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RESEARCH ARTICLE

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A QFD-based approach for the development of smart product-service systems

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Abstract

The paper proposes a novel method for the development of smart product-service systems (Smart-PSSs) by focusing on the analysis of customer requirements and the selection of those features that can practically enhance the smart capabilities of the offering. To achieve such a goal, a quality function deployment (QFD) based method is presented to specifically address the development of Smart-PSS solutions. The novel approach, named quality function deployment for smart-product service systems (QFD for Smart-PSS), relies on the deployment of smart characteristics and components besides the conventional product and service features. Such an approach allows a better granularity of the assessment and deployment of the system features by well defining the smart components in PSS. To preliminarily verify the applicability of the method, a case study concerning the development of a Smart-PSS solution for the elevators of a building is proposed. The results achieved show the potential benefits that the proposed approach can have both in the case of novel solutions and when an existing system has to be augmented. The method is at the initial stage of development and while this study can augment knowledge on the development of Smart-PSS, further research work is needed to extend its validation.

KEYWORDS

information and communication technology, multi-criteria decision making, product service system, quality function deployment for smart product service systems

1 | INTRODUCTION

In recent decades the need for developing sustainable industrial solutions has fostered the spread of new business models aimed to embrace circular economy (CE) principles,[1] thus enhancing the decrease in resources consumption and waste generation,[2,3] while augmenting the efficiency of reuse, refurbishment, remanufacturing, and recycling processes.[4] Accordingly, Ulaga and Reinartz[5] stressed the need for optimizing the whole product lifecycle to improve its environmental performance and positively impact the manufacturer's operations, since the use phase of the product is a key aspect to consider.[6] Services threaded together with the product's life cycle, such as maintenance and other after-sale services, directly affect both customer satisfaction and the optimization of the environmental performances of the whole

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system.[7,8] Hence, when developing a PSS, planning the use stage and the management of all the resources involved in it requires particular attention due to the long-term relationship that a PSS solution creates between the provider on the one hand, and customers and other stakeholders on the other.[9]

In such a context, the shift from traditional production approaches, which are based on the "take-make-dispose" resource model, to the product-service system (PSS) business model, which relies on the offering of a set of tangible and intangible goods,[10] is considered one of the most viable solutions to achieve a circular production system.[11-13] Product-service systems can satisfy customers' needs and generate value,[14] while enhancing the circularity of businesses by means of a functional outcome as a substitute for conventional product transactions and sales.[15,16]

In the extant literature, indeed numerous studies can be found that have investigated the multifaceted aspects of the PSS approach and its implementation in the industry,[17,18] most of them recognizing the PSS classification system provided by Tukker[19] as the most effective. Following such criteria, a product-oriented PSS (PO-PSS) occurs when the traditional sale of a product is accompanied by the provision of additional services that are offered to the customer to guarantee the proper product functionality. Differently, a PSS is use-oriented (UO-PSS) when the manufacturer provides the customer with the use or availability of a product while retaining its ownership. Instead, a result-oriented PSS (RO-PSS) consists of the provision to customers of services only while the product is solely managed by the provider/manufacturer. Likewise, Tukker's classification criteria, the ones proposed by Gao et al.[20] are also noteworthy to be mentioned since they focus more on the servitization in the industrial context, proposing the following PSS categories[21]:

1. product-oriented PSS (PPSS), where the ownership of the products is transferred to the customer while the related services to guarantee its proper functioning (e.g., maintenance services) are due by the manufacturer/provider;
2. application-oriented PSS (APSS), where the customers pay for the use of the product for an established period of time while the product's ownership is retained by the manufacturer/provider; in this context also the purchase of units of service is included as in the sharing or pooling systems; and
3. utility-oriented PSS (UPSS) models, where the customers purchase the output of the service provided without using the physical product directly.

Based on this classification, which mainly considers the manufacturers' perspective, it should be noted that the APSS approach is the one that can be more beneficial in the case of industrial complex systems (e.g., the so-called hi-tech products), where the role of after-sales services to ensure the functionality of the product and avoid its obsolescence is fundamental.[22,23] For example, the APSS approach is becoming very diffused in the case of equipment set up in buildings and facilities (i.e., escalators, elevators, HVAC [heating, ventilation, and air conditioning] systems, communication and security systems, etc.), as well as medical equipment.[20,24]

Most of these systems have similar features, such as the involvement of different stakeholders (notably, the third-party companies engaged in after-sales services), and the positioning in regulated markets (where a public procurement mechanism is required and/or safety and security requirements have to be taken into account besides traditional customer needs).[25] The latter issue implies that the manufacturer/provider guarantees maintenance services for the whole duration of the contract, ensuring at the same time the fulfillment of safety and environmental directives.[26-28] In addition, manufacturers shifting towards PSS business models should focus on how to deliver value to the customer, optimizing the bundle of goods and services that augment customer satisfaction.[29]

In such a context, modern technologies such as distant servers, remote monitoring, as well as other "Industry 4.0" solutions[30] can offer an augmented value to customers, while facilitating the manufacturer/provider in the management of the contract duties, bringing the PSS approach to a further level of development, which is usually addressed as "Smart PSS".[31,32] As underlined by Mourtzis,[33] the new technologies embedded in the Industry 4.0 solutions can allow new forms of personalization augmenting customer value and satisfaction. In other words, Industry 4.0 solutions can support the mass personalization paradigm (MPP), which is aimed at providing solutions capable of specifically meeting customer needs in an efficient manner.[34]

Smart-PSSs were defined as "the integration of smart products and e-services into single solutions delivered to the market to satisfy the needs of individual consumers" by Valencia et al.[35] who underlined that they refer to offerings characterized by a high content of information technology capable of transforming data into knowledge and integrating services within the product to better address customer needs. Accordingly, Liu et al.[36] observed that e-services allow better interaction and communication between all the PSS stakeholders and the customers as smart-connected products use information and communication technologies (ICTs) to gain and provide information.

Based on these enhanced capabilities, recent literature on Smart-PSS is increasing as well as industry practices aimed at integrating smart technologies to provide customers with innovative solutions.[37] This is confirmed by a review study by Acerbi et al.[38] who brought to light that manufacturers are more and more engaged in adopting digital tools to gain data on customers' behaviors and products' conditions during the use phase, to ensure the provision of tailored services. Accordingly, maintenance operations of the functionalities of the product can be augmented during its whole lifecycle, and useful data for future design improvements can be gained.[39] Thus, new challenges for engineers concern how these data are collected and used for operations.[40] To achieve such goals further research on decision-making tools to support engineers in the development of Smart PSS is needed. Accordingly, Zhou et al.[41] underlined the necessity of both practical and theoretical enhancements due to the increasing complexity of Smart-PSS to ensure adequate service capability and timely responses to customers. Moreover, the relationships among the features of the Smart-PSS solutions are more complicated than those of conventional PSSs, since the information received from the technologies of Industry 4.0 builds on additional complexity to the system.[42] As a consequence, the evaluation of Smart-PSS solutions has to be considered a complex multi-criteria decision-making (MCDM) problem.[43,44] However, as stressed by Zheng et al.[45] in the extant literature evaluation criteria are mainly targeted to the traditional PSS features, while a research gap exists in the analysis of the emerging features and capabilities of smart technologies in PSS design.

More in detail, Liu et al.[46] remarked that there are few studies to thoroughly evaluate the customer needs (CNs) and system requirements (SRs) of Smart-PSS. Hence, they claim further research at the conceptual stage of Smart-PSS development to holistically address them. Therefore, it is necessary to improve the tools for Smart-PSS design taking into account that their complexity requires a multi-criteria decision-making approach capable of specifically addressing the implementation of smart technologies in a PSS context. Thus, the main challenges when developing a Smart-PSS solution are related to: (i) creating customer value through the proper elicitation of customer needs and system requirements, including those that can be conducive to the implementation of smart solutions; (ii) providing a multi-criteria decision-making framework that enables engineers to simultaneously implement not only tangible and intangible features of the PSS solution, but also those related to smart technologies.

Based on these considerations, this study aims at reducing the above-mentioned research gaps by addressing these challenges. With this goal in mind, a quality function deployment (QFD) based approach for the development of smart PSS solutions was developed. As observed by Bertoni,[47] among the most diffused MCDM tools used in PSS design and development, QFD is often selected thanks to its ability to support engineers in the definition of the main PSS tangible and intangible features and assets, as well as to provide in a clear manner information on the relative importance between design requirements and the main customer needs. Actually, QFD can display these links between customer requirements and product/service attributes in a systematic and effective manner.[48] More in detail, the quality function deployment for PSS (QFD for PSS) method[49] was chosen as it allows a clearer mapping of the product/service attributes and their dependency on customer requirements.[50] However, to better address the complexity of Smart-PSS its augmentation was carried out by including the simultaneous consideration of smart features and assets (i.e., information characteristics [IChs] and components [ICos]) as well as the conventional product/service characteristics (PChs/SChs) and components (PCos/SCos). Such a novel approach can allow engineers to better capture and prioritize customer needs and system requirements providing a more granular analysis of these factors and their interdependence in PSS development.[51]

The rest of the article is organized as follows: Section 2 summarizes the background analysis for this study. Section 3 presents the methodological approach relying on the development of the quality function deployment for smart product service system (QFD for Smart-PSS) method. Section 4 demonstrates an illustrative case study based on the implementation of a Smart-PSS solution for a group of elevators, while Section 5 discusses the theoretical and practical implications of the study. Finally, conclusive remarks and perspectives are provided in Section 6.

