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Early stakeholder modeling and analysis: New mobility services (Product Service Systems of Systems)

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Abstract

Developing new mobility services such as electric vehicles and autonomous vehicles services requires not only the interaction and interoperation of independent systems such as electric vehicles, electric infrastructure, or off-board servers, but also the collaboration of independent business partners, namely, car manufacturers, energy providers, and service providers, developing, managing and operating these systems. Such services show both Product Service Systems and Systems of Systems characteristics and, as such, can be defined as Product-Service Systems of Systems. While extensive literature exists on developing and managing PSS product and service elements and SoS constituent systems, little research explicitly focuses on PSSoS stakeholders. In particular, the analysis of PSSoS stakeholder business partnerships and involvement in PSSoS development. PSSoS development is seen as the development, operation, and management of constituent systems. This paper contributes to addressing this gap and proposes an approach to manage stakeholder participation in the PSSoS business partnership and PSSoS development.

KEYWORDS
modeling, network topology, stakeholder analysis, system analysis, system engineering, Systems of Systems

1 | INTRODUCTION

Electric and autonomous vehicle-related services are gaining importance in the development of new mobility. Such services require not only the interoperation of independent systems [e.g., electric vehicles (EV) and electric infrastructure], but also the collaboration of independent business partners such as car manufacturers, energy providers, or service providers developing, managing, or operating these systems. These services are considered to be Product Service Systems of Systems (PSSoSs) defined as "sets of products, services, infrastructures, and networks where its constituent elements exhibit operational and managerial independence".[1] PSSoSs are both Product Service Systems (PSS)[2] and Systems of Systems (SoS).[3] Given that PSSs and SoSs have rarely been studied concomitantly in the literature, we rely on the PSS literature and SoS literature to address PSSoS questions.

An extensive literature exists on PSS design and development focusing on product and service elements[4] and PSS business modeling and value proposition.[5] A large body of knowledge also explores SoS architecture[6,7] and SoS management.[8] More recently, the PSS literature and the SoS literature have become more and more interested in identifying and characterizing the stakeholders taking part in PSS or SoS development. PSS literature identifies stakeholders involved in PSS development.[9–11] Studies in Refs. 12–15 focus on value co-creation. Other studies[16–19] propose collaborative value network models describing business partnerships PSS development and operation.

Regarding the SoS literature, most SoS frameworks[20,21] include a representation of SoS stakeholders defined as independent enterprises and organizations managing and operating SoS component systems.[3] The SoS literature describes strategic relationships[20] between SoS stakeholders and their relationships in the development and operation of the SoS constituent systems.[22,23]

Hence, the PSS literature and the SoS literature identify PSS and SoS stakeholders, characterize their relationships from a business partnership perspective, or describe their relationships in the development and operation of the PSS or SoS through product, service, or component system interaction and interoperation. However, to our knowledge, no research goes beyond qualitative analysis. On the other hand, quantitative methods to characterize stakeholders more generally have been proposed in project management and organization literature.[24] However, these methods, since adopted by many other fields,[25–27] have not been developed for PSS, SoS, or PSSoS stakeholders.

This paper aims to address this gap in the context of PSSoSs and specifically focuses on independent enterprises that collaborate, develop, and operate the PSSoS constituent systems. This research proposes a novel approach to qualify and quantify the importance and influence of PSSoS stakeholders. This approach is comprised of three steps. The first step aims to model PSSoSs as a heterogeneous network.[1] The second step aims at analyzing their importance in business partnerships and development. The third step proposes to quantify the influence of PSSoS stakeholders from both perspectives; business partnerships, and PSSoS development.

We propose the following structure of the paper. Section 2 reviews existing stakeholder analysis approaches and assesses their potential use in the context of PSSoSs. Section 3 presents the research approach. In Section 4, we describe the underlying PSSoS model. We also detail the analysis of PSSoS stakeholder importance and influence. In Section 5, we discuss an EV charging service industrial case study and its implications. Finally, a discussion and conclusion are given in Section 6.

2 | LITERATURE REVIEW

As PSSoS stakeholders are, by definition, similarly involved in the management, operation, and development of PSSoS component systems,[1] two main literature domains are of interest: 1) management literature and 2) design engineering literature. We focus in this paper on quantitative methods investigating stakeholders and their relationships.

In general terms, stakeholders are defined as "groups that have a stake in the activities that make up the business," including customers, suppliers, employees, financiers, communities, managers.[28] Based on this definition, stakeholder analysis has been historically the focus of management and organization research with stakeholder theory as its foundation.[24] Since then, several stakeholder analysis methods have been proposed. Several contexts have also been specifically addressed, for example, business management,[29] policy analysis,[30,31] environmental management,[27] or construction projects management.[25,26] Aragonés-Beltrán et al.[32] propose a method to analyze stakeholder influence from a product manager's perspective. The authors defined the influence of a stakeholder based on four clusters of criteria: knowledge, social skills, assets, and external factors such as the public image. The authors modeled the dependencies among stakeholders, the dependencies among influence criteria, and between stakeholders and influence criteria. They also relied on the Analytic Network Process Model to compute each stakeholder's influence index.

In particular, the literature focusing on construction projects, large-scale engineering projects, and software projects is interesting as these projects show similar characteristics to PSSoSs, namely, the complexity, the participation of various organizations, and the potential geographic distribution.[3,33] In the context of *construction project management*, another interpretation of stakeholder influence have been given. Zedan and Miller[34] reinterpret the influence attributes: power, proximity, and interest proposed by Bourne and Walker[29] to the context of construction project management, and more specifically to assess the influence of stakeholders on the energy efficiency of housing. Based on these attributes, the influence of stakeholders in the energy efficiency of housing is calculated as the sum of the power, proximity, and interest multiplied by the time factor indicating the overall time that a stakeholder is involved in the project. Another perspective on influence in construction projects has been proposed by R. J. Yang and Zou.[35] Considering specifically green construction projects, the authors highlight the importance of studying stakeholders and the risks associated with them. They focus on risks associated with stakeholders and use risk network topological measures [e.g., node (risk) eigenvector centrality]. In the same fashion, Dadpour et al. (2019)[36] underline the importance of stakeholder concerns and their impact on planning and executing construction projects. The authors propose a network of stakeholder concerns and use network metrics to characterize the power and influence of stakeholder concerns.

Considering *large-scale engineering systems*, we highlight the work around the PhD thesis of Feng[37] concerning stakeholder value network modeling.[38,39] In this research, the authors propose a qualitative/quantitative approach to characterize stakeholder power and influence, taking into consideration direct and indirect relationships between stakeholders. They propose to identify the stakeholders and consider their roles, objectives, and needs. Based on this stakeholder characterization, the "stakeholder value network" is proposed where nodes are stakeholders, and edges are quantified value flows reflecting specific needs of stakeholders and their perceived utility to recipient stakeholders. Finally, the authors define the Weighted Stakeholder Occurrence (WSO) and the Weighted Value Flow Occurrence (WVFO) to measure the importance of a stakeholder. The "stakeholder value network" has also been used and adapted to specific contexts such as space exploration[40] or industrial symbiosis.[41]

In the context of *large-scale software projects*, several authors have also taken an interest in prioritizing stakeholders and investigating their relationships. Ballejos and Montagna[42] argue that software project management is "integrally affected by stakeholders' perspectives and their participation," especially when it involves different organizations. Therefore, they propose an approach for quantifying the interest and influence of stakeholders in the project. The interest characterizes the needs of a stakeholder with regard to the project and its objectives. The authors propose different expressions to capture this interest: either a weighted sum of the stakeholders' interests in various project objectives or the most significant interest in a specific project objective. The influence depends on the role (e.g., decision-maker, developer, or sponsor) and power of the stakeholder, including positional power, personal power, and political power. Lim et al.[43] propose another method named "StakeNet" to identify and prioritize stakeholders based on their influence on the software project. The proposed six steps method relies on network topological measures to prioritize stakeholders. This method was further discussed in the case of systems of systems in Ref. 44.

To resume, most stakeholder analysis approaches in the management research domain consider skills,[32] interests, concerns,[36] or needs[38] as important attributes characterizing stakeholders. In most cases, different network topological measures are used to quantify the importance of a stakeholder (or a node). The difficulty lies in the fact that these measures do not give concrete insights into the manner of participation of different stakeholders in the development and operation in general. Another research current addresses this question with a focus on system design and development.

Luo et al.[45] recognize that most products are manufactured by firms collectively designing and producing the systems. These firms are linked through transactions. In this context, the authors proposed an analysis of transaction networks. More specifically, they characterize the hierarchy of the transaction network defined as the degree to which transactions flow in one direction, from "upstream" to "downstream,." In this research, the authors do not focus on the analysis of each stakeholder but on the characterization of hierarchy in transaction networks. Son and Cho[46] focus on collaborative R&D activities in the pharmaceutical industry. They considered pharmaceutical companies and enterprises, research institutes and universities, and hospitals and public bodies. The relationships between stakeholders represent their mutual engagement in projects. The authors relied on node network metrics to characterize the centrality of each organization in the collaboration network.

Another area of the literature considers stakeholders that are directly involved in product development. For instance, Morelli et al.[47] already analyzed technical communication within a product development organization seen as a way to improve product development activities. The authors differentiated coordination, knowledge, and inspiration communication. Later, Sosa et al.[48] empirically investigated the factors that influence communication, drivers, and barriers, especially for distributed product development. Batallas and Yassine[49] propose to use communication matrices and node network measures to identify information leaders and to distinguish internal coordinators, external coordinators, representatives, gatekeepers, and liaisons. Bashir[50] also uses network centrality measures to analyze the information flows among product development teams. Based on these measures, the author classifies product development teams in four other categories autonomous, receivers, transmitters, and transceivers. Parraguez et al.[51] rely on a dynamic cross-domain network approach to characterize the information flows in engineering design. In their approach, they consider not only the network of people communications but also the network of activities and their information flows, along with the network of people-activities, and that throughout the engineering design stages (as a temporal dynamic). In this work, cross-domain network measures are used to characterize the importance and influence of an activity rather than a stakeholder. Similarly, Wu et al.[52] analyzed the communication and collaboration mechanisms in social product development using multi-domain networks at actor and system levels, including customer needs, functional requirements, design parameters, and process variables. One can see that the majority of this research current has been focusing on communication and information flows. However, there is also research that addresses other attributes to characterize teams in view of better organization. For example, Chen and Lin[53] propose a model for team member rating based on multifunctional knowledge, teamwork capability, and working relationship ratings. This rating model aims at assessing the formation of multifunctional teams in concurrent engineering.

