS for IWS contribute to improving DT and disseminating intelligent solutions in the WI?
- What is the potential of training-educational-design workshops in developing skills to create new SPSS?

The research methodology adopted in the work included the following steps:

1. Literature analysis - a systematic literature review (SLR) was used in this step. The research was divided into three equal analyses. The first focused on reviewing the industrial application of SPSS/PSS, the second concerned SPSS/PSS design methods, and the third the need for a new business and technological solution for the WI. Leading scientific databases were used for SLR, where the phrases "SPSS/PSS in industry" and synonyms were searched. The search assumptions concerned publications from 2000-2023 in English. 150 scientific papers focusing on SPSS/PSS in industry were found.
   Then, the authors searched for "SPSS/PSS design" and synonyms in the previously indicated databases and time range and conducted SLR on SPSS/PSS design methods. This review identified 74 scientific papers presenting 70 SPSS/PSS design methods.
   Then, a study of the demand for a new business and technological solution for the WI was conducted using the same scientific databases and time range. The authors searched for the phrases "welding," "intelligent," and "businesses" and their synonyms. This analysis enabled the identification of 150 scientific papers indicating the need to develop new solutions for welding.
2. Analysis of the WI. This step focused on the analysis of manufacturers and users of welding machines. Industry reports, sector analyses, and statistical yearbooks were used here.
3. Research and analysis of a WS. A survey was conducted in a WS whose activity focuses on producing pressure vessels and steel elements for overhead cranes, hoists, and cranes. It concerns the situation related to the DT of the WS, SPSS, and IWS used there. The survey was composed of closed and open-ended questions. Some closed questions took values from 0 (very negative) to 10 (very positive).
4. Training, educational and design workshop on SPSS for IWS. In this step, interactive and multimedia training of WS employees was conducted on SPSS and IWS dedicated to the WI. Each substantive part contained a case study on SPSS, which precisely described how this model works in various industries. The method of operation and correct practices related to the use of IWS were presented. After the training, an educational exercise was conducted. It consisted of developing a solution combining SPSS and IWS. Participants worked in groups. They identified

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the problems that SPSS was to solve. Analyzing the WS from different perspectives, they determined its needs. Then, they identified the conventional and digital services they needed and the technologies that supported them. Finally, each group presented its solution, considering the benefits of the WS and the potential challenges associated with its implementation. After the groups' presentations, a feedback session was organized. In this session, other participants evaluated the projects, indicating areas for improvement and their strengths. Then, the recurring and most inspiring elements were selected based on the discussion. Finally, a summary discussion was held. During this session, the employees jointly concluded the SPSS design process for IWS and the knowledge and experience gained in connection with it.

5. Smart Product-Service System (SPSS) for Intelligent Welding System (IWS). This step concerned building SPSS for IWS. All the knowledge obtained in the previous research steps was used here. This allowed the researchers to develop an SPSS in which the tangible component is the IWS (welding robot, sensors and monitoring devices, supporting devices, network infrastructure), enriched with an intangible component, i.e., services, and a digital component in the form of a platform and a mobile application. Then, the researchers presented their solution to the company's employees and subjected it to a company-wide discussion and assessment. This allowed for the improvement of the presented solution and the development of the final SPSS.

3 Systematic Literature Review

3.1 Product-Service System in Industrial Practice

This stage focused on the analysis of SPSSs operating in the industry. Leading examples include Tesla, Philips Hue, Amazon Echo, John Deere, GE Predix, Apple Watch, Nest Thermostat, Siemens MindSphere, BMW ConnectedDrive, and Dyson Air Purifier. The analyzed SPSSs were developed in large corporations and used in various economic sectors. A long service life and high value characterize these solutions. They use advanced technology to collect and analyze data in real-time. They are supported by integrated digital platforms, allowing their users to access various digital services easily. Their level of technological advancement depends on the target group and industry. They have significant potential for adapting to customer requirements and maximizing efficiency. It should be emphasized that no solution used in welding was found among the analyzed SPSSs operating in the industry [21, 22].

3.2 Product-Service System Desing

The literature on SPSS/PSS design provides 70 design methods. Their analysis indicates that only 19 have been verified in industrial practice. The most significant number, 13 methods, have been assigned to the domestic appliances, consumer electronics, and other equipment sector, while 14 of them have not been assigned to any sector of the economy. Furthermore, the analysis does not provide SPSS/PSS design methods addressed to the WI. The analysis indicates that some methods are addressed to the design of several types of SPSS/PSS. Out of the 70 methods, as many as 20 can be used to design all types of PSS. In turn, the most significant number, 64 methods, can be used in the design of service-oriented SPSS/PSS. The analyzed methods emphasize the need to maximize customer value, analyze the product life cycle, and identify points of contact between

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manufacturers' capabilities and customers' needs and requirements. The analysis also indicates their high universality and various readiness levels for digital solutions [23, 24].

