Barata, J., Cunha, P.R.: In Search for a Viable Smart Product Model. In: BITA 2019 Proceedings. pp. 1–10. , Seville, Spain (2019).

In Search for a Viable Smart Product Model

João Barata[1[0000-0002-7456-594X]] and Paulo Rupino da Cunha[1[0000-0003-2701-5248]]

[1] CISUC, Department of Informatics Engineering, University of Coimbra, Pólo II, Pinhal de Marrocos, 3030-290 Coimbra, Portugal
{barata,rupino}@dei.uc.pt

Abstract. Smart products integrate physical and digital materialities, taking advantage of sensors, mobile technologies, and advanced data processing capabilities. This type of systems is a top priority for managers, offering the capacity to sense, communicate, adapt, and anticipate the needs of business stakeholders. We use the lens of the Viable System Model (VSM) theory to align business strategies and smart products. The proposed model was tested in a real case of information systems development for safety in construction. The findings emerge from a design science research that is part of a larger project to introduce smart technologies in the construction industry. A viable product model (VPM) represents the necessary and sufficient conditions for the smart product cohesion and endurance in different environments, aligned to the business needs. For theory, we present a product-level adoption of VSM and propose guidelines for business-smart product alignment. For practice, the results can assist managers in creating new smart products that adhere to their strategy and capable of dealing with unexpected events.

Keywords: Viable Product Model, Viable System Model, Industry 4.0, Smart Product, Construction.

1 Introduction

Products are increasingly digitalized, reconfiguring the socio-technical relationships with users, adding new capabilities to physical objects, and changing their traditional lifecycles. It has been recognized that "*the most important feature of digital innovation is successful generation of new IT-enabled products, processes, and services. Despite its salience, exploration of digital innovation outcomes has received very little attention in the literature*" [1]. Products, or, more precisely, the new smart and digital-physical products [2], concern different C-level executives of the organization, matching the relevance of IT for process improvement initiatives. We agree with [3] that "*IS scholars need to question and complement their received models of aligning IT to business* *strategy* (…), *must imagine new digital strategy frameworks that identify new sources of value creation such as generativity, heterogeneity, digital product platforms, and meaning-making capability* […developing] *new strategic frameworks that are aimed at deliberately harnessing the unique capabilities of digital technology that are embedded into products*".

Over three decades ago seminal studies identified the competitive importance of aligning business and IT investments [4], focusing strategic developments "*as the interplay between a dynamic environment and bureaucratic momentum*" [5] where the technologies are at the core of organizational transformation. More recently, "alignment" is seen as a dynamic process that requires continuous adjustments between business functions and applications [6]. Several studies suggest the positive impact of alignment in company performance, namely in the aspects of (1) IT-business communications; (2) value analytics; (3) approaches to collaborative governance; (4) nature of the partnership; (5) scope of IT initiatives; and (6) development of IT skills [7]. However, there is a lack of studies that address the emergent smart products and their alignment to organizational strategies.

Business/IT alignment (BITA) is essential for business viability, so it is warranted to examine it using the lens of influential theories such as the Viable System Model (VSM), originally proposed by the British theorist and professor Stafford Beer [8]. VSM has been widely discussed during the last decades and asserts the necessary and sufficient conditions for the viability of an organization [8–10]. The necessity to align business and IT at the product level [11] and the opportunity to explore a sound theory for *viable systems* in this context motivated two research goals for this paper:

1. Understand how the Viable System Model theory has been addressed in business/IT alignment literature for product level of analysis;
2. Design a Viable System Model for smart products, aligning industry 4.0 strategies and information technologies.

The rest of the paper is organized as follows. Section 2 explains our design science research approach, aiming to integrate smart technologies in construction safety. Subsequently, we review relevant literature on VSM and smart products. Section 4 presents the design and development of the Viable Product Model (VPM). In Section 5, we discuss the findings and suggest specific guidelines to align business and product-level IT adoption. Finally, we highlight the main contribution to the field of BITA, the study limitations, and the avenues for future research.