To resume, the approaches considering stakeholder definitions related to project and engineering either * consider firms participating in the design, development, or manufacturing of the product[45,46] and characterize their partnerships and engagements in the project, or * focus on product development teams and characterize their communication and collaboration via design activities and throughout the design process.[47,49–51]

In summary, in the management domain, stakeholder analysis approaches gave various interpretations of the importance and influence of a stakeholder. Approaches in the design engineering domain addressed two aspects: stakeholder partnerships and development implications. However, both domains did not specifically address PSSoS stakeholders. In section 3, we address this gap by identifying information pertaining to PSSoS business partnerships and development and giving relevant interpretations of PSSoS stakeholder importance and influence in these contexts.

3 | RESEARCH METHODOLOGY

The present paper is based on a previous research work published in Ref. 1. In Ref. 1, a thorough PSS and SoS literature review is conducted to identify PSS and SoS underpinnings and cross-cutting themes and consequently define PSSoS key concepts.

This work focuses on the concept of PSSoS Stakeholders defined in Ref. 1 and suggests a PSSoS stakeholders modeling and analysis approach. The adopted research approach is presented Figure 1.

4 | ANALYZING PSSOS STAKEHOLDER IMPORTANCE AND INFLUENCE IN BUSINESS PARTNERSHIPS AND DEVELOPMENT

In this section, we aim to quantify the importance and the influence of each PSSoS stakeholder in business partnerships and development.[54–56] The literature review showed that quantitative stakeholder analysis approaches give various interpretations

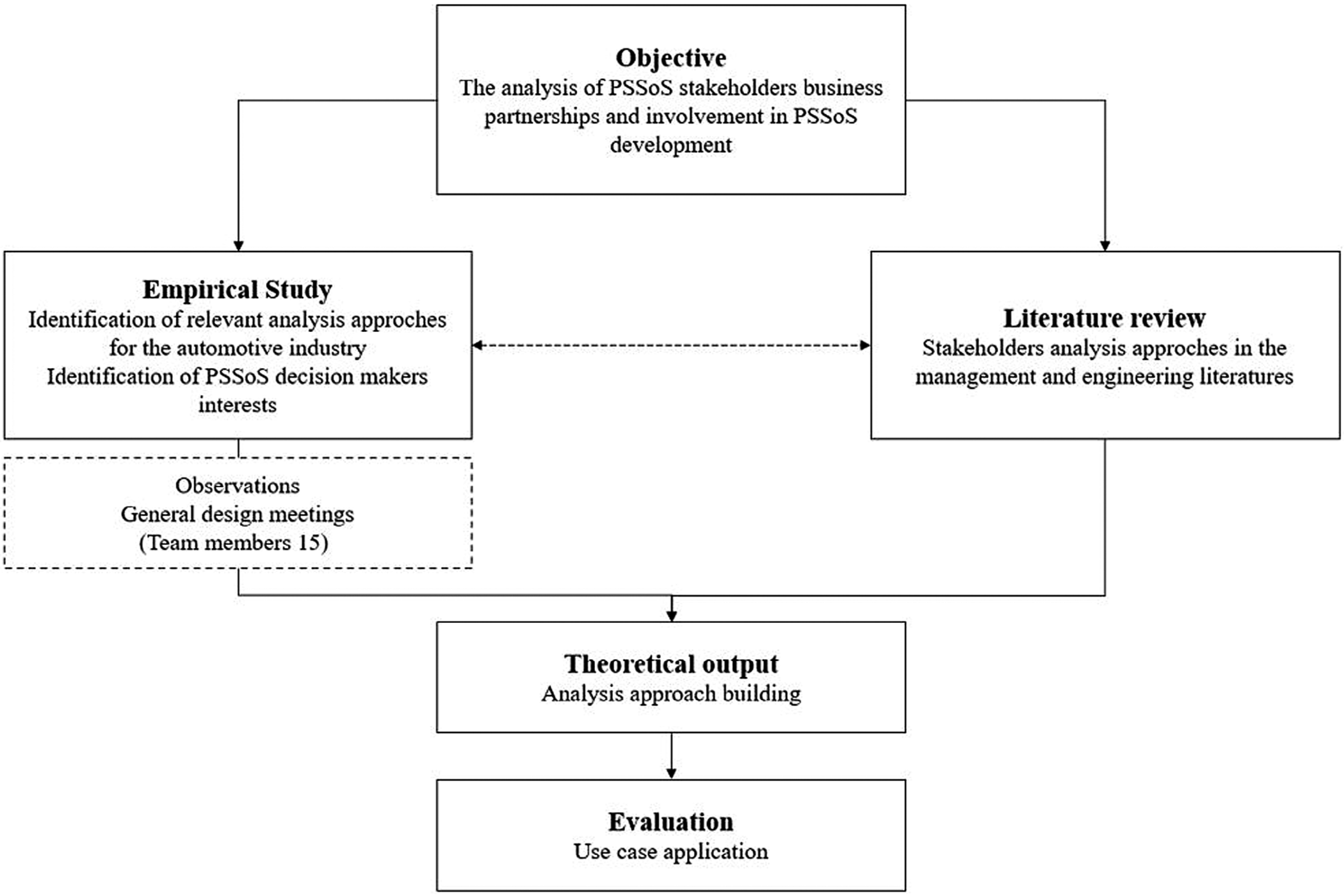

FIGURE 1 Research approach.

of the importance or influence of stakeholders depending upon the definition of a stakeholder, the type of information, and the objective (e.g., energy efficiency). Hence, we propose a high-level PSSoS network, based upon the ontology proposed in Ref. 1, to capture relevant information describing PSSoS stakeholder business partnerships and their implication in PSSoS development.

4.1 | PSSoS heterogeneous network

4.1.1 | PSSoS stakeholder collaboration

The PSSoS collaboration level aims to represent the collaboration or value co creation between PSSoS stakeholders In the PSSoS ontology,[1] "client," "constraint stakeholder," and "PSSoS stakeholders" are defined. In this research, we focus explicitly on the collaboration between the PSSoS stakeholders: "independent actors or enterprises, who collaborate, develop, and operate the PSSoS and the constituent systems." PSSoS stakeholders are connected through relations "collaborate with." This information can be represented as an undirected homogeneous network (Figure 2).

4.1.2 | PSSoS concepts related to PSSoS stakeholder business partnerships

"Service," "Value Chain Role," and "Service configuration," are concepts related to PSSoS stakeholders' business partnerships. The concept "service" is defined here as "what is sold to customers and what provides them value and achieves their goals." Each PSSoS stakeholder has a "value chain role," expressing their position in the value chain or the service delivery. "Service configuration" expresses how a service is put into operation in a specific context (e.g., Plug&Charge service in city A and city B). One PSSoS stakeholder can "participate" concretely in the delivery of one or many service configurations. Besides, services can be composed of several services; and one service can "call" another service that is already existing or to be developed. As service configuration concerns operational deployment, the same relationship "call" can be used between services configurations. This information can be used to identify the number of service configuration to which a PSSoS stakeholder is actively participating and their role in the business development. This information can be represented as a heterogeneous network[57] (pertaining to PSSoS business development (Figure 3).

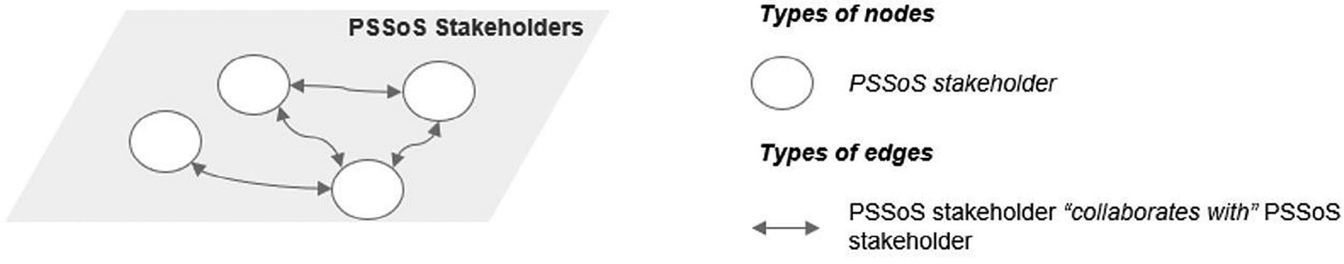

FIGURE 2 Network of PSSoS stakeholder collaborations.

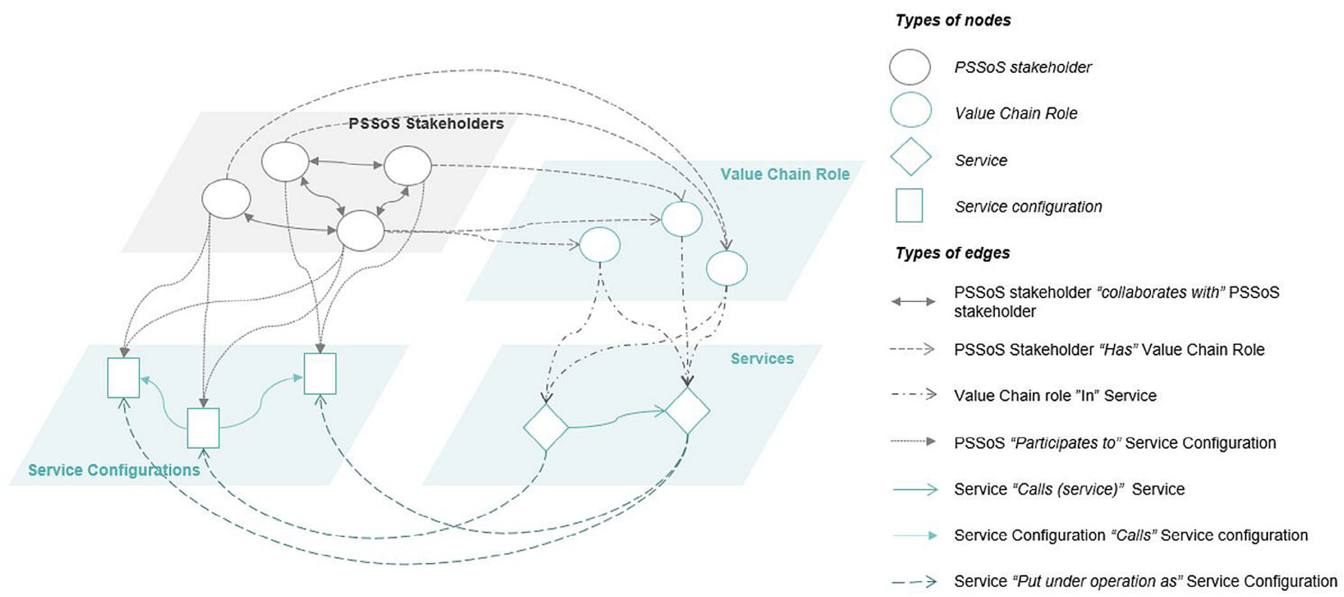

FIGURE 3 PSSoS concepts related to PSSoS stakeholder business partnerships.