2 | BACKGROUND ANALYSIS

2.1 | Smart product service systems

The shift from the traditional production system, based on the provision of physical goods, to the offer of integrated solutions that combine physical goods and services, where usually the ownership of the former is retained by the manufacturer/provider, is usually named servitization process.[52] Such a change has been characterized by the increased opportunity of integrating the so-called information and communications technology (ICT) tools with traditional products to achieve smart connected ones.[53] At the system level, as mentioned earlier, these smart products and service systems are combined and connected to allow new system functionalities,[54] capable of better satisfying customer needs.[37] On the one hand, smart products use ICT tools such as the Internet of Things (IoT) and cloud computing to gain, process, and deliver information thanks to the inclusion of sensors, software, and microchips. On the other hand, the integration of these tools in physical goods enables the provision of digital services facilitating the communication between the manufacturer/provider and customers.[55,56] The ever-increasing use of sensors, microchips, and software leads to the generation of a large number of data, the so-called Big Data, requiring the use of cyber-physical systems (CPS) for their management.[57] As per Lee et al.[58] the main features of such systems are individuated in a pyramidal architecture consisting of five steps, each one characterized by an increasing level of complexity of attributes, as follows:

1. Smart Connection, characterized by sensors and plug & play systems;
2. Data-to-information, where the main attributes are smart analytics systems, machine health components, and performance prediction systems;
3. Cyber, characterized by twin models for components, clustering for data mining;
4. Cognition, where collaborative diagnostics and decision-making systems are included;
5. Configuration, whose attributes allow the system to self-adjust and self-configure for resilience.

Accordingly, Porter and Heppelmann[59] provided a well-known classification of the main functions that a product should have to be considered smart (i.e., a smart connected product [SCP]):

1. monitoring, which guarantees to systematically keep track of the system status, its operativity, and the external environment, also providing information about the status changes;
2. remote control, which allows the check of the system functions by means of embedded software and clouds, providing the customization of the information available for the users;
3. optimization, which relies on the monitoring and control features to improve the performances of the system, allowing predictive diagnostics as well as proper maintenance activities; and
4. autonomy, consisting of a combination of the previous functions and allows the system auto-diagnostics and auto-repairing features.

As remarked by Zheng et al.[60] SCPs represent the third wave of industrial digitalization enabling Smart-PSS solutions, where ICT tools are embedded in the product, to augment the creation of customer value.

For the development of such solutions, Song et al.[61] proposed a list of criteria that should be used to evaluate a Smart-PSS during its development, mainly relying on the following aspects:

1. Cost, which includes manufacturing costs and resource utilization;
2. Reliability, which is related to the durability of the product and the capability of managing malfunctioning by means of ICT tools;
3. Digital controlling and smartness, which represent the intelligent level of the PSS;
4. Service level, relying on the ability to provide services, such as the speed of maintenance operations;
5. Interactive customization, to better suit customer demand;
6. Environmental performances, that is, the impact of the PSS along with its life cycle;
7. Work conditions, which are related to the operative conditions;
8. Usability, that is, the level of easiness to use; and
9. Health and safety, which concerns the safety requirements of the PSS along with its life cycle.

Based on this, they proposed a general framework for the assessment of Smart PSS alternatives by means of an augmented technique for order of preference by similarity to ideal solution (TOPSIS) methodology. However, the interrelationships between the different assessment criteria were not considered.

Similarly, Lee et al.[62] proposed a Smart-PSS development methodology that incorporates the theory of inventive problem solving (TRIZ) and service blueprint methods. On the one hand, such an approach provides more practical features in Smart-PSS development activities than other similar studies.[35,37] On the other hand, the definition of customer needs relies on interviews and real-site observation before, during, and after shopping, which might provide incomplete information.

Hence, although several approaches for Smart-PSS development can be found, they lack granularity when analyzing customers' requirements.[63] Moreover, it must be considered that in Smart-PSS design, software and hardware solutions as a unique bundle to provide digitalized services should also be considered as part of the engineering characteristics. However, few studies address this issue specifically.[64]

2.2 | Quality function deployment for product service systems

The capability of a product or a service to effectively fulfill market requirements represents a key factor in product development activities. Thus, understanding customers' needs and expectations while improving the quality level of the product/service has been greatly recognized in literature and a large number of tools and strategies have been proposed.[65-67]

In this ambit, the quality function deployment (QFD) method[68] represents one of the most used tools to evaluate and improve the quality of a product or service as it ensures a better understanding of the needs and expectations of the customers, facilitating their translation into technical characteristics. The core of this decision-making method is represented by the house of quality (HoQ), consisting of a set of matrices aimed at transforming customer demands into design targets and quality assurance points. In Figure 1, the first HoQ is schematized, where WHATs represent the customer's requirements (CRs), the HOWs are the engineering characteristics (ECs) and the HOW-MUCHs represent the target values that have to be achieved.

Traditionally, the method consists of four different phases, each characterized by a specific HoQ, ranging from product planning to production planning and quality control,[67] as illustrated in Figure 2.

Such a framework has been broadly investigated and augmented to better address specific product/service design objectives and numerous QFD-based tools can be found in literature.[69]

Besides, also some QFD-based approaches specifically dedicated to the development of PSS solutions have been proposed in recent years. For example, considering the last decade, Kim and Yon[70] adopted a two-phase QFD where the first HoQ was used to find the relationships between customer requirements or new services concepts (which replaced the CRs) and service concepts (i.e., the ECs), while in the second HoQ the relationships between service concepts and PSS

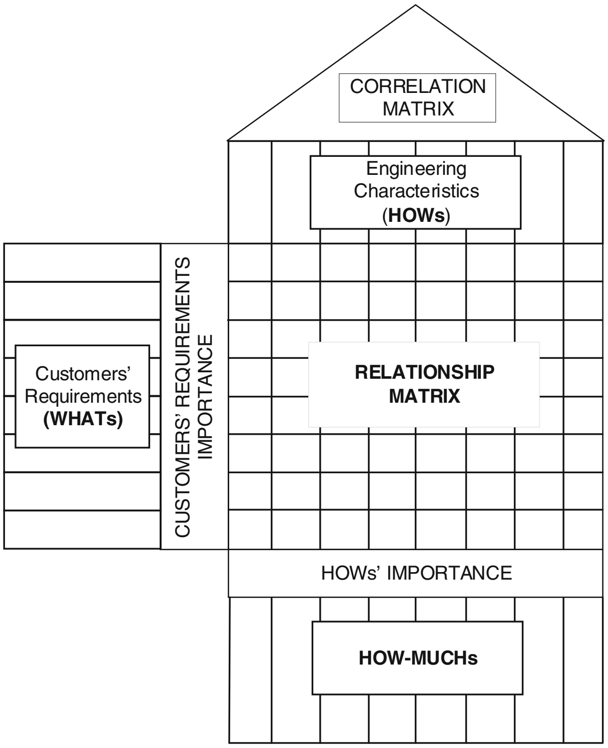


FIGURE 1 Illustration of the first house of quality (HoQ).

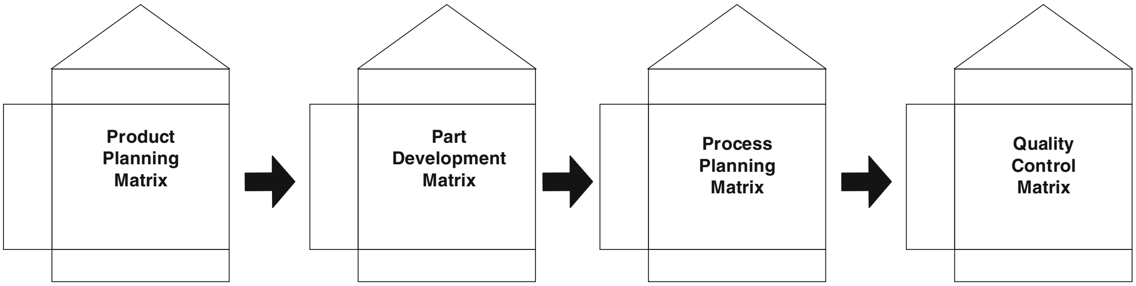


FIGURE 2 The four phases of the QFD method.

solutions are evaluated. Such an approach is integrated by the TRIZ method, aimed at solving the contradictions of the outcomes of each phase. Differently, Yin et al.[71] proposed a three-phase approach, where for each phase two different HoQ are used as follows:

1. in the first phase, starting from the CRs one HoQ concerns the product quality characteristics, while the second HoQ is related to the service quality characteristics;
2. in the second phase, starting from the product and quality characteristics included in the quality bill of materials (QBOM), the product and service bill of materials (BOM) attributes are derived and weighted;
3. in the third phase, these weighted attributes (from the product and the service standpoints) are correlated to the stakeholders' features.