2 Research Approach

The design-science research (DSR) paradigm [12] has its foundations in the work of [13]. DSR enables the creation and evaluation of artifacts to solve specific organizational problems, which can "*be in the form of a construct, a model, a method, or an instantiation*" [12], integrating informational, technological, and social aspects. Although the maturity of the use of industry 4.0 technologies (e.g. Internet of Things (IoT), mobile, cloud) is high in sectors such as automotive, their use in more traditional industries needs further research.

The research presented in this paper is part of a larger DSR project that aims to create smart products for occupational health and safety (OHS) in construction [14]. The project has involved two companies of a Portuguese construction group (C1: consulting, training, safety inspections; and C2: construction equipment supplier) that were interested in adopting industry 4.0 technologies in their businesses. After developing several prototypes for safety with IoT and a comprehensive system to improve OHS in construction, it became clear that the alignment of smart products for OHS required a viable model of the business and of the technological portfolio. It was necessary to represent the fundamental building blocks of smart products and their relation to the environment in the construction site, ensuring the conditions to become viable. The Viable System Model [8] seemed to be an interesting solution to test.

According to [15], after the (1) identification of the problem and motivation and (2) definition the objectives for a solution, DSR evolves through (3) design and development, (4) demonstration, (5) evaluation, and (6) communication. Our design and development proceeded with a structured literature review to identify the use of VSM for product modeling and, particularly, for the design of smart products. Afterward, we adopted VSM to the product level of analysis in BITA and demonstrate its use with a smart product for construction safety. The evaluation of the research enabled us to propose guidelines to model viable products, aligning technological innovations with the business strategy (industry 4.0 in our case). The communication step of DSR is in the form of a scientific publication and sharing our results with the participating companies.

3 Literature Review

We have selected Google Scholar for our review of the core literature. It was selected because it offers wide coverage of highly-cited documents and citations in three essential fields to the topic of business IT alignment, namely, (1) Business, Economics & Management, (2) Engineering & Computer Science, and (3) Social Sciences [16].

Surprisingly, a search in Google Scholar with the keyword combination "business IT alignment" AND "viable system model" (April 6, 2019; excluding patents and citations) only returned 43 results. Among these contributions we can find the keynote speech by Prof. Jose Perez Rios at PoEM 2013, presenting how VSM can be used for information systems development "*constructing models with sufficient variety (the capacity to deal with complexity) to respond to current problems*" [17]. We attended that inspirational keynote that was our starting point to reflect about the potential of VSM for product development efforts. Yet, none of the studies found in our initial search adopted VSM to ensure smart product development is aligned with company strategy.

In a second review round we used the keywords "viable system model" AND ("Iot" OR "internet of things"), since we were particularly interested in the smart product design supported by IoT. This search has yielded 117 results, suggesting that the efforts to adopt VSM in the IoT context are more popular. Nevertheless, we could not find any study for our purpose and extended the review with additional keywords, namely, "viable system model" + "smart product". We obtained 3 results, with only two of them using VSM [18, 19]. The work of [19] presents a research in progress for a VSM meta-model for manufacturing control with smart objects, while [18] reviews key literature to identify challenges in the design of systems that react to unpredicted events. We still could not find empirical studies for the product-level of alignment that merges physical and digital elements in new product development.

The third review round identified studies addressing product viability (not restricted to smart products) and VSM used the keyword combination "viable product model" in Google Scholar. This search returned 15 studies, however, none adopted VSM for the purpose of product viability. The second round of search terms using "viable system model" + "product level" (18 studies) and "viable system model" + "product model" with 25 results. Other keywords used in our research were "viable system model" + "smart product service system" (0 results) and "viable system model" + "product service system" with 22 results. Among these, we highlight [20] where VSM is used to analyze the integration of products and services in defense contracts. The authors argue that servitization requires a shift from a product-centric view to a relational-process view of solutions and evaluates variety in this type of contracts. This work – although not addressing the design of product-service systems and its alignment to organizational strategies – has strengthened our belief that VSM can provide a valuable lens for product-service system contexts. The next subsection discusses the fundamentals of VSM.