4.1.3 | PSSoS concepts related to PSSoS development

Concepts related to PSSoS development are "Service feature," and "Service function," "Service features" are defined as "the capabilities needed to provide the "service" and perceived by the customer and are represented as activities". "Service features" and their relationships can be used to represent what is commonly known in the development as the customer journey. A customer journey is considered as a sequence of "service features" and how they are linked together. In the development process, for each object developed, "functions" are defined in order to model what the object is doing or should do. Hence, each "Service feature" is accomplished by "functions." "Functions" are here defined as activities transforming input flows into output flows and are used to represent functional flows. In this paper, we focus on the functional level (Figure 4).

Previous research highlighted the difficulty of measuring topological measures on a heterogeneous network raises an interpretation issue.[58] One of the possibilities in managing these interpretation issues is to reduce dimensionality (hence transforming heterogeneous network into homogeneous networks).[58] In this research we propose to develop two homogeneous networks addressing PSSoS business partnership and development (Figure 5).

4.2 | From a heterogeneous network to a tow homogeneous networks reflecting PSSoS stakeholder importance in business partnerships and development

Advanced methods to analyse heterogeneous network have been proposed in the literature.[57] Such methods require significant databases (hundreds of notes and billions of interactions) and a deep understanding of its content to be able to interpret the results. Other methods suggest to reduce the heterogeneous networks dimensionality by aggregating the information contained in nodes and edges.[58] Aggregation inevitably involves a loss of information but allows to maintain an interpretability of the results especially in early-stage design.

As the collaboration on PSSoS development is new in the automotive industry and initial data are being gathered, we suggest in paragraphs 1 and 2 to reduce the dimensionality of heterogeneous network presented in section A and to the homogeneous networks and

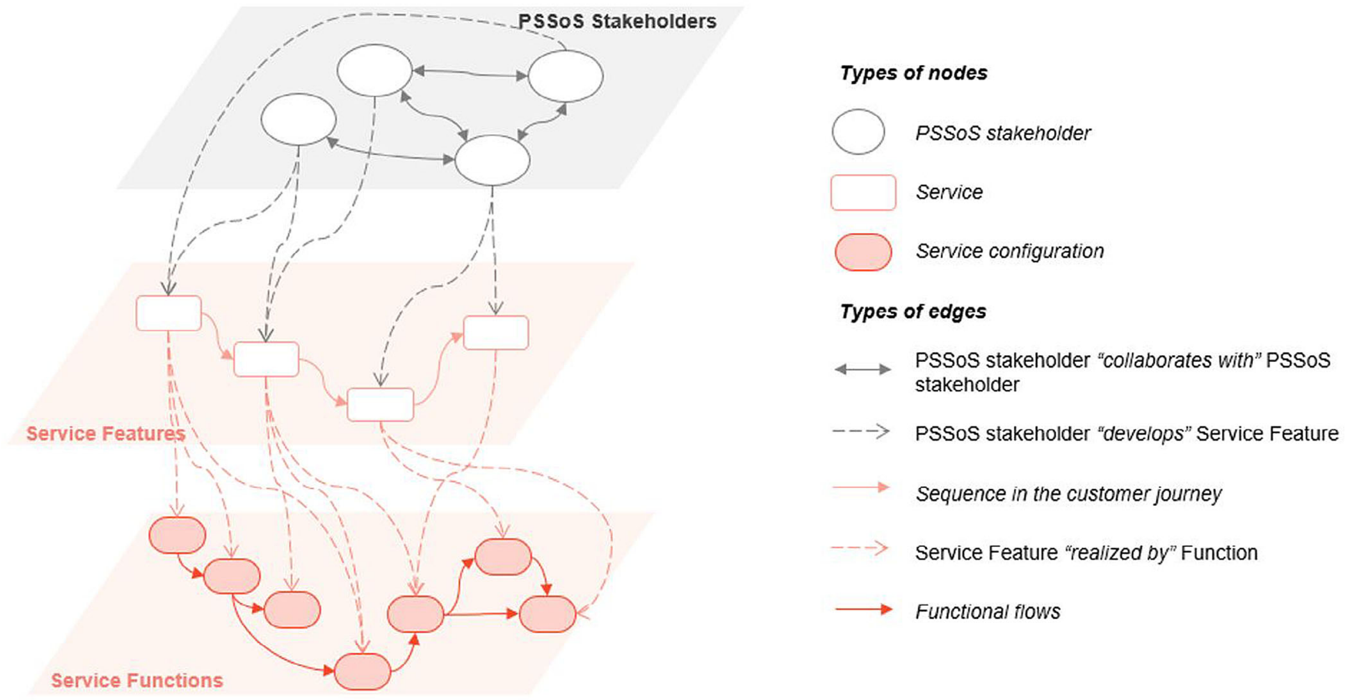

FIGURE 4 PSSoS concepts related to PSSoS development.

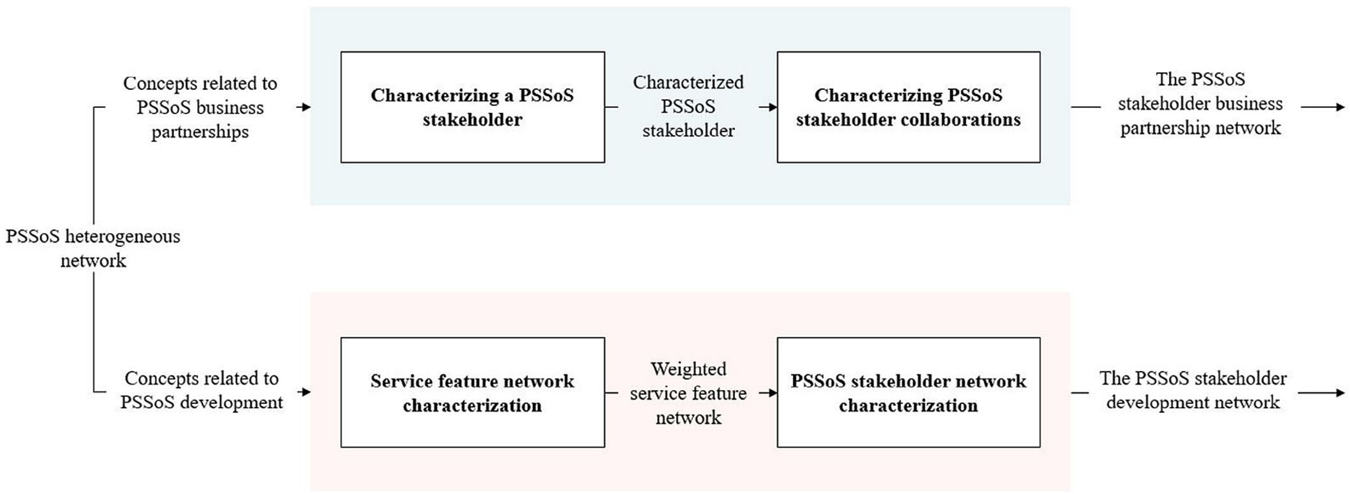

FIGURE 5 Process from a heterogeneous network to tow homogeneous networks.

construct two homogeneous networks: The first focuses on the PSSoS stakeholder business partnership and the second on PSSoS stakeholder involvement in the development.

4.2.1 | PSSoS stakeholder business partnership network

This section explains a step-by-step process of transforming the heterogeneous network to homogeneous network related to PSSoS business partnership (blue level). We propose a two-step process: 1) the characterization of each PSSoS stakeholder, and 2) the characterization of a collaboration between two PSSoS stakeholders.

Step 1: Characterizing a PSSoS stakeholder

This research aims to understand which and how a PSSoS stakeholder participates in service configurations. To do so, we propose to consider/put Value Chain Roles as attributes in the PSSoS Stakeholder network (Figure 6). In the ontology, PSSoS stakeholders are not related directly to the services, as this is a conceptual definition. However, a "service" is operationally deployed and concretely defined through "service configurations." To understand PSSoS stakeholder involvement, we consider services as attributes of the service configuration

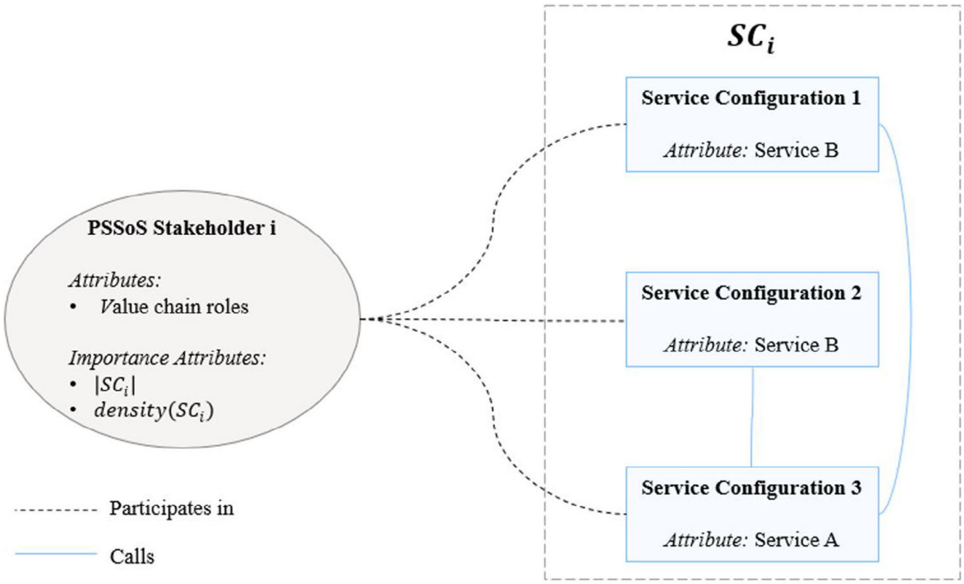

FIGURE 6 Characterizing a PSSoS stakeholder.

network (Figure 6). Here, a service can be seen as a "type" of a service configuration. For example, both service configurations "Navigation service city A" and "Navigation service city B" are "typed" "Navigation Service." This allows us to reduce the dimensionality of the initial network (represented in Figure 3) that contains information related to the PSSoS stakeholders participating in different service configurations. Here, we propose two analyses:

- the number of service configurations a PSSoS stakeholder participates in, noted $|SC_i|$, where SC_i is the set of service configurations the PSSoS stakeholder *i* participates in and,
- how these service configurations are linked together through the relationship "calls." As a reminder, the relationship "calls" indicates that a service configuration relies upon/uses another service configuration. For instance, some charging vehicle service configurations rely on or use navigation service configurations. To capture this, we consider the network of service configurations the PSSoS stakeholder participates in and measure its density ($ensity(SC_i)$ [Equation 1)] (indicating the extent to which configurations rely upon or use each other).

$$density\,(SC_i) = \frac{2 \times E_{calls}^{SC_i}}{|SC_i| \times (|SC_i| - 1)} \tag{1}$$

Where $E_{calls}^{SC_i}$ is the sum of the edges representing the relationship "calls" among the service configurations in SC_i.