Li et al.[72] developed a six-phase approach aimed at balancing the customer value and the organization value that are both delivered by the PSS business model. This methodology starts from the correlation between quality indicators and PSS characteristics (first HoQ) and terminates with the correlation between the costs of the process and the risk events. Peruzzini and Germani[73] proposed a two-phase approach where CRs are related to the PSS functionalities (first phase), and the latter are related to tangible/intangible assets (second phase). Kim et al.[74] proposed a traditional HoQ application to convert customer needs into product functions (first phase), while functions are matched up with desired requirements of different groups of users in the second HoQ. In a similar manner, Sousa-Zomer and Cauchick Miguel[48] developed a three-stage approach, where customers' requirements are translated into engineering metrics (first HoQ), engineering metrics into PSS functions (second HoQ), and PSS functions into PSS concepts (third HoQ). Hara[75] augmented the conventional HoQ to correlate the required quality of the product by the user and the required quality of the user's use by the manufacturer on the one hand, and the Quality element of the product and of the user on the other. A further approach to address PSS development is represented by the model proposed by Mazo and Borsato,[76] who correlated in the HoQ customers' requirements with the service engineering and product engineering characteristics (SECs and PECs), which namely represent the product and service performances. Similarly, the implementation of PECs and SECs is proposed by Geng et al.[77] who then filtered these characteristics by means of the Kano model. However, all these studies adapted conventional QFD features to PSS development in different contexts, always starting from the customers' requirements analysis.[46]

Unlike the above-mentioned approaches, several studies have proposed a more specifically adapted QFD-based tool for PSS development, that is, the quality function deployment for product service system (QFD for PSS) method, first proposed by Japanese researchers[78] to implement service and product features in a thorough manner.[49] The novelty of this two-stages approach (Figure 3) is represented by the use of the receiver state parameters (RSPs) instead of CRs. RSPs represent the "feelings" of customers related to a certain PSS aspect and thus they can be accounted as value or cost according to whether customers like or dislike them.[79]

This concept has been proposed in several studies, and some applications of the QFD for PSS method can be found in recent literature.[80-82] However, to the authors' knowledge, there are no applications of this method that specifically address the development of Smart-PSS solutions.

3 | MATERIALS AND METHODS

To reduce the above-mentioned research gaps and provide a specific tool that integrates the benefits of QFD together with the specific features needed to develop Smart-PSS solutions, we propose an augmented version of the QFD for PSS method, which we called QFD for Smart-PSS.

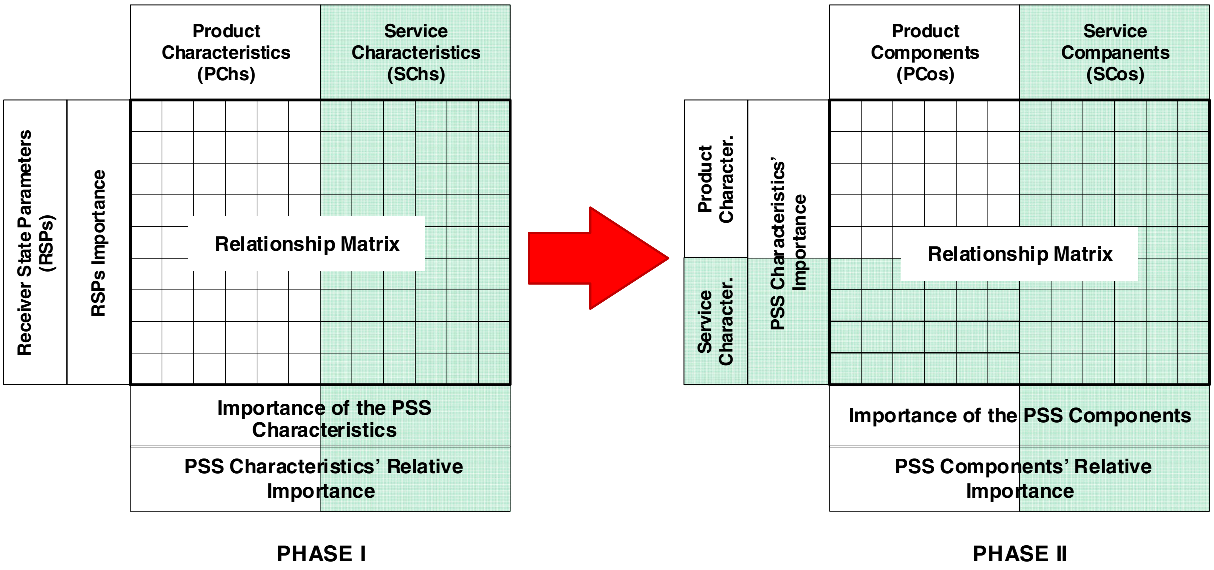


FIGURE 3 Representation of the QFD for PSS.

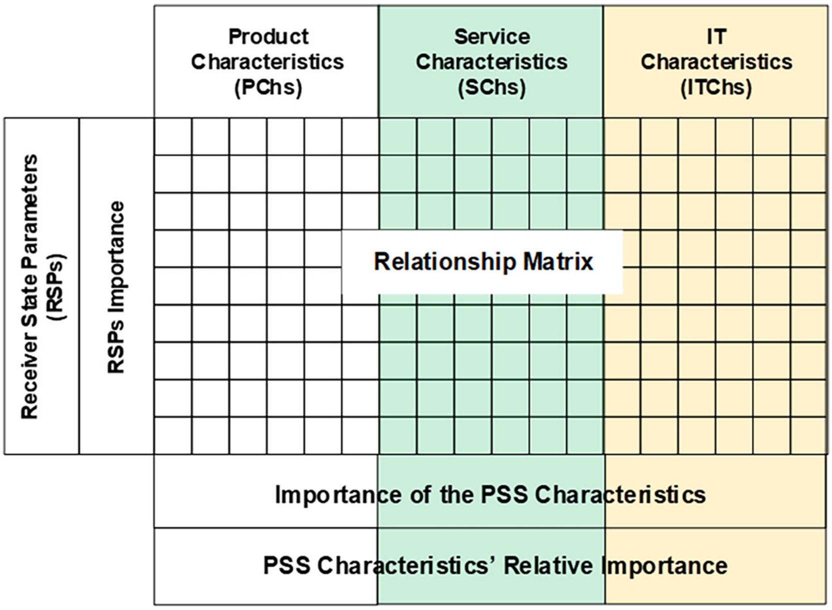


FIGURE 4 Scheme of the first phase of the QFD for PSS augmented by the smart characteristics.

Indeed, smart characteristics such as monitoring and remote control, which represent the main features of smart connected products, are not necessary for the proper functioning of the product (e.g., a washing machine or an elevator), but allow its "smartness". Hence, we can individuate some components that serve to fulfill a smartness function. For example, a sensor that allows the registering of the voltage difference of medical equipment is not needed in order for the machinery to function, but it can provide information on the deterioration of some components, thus alerting for preventive maintenance before the system malfunctioning.

Accordingly, when defining the PSS characteristics in the first phase of the QFD for PSS method, besides product characteristics (PChs) and service characteristics (SChs), a column reporting the "smart" characteristics (which we called "Information Technology Characteristics – ITChs") is included, as shown in Figure 4.

Similarly, in the second phase of the method, a third column concerning the "information technology components – ITCos" is included (Figure 5).

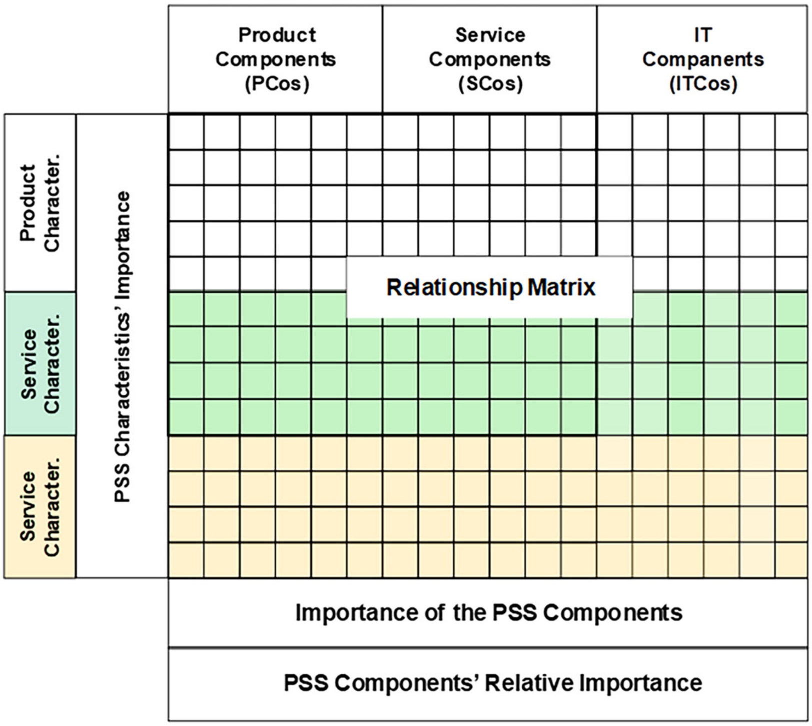


FIGURE 5 Scheme of the second phase of the QFD for PSS augmented by the IT components.