3.3 Demand for a New Business and Technological Solution for the Welding Industry

The analyzed literature indicates that dynamic changes in technology, environmental protection, and growing requirements of industrial partners are causing revolutions in the WI [17, 25]. It concerns not only individual machines but also complex systems, enabling a significant increase in the production capacity of WS [17]. Modernizing traditional welding processes through integration with advanced digital technologies plays a fundamental role in this revolution. This sector's needs include improving the quality of welds, minimizing defects, optimizing costs, increasing production efficiency through process automation, and using real-time monitoring [18, 19].

Growing needs require implementing AI-based systems that can predict weld quality parameters (penetration, weld thickness, self-adaptation to changing working conditions) [14, 26]. ML algorithms and infrared thermography technology (IRT) can be used to monitor and control processes [27]. All this will significantly minimize the occurrence of errors and material losses. Implementing innovative solutions such as IDT, multi-sensor IoT platforms, or vision systems for quality control enables real-time data analysis and optimization of welding processes [28]. They influence the maximization of efficiency and allow for meeting restrictive standards regarding quality and safety, including EN ISO 3834, EN 15085, or ISO/IEC 62264 [29, 30].

The implementation of innovative welding solutions such as IWS requires significant initial investments [31]. These investments are mainly related to purchasing and maintaining equipment, digital infrastructure, and employee training [32]. This shows that not every company can afford this type of solution [33]. Such initial costs are harrowing and sometimes unaffordable for micro, small, and medium WS with a limited budget [34]. Implementation costs and a long payback period discourage them additionally [35]. In this context, WS expect to develop and introduce flexible solutions to the market, giving them access to innovative solutions without incurring substantial investment costs [36]. Developing such solutions will allow for a faster transformation of the WI and the dissemination of new solutions [37, 38].

4 Welding Industry and Welding Machines

The most important markets of this WI include China, the USA, South Korea, Japan, India, and the countries of the European Union. Its global value in 2022 is 23.75 billion dollars. In Europe, it is an industry with a long tradition that generates innovation and many jobs. The WI is one of the key industries of the global economy, and it integrates versatility, durability, and strength. These features make this industry an indispensable element of other sectors (industrial production, construction, automotive, energy, and many others), in which they are responsible for the production of structures and parts. Products of this sector are precise in their artistry and flexible in generating complex shapes. These features guarantee their broad application and the possibility of adapting to various customer needs. The welding process allows for the production of strong and durable connections (welds) between metals or thermoplastics, which are often characterized by strength equal to or greater than the materials they connect. Welding integrates versatility, durability, and strength.

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The WI is founded on machines ranging from portable conventional welding machines to technologically advanced robotic welding stations. They are characterized by a long service life, versatility, and the possibility of implementing innovative solutions. Technological progress influences the dynamic development in welding precision and efficiency, as well as improving work safety and reducing environmental impact. Currently, the leading manufacturers of this equipment include Kemppi, Fronius International, Electric, ESAB, Miller, and Lincoln Electric. These companies offer a wide range of machines and devices in various equipment options for the WI, together with essential services during the warranty period.

In the era of dynamic DT, well-known welding processes, although practical, encounter several limitations related to efficiency, precision, environmental protection, and costs. This indicates the need for change and combating challenges to prevent stagnation. The answer to this is IWS, which revolutionizes the way welding work is performed. They introduce advanced digital technologies to the industry and allow repetitive work automation, which significantly increases quality and efficiency. Thanks to such solutions, it is changing its face, becoming environmentally friendly and modern. Implementing these solutions involves high initial costs, primarily equipment and digital infrastructure investment. The investment size can be a massive barrier for micro, small, and medium-sized WS because they usually have minimal budgets for updating their machinery. However, the long-term benefits resulting from the implementation of IWS usually outweigh the very high initial costs. Therefore, the WI is looking for solutions that will reduce financial barriers and allow for the popularization of IWS.

5 Welding Shop Analysis

5.1 Characteristics of the Analyzed Welding Shop

The analyzed WS focuses on pressure vessels and steel elements for cranes, lifts, and jib cranes. This small company has been operating on the market for over 15 years. The analyzed WS uses MAG, TIG, MIG, and MMA welding methods. In production, unalloyed steel of ordinary quality and unalloyed steel of increased strength are used. The machine park consists of 10 machines and 1 robot. There are 6 welding machines and 1 device for thermal cutting of metal materials with plasma and oxygen. The WS also has a shot-blasting plant converted into a machine for the surface treatment of metal materials using the shot. The annual mass of manufactured structures is about 240 tons, and the consumption of additional materials is about 300 kilograms. The structures are manufactured here by EN ISO 3834 (lift structures), and the EN ISO 3834 standard (pressure structures). The overall percentage share of welding processes in the production of the entire structure is 40%, while automated welding is 20%. The company employs 5 welders, 4 people in the welding supervision staff, and 6 people in the non-destructive testing staff. The company has used the machines for no more than 15 years. The ones currently in use are 10 years old. New machines are purchased once every 2 years for the company's funds. The company operates in a 1-shift system (8 hours of work) and produces 30 products. In 2023, it achieved an annual turnover of about EUR 800,000. In recent years, the analyzed company began to invest in welding automation, as evidenced by purchasing a welding robot worth EUR 50,000, which increased production efficiency.