The number of service configurations and their density inform on the PSSoS stakeholder's importance in the business partnerships. Figure 6 sums up how PSSoS stakeholders are characterized.

Step 2: Characterizing PSSoS stakeholder collaborations

To characterize the collaboration between two PSSoS stakeholders, we consider the service configurations they both participate in. Similarly to the characterization of a PSSoS stakeholder, we measure the number, and the density of the service configurations both PSSoS stakeholders participate in, denoted $|SC_i \cap SC_j|$ and $density(SC_i \cap SC_j)$, (Equation 2), respectively, with *i* and *j* the indices of the two collaborating PSSoS stakeholders.

$$density\,(SC_i \cap SC_j) = \frac{2 \times E_{calls}^{SC_i \cap SC_j}}{|SC_i \cap SC_j| \times (|SC_i \cap SC_j| - 1)} \tag{2}$$

Since the number and density measures are complementary because the first pertains to the size and the second the coupling between service configurations,[59] we give a weight $W_{(i-j)}^{BP}$, Equation 3 to the collaboration relationships between PSSoS stakeholders *i* and *j*.

$$W_{i-j}^{BP} = |SC_i \cap SC_j| + \frac{density\,(SC_i \cap SC_j)}{density\,(SC_i \cup SC_j)} \tag{3}$$

Figure 7 shows how PSSoS stakeholder collaborations are characterized.

4.2.2 | The network of PSSoS stakeholder involvement in the development

In line with section B.1, we describe a step-by-step process to transform the heterogeneous network to a homogeneous network related to the involvement of PSSoS stakeholders in the development (orange level). In this case, we propose a two-step process: step 1) characterizes service features and their relationships, and step 2) characterizes PSSoS stakeholders and their relationships in the development.

The proposed process is structured in accordance with the activities of the design teams. As a matter of fact, service and system design teams usually start by defining the service (value to the customer), the potential collaboration between PSSoS stakeholders to achieve

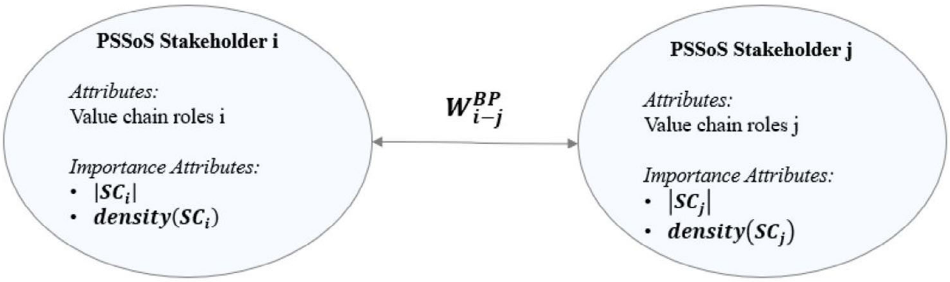

FIGURE 7 The PSSoS stakeholder business partnership network (elements).

it, and service configurations. They proceed by describing the customer journey (through service features) and then detail functions and functional flows to realize service features. Finally, functions are allocated to systems. Hence, each step further details the development of the concept defined in the previous one. For instance, functions and functional flows detail how service features are developed. Therefore, once all the steps are completed, we characterize each network by the more detailed one. The functional network characterizes the feature network. The characterized feature network characterizes the involvement and interdependencies between PSSoS stakeholders in the development.

In the following, we detail the characterization of the service feature network (step 1) that will be used to characterize the PSSoS stakeholder network (step 2).

Step 1: Service feature network characterization

This step aims to reduce the dimensionality of the heterogeneous network in the "orange" level (Figure 4). For this purpose, we propose first to characterize the network of service features based on the information pertaining to their realization contained in the service function network (Figure 4).

We propose to characterize service features and their interactions based upon the functional network (built upon functional flows).

Two measures are used to characterize the development complexity of a service feature:

- the number of functions realizing it (service feature scope), noted $|F_i|$, with i the service feature identifier, and
- the density of their interactions $density(F_i)$, Equation 4

$$density\,(F_i) = \frac{2 \times E^{F_i}_{functional\ flows}}{|F_i| \times (|F_i| - 1)} \tag{4}$$

Where $E^{F_i}_{functional\ flows}$ is the sum of the edges representing the functional flows between the functions in F_i.

As for service feature relationships (expressing a sequence in the customer journey), we analyse them through a size and two coupling complexity measures:

- the number of functions realizing both service features (size) denoted $|F_i \cup F_j|$, with i and j the service feature Ids, and
- the functional overlap defined as the number of functions participation in the realizations of both features denoted $|F_i \cap F_j|$ (coupling)
- the functional interaction index (denoted FII_{i-j}, Equation 5) defined as the ratio of functional interactions linking the feature scopes and the functional interactions within service features scopes (coupling). The functional interaction index is null if there are no functional interactions among all the functions or between F_i and F_j. In case, the only interactions occur between F_i and F_j and not within F_i and F_j, the FII_{i-j} is equal to 1.

$$FII_{i-j} = \begin{cases} \dfrac{E^{F_i \cup F_j}_{functional\ flows} - E^{F_i}_{functional\ flows} - E^{F_j}_{functional\ flows}}{E^{F_i}_{functional\ flows} + E^{F_j}_{functional\ flows}}, \\ \quad if\left(E^{F_i}_{functional\ flows} + E^{F_j}_{functional\ flows}\right) \neq 0 \\ 1, \quad if\left(E^{F_i}_{functional\ flows} + E^{F_j}_{functional\ flows}\right) = 0 \\ \quad and\left(E^{F_i \cup F_j}_{functional\ flows}\right) \neq 0 \\ 0, \quad if\left(E^{F_i}_{functional\ flows} + E^{F_j}_{functional\ flows}\right) = 0 \\ \quad and\left(E^{F_i \cup F_j}_{functional\ flows}\right) = 0 \end{cases} \tag{5}$$

Figure 8 shows how the service feature network is characterized.

We weight the interaction between two service features i and j based on the size and coupling measures of the functions realizing the service features (Equation 6).

$$W^{SF}_{i-j} = FII_{i-j} + \frac{|F_i \cap F_j|}{|F_i \cup F_j|} \tag{6}$$

Step 1 results in the definition of a weighted service features network described in Figure 9.

Step 2 : PSSoS stakeholder network characterization

The objective of this research is to characterize the involvement and interdependencies between PSSoS stakeholders in the development. In this step, we characterize the PSSoS stakeholder network in the development based on the Service Features characterization done in step 1.

In the context of PSSoS development, we relate the importance of PSSoS stakeholders to the development difficulty of the service

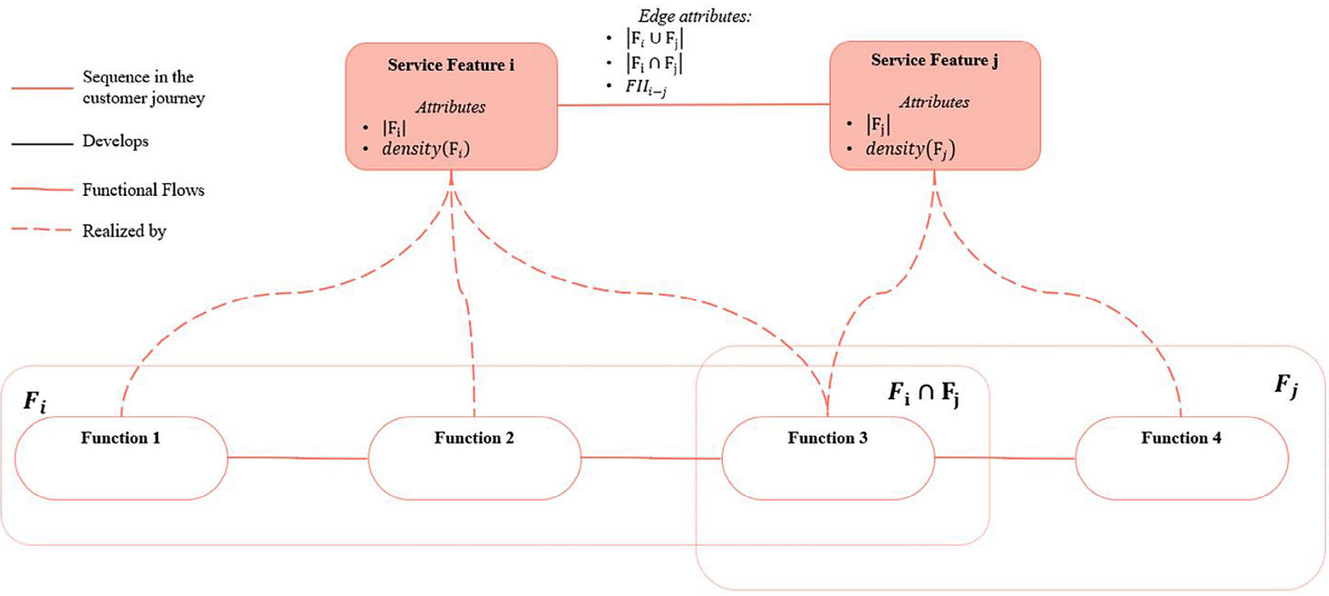

FIGURE 8 Characterizing the service feature network.