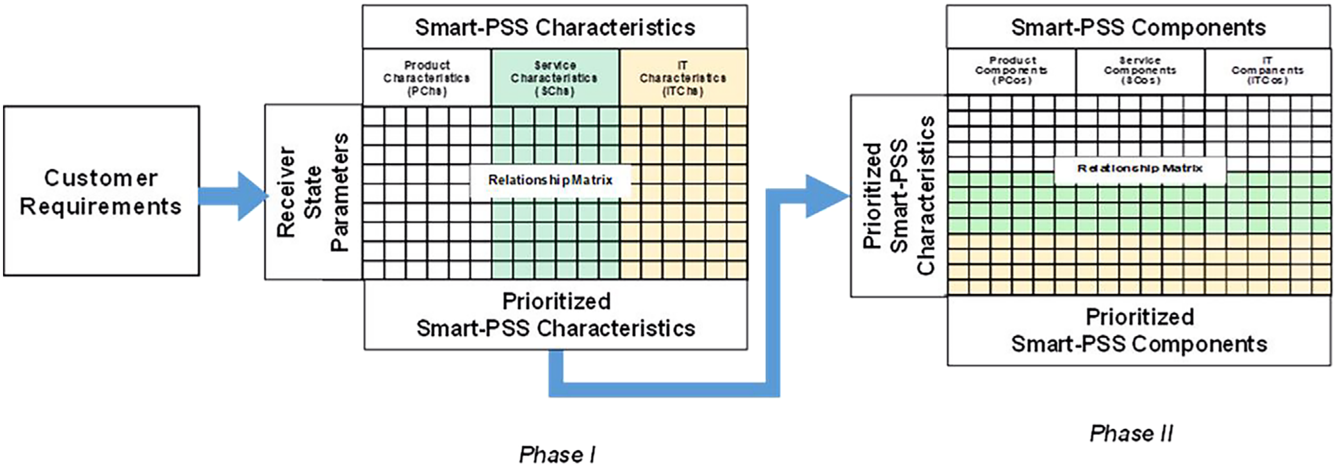


FIGURE 6 General scheme of the QFD for Smart-PSS method.

Overall, the main phases of the QFD for Smart-PSS method are schematized in Figure 6.

It must be noted that one of the main differences between the conventional QFD and the proposed method is represented by the use of the receiver state parameters (RSPs) instead of the customer requirements (CRs) as input for the first HoQ. As mentioned in Section 2, RSPs represent a set of external parameters that can modify the status of the PSS receiver, that is, the customer feeling towards a certain aspect of the PSS. As argued by Sakao and Shimomura,[50] a RSP is an observable and controllable variable since it stands for a quantitative value making it possible to carry out a comparison between two RSPs more easily than when comparing two CRs. Thus, the use of RSPs allows a more objective comparison of the customers' preferences. To better highlight the novelty of the proposed approach and its crucial differences with the basic QFD and the QDF for PSS approach, in Table 1 a comparison is proposed.

As far as the evaluation criteria are concerned, at this first stage of development of the method, we adopted the same as the ones used for the conventional HoQ,[67] where the score in the relationship matrix is based on a 0-1-3-9 scale (i.e., 0 means no relationship; 1 means a weak relationship; 3 means a medium relationship; 9 means a strong relationship).

TABLE 1 Comparison of the main characteristics of traditional QFD, QFD for PSS, and QFD for Smart-PSS.

Tool	Traditional QFD (phases I and II)	QFD for PSS	QFD for Smart-PSS
Source	**[55, 56]**	**[67, 38]**	Current study
Input phase I	Customer requirements (CRs)	Receiver state parameters (RSPs)	Receiver state parameters (RSPs)
Output phase I/ input phase II	Prioritized engineering characteristics (ECs)	Prioritized PSS characteristics (PChs and SChs)	Prioritized Smart-PSS characteristics (PCos, SCos, and ITCos)
Output phase II	Prioritized parts characteristics (PCs)	Prioritized PSS components (PCos and SCos)	Prioritized Smart-PSS components (PCos, SCos, and ITCos)
General outcome	Identification and prioritization of customer requirements	Identification and prioritization of PSS features that can comply with customer requirements	Identification and prioritization of smart PSS features that can comply with customer requirements
Main features	CRs for the product/service are expressed in the customers' language. ECs include both product and service attributes, without any differentiation. The same happens to the analysis of PCs.	CRs are translated into RSPs improving their mutual comparability. The differentiation between product and service features (characteristics and components) allows a thorough analysis of the PSS solution.	CRs are translated into RSPs improving their mutual comparability. The differentiation in product, service, and IT features (characteristics and components) allows a more comprehensive analysis of the PSS offering bringing to light its smart attributes.

Besides, the level of importance of each RSP in the first HoQ is determined by means of the judgments provided by a team of experts, which use a 1 to 5 scale to rate the importance of each parameter (where 1 stands for not important and 5 is very important). Thus, the following equation is used to determine V_j, which is the value of each characteristic:

$$V_j = \sum_{i}^{j} RI_i \text{ x } S_{ij} \tag{1}$$

where "*j*" indicates the columns (i.e., PChs, SChs, and ITChs), "*i*" indicates the rows (RSPs), RI_i is the Raw Importance and S_{ij} is the relationship score between the j-th PChs, SChs, and ITChs on the one side, and the i-th RSPs on the other.

The practical application of the QFDforSmartPSS method can be described by the procedure reported in Table 2, where also the supportive tools used to carry out each activity are included, such as the critical to quality (CTQ) method[83] and customer surveys to better capture the customer needs and expectations, as well as the judgments provided by a group of experts for technical support in the practical application of the proposed methodology.

As indicated in Table 2, the definition of both characteristics and components of the Smart-PSS solution is carried out by a group of experts each time depending on the case study context, in a similar manner as the definition of engineering characteristics ECs and parts characteristics (PCs) are defined when using the conventional QFD.

Such a framework can be used as a step-by-step guideline to develop a Smart-PSS concept, where RSPs, Smart-PSS characteristics, and Smart-PSS components are the main features of the PSS solution. This is consistent with the need to define a minimum set of requirements to gain the main customer needs and to define the technical characteristics of the solution, which will represent the backbone of the PSS model, as argued by Vasantha et al.[18]

The procedure illustrated in Table 2 is related to the application of the method without the use of other techniques that are usually used to augment the HoQ performances, such as fuzzy logic, analytic network process (ANP), analytic hierarchy process (AHP), law of comparative judgments (LCJ), or Kano model.[84] Even though these tools are not considered in the current study, they can be used for the improvement of the results of the QFD for Smart-PSS method in the same manner as they are used for the conventional QFD.

TABLE 2 General framework of the proposed approach.

Activity	Input	Activity	Output	Supportive tools
1	Customer information	Identification of customer needs	Customer requirements (CRs)	Customer surveys, CTQ
2	CRs	Analysis of CRs and transformation into RSPs	RSPs	Group of experts
3	RSPs	RSPs evaluation	Prioritized RSPs	Group of experts
4	Provider information	Definition of the technical characteristics	Smart-PSS Characteristics (PChs, SChs, and ITChs)	Group of experts
5	Provider information	Assessment of the relationships between the RSPs and the Smart-PSS characteristics	Prioritized Smart-PSS characteristics	Group of experts
6	Provider information and Smart-PSS characteristics	Definition of the Smart-PSS components	Smart-PSS components (PCos, SCos, and ITCos)	Group of experts
7	Provider information	Assessment of the relationships between Smart-PSS characteristics and Smart-PSS components	Prioritized Smart-PSS components	Group of experts
8	Prioritized Smart-PSS components	Functional assessment	Smart-PSS conceptual solution	Group of experts

4 | CASE STUDY

In this section, an illustrative case study is reported to better explain the proposed method and its effectiveness. The case study concerns a six-floor public department building, which is equipped with four elevators (three for people and one for freight). Actually, with the large stream of people daily using these facilities and their degraded state due to obsolescence, the management (hereinafter referred to as Company X) decided to carry out a feasibility study to replace them. In particular, a PSS solution for the provision of four new elevators and their maintenance services was analyzed. Due to privacy concerns, only partial results are provided in this section based on a non-disclosure agreement.

4.1 | Smart-PSS characteristics definition

Company X's team of experts participated in defining the survey questions and questionnaires needed to gather the sought information. Then we proceeded in collecting information on the customers' needs by means of interviews with the technicians of Company X in charge of managing the elevators as well as questionnaires to frequent elevator users to better gain their expectations. The respondents' identity was kept anonymous, and the questions were asked separately. We collected 77 responses and 52 were considered complete: they provided complete answers to all our inquiries. The questions addressed the respondents' views on the product's quality, its associated services, as well as the ordinary and extraordinary maintenance activities. Only questionnaires and surveys where all the questions were met with an answer, by the same respondent, were kept. This allowed us to define the customers' requirements list by means of the CTQ method, applied as in Figure 7.