3.1 Viable System Model

The work of Stafford Beer was hugely influenced by W. Ross Ashby (1903–1972), author of the law of requisite variety – a measure of the number of states a system can take up, stating that it could succeed "*only if it disposed of as much variety as the environment in which it existed*" [21]. Ashby created an electromechanics device named homeostat that simulated the ability of organisms to keep the blood temperature constant independently of the environmental conditions [22]. This device was an inspiration to the efforts of S. Beer to create adaptive organizations, including the automatic factory controlled by computers [8, 21]. In fact, "*VSM is primarily a tool to observe institutions and to support connectivity in the quest for desirable transformation*" [10].

Our study resorts to key VSM definitions summarized by [10]. First, a viable system is "*able to maintain a separate existence*", possessing the capacity to respond to known and unexpected events (e.g. catastrophes). Second, an organization "*is a 'closed' network of people in interaction producing a whole*" with rules and mechanisms for decision making, identified by human relations. Third, the organization structure "*emerges from stable forms of communication, or mechanisms, which permit the parts* [e.g. people roles or departments] *of an organisation to operate together as a whole* […and] *suggests the relevance of understanding both the contribution of technology and other resources to organisational processes and the influence of structure in the design of communication and information systems*".

There are two key mechanisms for viability, namely, *cohesion* and *adaptation* [8, 10, 21]. The first mechanism allows people to produce collective meaning, aligning individual (autonomous) interests with the entire organization. This mechanism involves functions of implementation, cohesion, negotiation, coordination between different units (e.g. lateral communication) and monitoring. The second mechanism is an adaptation, because organizations must evolve according to the (internal/external) environmental changes that occur over time, requiring appropriate policies and intelligence functions. Both mechanisms are essential for recursive organizations (all its units have a structure that enables knowledge meaning creation, regulation and implementation [10]) where all its sub-systems are also viable systems [23]. The VSM model is represented in Figure 1.

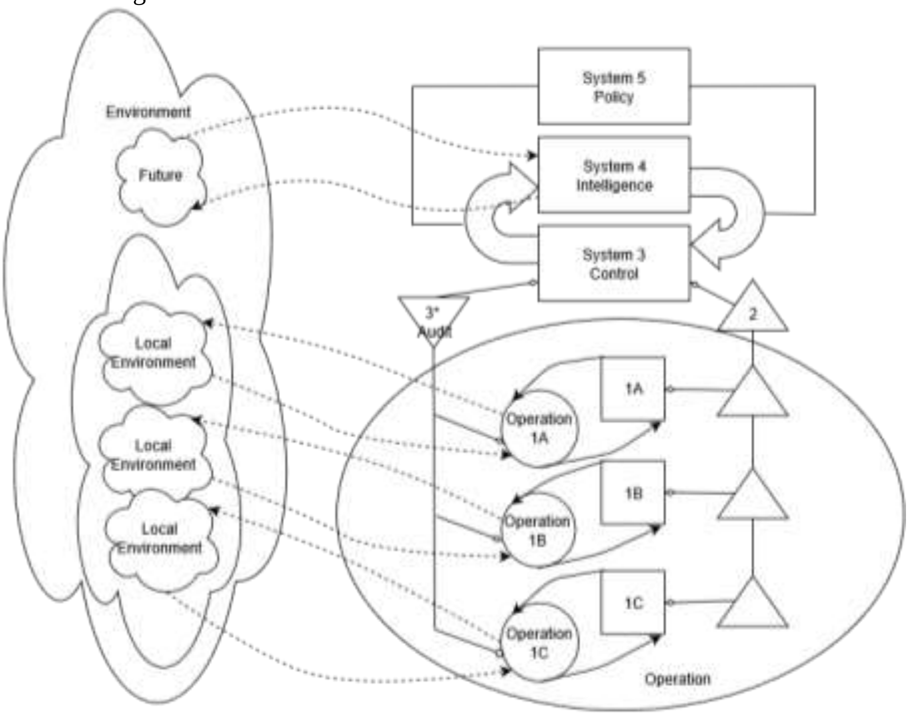

Fig. 1. Viable System Model (adapted from [8]).

