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Value-in-use of e-maintenance in service provision: survey analysis and future research agenda

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Abstract: Servitisation strategies entail many benefits to manufacturing industry. In this context, e-maintenance can bring support to new industrial services by enhancing the effectiveness of service delivery processes, thus, improving the ultimate benefits obtained by service provision. This article presents a study on the value-in-use that different technological innovations can offer to maintenance service provision. The final results of a survey capturing experts' knowledge into a method for value analysis are discussed and eventually a future research agenda is suggested to investigate further how the use of e-maintenance technologies can potentiate the value-in-use of industrial service provision.

Keywords: E-maintenance, maintenance technology, value-in-use, value creation, value analysis, servitisation, maintenance services, manufacturing digitization.

1. INTRODUCTION

The global trend of servitisation in manufacturing industry has stimulated a more or less stabilized 30% of manufacturing companies to offer services within their customer offerings (Neely, 2008; Neely et al., 2011). Companies embracing servitisation strategies seek to unify their offerings of products and services into bundled Product Service Systems (PSS) offerings. These PSS offerings can integrate services at the point of sale, related to product use or product life extension, or revalorising the product at the end-of-life (Montt, 2002). PSS will include a product plus a selection of different services to be added to the offering. The final goal is to provide customer support in order to ensure the trouble-free use of the product along its life cycle (Goffin and New, 2001) while manufacturing companies obtain benefits related to higher growth, profit and technological innovation (Dachs et al., 2014).

There are many benefits derived from servitisation strategies in manufacturing. On the one hand, the knowledge on product use and customer contexts will serve manufacturers to technologically improve and innovate their products and offerings. On the other hand, the use of technologies within the PSS offering can improve the delivery of the service, and the benefits obtained by both customer and service provider. These advantages are clear and well discussed – many contributions in literature has focused in answering "why" –, the interest is nowadays shifting on the way – "what and how" – servitisation can be effectively and efficiently deployed. The present paper focuses on this matter and, in particular, on the adoption of ICT and digital resources for the deployment of new services in manufacturing.

Indeed, ICT and digital resources are employed by servitised manufacturers in the delivery of their services (Baines and Lightfoot, 2014; Schroeder and Kotlarsky, 2015). There are different types of technologies that could be used in different PSS offerings in order to enhance customer support during the use of the product. According to Grubic (2014), technologies that provide real-time information from the field can mitigate the risks that manufacturers undertake in certain PSS offerings. Another example is the use of predictive tools to interpret product data as an enabler of product-related services such as condition-based maintenance, provided as an add-on service to product acquisition, or as part of result-oriented PSS in which manufacturers take responsibility on maintenance activities in order to comply with certain availability agreements. Overall, the implementation of e-maintenance technologies could then support the servitised offerings, through ensuring service performance and quality during the whole product life (Iung, 2003).

The increased focus on services has shifted the concept of value associated to customer offerings in manufacturing companies. This new perspective is not based anymore on the value-in-exchange, i.e. exchange of goods and money, but rather on the value-in-use, i.e. the perceived benefits of the service from the customer viewpoint (Vargo et al., 2008; Vargo and Lusch, 2008). Conversely, the understanding of value-in-use is still in its early stages of research, thus, focusing great attention in research communities (Ostrom et al., 2010; Lightfoot et al., 2013). Therefore, customers evaluate industrial services in terms of the benefits offered / gained rather than their solely price. This brings new challenges to industrial PSS offerings; "*the nature of value* *and its role in the delivery of equipment-based services*" (Smith et al., 2012).

The authors have previously investigated the concept of value for decision making in manufacturing technologies acquisitions (Macchi et al., 2012, Macchi et al., 2014). This article is a further development of an exploratory research on the value-in-use in service provision, added by maintenance technologies (Holgado and Macchi, 2014; Holgado, 2014). In fact, it provides a complete set of results taken from a survey analysis, also suggesting a future research agenda in order to envision how value-in-use could be enhanced by potentiating the use of maintenance technologies. Concretely, this article aims at providing some evidence to answer the following research question: *What is the value-in-use of e-maintenance tools and applications in service provision?*

The article is structured as follows. The next section provides the background, including a list of e-maintenance tools and applications identified, the method for value analysis and the value dimensions used in this research. Subsequently, the main results are presented and discussed in sections 3 and 4. Moreover, Section 4 introduces a suggested research agenda. The article ends with brief concluding remarks.