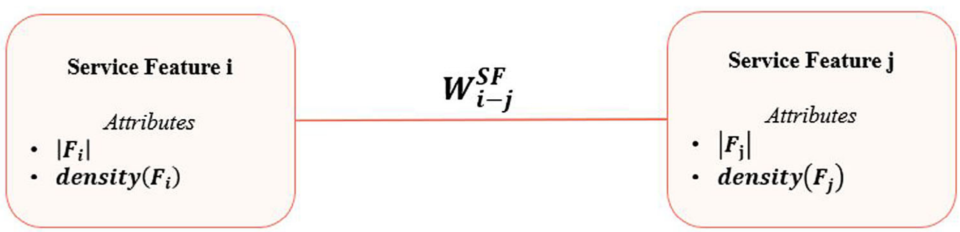

FIGURE 9 Weighted service feature network (elements).

features they develop. Therefore, a PSSoS stakeholder is characterized by:

- The number of service features they develop, $|SF_i|$, with i the PSSoS stakeholder identifier
- The maximum number of functions realizing these service features noted $max(F)_i$, which indicates their development complexity (Equation 7).

$$max(F)_i = max_{j \in |SF_i|}\left(|F_j|\right) \quad (7)$$

- The maximum (functional interaction) density of these service features (Figure 9), which is another indication of their complexity (Equation 8)

$$max(density)_i = max_{j \in |SF_i|}\left(density\left(F_j\right)\right) \quad (8)$$

- Since the service feature network is weighted according to step 1 (Figure 9), we adapt the notion of network density to the weighted network of service features the PSSoS stakeholder develops. Equation 9 (Equation 9) shows how the weighted density is measured with E^{SF_i} the number of edges within SF_i. If the PSSoS stakeholder develops only one service feature (one node), the denominator of Equation 9 is equal to zero. In this case, the one node network is considered not dense and the weighted density is equal to zero.

$$Weighted\ density\ (SF_i) = \begin{cases} \frac{2\times\sum_{j,k\in SF_i}\left(W_{j-k}^{SF}\right)}{\left(|SF_i|+\sum_{j,k\in SF_i}\left(W_{j-k}^{SF}\right)-E^{SF_i}\right)\times\left(|SF_i|+\sum_{j,k\in SF_i}\left(W_{j-k}^{SF}\right)-E^{SF_i}-1\right)}, & if\ |SF_i| \neq 1 \\ 0, & if\ |SF_i| = 1 \end{cases} \quad (9)$$

Figure 10 summarizes the characterization of a PSSoS stakeholder in the development.

With regards to PSSoS stakeholder interactions in the development, we consider the number of service features the PSSoS stakeholders develop noted $|SF_i \cup SF_j|$ where i and j are the PSSoS stakeholders ids, as well as the service features interaction index $SFII$ (Equation 10).

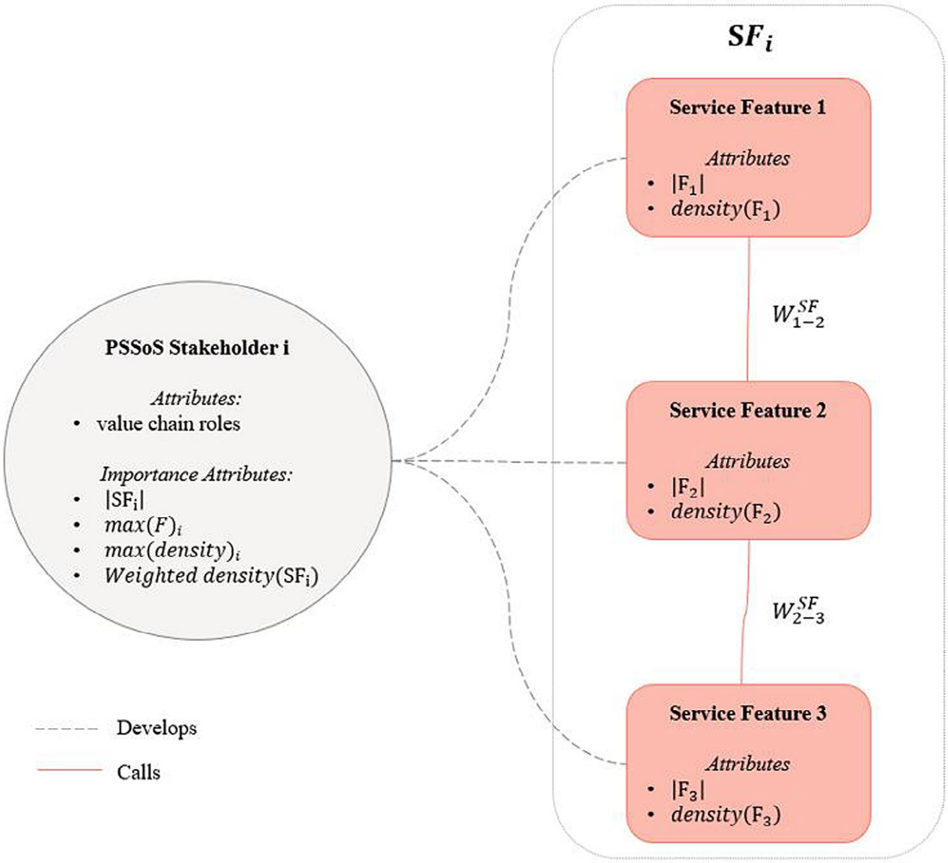

FIGURE 10 Characterization of PSSoS stakeholder in the development.

$$SFII_{i-j} = \begin{cases} \dfrac{\sum_{k,l\in(SF_i\cup SF_j)} W^{SF}_{k-l} - \sum_{k,l\in SF_i} W^{SF}_{k-l} - \sum_{k,l\in SF_j} W^{SF}_{k-l}}{\sum_{k,l\in SF_i} W^{SF}_{k-l} + \sum_{k,l\in SF_j} W^{SF}_{k-l}}, \\ \quad if \left(\sum_{k,l\in SF_i} W^{SF}_{k-l} + \sum_{k,l\in SF_j} W^{SF}_{k-l}\right) \neq 0 \\ 1, \quad if \left(\sum_{k,l\in SF_i} W^{SF}_{k-l} + \sum_{k,l\in SF_j} W^{SF}_{k-l}\right) = 0, \\ \quad and \left(\sum_{k,l\in(SF_i\cup SF_j)} W^{SF}_{k-l}\right) \neq 0 \\ 0, \quad if \left(\sum_{k,l\in SF_i} W^{SF}_{k-l} + \sum_{k,l\in SF_j} W^{SF}_{k-l}\right) = 0 \\ \quad and \left(\sum_{k,l\in(SF_i\cup SF_j)} W^{SF}_{k-l}\right) = 0 \end{cases} \tag{10}$$

Figure 11 sums up the characterization of PSSoS Stakeholder collaborations in the development.

The measure of service features involved in the collaboration of two stakeholders and the Service Feature interaction index are complementary. Therefore, in a similar fashion as for the PSSoS business partnership network (bleu level), we give a weight $W^{Dev}_{(i-j)}$, Equation 11 to the collaboration relationships between PSSoS stakeholders i and j. $|SF|$ is the total number of service features.

$$W^{Dev}_{i-j} = \frac{|SF_i \cup SF_j|}{|SF|} + SFII_{i-j} \tag{11}$$

Figure 12 describes the constituent elements of the resulting PSSoS weighted homogeneous network: the PSSoS stakeholder development network.

To summarize, in paragraphs B.1) and B.2), we characterized PSSoS Stakeholder importance in business partnerships and development through different measures. These measures suggest the individual importance of a PSSoS stakeholder by looking at the service configurations they participate in, and the service features they develop. However, these measures do not consider the importance of a PSSoS stakeholder regarding the interactions a PSSoS stakeholder has with other PSSoS stakeholders.

In the following section IV.C, we use the measures characterizing PSSoS collaborations in business partnerships [paragraph IV.B.1)) and development (paragraph IV.B.2)] to quantify the importance of a PSSoS stakeholder with regards to the interactions he/she has with other PSSoS Stakeholders. To clearly distinguish the importance of a PSSoS stakeholder with regards to his/her interactions from the individual or local PSSoS stakeholder importance, we name it PSSoS stakeholder influence.

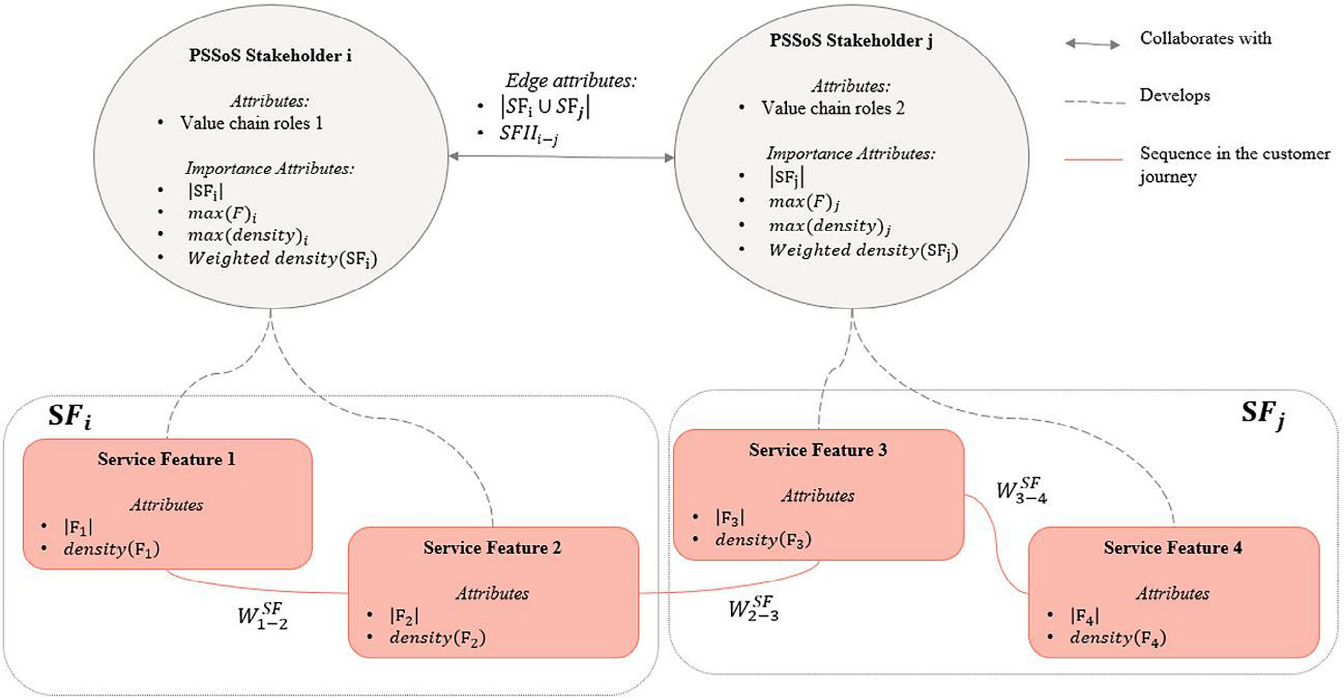

FIGURE 11 Characterizing the PSSoS stakeholder collaboration in the development.