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5.2 Survey of the Welding Shop

In the survey, the WS rated its level of use of: NT at 4, AI at 5, wearable technologies (WT) at 2. The level of satisfaction with the use of NT is 4, AI is 5, and WT is 3. Additionally, it indicates the need to develop AI-based solutions for welding (9). The company also drew attention to the need for harmonious cooperation between people and welding equipment. This factor was rated very high (9). The same rating (9) was given to support for operators and welders in the form of virtual AI consultants and the development of human-machine interfaces. Staff training is becoming a significant need in the field of NT and IWS. This is supported by a rating of 6. This fact is related to the company's concerns in using these solutions by its employees (1). The WS also indicates the need for data protection (9) and is afraid of cyberattacks (7). The study shows that the WSop shows high interest in the development of automation in welding and IWS, as evidenced by the ratings of 8 and 9. The company indicates the need to improve welding efficiency and increase the repeatability and precision of welds. It also emphasizes that this is possible thanks to the use of IWS supported by AI and ML. The company rated 9 for the use of real-time monitoring systems. This fact refers primarily to the need to optimize welding processes (7), reduce defects (8), and minimize the impact on the environment (9). In questions about the use of NT, the company rated the possibility of using IoT as 8, IDT as 7, augmented reality (AR) as 7, and Big Data as 6. The company noted that the above NT can improve resource management, connect welding equipment, and collect, simulate and analyze data and the welding process. The company draws attention to the services accompanying the purchase of machines (7) and indicates that their purchase should be associated with a service contract (8). It rates the need to add digital services to welding equipment very high, at 7. An important factor for the WS is the reduction of material and energy consumption and the reduced waste generated. This is reflected in the rating of 7. This emphasizes the need to invest in new, low-emission technologies and business solutions that fit into the trend of environmental protection. Issues related to incurring investment costs in IWS were rated 3. This indicates concerns and difficulties in implementing such a capital-intensive investment for a company of this size. The WS indicates that support for it would be an alternative IWS financing model tailored to its needs, which it rates 8. It would eliminate high investment costs and enable the use of new solutions. The company shows a high level of interest in solutions based on SPPS, as evidenced by the rating of 7. The factors motivating the use of SPSS indicate an increase in resource management efficiency, no need to incur high investment costs, reduction of barriers related to the use of expensive NT, and quick access to consumables and spare parts.

6 Training, Educational and Design Workshop

6.1 Training and Educational Session

At this stage, training was conducted. It was designed to be a comprehensive educational program, combining practical and theoretical elements. Interactive multimedia elements with case study analysis were used here. The training aimed to improve WSop employees' competencies inf DT, SPSS, and IWS.

The first stage of the training was a theoretical introduction to SPSS and IWS. The company's employees were introduced to the concept of product and service integration and the origins of PSS/SPSS. Issues related to the classification and design of PSS/SPSS were discussed. Information about IWS, their use, application, and the possibilities and opportunities they offer in welding were

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presented. Issues related to digital technologies, their evolution, and their impact on welding precision, efficiency, and quality were also discussed. At this stage, multimedia presentations enriched with animations were used. Additionally, an interactive quiz was conducted after each discussed issue.

The next stage of the training concerned a case study session. It was presented how PSS/SPSS works in various industrial sectors. The focus was on the leading cases: Tesla, Philips Hue, Amazon Echo, John Deere, GE Predix, Apple Watch, Nest Thermostat, Siemens MindSphere, BMW ConnectedDrive, Dyson Air Purifier. Each case was discussed in detail, and its unique features were described. Their strengths and benefits for manufacturers and customers were indicated. In this stage, multimedia presentations were used, enriched with videos with expert statements and opinions. Additionally, after each discussed case study, a question and answer session was held to encourage WS employees to ask questions about the presented cases.

The third stage of the training focused on a detailed presentation of the IWS. It presented what the IWS consists of, how it works, and how much it costs. The WS employees were shown some of the functions, including the operation of vision systems and sensors to monitor welding parameters in real-time, automatic calibration of welding equipment, and IoT to connect it and send data for analysis in the cloud. Videos, photos, animations, comparative studies, and simulation software supported this stage. In addition, at the end of this stage, each participant had the opportunity to familiarize themselves with the software and conduct an individual IWS simulation. Employees tested how changes in various parameters affect the quality of welds. Then, the simulations were compared with the results achieved in the company.

The fourth stage of the training concerned correct practices related to implementing IWS. Attention was focused on capital needs and the need to train staff. Methods of planning welding processes using NT and issues related to predictive maintenance and maintenance were discussed. In this case, attention was paid to analyzing operational data from sensors. Issues of data management, production optimization, and digital security were discussed. This stage presented possible errors, barriers to implementation, and methods for avoiding them. Films provided support here with examples of WS and individual interviews with WS employees.