2. BACKGROUND

2.1 E-maintenance Tools and Applications

Dachs et al. (2014) empirically found a positive relationship between innovation in products and processes and servitisation strategies. This may be partly due to their potential capability to enable new services. Indeed, e-maintenance has been defined as "*maintenance support which includes the resources, services and management necessary to enable proactive decision process execution*" (Muller et al., 2008) and it is seen as a means for supporting customers anywhere and anytime (Lee, 2001).

The following is a non-exhaustive list of 10 categories of e-maintenance tools and applications that either alone or combined can provide new functionalities, thus, enabling new maintenance related service offerings: Smart devices & sensors, e-CMMS, Inspection tools, Diagnosis tools, Prognosis tools, Cloud-based tools, Simulations tools, Location & tracking tools, Augmented reality (AR) tools. Table 1 presents a summary of the key functionalities that each category is envisaged to enable. A more extended review and description of the different categories and their functionalities can be found in Holgado and Macchi (2014).

Table 1. Functionalities provided by the e-maintenance tools and applications (adapted from Holgado and Macchi, 2014)

Category	**Functionalities**	**References**
Smart devices	Support operator in the field and take remote action from anywhere	Crespo Marquez and Iung, 2008; Iung et al., 2009
Smart sensors	Identify and report any malfunction of system or equipment. Remote configuration and calibration	Zhang et al., 2004
e-CMMS	Fast and flexible scheduling; monitor and manage preventive maintenance activities	Iung et al., 2009
Inspection tools	Detect equipment or system failures and indicate equipment or system under-performance	Kumar et al., 2009
Diagnosis tools	On-line fault diagnosis, isolation and root cause identification	Jardine et al., 2006; Crespo Marquez and Iung, 2008
Prognosis tools	Estimate the remaining useful life (RUL) of system, equipment or components, based on current condition and projected usage	Jardine et al., 2006; Crespo Marquez and Iung, 2008
Cloud-based tools	On-demand network access to a shared pool of information resources	Dillon et al., 2010
Simulation tools	Compare the effects of different maintenance policies and different scenarios for equipment deterioration and failure	Takata et al., 2004; Crespo Marquez et al., 2009
Location and tracking tools	Support operator, component and equipment identification. Storage of conventional data on the machine and traceability of the past maintenance actions. Enable geolocalisation.	Adgar et al., 2007; Iung et al., 2009
AR tools	Support man/machine or man/man exchange of information. Guidance to operators for maintenance intervention execution	Takata et al., 2004; Iung et al., 2009; Espindola et al., 2013

2.2 Method for Value Analysis

The value analysis has been done according to a particular method to evaluate the value added by the above categories of e-maintenance tools and applications to the provision of maintenance services (Holgado, 2014). This method consists of three steps.

The first step defines the dimensions of value to be used. The dimensions have been selected from the available literature and focus on the delivery of the service as a main point of contact between the customer and the service provider. They are the following (Ali-Marttila et al., 2013; Sinkkonen et al., 2013): Service Reliability, i.e. the service is performed how and when it was agreed; Operator knowledge, i.e. the service personnel has the adequate know-how to perform the service; Safety at work, i.e. the service is done according to safety policies and increases equipment operational safety; Environmental safety, i.e. environmental safety hazards are mitigated / eliminated during the service; Service price, i.e. price of the service with respect to the received / provided activity; Technical quality, i.e. the service outcome is obtained as expected and during the agreed time.

The second step defines a rating scale. A 7-point Likert-type scale was selected ranging from very negative contribution (1) to very positive contribution (7), with an intermediate score for "indifferent/no knowledge" (4). This numerical double approach allows a simpler calculation of average values for each category analysed and visual representation.

The third step defines a method to visualise the results. A radar chart was suggested by Ali-Marttila et al. (2013) as an adequate means to visualize the value gap between customer and provider perceived benefits. It is also adopted here due to its flexibility to represent one or more categories in the same chart and comparability between different charts.