The VSM includes at least five main levels or systems that are inspired by biology [10]. System 1 includes the primary activities that support the business (e.g., different subsidiaries of an organization as presented by [21]). According to [9], these autonomous units "*conduct and optimize the daily business-in the 'here and now'*". System 2, like the nervous system, allows communication and interconnections between System 1 elements and with System 3 (executive management), related to the controls and resources that allows managers to react to changes in Systems 1-2. System 4 is responsible for monitoring and understanding adaptation needs (e.g., research and development, orientation toward the long-term), collecting and showing information from the outside world, and lower levels of VSM. Finally, System 5 directs the whole organization, defining policies, norms, values, and balancing the different parts of the firm [8–10].

According to [8], the performance of System 1 activities can be measured according to its actuality (what the activity is accomplishing now with existing resources), capability (what it should be achieving now with the same resources) and potentiality (*ought to be*, developing resources and removing constraints – a main responsibility of System 4). Moreover, recursion is a key aspect in VSM because "*any viable system contains, and is contained in, a viable system*" [8], allowing to consider multiple levels of abstraction in the model creation. Each System 1 element can be seen as a viable system.

There are multiple relationships to consider [8, 9]. The vertical channel (relation between System 1 and System 3) includes the negotiation of objectives and exceptional intervention if cohesion is at risk. Relationship 1-2-3 attempts to reduce complexity and filters information from System 1, while 3* allows auditing the company system. Relationship 3-4 includes the process of strategic development and stability, balancing long-term *vs* short term needs, and the internal and external environment analysis. Finally, relationship Systems (3-4)-5 aims to moderate interactions between Systems 3 and 4, solving conflicts. Problems in these systems and their relations pose risks to the viability of the organization, which is composed of a structure with multiple layers that recursively interact. In this context, a "*product is thus not a separate object; objects are recursively constructed objects in language. The perceiver and the perceived arise together in the discourse of value creation*" [24]. More recently [24] adopted the VSM and requisite variety to propose a framework describing the systemic relations of value co-creation for product innovation and development.

The next subsection explores VSM for the product level of alignment.

3.2 Towards a Viable Product Model with VSM

The VSM lens has been recently used to address business/IT alignment issues, for example, in the work of [25] and [26] for IT governance. VSM can be used for diagnosing and designing organizations, as illustrated in the five case studies of [27], namely, "*transformation of a company*", "*redesign of a meta-system*" for the top management, "*enhancing cohesion*" of different divisions of the organization, "*developing strategy*", and "*examining corporate ethos*" to change auditing approaches.

Some examples adopt VSM for enterprise architecture management [28, 29], but most of the studies adopting the VSM address the organizational context and its self-regulation capacity, namely, corporations, public organizations, or nations [9]. Interestingly, a decisive influence in the VSM theory comes from a specific machine with the capacity to 'sense' the environment – Ashby's homeostat. Therefore, VSM should be a potential theory for the design of smart 'viable' products that can sense the environment and adapt to different conditions that are relevant to the business strategy.

We found two contributions particularly relevant for our purpose, one of them presented by [30], who adopted VSM for a product level of analysis in the shop floor. This study exemplifies the use of intelligent product model for a production and control system using RFID in industrial applications. The second study applied VSM to the analysis of a smart network for electricity production. The authors of [31] have studied how the "*smart capability functions at a strategic, business process and technical level*", contributing for a product-oriented view of VSM theory. Both refer to the production/manufacturing stages, opening an opportunity to expand research in this area addressing the case of smart products. Our research focuses on the structure and mechanisms (e.g., cohesion, adaptation) for BITA at the smart product level of analysis.

4 A Viable Smart Product Model for OHS in Construction

The design and development involved two researchers and a master's student of informatics, responsible for the coding in the prototype development phase of DSR. The initial phase was conducted in close collaboration with the practitioners designated by the construction group, namely, two OHS assessors, the top managers of the construction equipment company and of the consulting company, and two construction technicians designated to assist in field testing. The first artifact used for occupational health and safety in construction using smart technologies aimed at presenting a global picture of the infrastructure, equipment, and main purposes of the stakeholders (Figure 2).