6.2 Design Session

The next stage of the workshop was a design session with an educational exercise, which consisted of developing a solution combining SPSS and IWS. Based on the knowledge they had already acquired, the employees carried out this exercise in groups representing different areas of the company's operations. Each group began its project by identifying the WS problems. In the next step, each group identified the needs of the WS. Then, the employees identified the conventional and digital services that should be added to IWS in the developed SPSS. Then, the groups focused on NT, which would support SPSS. In the next part, they indicated financing models that would benefit the company. The results of each group's work are presented in Table 1.

Table 1. Requirements set for PSS for IWS by welding shop employees.

	Group 1	Group 2	Group 3	Group 4
Problems	Calibration difficulties	Lack of process repeatability	Insufficient surface preparation	Welding robot programming
	Production downtime	Excessive consumption of raw materials and materials	High costs of quality corrections	Long project implementation time
	Ineffective diagnostics and maintenance of equipment	Excessive energy consumption	A large number of weld defects	Long response time to emerging problems

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	Insufficient use of process data	Generation of large amounts of waste	Insufficient visual inspection of welds	Lack of technical support for equipment
Needs	Automation of complex processes	Optimization of production processes	Improve equipment maintenance	Shortening project implementation time
	Access to new technological solutions	Elimination of production downtime	Minimize the risk of defects	Reduction of human errors
	Improvement of the use of process data	Comprehensive analysis of welding processes	Increase welding accuracy, precision and repeatability	Improvement of ergonomics and work safety
	Remote monitoring of welding parameters in real time	Waste disposal	Improve quality control	Welding robot programming training
Conventional Services	Monitoring and diagnostics of welding equipment	Recycling and waste management	Supply of filler metal and technical gases	Training
	Installation and commissioning	Equipment rental	Supply of raw materials and materials	Welding equipment service and maintenance
	Maintenance of tools and auxiliary equipment	Take-back	Supervision of the welding process	Analysis of failure causes
	Optimization of welding processes	Spare parts and consumables	Technical consulting	Warranty
Digital Services	Automatic calibration	Monitoring of welding process contamination	Automatic quality analysis	Training platform
	Automatic firmware updates	Automatic energy management	Remote technical support in real time	Cybersecurity services
	Offline programming for welding robots	Adjustment of machine parameters to individual needs	Access to welding parameter libraries	Predictive service
	Advanced multidimensional analyses in real time	Remote monitoring of welding parameters in real time	Automatic detection of weld defects	Cloud data analysis
New Technologies	IoT	AI	IDT	Augmented reality (AR)
	Cloud Computing (CC)	ML	CAE (Computer-Aided Engineering) platforms	Virtual reality (VR)
	Big Data (BD)	Edge Computing (EC)	Metaverse (M)	Blockchain
Forms of Financing	Subscription model with monthly fees	Rental with purchase option	Leasing	Payment for time of use

Then, a presentation session was held. During this time, each group presented the results of their work (Table 2) and discussed them in detail. Each group highlighted the unique elements of their solutions, which resulted from their experiences and analyses of the WS. The presentations showed that Group One focused on welding automation, Group Two on issues related to sustainable development, Group Three on quality issues, and Group Four on staff development.

After the presentations, a feedback session was held. Participants asked questions, discussed strengths and areas requiring improvement of the developed solutions, and indicated the benefits resulting from them. This session showed that the solutions proposed by each group complement each other. It also indicated recommendations regarding SPSS. The results of this session's work are presented in Table 2.

Table 2. Feedback session - results of the work.

Strengths	Areas for improvement	Benefits	Recommendations
Automation and digitalization of processes	Better integration of digital systems with existing infrastructure	Increased production efficiency	Combination of solutions proposed by the groups
NT application	Employee training	Improved weld quality	Cooperation with the IWS manufacturer and suppliers
Minimization of energy consumption and waste reduction	Consideration of data security issues	Reuse of materials	Education of staff regarding long-term savings
Promotion of sustainable development	Adaptation to changing standards and regulations	Support for the DT of welding	Systematic analysis of the WS needs
Financial flexibility and cost reduction	Reduction of emissions and carbon footprint	Alignment with environmental protection programs	Cooperation in interdisciplinary teams

7 Smart Product-Service System for Intelligent Welding System

The final solution was developed in this chapter using the knowledge and fundamentals of PSS/SPSS design acquired so far. In the developed solution, the tangible component is the Intelligent Welding System (welding robot and welder, sensors and monitoring devices, supporting

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devices, network infrastructure), enriched with an intangible component, i.e. services, and a digital component in the form of a platform and mobile application. Then, the researchers presented their solution to the company's employees and subjected it to a company-wide discussion and evaluation. This allowed for the improvement of the presented solution and the development of the final SPSS. The results of the work are presented in Table 3, Figure 1, Table 4.