The method was informed by a survey in order to collect expert knowledge on both maintenance field and servitisation field. The initial test of the survey involved a limited number of experts and their feedback was collected to improve the questionnaire content and format. Preliminary results based on the initial test were presented in (Holgado and Macchi, 2014) in order to incorporate feedback from wider academic community. The second step involved a broader set of experts, selected using a non-probabilistic judgment approach (Forza, 2002). The target population included both researchers and company managers working on the areas of maintenance technologies and/or industrial services.

The final sample contains respondents from academy (73%) and industry (27%), with an average of 8,15 years in the same company and an average of 5,45 years in the same role. Respondents are from 8 European and 2 American countries, although there is clearly higher representation of Italian experts (41%). Expertise in the sample within the industry experts is equally divided into maintenance technologies and service provision, while academic respondents expressing somewhat confidence in the service field (89%) were slightly more than those expressing confidence in maintenance field (81%). A summary of final survey results is presented next.

3. RESULTS

As part of the survey, the respondents were asked to indicate whether each category of e-maintenance tools contribute positively or negatively to each value dimension, according to their experience / knowledge. Their judgment was appointed a number, adopting the scores in the 7-point Likert scale and represented in radar charts, in accordance to the method for value analysis. Several analysis of the data were also performed in order to extract the maximum information from the expertise reflected in the responses.

Firstly, a ranking of tool categories was performed by calculated the average score in all value dimensions assigned to the 10 tool categories. Fig. 1 shows the overall scores obtained by each category. It can be noted that globally all categories obtained scores in the positive spectrum of the scale (>4), however, two categories – simulation and cloud-based tools – are below the consideration of being somewhat positive (5) in a global viewpoint, according to respondent answers. In addition, this overall ranking was also done separately for those respondents that stated a high level of confidence in the field of maintenance technologies and in the field of service provision. Interestingly, the tool categories perform similarly in comparison with the ranking obtained considering all respondents except for one tool category, inspection tools, that overtakes the rest and becomes first in the ranking for both groups of experts. This apparently reflects a higher confidence in the contribution that these tools can bring to the value dimensions from their perspective, which seems to be not commonly shared among all respondents.

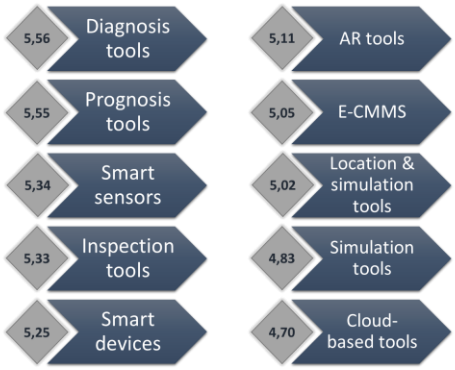

Fig. 1. Overall scores of the tool categories in a very negative (1) to very positive (7) scale.

Secondly, the detached scores obtained by each tool category in the defined value dimension were calculated as averages of the scores received. The obtained scores were recalculated into a positive scale that considers only the positive side of the Likert scale (>4), thus reflecting only from 0.00 (originally score 4) till 3.00 (originally score 7) points. These positive scores were then exposed in radar charts for each tools category. This visualisation technique allowed to identify certain patterns among the 10 tool categories. Fig. 2 shows the different patterns identified in graphs 2.A, 2.B and 2.C, while the three tool categories that couldn't be grouped are represented in graph 2.D. Inspection, diagnosis and prognosis tools had very similar shapes in the charts, with prognosis scoring slightly higher in most of the dimensions (graph 2.A). Similar shapes were also identified in the next chart: however, smart devices obtained higher scores in most dimensions, except environmental safety, respect to location & tracking tools (graph 2.B). Simulation tools and e-CMMS charts reflected also similar shapes, with e-CMMS having higher contributions in most dimensions, except an equal score in service price and a perceived lower contribution to environmental safety that simulation tools (graph 2.C). The remaining three tool categories did not resemble similar shapes with others or between each other (graph 2.D). Smart sensors outline in several dimensions: service reliability is the most important, besides technical quality and environmental safety. AR tools are associated with a higher contribution to operator knowledge and safety at work. Cloud-based tools had mostly lower contributions in the value dimensions.