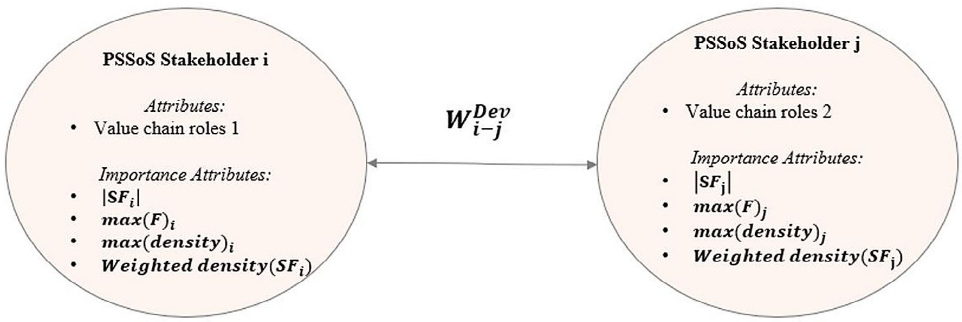

FIGURE 12 The PSSoS stakeholder development network (elements).

4.3 | Analysis of SoS stakeholder business partnership influence and development influence

In the literature, different network centrality measures have been used to quantify stakeholder importance or influence. To capture a PSSoS stakeholder's influence in business partnerships and development, we chose to use the eigenvector centrality in both networks: the weighted PSSoS stakeholder business partnerships network and the weighted development PSSoS stakeholder network.

In general terms, the eigenvector centrality measures how central a node in the network is in relation to how central all the other nodes are. Unlike the degree centrality, the eigenvector centrality does not only consider the node direct neighbors but rather the whole network. The eigenvector centrality can be interpreted as the influence of the node in the network. The influence of a node i, x_i can then be written as Equation 12 (λ being a constant):

$$A^t p = \lambda_p p \tag{12}$$

Matrix A is the adjacency matrix of the network. Since the networks we consider in this paper are undirected and weighted (the PSSoS stakeholder business partnerships network and the PSSoS stakeholder development network), A is a symmetric matrix and its coordinates $a_{(i,j)}$ are the weights of the edges between nodes i and j.

With regards to the PSSoS stakeholder business partnership network, a high value of eigenvector centrality hints at the fact that PSSoS stakeholders tend to have business partnerships with PSSoS stakeholders that themselves have many business partnerships. This indicates the importance of a PSSoS stakeholder in the overall business scene, for example, the importance of a PSSoS stakeholder in the electric vehicle related services and businesses. Such a PSSoS stakeholder tends to be highly influential.

In the context of PSSoS development, SoS stakeholders (development network) with high values of eigenvector centrality are highly influential in developing the PSSoS. They develop service features and functions that are highly related to service features and functions that other influential PSSoS stakeholders develop.

5 | CASE STUDY, RESULTS, AND ANALYSIS

5.1 | PSSoS case description

To illustrate the use of the approach presented in sectionIV, an industrial project has been considered. This study focuses on the development of EVs charging services and V2G related services. In the following, we consider one service, "the Plug and Charge service," and its related information. The "Plug & Charge service" has been chosen because of data availability, and coherence between information related to PSSoS business partnerships and development. This service allows the customer to automatically start charging his/her vehicle (i.e., without manual authentication). The service implies that plugging the EV to the charging station allows identifying the EV and that unplugging the EV stops the charging and generates the payment.

Service and system design teams identified seven potential PSSoS stakeholders collaborating to realize this service and six value chain roles. The project teams distinguished three main service configurations in which the PSSoS stakeholders participate (blue level). As for the service development (orange level), 16 service features, and 48 service functions have been defined. Fifteen systems, including the EV, the charging station, and various servers realize these functions. The relationships between different elements have been retrieved from documents and model-based systems engineering tools.

The network of the collaboration between PSSoS Stakeholders (grey level) is given in Figure 13 where the seven PSSoS stakeholders are identified by their IDs going from 0 to 6.

5.2 | Resulting homogeneous networks

5.2.1 | Business partnership network and PSSoS stakeholder importance in business partnerships

The value chain roles are defined as attributes of PSSoS stakeholders. For instance, the PSSoS stakeholder 5 is an Original Equipment Manufacturer (OEM) that can also play an electric mobility service operator's role. PSSoS stakeholder 4 is another potential electric mobility operator. Both PSSoS stakeholders 0 and 1 are charging station owners and operators. The other PSSoS stakeholders, they mainly develop, manage, and operate different offboard servers required to realize the service.

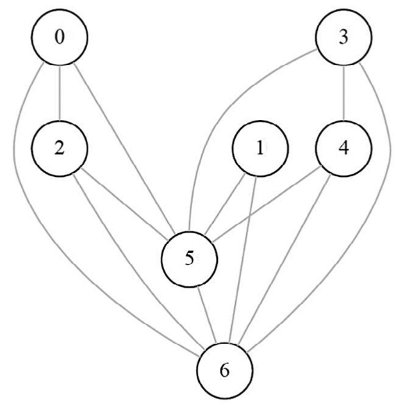

FIGURE 13 Network of the collaboration between plug and charge service PSSoS stakeholders.

TABLE 1 Measures characterizing the importance of PSSoS stakeholders in business partnerships.

PSSoS Stakeholder ID	Number of service configurations	Density of service configuration
0	1	0
1	1	0
2	1	0
3	1	0
4	1	0
5	3	0
6	3	0

Since we consider a single service (Plug and Charge), the three service configurations are of the same "type" (Plug and Charge Service in operation). As such, these service configurations are rather independent and do not "call" one another. Therefore, the densities of service configuration networks and sub-networks are null in this context.

Following the approach presented in IV.B.1), each PSSoS stakeholder (node) is characterized by the number of service configurations he/she participates in and by their density. As for collaborations between PSSoS stakeholders, they are characterized by the number of service configurations, both PSSoS stakeholders participate in and their density. Results are presented in Tables 1 and 2.

Figure 14 is a representation of the weighted PSSoS stakeholder business partnership network. The node size represents the number of service configurations the PSSoS stakeholders participate in, their colour the service configurations density. The edge thickness represents their weights.

Results show that both stakeholders 5 and 6 are important in business partnerships as they participate in all service configurations. The other PSSoS stakeholders are rather local players participating each in one specific service configurations. On a broader data set, such information gives hints on the important PSSoS stakeholder

TABLE 2 Measures characterizing PSSoS stakeholder business partnerships.

Collaboration between PSSoS stakeholders		Number of service configurations	Density of service configuration
PSSoS Stakeholder ID	PSSoS Stakeholder ID		
0	2	1	0
0	5	1	0
0	6	1	0
1	5	1	0
1	6	1	0
2	5	1	0
2	6	1	0
3	4	1	0
3	5	1	0
3	6	1	0
4	5	1	0
4	6	1	0
5	6	3	0

participating in the realization of EV related services in different locations, for example.

5.2.2 | PSSoS development relationships network and SoS stakeholder development importance

In the PSSoS development context, our approach proposes to 1) characterize the service features network, and 2) characterize the PSSoS stakeholder network.

Based on the Service Feature Network characteristics, our approach defines measures to characterize the importance of PSSoS stakeholders and their relationships in the development. Results are presented in Tables 3 and 4.

According to Figure 15, PSSoS stakeholder 2 develops the largest number of service features. This result is expected as the PSSoS stakeholder 2 manages and operates the main offboard platform providing all information (on, e.g., vehicles, contracts) enabling the service. However, the service features realized by PSSoS stakeholder 2 are not as dense as those developed by PSSoS stakeholders 3, 4, and 5. As such, a failure in a service feature developed by PSSoS stakeholders 3, 4, and 5 potentially compromises the service's delivery. This result is coherent with empirical evidence since PSSoS stakeholders 3, 4 are service providers, and 5 is a car manufacturer. The maximum number of functions and their maximum density indicate the complexity of the features developed by a PSSoS stakeholder. In this case, the service feature developed by PSSoS stakeholder 6 is shown to be non-complex. This is explained by the fact that the service feature developed by PSSoS stakeholder 6 is used for all service configurations, and mostly because system engineers did not detail its functions.