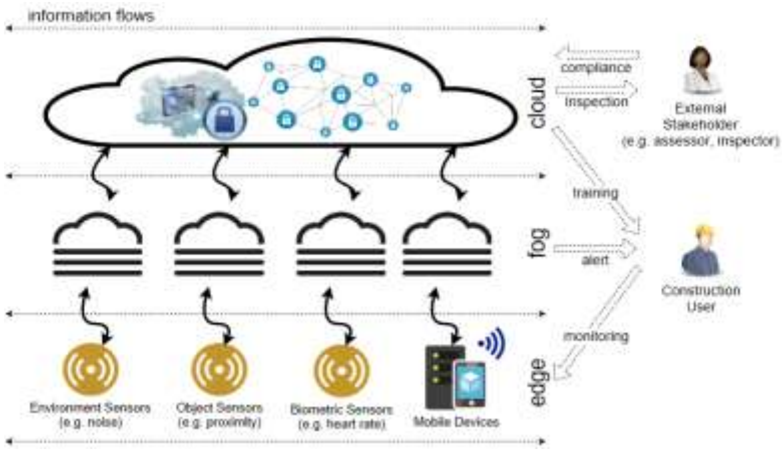

Fig. 2. Integrated Smart OHS [14].

There are three key elements in the cyber-physical IoT infrastructure (bottom-left).

- The *personal mobile device*: worker monitoring and alert system based on a smart wristband – biometric information, RFID, and GPS;
- The *environment sensors kit* (unpractical to include in the worker wearables), including light, temperature and humidity, noise, and air quality (requires GPS);
- The *objects sensors*, including RFID antennas (collision detection or fall protection), PPE - personal protection equipment (e.g., helmet), and site access.

The system is used for alerting the user, gathering biometric data, and identification, for example, for collision detection systems using RFID. Moreover, it concentrates the environmental parameters in a portable, low-cost toolkit, making it affordable to use in different areas of the site. Finally, it ensures wearable use (identifies PPE) – if the wearable is not in use, the worker may not enter the site or use specific equipment. The arrows represent the value obtained from data analysis (training, alerts, and inspections), and the purpose of data collected via IoT (monitoring and compliance). On the bottom-right, the external stakeholders that need to access OHS data are represented, and, on the top, we can see the cloud infrastructure. The smart OHS system needed to ensure that it provided cohesion and adaptation to the environmental conditions: a viable product model. The model for the product level of analysis is presented in Figure 3.

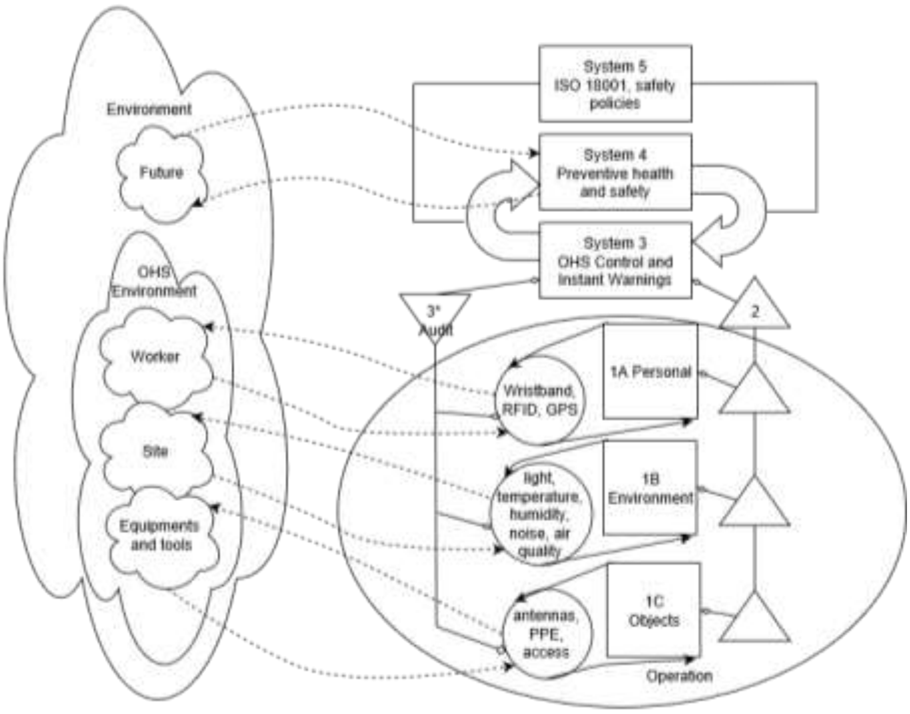

Fig. 3. Viable Product Model – Smart OHS system.