Then, together with the technicians of Company X and two experts from two different elevator retailing/maintenance companies, the CRs were translated into RSPs, and their importance was brought forth: in Table 3, the average values achieved considering a 1–5 rating scale (1 = not important; 5 = very important). It has to be noted that the transformation of CRs into RSPs requires an abstraction process to focus on what the PSS receivers would like to have optimized, rather than a general need. For example, the CR "User-friendly equipment" was translated into the following RSPs: RSP1 "Easiness to use" and RSP2 "Intuitive Human-Machine Interface (HMI)".

Then, the company's technicians and a group of experts outlined the characteristics of the product, the services and IT needed to satisfy the RSPs (Table 4).

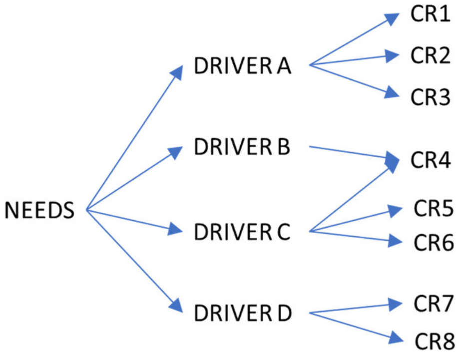


FIGURE 7 Illustration of the CTQ method.

TABLE 3 Description of the RSPs and their importance.

RSP	RSP importance
RSP1. Easiness to use	4.1
RSP2. Intuitive human-machine interface (HMI)	3.5
RSP3. Ergonomics (comfortable cabin)	3.6
RSP4. Full monitoring and real-time information	3.8
RSP5. Availability	4.2
RSP6. Short intervention time	4.6
RSP7. Short replacement/repair time	4.4
RSP8. Technical support availability	3.1
RSP9. Upgradability	2.8

These characteristics were then evaluated against the RSPs to determine the relationships between them. The results are portrayed in Figure 8, where the box corresponding to 0 (i.e., no relationship) was left empty to optimize the figure's readability.

The output of the first phase of the method brings to light the relevance of Sch3 (Time for response) and SCh1 (Information for intervention requests) for what concerns the service characteristics, while from the IT characteristics point of view ITCh4 (Availability of a system that should allow the connection with the provider) and ITCh3 (Availability of a maintenance monitoring system) resulted as the most important. The relative importance of each characteristic is brought forward more clearly in Figure 9.

4.2 | Smart-PSS components definition

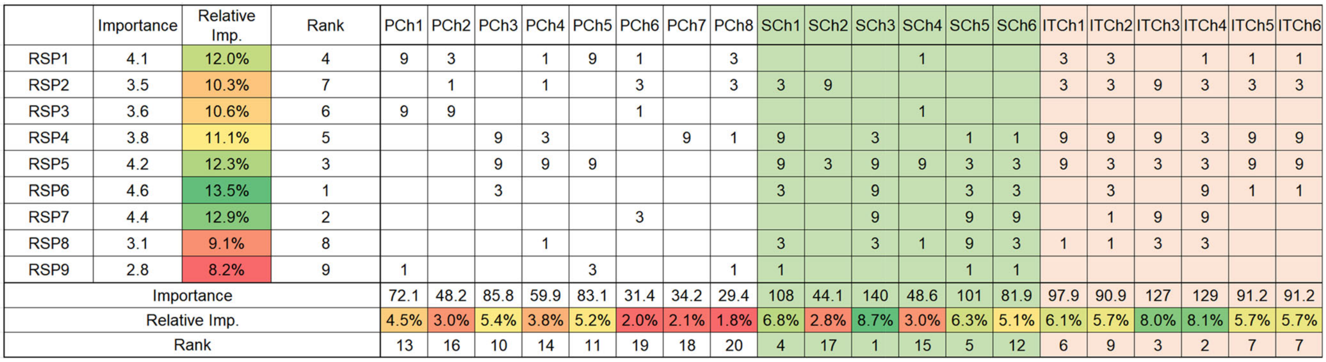
In a similar manner, the components related to the characteristics were defined with the company's engineers: in Table 5 a list of the components is reported where due to privacy concerns some PCos and SCos were omitted.

The relationships between characteristics and components were assessed through the second HoQ in a similar manner to the first HoQ. An excerpt is shown in Figure 10 whereas the importance levels of the components are presented in Figure 11.

The results of this second phase outlined that among the service components the most relevant are SCo2 (Certified training for remote support operators), SCo7 (Periodic training of third-party maintenance and field service engineers), and SCo3 (Training of customer care operators) respectively, while among the IT components they are ITCo10 (Supervisory Control And Data Acquisition (SCADA) software), ITCo11 (Gateway devices to communicate operation conditions and information wirelessly), and ITCo8 ("Smart" scheduling for the optimization of maintenance activities based on operational and usage history).

TABLE 4 List of the Smart-PSS characteristics.

Smart-PSS characteristics		
Product characteristics	**Service characteristics**	**IT characteristics**
PCh1–Product size: the cabin's dimensions should be adequate to allow easy use and lift 4 people.	SCh1–Information for intervention requests.	ITCh1–Availability of a self-testing system to be used periodically by the maintenance service company.
PCh2–Keypad type: the buttons' size and or the screen size and resolution should be adequate.	SCh2–Calendar time of training: periodic training for the correct use of the machine, notably when updates are available.	ITCh2–Availability of a storage system of data concerning the elevator's functioning.
PCh3–Mean time before failure (MTBF): the elevator must function for prolonged working days before the occurrence of failures.	SCh3–Time for response: short time to reply to intervene.	ITCh3–Availability of a maintenance monitoring system: a predictive maintenance plan should be used by means of a specific database.
PCh4–Alarm warning: in case of malfunctioning an alarm should inform the users and the rescue team in the building.	SCh4–Calendar time of spare parts delivery: components that need to be replaced periodically are delivered according to an agreed-on schedule.	ITCh4–Availability of a system that should allow the connection with the provider to automatically inform of the need for a maintenance intervention in case of malfunctioning/failures.
PCh5–Number of rescue operations: the number of steps to carry out for rescuing people in case of malfunctioning should be minimum.	SCh5–Operational time of customer care: the customer care unit should be available to reply to customer calls.	ITCh5–Availability of a camera to monitor the cabin for safety reasons.
PCh6–System modularity: a modular design enables easier upgrades of components and maintenance interventions.	SCh6–Quality of customer care: this service should have the capacity to assist the customer (i.e., Company X) effectively.	ITCh6–Availability of a track system to monitor the position of the cabin.
PCh7–Safety (when using the elevator and in case of its malfunctioning)		
PCh8–Quality of user manual: the elevator should be accompanied by a manual describing its components and guiding the rescue team and technical staff, including interactive software		



	Importance	Relative Imp.	Rank	PCh1	PCh2	PCh3	PCh4	PCh5	PCh6	PCh7	PCh8	SCh1	SCh2	SCh3	SCh4	SCh5	SCh6	ITCh1	ITCh2	ITCh3	ITCh4	ITCh5	ITCh6
RSP1	4.1	12.0%	4	9	3		1	9	1		3				1			3	3		1	1	1
RSP2	3.5	10.3%	7		1		1		3		3	3	9					3	3	9	3	3	3
RSP3	3.6	10.6%	6	9	9				1						1								
RSP4	3.8	11.1%	5			9	3			9	1	9		3		1	1	9	9	9	3	9	9
RSP5	4.2	12.3%	3			9	9	9				9	3	9	9	3	3	9	3	3	3	9	9
RSP6	4.6	13.5%	1			3						3		9		3	3		3		9	1	1
RSP7	4.4	12.9%	2						3					9		9	9		1	9	9		
RSP8	3.1	9.1%	8				1					3		3	1	9	3	1	1	3	3		
RSP9	2.8	8.2%	9	1				3			1	1				1	1						
Importance				72.1	48.2	85.8	59.9	83.1	31.4	34.2	29.4	108	44.1	140	48.6	101	81.9	97.9	90.9	127	129	91.2	91.2
Relative Imp.				4.5%	3.0%	5.4%	3.8%	5.2%	2.0%	2.1%	1.8%	6.8%	2.8%	8.7%	3.0%	6.3%	5.1%	6.1%	5.7%	8.0%	8.1%	5.7%	5.7%
Rank				13	16	10	14	11	19	18	20	4	17	1	15	5	12	6	9	3	2	7	7

FIGURE 8 Results of the first HoQ (phase I).