Thirdly, an analysis of the intermediate scores was done. The intermediate score in the 7-point Likert scale was named "Indifferent / No knowledge" and assigned score 4 in the numerical scale. Respondents assigned this response in cases that they believe that the contribution of the tools category to a value dimension was null or in cases that they do not have the knowledge to make a judgment. Therefore, the analysis of the frequency of score 4 could generate further insight into our study. The frequency was calculated as a percentage of the total responses. Fig. 3 shows the number of value dimensions in which each tool obtained a frequency of score 4 superior than the average, which was calculated as 27.6%. Cloud-based tools obtained frequency in 5 out of 6 value dimensions and simulation tools in 4 out of 6 value

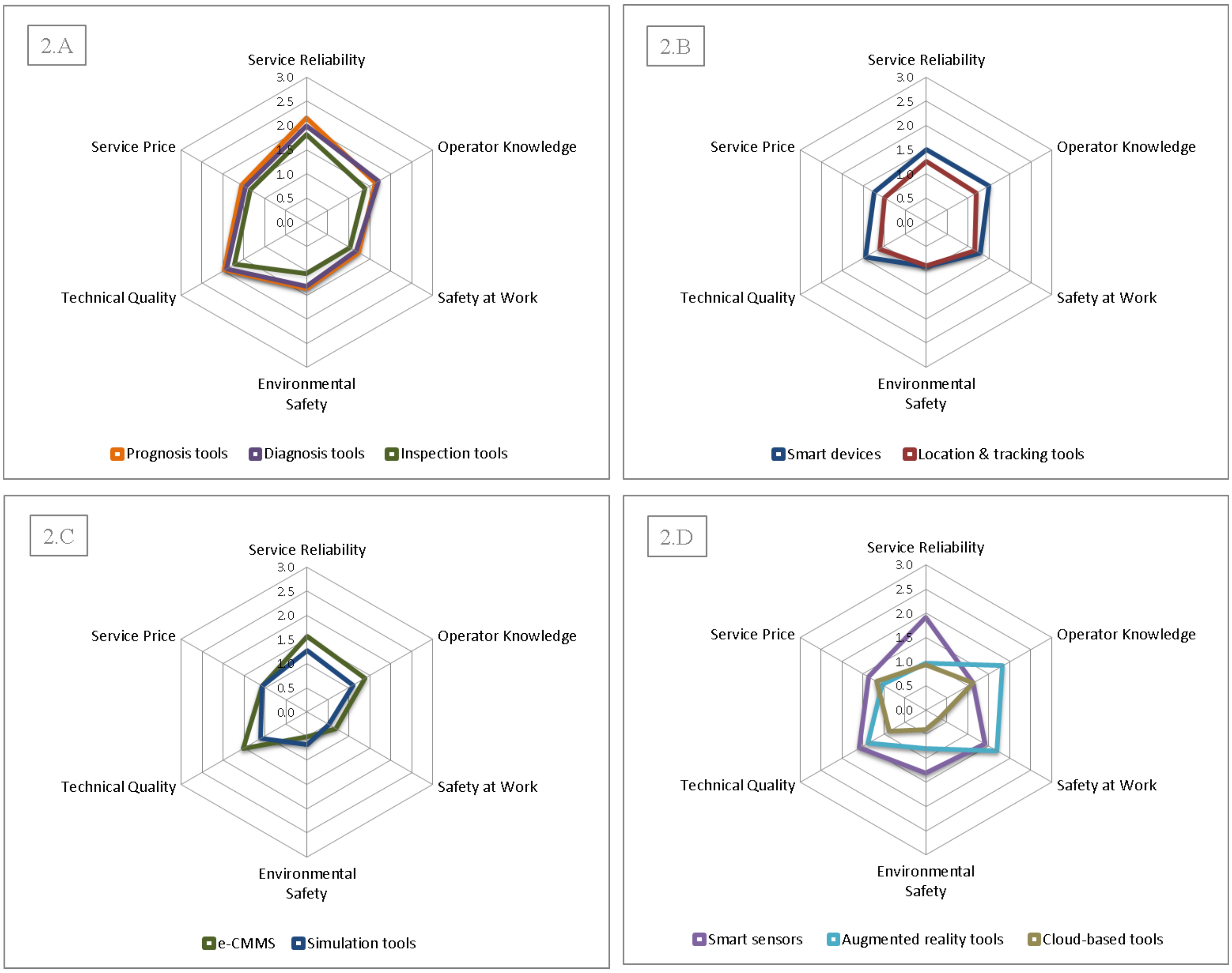

Fig. 2. Visual representations of the results obtained by each tools category in the defined value dimensions.