The company producing the IWS makes it available to its customers and provides them access to a wide range of services. Settlements are based on a flexible financing model tailored to the needs of the WS and dependent on the period of use of the IWS. Ownership and maintenance of the IWS remain with the manufacturer; the WS only uses this solution. The priority for the WS is to use a modern solution that will positively impact its digitalization and increase the number of welded structures produced. After the specified period of use, it is possible to replace the IWS with a newer or updated model.

Table 3. Smart Product-Service System for Intelligent Welding System – Components.

Category	Component	Description
Tangible Component	Welding robot and welding machine	Welding automation, increasing welding efficiency and precision
	Sensors and monitoring devices	Collecting various types of data on the welding process and its parameters
	Support devices	Accessories that increase the functionality and capabilities of welding (welding tables, manipulators)
	Network infrastructure	Hardware and software enabling communication between devices and employees
Intangible Component	Conventional services	Analysis of failure causes, technical consulting, supply of raw materials and materials, supply of filler metal and technical gases, warranty, installation and start-up, monitoring and diagnostics of welding equipment, supervision of the welding process, optimization of welding processes, recycling and waste management, service and maintenance of welding equipment, training, take-back, maintenance of tools and auxiliary equipment, equipment rental
	Digital services	Cloud data analysis, automatic quality analysis, automatic calibration, automatic firmware updates, automatic detection of weld defects, automatic energy management, access to welding parameter libraries, adjustment of machine parameters to individual needs, monitoring of welding process contamination, offline programming for welding robots, predictive service, training on a digital platform, cybersecurity services, advanced multidimensional analyses in real-time, remote monitoring real-time welding parameters, real-time remote technical support
Digital Component	IWS digital platform	A tool that connects welding equipment, services, and data into a coherent ecosystem within SPSS
	IWS mobile application	A tool that allows access to the IWS digital platform functions from mobile devices
New Technologies	IoT	Integration of devices in the network, allowing real-time data exchange
	AI	Automatic welding parameter settings and data analysis
	AR/VR/M	Visualization of welding processes and training in a virtual environment
	IDT	Creation of digital models of IWS and welding processes for simulation and optimization
	CC	Storage and analysis of large data sets on the use of IWS and welding processes
	EC	Data processing directly on welding equipment
	ML	Identification of patterns based on welding data and optimization of processes based on data
	Blockchain	Ensuring transparency and data security during the life of the IWS
	BD	Analysis of large data sets on information on current, voltage, wire feed speed, welding speed and time, and job numbers.

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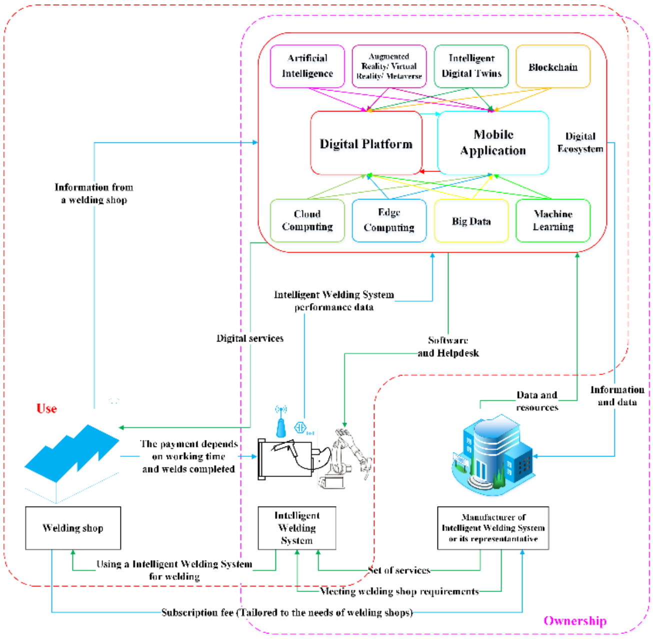

Fig. 1. Smart Product-Service System for Intelligent Welding System - Concept.

Table 4. Smart Product-Service System for Intelligent Welding System - Concept.

Area	Assumptions
Property	The manufacturer remains the owner The manufacturer is responsible for maintaining the IWS The customer uses IWS tailored to their needs in the financial model.
Sales	Flexible financing model Additional functions or services are available for purchase on request Long-term cooperation between the customer and the manufacturer instead of a one-time sale
Services	Access to a broad service package Combination of conventional and digital solutions Additional services on request
Digital Transformation	Integration of NT with the customer's digital infrastructure Real-time data collection and analysis Access to a digital platform and mobile application
Customer Benefits	Elimination of high capital investments Tailoring the IWS to the specific needs of the WS Reduced responsibility for maintaining the IWS
Manufacturer Benefits	Long-term and stable revenues thanks to new financing models Long-term customer relationships and increased customer loyalty Collection and analysis of data from the IWS's service life
Environmental Benefits	Elimination of overproduction of devices thanks to long-term equipment operation Recycling, reduction of waste and emissions of harmful substances Reduction of the consumption of raw materials, materials and electricity

Implementing SPSS for IWS benefits all parties involved in the transaction. The WS focuses on its core business and does not engage in activities related to maintaining the IWS. In addition, it saves financial resources and time. It does not engage in employee training and additional equipment because it provides this as part of SPSS. Additionally, troubleshooting and replacing parts is also the manufacturer's responsibility. This approach allows the WS to maximize tasks and reduce costs. Thanks to this solution, the manufacturer no longer focuses only on producing and selling

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IWS but instead enters into long-term cooperation with the WS. This guarantees the stability of revenues and the availability of IWS operating data, which will allow the development of new generations of welding equipment, digital platforms, applications, and services tailored to the needs of the WS.