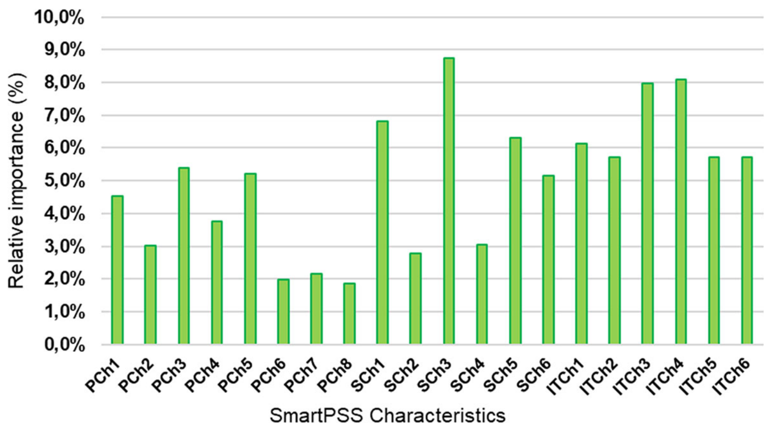
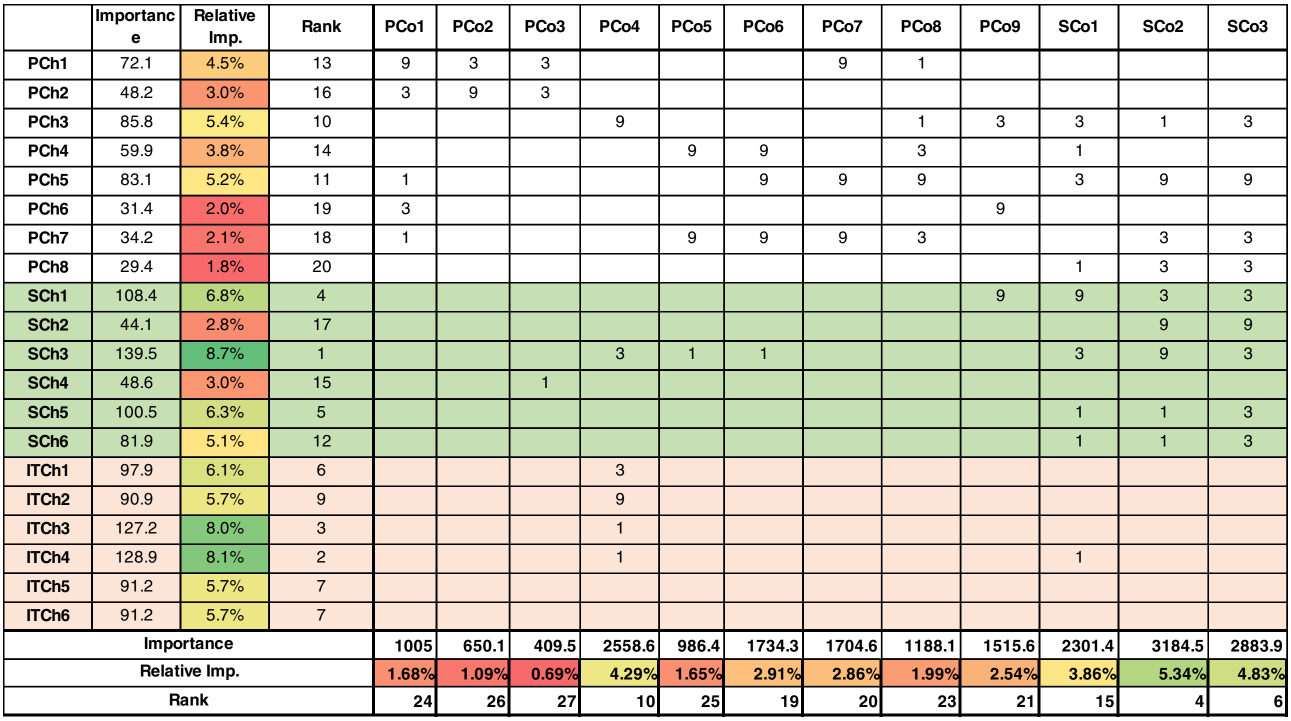


FIGURE 9 Relative importance of the product, service, and IT characteristics.

TABLE 5 List of the Smart-PSS components.

Smart-PSS components		
Product components	**Service components**	**IT components**
PCo1–Standardized dimensions and capacity	SCo1–Dedicated hotline for remote support	ITCo1–Database dedicated for customer information storage
PCo2–USB keyboard and mouse	SCo2–Certified training for remote support operators	ITCo2–e-Service manual (accessible online)
PCo3–Full high definition (FHD) monitor	SCo3–Training of customer care operators	ITCo3–e-Learning portal for user training
PCo4–Self-check at regular intervals, that is, 24 h.	SCo4–Periodic training schemes	ITCo4–Algorithms to select the optimal repair/service center (e.g., based on customer location and breakdown information)
PCo5–LED alarm notification	SCo5–Decentralized service centers	ITCo5–Automated chat assistant
PCo6–Sound alarm notification	SCo6–Min-Max delivery planning schedule for spare parts	ITCo6–Availability of a LOG file for self-check results
PCo7–Presence of emergency escape hatches	SCo7–Periodic training of third-party maintenance and field service engineers	ITCo7–History records related to the functioning and maintenance activities
PCo8–Door opening and closing sensors		ITCo8–Automated scheduling for the optimization of maintenance activities based on operational and usage history
PCo9–Backup power supply		ITCo9–Remote video access for off-site monitoring
		ITCo10–Supervisory control and data acquisition (SCADA) software
		ITCo11–Gateway devices to communicate operation conditions and information wirelessly



	Importance	Relative Imp.	Rank	PCo1	PCo2	PCo3	PCo4	PCo5	PCo6	PCo7	PCo8	PCo9	SCo1	SCo2	SCo3
PCh1	72.1	4.5%	13	9	3	3				9	1				
PCh2	48.2	3.0%	16	3	9	3									
PCh3	85.8	5.4%	10				9				1	3	3	1	3
PCh4	59.9	3.8%	14					9	9		3		1		
PCh5	83.1	5.2%	11	1					9	9	9		3	9	9
PCh6	31.4	2.0%	19	3								9			
PCh7	34.2	2.1%	18	1				9	9	9	3			3	3
PCh8	29.4	1.8%	20										1	3	3
SCh1	108.4	6.8%	4									9	9	3	3
SCh2	44.1	2.8%	17											9	9
SCh3	139.5	8.7%	1				3	1	1				3	9	3
SCh4	48.6	3.0%	15			1									
SCh5	100.5	6.3%	5										1	1	3
SCh6	81.9	5.1%	12										1	1	3
ITCh1	97.9	6.1%	6				3								
ITCh2	90.9	5.7%	9				9								
ITCh3	127.2	8.0%	3				1								
ITCh4	128.9	8.1%	2				1						1		
ITCh5	91.2	5.7%	7												
ITCh6	91.2	5.7%	7												
Importance				1005	650.1	409.5	2558.6	986.4	1734.3	1704.6	1188.1	1515.6	2301.4	3184.5	2883.9
Relative Imp.				1.68%	1.09%	0.69%	4.29%	1.65%	2.91%	2.86%	1.99%	2.54%	3.86%	5.34%	4.83%
Rank				24	26	27	10	25	19	20	23	21	15	4	6

FIGURE 10 Excerpt of the second HoQ (phase II).

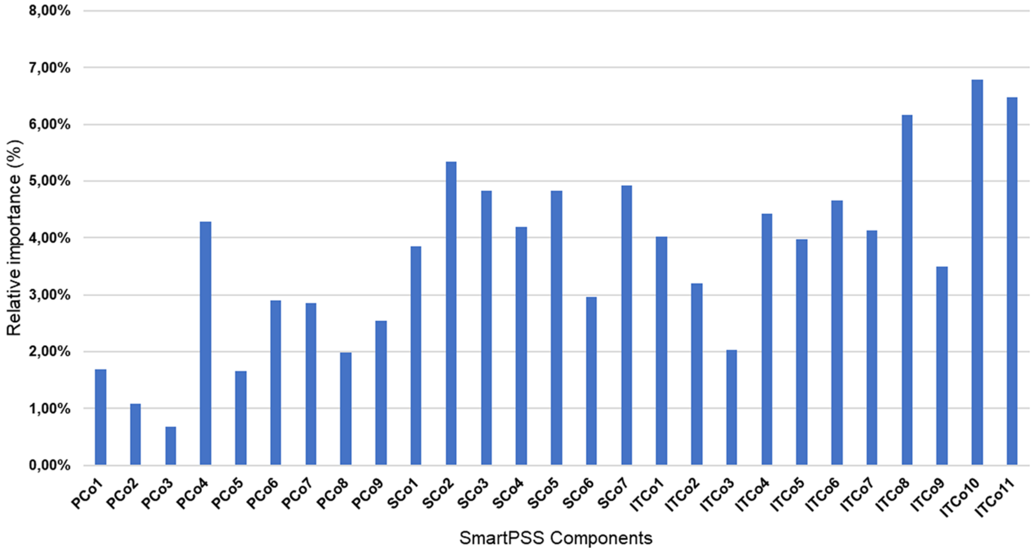


FIGURE 11 Relative importance of the product, service, and IT components.