dimensions. This lack of knowledge or indifference in their contribution to the value dimensions explains the low scores that these categories obtained in overall (see Fig. 1). Other tool categories seem to have more certain contribution, either positive or negative, to the analysed value dimensions. For example, locations & tracking tools category did not obtain high overall / detached scores, however, it seems that the respondents were more certain on its low contribution due to the scarce frequency of score 4.

The analysis of frequency of score 4 given to the value dimensions revealed that safety at work and environmental safety are those receiving most frequently this score. Indeed, the only dimension in which score 4 was higher than the average was environmental safety, which is the dimension getting most scores 4 for most categories. As mentioned above, this could reflect either a lack of an effect on those dimensions by the use of the e-maintenance tools or a lack of certainty / knowledge from the respondents' side. The value dimension receiving less score 4 in the responses was the service price, in which none of the tool categories has a frequency of score 4 superior to the average. The rest were ordered as follows (from lower to higher frequency over average): service reliability, technical quality, operator knowledge, safety at work, environmental safety. Fig. 4 shows the comparison between the top two and the lower two value dimensions. The red line represents the average value of frequency in scores 4 for all tools and all dimensions.

An additional analysis was again performed for those respondents that stated a high level of confidence on maintenance technologies and on service provision, respectively. This analysis of the frequency of score 4 for each group of experts separately revealed just few differences with respect to the analysis done considering the whole sample. Those respondents stating higher level of confidence in maintenance technologies field assigned less frequently a score 4 to diagnosis tools (14.3%) than to prognosis tools (28.6%) with respect to environmental safety, while in the overall sample (and in the group of those respondents stating higher level of confidence in service provision) both tool categories have obtained similar results. In fact, in the case of prognosis tools, the percentage falls above the average for this group of respondents. Another interesting observation is that both groups of respondents stating higher levels of confidence in the fields do less frequently assign a score 4 to smart devices in the dimension safety at work (26.7% in the group with higher confidence in the maintenance technologies field and 20% in the group with higher confidence in service provision, while the whole sample results show 32.4%).

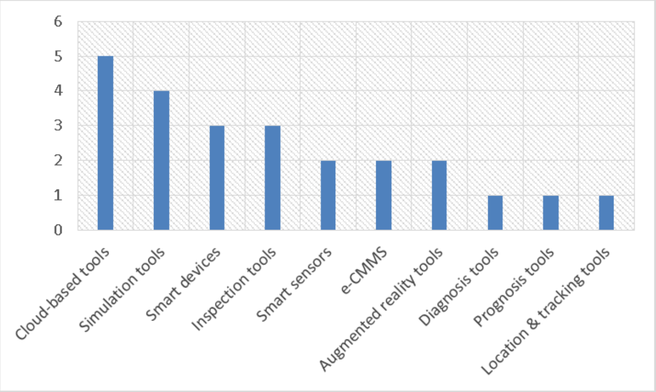

Fig. 3. Number of value dimensions with frequency in "Indifferent / No knowledge" higher that the average.