The SPSS proposed here plays a fundamental role in the operation and reliability of welding equipment while offering significant benefits to WS and manufacturers. Implementing SPSS in the context of IWS enables the integration of welding equipment, services, and new digital technologies, significantly improving the availability of modern solutions for the WI at an affordable price. Systematic service and real-time monitoring guarantee the diagnosis of possible failures and the implementation of preventive measures. This eliminates the occurrence of downtimes and the related costs. In addition, it allows IWS to adapt to the needs of WS through systematic technical modifications and software updates. This is aimed at dynamic adaptation to the changing market situation and working conditions and extending the service life of the IWS.

The implementation of NT in the developed solution significantly accelerates the DT of WS, which leads to changes in the management of welding processes and organizational culture. It translates into a wide range of benefits beyond conventional and well-known improvements in welding processes. The manufacturer undergoes a specific transformation of the operating model, thanks to which it can flexibly respond to market requirements and needs changes. In turn, WS gain the ability to maximize control of welding processes, as well as their efficiency and quality. NT supports the automation of repetitive tasks, thus maximizing work efficiency. NT also provides support for the manufacturer in the development of new services. This allows for offering WS broader and more complex solutions. Additionally, it supports sustainable development. This involves reducing energy consumption, raw materials, and generated waste. The implementation of NT also supports the development of knowledge and skills of WS employees. This is possible thanks to the manufacturer providing AR/VR/M-based training via a digital platform and mobile application, which increases flexibility. Additionally, platforms and applications enable remote access to data and management of welding equipment from any location.

8 Conclusion

This paper focuses on the WI. This industry is characterized by the technical complexity of processes and the diversity of welding methods. Micro, small, and medium-sized enterprises dominate it. Recent years have been associated with its slow automation and digitalization, which was limited by barriers related to the need for massive investments, discouraging companies.

The analysis of the available literature and the welding market indicates the need for new solutions for the WI. This article fills this gap in the use of SPSS for IWS. It discusses theoretical and practical issues related to it. On the other hand, developing a new SPSS for welding was carried out through surveys and training-educational-design workshops conducted in a WS. Only the most important elements are presented here, emphasizing the importance and necessity of developing such models.

Based on the conducted surveys and training, educational and design workshops, the following conclusions can be drawn:

- Economic aspects – the model proposed in the article enables WS to access IWS without high initial investments, which is particularly important for micro, small, and medium-sized enterprises. A flexible form of financing, which is also tailored to the needs of WS, minimizes the

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entry barriers of modern solutions based on automation and digitization for the analyzed industry.

- SPSS development – The workshops that were conducted constitute an effective form of SPSS development. They enable identifying those consistent with WS specific requirements and needs. The involvement of the company's employees allows for the adjustment of SPSS to actual market requirements. All this maximizes the effectiveness of implementation and supports the implementation of NT in this industry.
- Knowledge and competence development – The workshops conducted significantly affect the development of knowledge and competencies of the company's employees in the SPSS, IWS, and NT fields. Additionally, they raise their awareness of new business solutions for enterprises. Finally, they support education and teach skills necessary for DT, which help to use in practice.
- SPSS for IWS introduces advanced integration of physical, service, and digital NT elements to develop a comprehensive ecosystem that meets the needs and requirements of the modern WI. This includes using a wide range of NT, thanks to which SPSS optimizes welding processes, increases welding quality and precision and improves operational efficiency by dynamically adapting to changing production conditions.
- Environmental protection - including NT elements and services in the physical element of welding equipment allows for reducing the WI impact on the environment. Additionally, it allows for extending its service life, regeneration, and reuse, reducing the need to manufacture new equipment.
- When creating SPSS for the analyzed sector, it is necessary to consider the fulfillment of restrictive standards regarding quality and safety, including EN ISO 3834, EN 15085, or ISO/IEC 62264. Compliance with them will guarantee an increase in the competitiveness of the developed solution.
- The use of NT in this solution will significantly improve welding processes, reduce the number of defects, minimize energy and material consumption, and support waste management. Additionally, their implementation will enable monitoring and optimizing processes in real-time, translating into an increase in companies' competitiveness level using SPSS.

In addition, the surveys and training-educational-design workshops provided a solid foundation for developing and implementing the SPSS model for IWS. They indicate what elements must be addressed and what factors are worth considering when designing a personalized and digitally advanced SPSS-based solution.