It must be noted that for the satisfaction of the PCo1 (Standardized dimensions and capacity) the group of experts outlined the need to comply with the following technical standards: ISO 22201-1:2017[85] and ISO 22559-1:2014.[86] Then, when considering the service components, the implementation of a planning schedule for spare parts (SCo6) was foreseen through the use of the reliability centered spares (RCS) technique to determine the optimum number of spare parts requirements based on the needs and maintenance operations for a certain period, while the use of the min-max stock is suggested to define the minimum and maximum spare parts inventory, in line with Angelina et al.[87]

As far as the IT components are concerned, the implementation of a building information modeling (BIM) solution was foreseen to satisfy the ITCo8 (Automated scheduling for the optimization of maintenance activities based on operational and usage history). Indeed, the use of BIM tools consists of a task-specific application such as energy analysis or activities' scheduling, by means of software and platforms, which can allow the management of data and the company interfaces.[88,89]

More in detail, as outlined by Farghaly et al.[90] the use of BIM tools enables the management of a large amount of information concerning the following categories and parameters:

1. Space/location;
2. Classification;
3. Specifications;
4. Warranty; and
5. Maintenance.

In the classification category, the Revit software[91] can be used, as it represents one of the most diffused solutions for BIM parametric modeling. It must be noted that in the Revit software any type of maintenance intervention can be stored: in our case study, an abacus for ordinary maintenance interventions and another one for extraordinary maintenance ones were implemented.

4.3 | System implementation

A preliminary analysis for the implementation of a potential Smart-PSS was made in collaboration with Company X and the group of experts. In particular, by means of the software DigiPara Elevatorarchitect,[92] the four novel elevators were modeled based on the list of the components that emerged from the analysis: for example, for the remote monitoring of the ropes the use of magnetostrictive transducers was foreseen. In Figure 12, the simplified scheme of one of the elevators

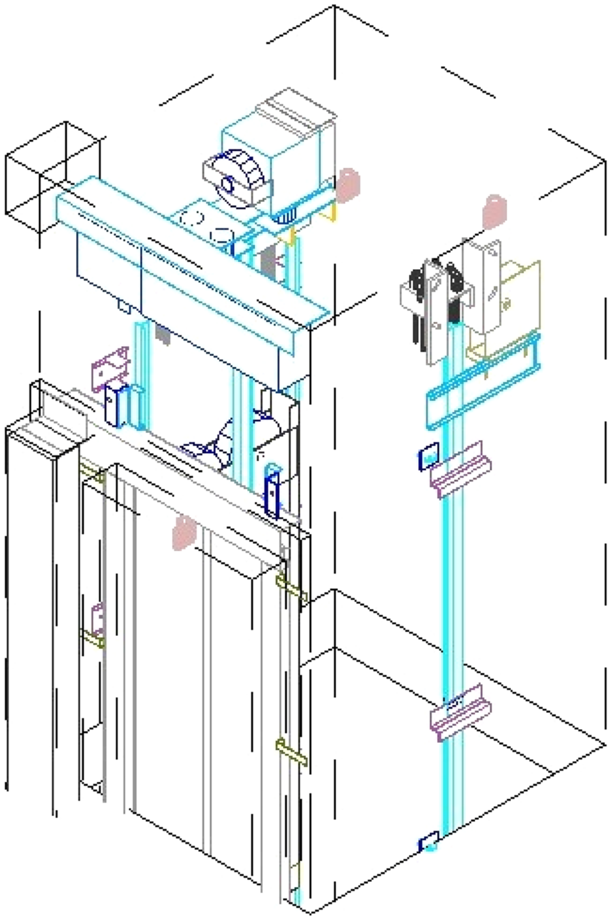
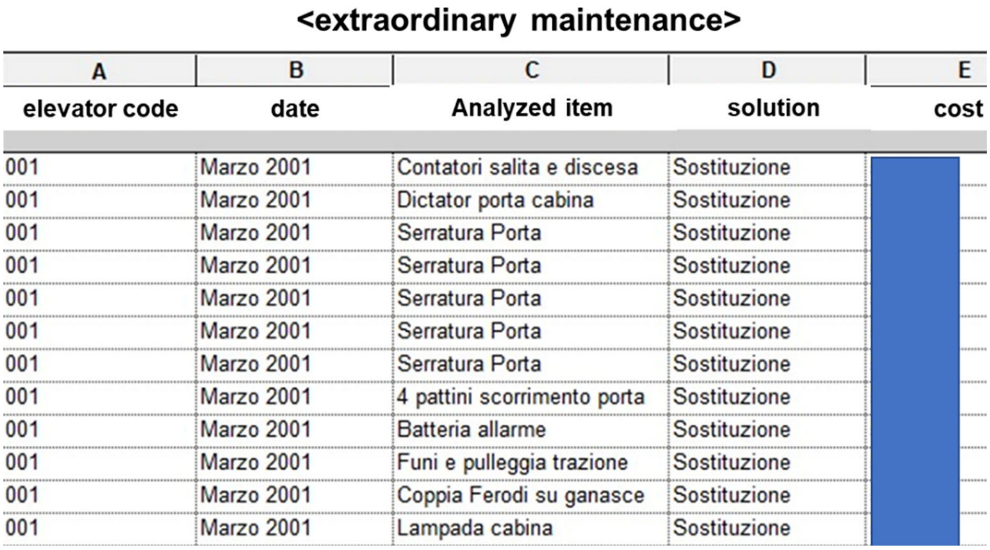


FIGURE 12 3D model of one of the elevators.



<extraordinary maintenance>

A	B	C	D	E
elevator code	date	Analyzed item	solution	cost
001	Marzo 2001	Contatori salita e discesa	Sostituzione	[redacted]
001	Marzo 2001	Dictator porta cabina	Sostituzione	[redacted]
001	Marzo 2001	Serratura Porta	Sostituzione	[redacted]
001	Marzo 2001	Serratura Porta	Sostituzione	[redacted]
001	Marzo 2001	Serratura Porta	Sostituzione	[redacted]
001	Marzo 2001	Serratura Porta	Sostituzione	[redacted]
001	Marzo 2001	Serratura Porta	Sostituzione	[redacted]
001	Marzo 2001	4 pattini scorrimento porta	Sostituzione	[redacted]
001	Marzo 2001	Batteria allarme	Sostituzione	[redacted]
001	Marzo 2001	Funi e pulleggia trazione	Sostituzione	[redacted]
001	Marzo 2001	Coppia Ferodi su ganasce	Sostituzione	[redacted]
001	Marzo 2001	Lampada cabina	Sostituzione	[redacted]

FIGURE 13 Example of the Revit abacus concerning extraordinary maintenance interventions.

is illustrated: such a concept represents a preliminary layout of the elevator carried out by means of a specific software for the implementation of a BIM model.

As far as the use of the Revit software is concerned, for each elevator, two abaci were implemented concerning ordinary and extraordinary maintenance interventions starting from January 2000 up to December 2019. In Figure 13, an excerpt of the Revit abacus used for the storing of data related to past maintenance interventions of one elevator is reported.

In particular, in the first column of the abacus the elevator code is reported (column A); column B refers to the maintenance intervention date (March 2001); column C indicates the type of components that were analyzed (e.g., four roller guide shoes); column D indicates the action carried out, which consisted in the components' replacement; column E refers to the cost of each maintenance activity carried out, which was hidden due to privacy concerns.

5 DISCUSSION

The case study output allowed us to define the main features of a Smart-PSS solution, which Company X is currently deploying for its new elevators' system implementation. In particular, the use of the QFD for Smart-PSS was considered very beneficial in bringing to light the elements that differentiate the novel smart solution from a conventional one, allowing engineers to better focus their attention on those smart characteristics and components that are customer relevant.

Concretely, the importance of the smart characteristics consists of 39%, the service characteristics 33% and the product 28%. The components follow the same trend, that is, the smart components' importance is of 51%, the services' 30%, and the product's 19%. In other words, the importance of "smart" characteristics and components is highlighted, outweighing those related to the product and the service.

At this point, one might argue that from the methodological point of view no significant differences exist between the proposed method and QFD for PSS, pointing out that IT characteristics and IT components can be ascribed to product or service characteristics and components. This can be true to some extent. However, the proposed multi-criteria decision-making tool allows a better granularity of the assessment and deployment of the system features. The latter issue is consistent with Zheng et al.[60] who stressed the importance of well-defining the smart and connectivity components in PSS.

Indeed, on the one hand, the proposed approach enabled engineers to filter the voice of customers into objective requirements that can lead to a more thorough improvement of both the physical and service features of the system, together with those related to IT technologies such as databases, clouds, remote monitoring, mobile applications, and so forth. On the other hand, the augmented QFD method proposed in this study revealed its usefulness not only in the development of novel solutions, but also in the improvement of already existing systems towards smart configurations that can increase value both for customers and manufacturers/providers.