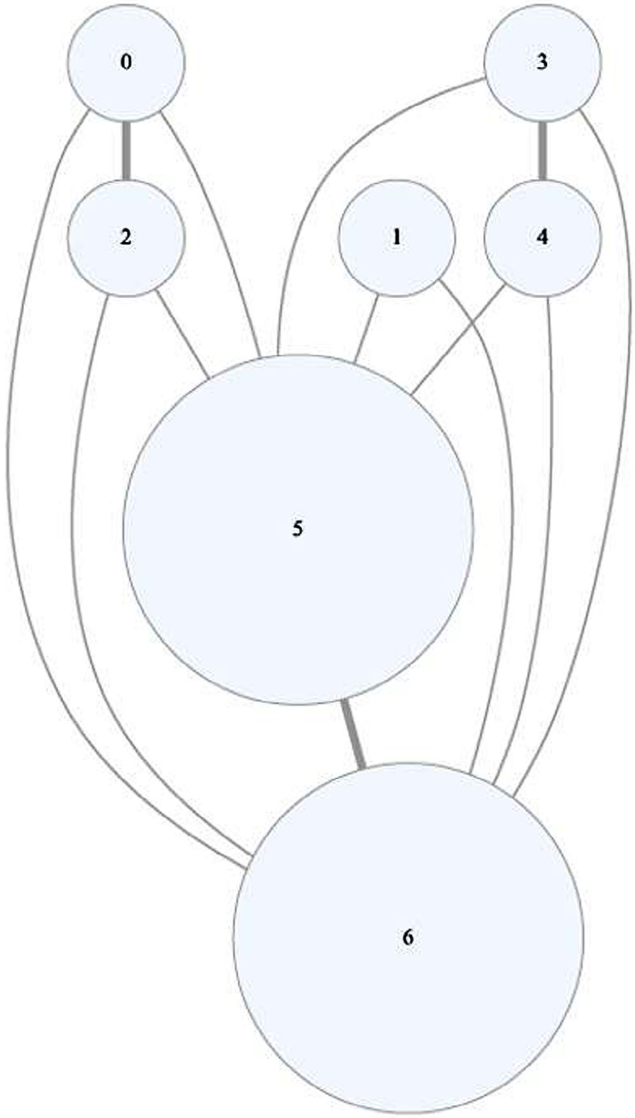

FIGURE 14 The weighted PSSoS stakeholder business partnerships.

Figure 15 is a representation of the weighted PSSoS stakeholder development network (see section IV.B). The node size represents the number of service features the PSSoS stakeholders develops, their colour the weighted density of the service features. The edge thickness represents their weight.

5.3 | PSSoS stakeholder influence in business partnerships and development

In section 4, the importance of PSSoS stakeholders is quantified using different measures. As for the influence of these PSSoS stakeholders, we consider both weighted graphs (Figures 14 and 15) and use centrality measures (taking into consideration the weights of network edges) to quantify the influence of each PSSoS stakeholder. Results are

TABLE 3 Measures characterizing the importance of PSSoS stakeholders in development.

PSSoS stakeholder Id	Number of service features	Service features weighted density	Maximum number of functions	Maximum functional density
0	2	0.0	2	1.0
1	2	0.0	2	1.0
2	11	0.17	4	1.0
3	5	0.44	8	1.0
4	2	1.0	3	0.66
5	6	0.21	7	0.3
6	1	0	2	0

TABLE 4 Measures characterizing PSSoS stakeholder collaboration in development.

Collaboration between PSSoS stakeholders			
PSSoS Stakeholder ID	PSSoS Stakeholder ID	Service Features Interaction Index	Number of service features
0	2	0.11	12
0	5	0.84	8
0	6	1	3
1	5	0.84	8
1	6	1	3
2	5	0.09	13
2	6	0.23	12
3	4	1.24	7
3	5	1.81	11
3	6	0.34	6
4	5	1.71	8
4	6	3.0	3
5	6	1.20	7

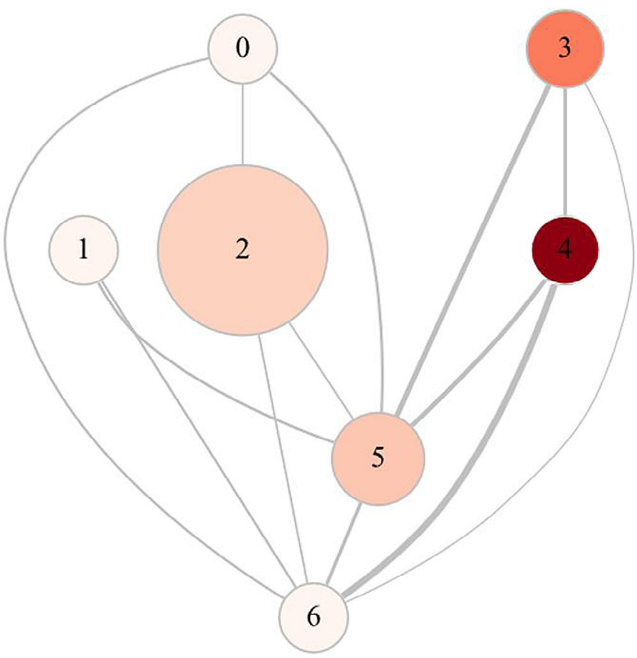

FIGURE 15 The weighted PSSoS stakeholder development network.

presented in Table 5. The influence is also measured for the unweighted PSSoS stakeholder network for the sake of comparison.

Table 5 shows that both the unweighted collaboration network and the weighted PSSoS stakeholders' business partnership network (Grey and Blue levels) give similar results. This is partly due to the limited scope of the considered data. The measures do not largely differentiate PSSoS stakeholders but rather group them: PSSoS stakeholders 5 and 6 rank 1, PSSoS stakeholders 2, 3, 4, and 0 rank 3, and 1 rank 7. We notice that each group's value chain roles are similar: 5 and 6 manufacturing industry-related value chain roles, 2, 3, 4, and service providers or servers and offboard platforms operators. PSSoS stakeholder 1 is the charging station owner. As for results for the PSSoS stakeholder development network (Orange Level), the influence ranks are different. This shows that both perspectives are complementary.

6 | DISCUSSION AND CONCLUSION

Most proposed (PSS and SoS) stakeholder analysis approaches are rather qualitative. In the meantime, quantitative stakeholder analysis approaches have been proposed by other research domains (e.g., management and design engineering) not necessarily addressing PSSoS stakeholder. This paper addresses this gap and presents a PSSoS stakeholder quantitative analysis approach. The analysis aimed to quantify the importance and influence of PSSoS stakeholders in business partnerships and development. For interpretability purposes, the proposed approach reduces the dimensionality and builds two homogeneous networks of PSSoS stakeholder collaborations, reflecting the PSSoS stakeholders' importance and their collaborations in business partnerships and development. The eigenvector centrality has finally been used to measure the business partnerships and development

TABLE 5 PSSoS stakeholders influence in business partnerships and development.

PSSoS Stakeholder Id	Network of PSSoS stakeholder collaborations (Grey Level)		PSSoS stakeholder business partnership network (Blue Level)		PSSoS stakeholder development network (Orange Level)	
	Eigenvector Centrality Measure	Rank	Eigenvector Centrality Measure	Rank	Eigenvector Centrality Measure	Rank
0	0.33	3	0.34	3	0.21	5
1	0.25	7	0.17	7	0.19	6
2	0.33	3	0.34	3	0.17	7
3	0.33	3	0.34	3	0.37	4
4	0.33	3	0.34	3	0.49	2
5	0.50	1	0.51	1	0.52	1
6	0.50	1	0.51	1	0.49	3

influences of PSSoS stakeholders. The Plug and Charge Service has been used to show the usability of the proposed analysis approach.

The main advantage of the presented approach is that it is specifically designed to analyse PSSoS stakeholders. The proposed analysis approach also keeps a holistic perspective on PSSoSs, including business partnership and development perspectives. From a business partnership perspective, it allows for a PSSoS decision-maker to identify PSSoS stakeholders engaged in several service configurations and potentially important and influential collaborators. From a PSSoS development perspective, the analysis approach shows the importance of each PSSoS stakeholder in the PSSoS development seen as the functional (Service Features and Functions) complexity of the system he/she develops. This approach also permits to identify influential PSSoS stakeholders in the development seen as those highly relied upon in the functional realization of the PSSoS. Such information can help a PSSoSs decision-maker in the PSSoS design by redesigning service features and functions less dependent on what other PSSoS stakeholders develop. From a practical perspective, the proposed method allows to generate the PSSoS network and computes the relevant indicators taking the information directly from the tools system engineers usually use.

However, reducing dimensionality generates a loss of information. In some cases, a loss of information might lead to flawed decisions, which is a well-known problem in decision-making.[60] Besides, different measures can be used to characterize networks. In this study, we mainly rely on how the automotive industry participates in mobility PSSoS development and its needs to define the dimensionality reduction strategy and choose and interpret measures to quantify PSSoS stakeholder importance influence. However, other examples and domains should be considered and studied to confirm the proposed approach genericity.

Furthermore, the results of the proposed PSSoS stakeholder analysis approach and their interpretation depend on the model level of granularity and the available data. The collaboration on PSSoS development is new in the automotive industry and initial data are being gathered. As the industry gains maturity in PSSoS development, future work could be to enrich PSSoS related datasets and as such improve the ability to interpret network metrics improved. Therefore, advanced methods addressing more complex networks[57] can ultimately be considered in the context of PSSoS development.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request

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REFERENCES

1. Fakhfakh S, Jankovic M, Hein AM, Chazal Y, Dauron A. Proposition of an ontology to support Product Service Systems of Systems Engineering. *Syst Eng*. 2021;24:293-306. doi:10.1002/sys.21578
2. Mont O. Clarifying the concept of product—service system. *J Clean Prod*. 2002;10:237-245. doi:10.1016/S0959-6526(01)00039-7
3. Maier MW. Architecting principles for Systems-of-Systems. *INCOSE Int Symp*. 1996;6:565-573. doi:10.1002/j.2334-5837.1996.tb02054.x
4. Vasantha GVA, Roy R, Lelah A, Brissaud D. A review of product-service systems design methodologies. *J. Eng. Des.* 2012;23:635-659. doi:10.1080/09544828.2011.639712
5. Reim W, Parida V, Ortqvist D. Product e Service Systems (PSS) business models and tactics—a systematic literature review. *J Clean Prod*. 2015;97. doi:10.1016/j.jclepro.2014.07.003
6. Mohsin A, Janjua NK, Islam SM, Valdemar Vicente Graciano N. Modeling approaches for System-of-Systems dynamic architecture : overview, taxonomy and future prospects. *Architecture*. 2019;13:49-56.
7. Ingram C, Payne R, Perry S, Holt J, Hansen F, Couto L. Modelling patterns for systems of systems architectures. IEEE Int. Syst. Conf. Proc. 2014:146-153.