Our contribution to education and design is the innovative approach to creating SPSS for IWS. With an emphasis on practical aspects and experiences in PSS/SPSS and welding production, we conducted a dynamic training-educational-design workshop. It equipped the WS employees with the practical knowledge and skills to develop new SPSS solutions for the WI. It allowed the authors to develop a new solution that is unavailable in the open scientific literature so far.

Future research directions should focus on developing the approach based on the workshops presented in this article, including additional digital tools and stages of training and individual and creative projects in PSS/SPSS. They prioritize innovations in education and the design of PSS/SPSS in enterprises; it is important to continue cooperation between universities and industry. This will ensure the transfer of scientific knowledge to industry and will allow the introduction of solutions into business practices that have not been used in enterprises so far. In addition, it will enable the generation of personalized solutions for specific enterprises.

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Acknowledgments. Love and praise God..

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References

1. Gaiardelli, P., Pezzotta, G., Rondini, A., Romero, D., Jarrahi, F., Bertoni, M., Wiesner, S., Wuest, T., Larsson, T., Zaki, M., Jussen, P., Boucher, X., Bigdeli, A.Z., Cavalieri, S.: Product-service systems evolution in the era of Industry 4.0. Serv Bus. 15, 177–207 (2021)
2. Vezzoli, C., Ceschin, F., Osanjo, L., M'Rithaa, M.K., Moalosi, R., Nakazibwe, V., Diehl, J.C.: Sustainable Product-Service System (S.PSS). In: Designing Sustainable Energy for All. pp. 41–51. Springer International Publishing, Cham (2018)
3. Annarelli, A., Battistella, C., Costantino, F., Di Gravio, G., Nonino, F., Patriarca, R.: New trends in product service system and servitization research: A conceptual structure emerging from three decades of literature. CIRP Journal of Manufacturing Science and Technology. 32, 424–436 (2021)
4. Salwin, M., Lipiak, J., Kulesza, R.: Product-service system–a literature review. Research in Logistics & Production. 9, 5–14 (2019).
5. Mont, O.K.: Clarifying the concept of product–service system. Journal of Cleaner Production. 10, 237–245 (2002).
6. Negash, Y.T., Calahorrano Sarmiento, L.S., Tseng, M.-L., Jantarakolica, K., Tan, K.: Sustainable product-service system hierarchical framework under uncertainties: The pharmaceutical industry in Ecuador. Journal of Cleaner Production. 294, 126188 (2021)
7. Ren, M., Zheng, P.: Towards smart product-service systems 2.0: A retrospect and prospect. Advanced Engineering Informatics. 61, 102466 (2024)
8. Shao, S., Xu, G., Li, M.: The design of an IoT-based route optimization system: A smart prod-uct-service system (SPSS) approach. Advanced Engineering Informatics. 42, 101006 (2019)
9. Chen, Z., Ming, X., Zhou, T., Chang, Y., Sun, Z.: A hybrid framework integrating rough-fuzzy best-worst method to identify and evaluate user activity-oriented service requirement for smart product service system. Journal of Cleaner Production. 253, 119954 (2020).
10. Salwin, M., Andrzejewski, M., Kraslawski, A.: Information Asymmetry in Product-Service System Design - Example of the Pharmaceutical Industry. Procedia Manufacturing. 55, 282–289 (2021).
11. Chiu, M.-C., Chu, C.-Y., Kuo, T.C.: Product service system transition method: building firm's core competence of enterprise. International Journal of Production Research. 57, 6452–6472 (2019)
12. Szala, M., Łatka, L., Awtoniuk, M., Winnicki, M., Michalak, M.: Neural Modelling of APS Thermal Spray Process Parameters for Optimizing the Hardness, Porosity and Cavitation Ero-sion Resistance of Al2O3-13 wt% TiO2 Coatings. Processes. 8, 1544 (2020)
13. Liu, J., Ji, Q., Zhang, X., Chen, Y., Zhang, Y., Liu, X., Tang, M.: Digital twin model-driven capacity evaluation and scheduling optimization for ship welding production line. J Intell Manuf. 35, 3353–3375 (2024)
14. Gyasi, E.A., Kah, P., Penttilä, S., Ratava, J., Handroos, H., Sanbao, L.: Digitalized automated welding systems for weld quality predictions and reliability. Procedia Manufacturing. 38, 133–141 (2019)
15. Szczucka-Lasota, B., Szymczak, T., Węgrzyn, T., Tarasiuk, W.: Superalloy—Steel Joint in Mi-crostructural and Mechanical Characterisation for Manufacturing Rotor Components. Materials. 16, 2862 (2023)
16. Amasawa, E., Shibata, T., Sugiyama, H., Hirao, M.: Environmental potential of reusing, renting, and sharing consumer products: Systematic analysis approach. Journal of Cleaner Production. 242, 118487 (2020)
17. Skowrońska, B., Szulc, B., Morek, R., Baranowski, M., Chmielewski, T.M.: Selected properties of X120Mn12 steel welded joints by means of the plasma-MAG hybrid method. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications. 14644207241256113 (2024)
18. Wang, B., Li, Y., Freiheit, T.: Towards intelligent welding systems from a HCPS perspective: A technology framework and implementation roadmap. Journal of Manufacturing Systems. 65, 244–259 (2022)
19. Wang, B., Hu, S.J., Sun, L., Freiheit, T.: Intelligent welding system technologies: State-of-the-art review and perspectives. Journal of Manufacturing Systems. 56, 373–391 (2020)
20. Skowrońska, B., Chmielewski, T., Golański, D., Szulc, J.: Weldability of S700MC steel welded with the hybrid plasma + MAG method. Manufacturing Rev. 7, 4 (2020)