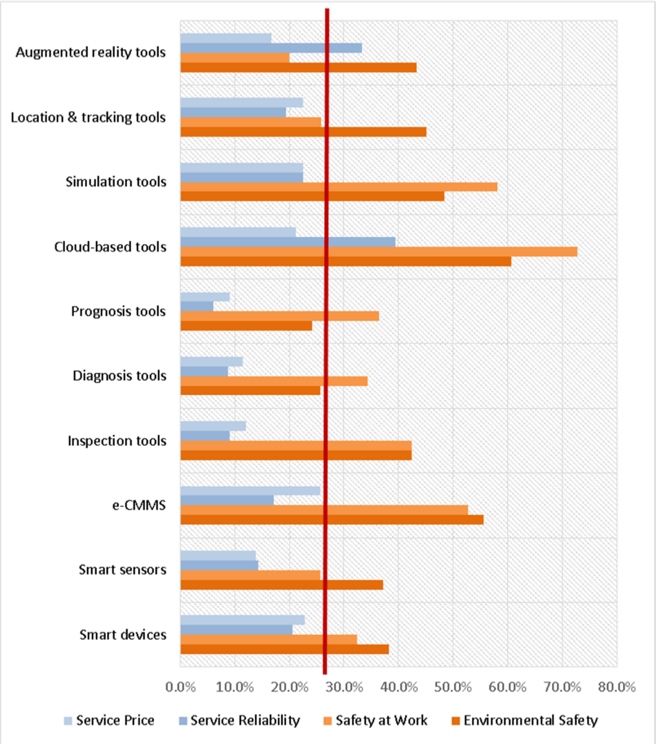

Fig. 4. Frequency in "Indifferent / No knowledge" in some value dimensions respect to the tool categories.

4. DISCUSSION AND RESEARCH AGENDA

The results above bring insight into the value-in-use of e-maintenance tools and applications in service provision. The value analysis was informed by the judgment of both experts in the field of maintenance technologies and of service provision. Therefore, the subjectivity of these results should be also taken carefully into account. Anyhow, the blend of their heterogeneous perspectives is adequate for our objective and highly valuable to bring forward the research agenda.

The survey results reveal that diagnosis and prognosis tools are promising means to increase the benefits obtained, i.e. the value-in-use, in service provision. Investing in these tools is expected to have the highest impact in two main dimensions - service reliability and technical quality – whereas the enhancement of operator knowledge will be also considerably influenced and its impact cannot be neglected. Besides, smart sensors could be seen as complementary to diagnosis and prognosis tools, thus their combined used could bring further improvements in service reliability. Last but not least, AR tools seem to be an adequate target to further investigate their specific impacts on operator knowledge and safety at work.

The knowledge gaps perceived in the survey results on certain value dimensions, such as environmental safety and safety at work, could have different causes. The awareness on the contributions to these dimensions seems to be low and could be a result of a lack of business cases demonstrating the potential tools impact on those dimensions. However, we cannot neglect the possibility of a scarce contribution of the tools to those dimensions, neither. This would imply a need to investigate other technological innovations which could improve safety dimensions in service provision.

The research agenda should also consider the prospects of the currently on-going transformation in manufacturing due to digitization. In this regard, e-maintenance is expected to further advance to a greater value with the development of Cyber-Physical Systems (CPS), i.e. "*smart systems that encompass computational (i.e., hardware and software) and physical components, seamlessly integrated and closely interacting to sense the changing state of the real world*" (NIST, 2013). The interconnection of physical machines with their cyber level counterparts would even support industry to achieve the benefits of peer-to-peer monitoring and comparisons in fleet of machines. Indeed, when a cyber-level infrastructure is available, machines could operate in a way "*conceptually similar to social networks*" (Lee et al., 2015), and diagnosis and prognosis tools would be potentiated in such networks. Thanks to this transformation, it is expected that simulation tools (at cyber level) and cloud-based tools (forming the cyber-level infrastructure) will be perceived with stronger contributions to several dimensions in service provision.

5. CONCLUDING REMARKS

The research results on the value-in-use of e-maintenance tools and applications in service provision captured insights on the current perception of experts in academia and industry. Some discussion points have been inferred into a research agenda, taking into account the digitisation of manufacturing industry. The concept of value-in-use leading this study is aligned with the shift into a service dominant logic of service offerings, due to servitisation of manufacturing industry.

This article advances the understanding of *what is the value-in-use of e-maintenance tools and applications in service* *provision*. Nevertheless, some limitations of the study could be addressed though a wider inquiry to: (i) enlarge the sample of interviewees and focalise separately on each group of experts; (ii) revisit the list of tool categories to include others such as CPS, Internet of Things, additive manufacturing.

Finally, taking forward the concept of value-in-use to bring an additional outlook in future research, oriented to answer the subsequent question: *how to introduce e-maintenance tools and applications to improve the value-in-use in service provision*. The operationalisation of the value-in-use concept will bring further insight when studying the specific cases of particular services which are offered by a provider and evaluated from the target customer's perspective.

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