8. Sauser B, Boardman J. Taking hold of System of Systems Management. *Eng Manag J*. 2008;20:3-8.
9. Kimita K, Watanabe K, Hara T, Komoto H. Who realizes a PSS? An organizational framework for PSS development. *Procedia CIRP*. 2015;30:372-377. doi:10.1016/j.procir.2015.02.143
10. Costa S, Diegues L. Who are the stakeholders mentioned in cases of Product-Service System (PSS) design? Int. Conf. Eng. Des. 2019:5-8. doi:10.1017/dsi.2019.320
11. Yip MH, Phaal R, Probert DR. Stakeholder engagement in early stage product- service system development for healthcare informatics. *Eng Manag J*. 2015;9247. doi:10.1080/10429247.2014.11432020
12. Yin D, Ming X, Liu Z, Zhang X. A fuzzy ANP-QFD methodology for determining stakeholders in Product-Service Systems development from ecosystem perspective. *Sustainability*. 2020;12:3329. doi:10.3390/su12083329
13. Liu Z, Ming X, Song W, Qiu S, Qu Y. A perspective on value co-creation-oriented framework for smart product-service system. *Procedia CIRP*. 2018;73:155-160. doi:10.1016/j.procir.2018.04.021
14. Pezzotta G, Cavalieri S, Romero D. Collaborative product-service systems engineering: towards an active role of customers and stakeholders in value co-creation, 2017. Int. Conf. Eng. Technol. Innov. Eng. Technol. Innov. Manag. Beyond 2020 New Challenges, New Approaches, ICE/ITMC 2017 - Proc. 2018-Janua 2018;1247-1254. doi:10.1109/ICE.2017.8280023
15. Zine PU, Kulkarni MS, Chawla R, Ray AK. A framework for value co-creation through customization and personalization in the context of machine tool PSS. *Procedia CIRP*. 2014;16:32-37. doi:10.1016/j.procir.2014.01.005
16. Mougaard K, Howard TJ, McAloone TC, Neugebauer L, Bey N. Establishing collaborative networks for the conceptualisation of PSS. *Proc Int Des Conf Des DS*. 2012;70:249-258.
17. Yoonyee P, Sang BJ. Need network analysis: a process to understand the stakeholder need structure in multi-actor service systems. *Proc Int Conf Eng Des ICED*. 2017;4:693-702.
18. Orellano M, Medini K, Lambey-Checchin C, Neubert G. A system modelling approach to collaborative PSS design. *Procedia CIRP*. 2019;83:218-223. doi:10.1016/j.procir.2019.03.089
19. Lelah A, Mathieux F, Brissaud D. Building a network of SME for a global PSS infrastructure in complex high-tech systems : example of urban applications. 3rd CIRP Int. *Conf Ind Prod Serv Syst*. 2011. doi:10.1007/978-3-642-19689-8
20. Hause M. The unified profile for DoDAF/MODAF (UPDM) enabling systems of systems on many levels. *2010 IEEE Int Syst*. 2010:426-431. doi:10.1109/SYSTEMS.2010.5482450. Conf. Proceedings, SysCon 2010.
21. Axelsson J, Fröberg J, Eriksson P. Architecting systems-of-systems and their constituents : a case study applying Industry 4.0 in the construction domain. *Syst Eng*. 2019;22:455-470. doi:10.1002/sys.21516
22. Uday P, Marais K. Designing resilient systems-of-systems: a survey of metrics. *Methods, and challenges. Syst Eng*. 2015;18:491-510. doi:10.1002/sys.21325
23. Fang Z, Davendralingam N, Delaurentis DA. Multistakeholder dynamic optimization for acknowledged System-of-System architecture selection. *IEEE Syst J*. 2018;12:3565-3576.
24. Mitchell RK, Agle BR, Wood DJ. Toward a theory of stakeholder identification and salience: defining the principle of who and what really counts. *Acad Manag Rev*. 1997;22:853-886.
25. Oppong GD, Chan APC, Dansoh A. A review of stakeholder management performance attributes in construction projects. *Int J Proj Manag*. 2017;35:1037-1051. doi:10.1016/j.ijproman.2017.04.015
26. Mok KY, Shen GQ, Yang J. Stakeholder management studies in mega construction projects : a review and future directions. *JPMA*. 2014;33:446-457. doi:10.1016/j.ijproman.2014.08.007
27. Reed MS, Graves A, Dandy N, et al. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *J Environ Manage*. 2009;90:1933-1949. doi:10.1016/j.jenvman.2009.01.001
28. Parnar BL, Freeman RE, Harrison JS, Wicks AC, DeColle S, Purnell L. Stakeholder theory: the state of the art. *Acad Manag Ann*. 2010;4:403-445.
29. Bourne L, Walker DHT. Visualising and mapping stakeholder influence. *Manag Decis*. 2005;43:649-660. doi:10.1108/00251740510597680
30. Varvasovszky Z. Stakeholder analysis : a review. *Health Policy Plan*. 2000;15:239-246.
31. Berardo R. Bridging and bonding capital in two-mode collaboration networks bridging and bonding capital in two-node. Policy Stud *Organ*. 2014;42:197-225. doi:10.1111/psj.12056
32. Aragonés-Beltrán P, García-Melón M, Montesinos-Valera J. How to assess stakeholders' influence in project management? A proposal based on the Analytic Network Process. *Int J Proj Manag*. 2017;35:451-462. doi:10.1016/j.ijproman.2017.01.001
33. Keating CB, Katina PF. Systems of systems engineering: prospects and challenges for the emerging field. *Int J Syst Syst Eng*. 2011. doi:10.1504/IJSSE.2011.040556
34. Zedan S, Miller W. Quantifying stakeholders ' influence on energy efficiency of housing : development and application of a four-step methodology. *Constr Manag Econ*. 2018;6193:1-19. doi:10.1080/01446193.2017.1411599
35. Yang RJ, Zou PXW. Stakeholder-associated risks and their interactions in complex green building projects : a social network model. *Build. Environ*. 2014;73:208-222. doi:10.1016/j.buildenv.2013.12.014
36. Dadpour M, Shakeri E, Nazari A. Analysis of stakeholder concerns at different times of construction projects using Social Network Analysis. *Int J Civ Eng*. 2019;17:1715-1727. doi:10.1007/s40999-019-00450-1
37. Feng W. Strategic Management for Large Engineering Projects. Massachusetts Institute of Technology; 2013.
38. Feng W, Crawley EF, de Weck O, Keller R, Robinson B. Dependency structure matrix modelling for stakeholder value networks. *Depend Struct Model Conf DSM*. 2010;501:2007-2007.
39. Fu F, Feng W, Li Z, Crawley EF, Ni W. A network-based modeling framework for stakeholder analysis of China's energy conservation campaign. *Energy*. 2011;36:4996-5003. doi:10.1016/j.energy.2011.05.044
40. Cameron BG, Seher T, Crawley EF. Goals for space exploration based on stakeholder value network considerations. *Acta Astronaut*. 2011;68:2088-2097. doi:10.1016/j.actaastro.2010.11.003
41. Hein AM, Jankovic M, Feng W, Farel R, Yune JH, Yannou B. Stakeholder power in industrial symbioses: a stakeholder value network approach. *J Clean Prod*. 2017;148:923-933. doi:10.1016/j.jclepro.2017.01.136
42. Ballejos LC, Montagna JM. Modeling stakeholders for information systems design processes. *Requir Eng*. 2011;16:281-296. doi:10.1007/s00766-011-0123-2
43. Lim SL, Quercia D, Finkelstein A. StakeNet: using social networks to analyse the stakeholders of large-scale software projects. *Proc—Int Conf Softw Eng*. 2010;1:295-304. doi:10.1145/1806799.1806844
44. Lim SL, Ncube C. Social networks and crowdsourcing for stakeholder analysis in System of Systems Projects. *Int Conf Syst Syst Eng*. 2013:13-18.
45. Luo J, Baldwin CY, Whitney DE, Magee CL. The architecture of transaction networks : a comparative analysis of hierarchy in two sectors. *Ind Corp Chang*. 2012;21:1307-1335.
46. Son S, Cho J. Social network analysis of collaborative R & D activities in pharmaceutical industry—Topological properties of EU 's innovative medicines initiative. *Int J Appl Eng Res*. 2017;12:9799-9806.
47. Morelli MD, Eppinger SD, Gulati RK. Predicting technical communication in product development organizations. *IEEE Trans Eng Manag*. 1995;42(3):215-222.

48. Sosa ME, Eppinger SD, Pich M, McKendrick DG, Stout SK. Factors that influence technical communication in distributed product development: an empirical study in the telecommunications industry. *IEEE Trans Eng Manag*. 2000;49:45-58.
49. Batallas DA, Yassine AA. Information leaders in product development organizational networks : social network analysis of the design structure matrix. *IEEE Trans Eng Manag*. 2006;53(4):570-582. doi:10.1109/TEM.2006.883706
50. Bashir H. A new approach for classifying cross-functional teams in product development projects. *Int Conf Ind Eng Oper Manag*. 2019:903-909.
51. Parraguez P, Steven D, Maier A. Information flow through stages of complex engineering design projects : a dynamic network analysis approach. *IEEE Trans Eng Manag*. 2015. doi:10.1109/TEM.2015.2469680
52. Wu D, Rosen DW, Panchal JH, Schaefer D. Understanding communication and collaboration in social product development through social network analysis. *J Comput Inf Sci Eng*. 2016;16:1-10. doi:10.1115/1.4031890
53. Chen SG, Lin L. Modeling team member characteristics for the formation of a multifunctional team in concurrent engineering. *IEEE Trans Eng Manage*. 2014;51(2):111-124. doi:10.1109/TEM.2004.826011
54. Fakhfakh S, Hein AM, Chazal Y, Jankovic M. A meta-model for product service systems of systems. Int Des Conf Des, 2020:1235-1244.
55. Hein AM, Poulain B, Jankovic M, Chazal Y, Fakhfakh S. Product service system design in a System of Systems context: a literature survey. *Int Des Conf*. 2018:2891-2902. doi:10.21278/idc.2018.0358
56. Fakhfakh S, Hein AM, Jankovic M, Chazal Y. Towards an uncertainty framework for Product Service Systems of Systems. *ICED19*. 2019;1(1):3121-3130.
57. Cen Y, Zou X, Zhang J, Yang H, Zhou J, Tang J, Representation learning for attributed multiplex heterogeneous network. Proc. ACM SIGKDD Int. Conf. Knowl. Discov. Data Min. 2019 1358-1368. doi:10.1145/3292500.3330964
58. Parraguez-Ruiz P. *A Networked Perspective on the Engineering Design Process*. Technical University of Denmark; 2015.
59. Ameri F, Summers JD, Mocko GM, Porter M. Engineering design complexity: an investigation of methods and measures. *Res. Eng. Des.* 2008;19:161-179. doi:10.1007/s00163-008-0053-2
60. Kujawski E. Analysis and critique of the system readiness level. *IEEE Trans Syst Man Cybern Syst*. 2013;43:979-987.

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