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21. Salwin, M., Andrzejewski, M.: Product-Service System: A New Opportunity for the Plastics Processing Industry. Procedia Computer Science. 246, 4541–4551 (2024)
22. Salwin, M., Kraslawski, A.: Product-Service System business model for plastics industry. Jour-nal of Cleaner Production. 451, 141874 (2024)
23. Salwin, M., Chmielewski, T.: Smart Product-Service System for Parking Furniture—Sale of Storage Space in Parking Places. Sustainability. 16, 8824 (2024).
24. Salwin, M., Kraslawski, A., Andrzejewski, M., Hryniewicka, M.: Product-Service System Design - A Case Study for Parking Furniture Industry. In: Hamrol, A., Grabowska, M., and Hinz, M. (eds.) Advances in Manufacturing IV. pp. 41–56. Springer Nature Switzerland, Cham (2024)
25. Skowrońska, B., Chmielewski, T., Baranowski, M., Kulczyk, M., Skiba, J.: Friction weldability of ul-trafine-grained titanium grade 2. Journal of Advanced Joining Processes. 10, 100246 (2024)
26. Gyasi, E.A., Handroos, H., Kah, P.: Survey on artificial intelligence (AI) applied in welding: A future scenario of the influence of AI on technological, economic, educational and social chang-es. Procedia Manufacturing. 38, 702–714 (2019)
27. Skowrońska, B., Bober, M., Kołodziejczak, P., Baranowski, M., Kozłowski, M., Chmielewski, T.: Solid-State Rotary Friction-Welded Tungsten and Mild Steel Joints. Applied Sciences. 12, 9034 (2022)
28. Boaretto, N., Centeno, T.M.: Automated detection of welding defects in pipelines from radio-graphic images DWDI. NDT & E International. 86, 7–13 (2017)
29. Węgrzyn, T., Gołombek, K., Szczucka-Lasota, B., Szymczak, T., Łazarz, B., Lukaszkowicz, K.: Docol 1300M Micro-Jet-Cooled Weld in Microstructural and Mechanical Approaches concern-ing Applications at Cyclic Loading. Materials. 17, 2934 (2024)
30. Szczucka-Lasota, B., Węgrzyn, T., Jurek, A.: Formation of Oxides and Sulfides during the Weld-ing Process of S700MC Steel by Using New Electrodes Wires. Materials. 17, 2974 (2024)
31. Cai, W., Jiang, P., Shu, L., Geng, S., Zhou, Q.: Real-time laser keyhole welding penetration state moni-toring based on adaptive fusion images using convolutional neural networks. J Intell Man-uf. 34, 1259–1273 (2023)
32. Fernández, J., Valerieva, D., Higuero, L., Sahelices, B.: 3DWS: reliable segmentation on intelli-gent welding systems with 3D convolutions. J Intell Manuf. 36, 5–18 (2025)
33. Chen, C., Lv, N., Chen, S.: Data-Driven Welding Expert System Structure Based on Internet of Things. In: Chen, S., Zhang, Y., and Feng, Z. (eds.) Transactions on Intelligent Welding Manu-facturing. pp. 45–60. Springer Singapore, Singapore (2018)
34. Fang, H.C., Ong, S.K., Nee, A.Y.C.: Adaptive pass planning and optimization for robotic welding of complex joints. Adv. Manuf. 5, 93–104 (2017)
35. Afian, A., Mustikowati, R.I., Sari, A.R., Halim, D.M., Khoir, N.U.: Mentoring the Importance of Finan-cial Literacy and Digital Literacy in the Welding Workshop Business. JPM. 5, 206–210 (2024)
36. Chen, S.-B.: On Intelligentized Welding Manufacturing. In: Tarn, T.-J., Chen, S.-B., and Chen, X.-Q. (eds.) Robotic Welding, Intelligence and Automation. pp. 3–34. Springer International Publishing, Cham (2015)
37. Bolotov, S.V., Zakharchenkov, K.V., Krutolevich, S.K.: Intelligent Hardware and Software Sup-port and Increasing the Efficiency of Welding Processes. Pattern Recognit. Image Anal. 34, 686–691 (2024)
38. Sałaciński, T., Chrzanowski, J., Chmielewski, T.: Statistical Process Control Using Control Charts with Variable Parameters. Processes. 11, 2744 (2023). https://doi.org/10.3390/pr11092744.

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