From the managerial point of view, in order to analyze the potential effects of the results achieved on the company management, a follow-up meeting with the group of experts was carried out, whose outcomes can be synthesized as follows. The QFD for Smart-PSS method can ensure a thorough analysis of customers' needs and all stakeholder's expectations. The method provided useful information on the Smart-PSS features, whose evaluation and improvement can be achieved in a more complete manner. Moreover, it was noted that companies can benefit from the proposed approach when planning investments aimed at the "Industry 4.0 transition" such as the ones that are financed by the European Union in the ambit of the Recovery Plan[93] and NextGenerationEU[94] policies. As a matter of fact, the application of these policies at the national level is declined in funding to support companies in the implementation of smart technologies to improve their activities and the possibility of specifically addressing smart features given by the proposed approach was considered very positive.

Actually, as noted by the group of experts, the proposed approach can be used for upgrading already existing systems, such as equipment set up in buildings and facilities, by providing smart solutions that are properly integrated into the system. This aspect provides a response to the request by Liu et al.[46] for more research on the conceptual development of Smart-PSS. Accordingly, the proposed approach can contribute to augmenting knowledge on the use of smart solutions in facility management, which is becoming an increasingly pressing issue, as stressed by Gao and Pishdad-Bozorgi.[95] This is confirmed by the output of the analysis, which brought to light the higher relevance of smart features (both at the characteristics and at the components level) compared to the conventional ones.

Considering smart features apart from the product/service ones can enhance the development of more accurate and realistic solutions.[96] The novel HoQ schemes allow the comparison of the IT features of the system with those related to physical and service items, providing a more specific assessment of the smart characteristics and components of the system and thus bringing to light its "smartness". This result is also in line with the research findings by Gaiardelli et al.[97] who observed that nowadays some digital features are enclosed with the PSS solution often in the form of an enabler of advanced products/services, while new technologies are not necessarily part of the solution. Moreover, this can reduce the risk for inexperienced managers and practitioners of opting for choices that could reduce the customers' satisfaction when shifting from conventional PSS to Smart-PSS.

To sum up, the merit of this study consists in the proposition of a specific method for the development of Smart-PSS solutions, which relies on the reliability of the QFD approach on the one hand, providing a novel approach to practically implement smart features on the other. The proposed approach can enhance the elicitation of customer requirements by providing a logical and comprehensive procedure that supports engineers to achieve Smart PSS concepts in practice.

Considering the extant studies mentioned in the previous sections that addressed the implementation of PSS solutions by means of QFD-based approaches, numerical results produced from the QFD for Smart-PSS method allow engineers to discover the relative importance of the smart attributes of the PSS solution: this enables a more thorough analysis of the offering and sheds light on the resources behind each IT feature. Accordingly, the proposed method can augment PSS knowledge in the field of PSS providing a MCDM approach that specifically addresses the development of Smart-PSS solutions. In other words, the method provides a better granularity and homogeneity of the assessment of the system's characteristics and components by simultaneously considering the interactions between product features, service features, and smart/ITC features. This also accomplishes the research hints by Pirola et al.[39] whose research agenda highlights the need to concomitantly focus on servitization and digital features in PSS development due to their potential of mutual reinforcement in value creation for both customers and PSS providers.

From the methodical standpoint, the use of QFD-based approaches for the development of PSS solutions does not represent a novelty in literature, as explained in Section 2, although no specific research on the augmentation of QFD with features aimed at specifically addressing the design and development of Smart characteristics of the PSS solution can be found, as summarized in Table 6. For example, even though Kim et al.[74] proposed a QFD-based approach for the development of the T Smart Learning solution, the methodology used does not include specific features that deal with the smart characteristics of the PSS under development. Conversely, in the QFD for Smart-PSS method proposed in this study, IT attributes are specially addressed in both the HoQs, thus allowing the assessment of their interaction with the other PSS elements (i.e., the product's and services' attributes) both at the characteristics' and components' level.

However, despite its advantages, the proposed method has some limitations that are mainly related to the fact that this is the first application of the QFD for Smart-PSS method. Hence, the results achieved are limited to the case study context, while further research is needed to increase its external validity. Actually, the proposed approach was tested on an application-oriented PSS (APSS), while other types of PSS business models were not investigated.

TABLE 6 Comparison of the current study with previous research.

Research study	Tools	QFD phases	Input	Output	Inclusion of Smart/ITC features
Kim and Yoon[70]	QFD and TRIZ contradiction matrix	3	Customer requirements (CRs) or new service concepts	Sub-services and product elements	No
Yin et al.[71]	QFD and fuzzy analytic network process (fuzzy ANP)	3	Customer requirements (CRs)	Prioritized product-related and service-related stakeholders	No
Li et al.[72]	QFD and supply-chain operations reference (SCOR)	6	Quality indicators and return on investment (ROI)	Prioritized risk events and business model optimization	No
Peruzzini et al.[73]	QFD, Life cycle assessment (LCA) and life cycle cost analysis (LCCA)	2	Customer needs	Prioritized tangible and intangible assets and related sustainability level	No
Kim et al.[74]	QFD and analytic hierarchy process (AHP)	1	Customer needs	Prioritized service features and product functions	No
Sousa-Zomer and Miguel[48]	QFD, Fuzzy logic, comparison matrix for sustainability criteria	3	Stakeholders' requirements	Prioritized PSS functions	No
Hara[75]	QFD	1	Required quality of product by user and required quality of user's use by manufacturer (RQs)	Prioritized quality elements of product and of user (QEs)	No
Mazo and Borsato[76]	QFD augmented by the proportion matrix	3	Customer requirements (CRs)	Prioritized resources that are necessary to meet customer requirements	No
Geng et al.[77]	QFD, fuzzy logic, data envelopment analysis (DEA), Kano model, non-linear programming	1	Customer requirements (CRs)	Prioritized product-related and service-related ECs (P-ECs and S-ECs)	No
Arai and Shimomura[78]	QFD for PSS	2	Receiver state parameters (RSPs)	Prioritized PSS components (PCos and SCos)	No
Haber et al.[82]	QFD for PSS and Kano model	2	Receiver state parameters (RSPs)	Prioritized PSS components (PCos and SCos)	No
Current study	QFD for Smart-PSS	2	Receiver state parameters (RSPs)	Prioritized Smart-PSS components (PCos, SCos, and ITCos)	Yes

The research method adopted in this study can be considered a "case study" approach[98] and to investigate its applicability it was implemented in the elevators sector. Accordingly, as noted by Cash al.[99] the results obtained from a single case study lack external validity. However, numerous authors agree on the fact that a single case study can be used as a research tool for exploratory investigation, capable of giving rise to new understandings.[98,100]

Moreover, extended data validation and a life cycle assessment should be carried out to better evaluate the feasibility and viability of the proposed approach. Moreover, another criticality is related to the knowledge management issue of BIM in particular and digital tools in general, which was not considered in the current study. In fact, on the one hand, the implementation of an APSS approach partially solves this problem since the provider as the owner of the equipment retains key information related to its life cycle. On the other hand, smart solutions imply information exchange with the customer and other stakeholders, which requires the provision of proper data management.

Finally, it must be noted that, even though some examples related to advanced models for QFD for PSS exist,[71,101] in this study the use of tools to augment the effectiveness of the HoQ was not taken into account as it was not the core of the research. Accordingly, further research on the integration of the proposed method with tools such as AHP or ANP techniques can provide clearer information on the interaction between product, service, and IT features.

6 | CONCLUSIONS

This study proposes a method aimed at better translating customer needs into Smart-PSS functionalities by means of an augmented version of conventional QFD so as to have a more comprehensive grasp of the needed characteristics to conceive a more appropriate solution that can effectively meet its customers' requirements. Therefore, augmenting the QFD with smart characteristics is considered a step in the right direction.

The QFD for Smart-PSS tool can be considered a novelty in the field of PSS development representing a way to evaluate the customer needs and system requirements of a Smart-PSS in a holistic manner without undermining any scope of characteristics compared to another (i.e., product, service and smart characteristics are captured simultaneously). The tool was tested at Company X as a means of putting the theory to practice and gauging its applicability. Accordingly, the results achieved can be considered a step forward in the research on decision-making tools to practically support engineers in the development of Smart PSS solutions.

However, the proposed approach is at the initial stage of development and further research work is needed to extend its validation. In fact, the study presented above is based on an APSS: other PSS models exist and should be considered. In other words, further research is required to define the applicability scope of such a tool and refine it. Additionally, the approach would benefit from a life cycle assessment consideration for a more holistic view of the solution and a better understanding of its impact on the product's behavior.

Moreover, future work ideas and directions should focus on the shift towards the so-called "Industry 5.0" solutions that on the one hand rely on digitalization and AI-driven technologies to augment production efficiency and flexibility, while on the other are aimed at augmenting the systems' agility and resiliency with the utilization of flexible and adaptable solutions.[102]

Accordingly, the authors hope that this study can be regarded as a first step and invite more open research and discussions both from academics and practitioners.

AUTHOR CONTRIBUTIONS

Mario Fargnoli: Conceptualization (equal); methodology (equal); validation (equal); writing – review and editing (equal). **Nicolas Haber:** Conceptualization (equal); methodology (equal); validation (equal); writing – review and editing (equal).

CONFLICT OF INTEREST STATEMENT

The author declares no potential conflict of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1002/eng2.12665.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy or ethical restrictions.

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