The design of a viable smart product must consider the five interrelated systems included in the VSM theory [8], enabling cohesion and adaptation mechanisms. System 1 includes the key operation units of the smart OHS that will be implemented via IoT, namely, (1A) *personal mobile device*: worker monitoring and alert system based on a smart wristband, (1B) *environment sensors kit* requiring feedback (System 2) from the personal mobile device 1A; and (1C) *objects sensors* that will require feedback from 1A and 1B. System 2 represents the feedback system made possible by the IoT sensors that interact with the local environment - aligned with the strategy for smart OHS. System 3 implements the immediate actions (e.g. avoid unauthorized access to the site or alert of imminent fall or collision with equipment), while providing audit from health and safety assessors and consultants. System 4 includes the algorithms to generate alerts or safety warnings, for example, warn the user to rest according to the weather conditions (collected via weather sensors) and biometric signals. Finally, System 5 is materialized by the health and safety regulations, ensuring alignment between the operation (1, 2), the environment and the metasystem (3-4-5).

We identify different levels of recursion [8, 10] in VPM because each autonomous product (1A, 1B, 1C) is also a viable product according to the VSM, interacting within the operation system and with the structural recursion levels above. This DSR enabled the formulation of the following design principles for viable smart product models:

- *Adopt a top-down approach starting the model with System 5 and then System 4 elements*. Smart products must be a result of overall company policies and future development expectations. Therefore, System 5 must clarify the policies (in our case, occupational health and safety and industry 4.0) and then System 4 envisions candidate technologies and the potential adaptation to future events.
- *Update System 3 (control) as System 4 and System 1 evolve*. It is necessary to balance resources needed to develop System 1 parts of the smart product and the adaptation requirements identified in System 4.
- *Follow an outside-in approach to design System 1*. Contrarily to the usual application of VSM for diagnosing the business, parts (or all) of System 1 components may not yet exist when planning smart products that adhere to the environment. Therefore, it is important to detail the complete setting for the smart product operation.
- *Promote synergies with System 2*, which provides cohesion between all the components of the smart product, lateral communication, and vertical communication with System 3 (which, in turn, allows auditing (3*) via sensors existing in System 1 level).
- *Present the VSM theory using the human body analogy*. We confirmed in this case the findings of [32], that VSM does not provide a common language for managers, requiring a previous presentation of the concepts.
- *Adopt a cyclic approach to the design of the viable product model*. A single iteration (System 5&4-4&3-1&3-2) provides an initial version of the model, but it is necessary to understand the implications of System 1 for the higher levels. For example, specific technologies may not be applicable (e.g., too expensive), requiring manual control procedures at level 3 (e.g., human audits). Designers should navigate through the five levels of the VPM for consistency and reevaluate the capabilities of the system.

5 Discussion

Smart products must be aligned with the business strategy, in cohesion with other organizational systems and ensuring adaptation to environmental changes. As stated by [33] "*if the technologies driving Industry 4.0 develop in silos and the OHS initiatives of manufacturers are fragmentary, hazards will multiply and some of the gains made in accident prevention will be lost*". According to the company managers in our project consortium, a comprehensive model for wearable technologies in construction needs to support (1) training, (2) monitoring critical parameters, (3) user alerts (e.g., collision, fall), and (4) voluntary regulatory compliance (OHS standards audit and evidence). A VPM approach surfaces the different purposes of technology, its interactions with the local environment, and recursion with managerial functions.

Few studies have used VSM theory as an inspiration for product developments that are aligned to the business. Most of the research focuses on diagnosing [32] or transforming already existing organizations [27]. Our study shows that VPM can be used for the development of smart products integrated with the business strategy.

We presented the final model to the companies participating in our research to understand the communication capabilities of this artifact. They found the relation between the environment and System 1 important to understand the needs of regulations, and System 3 to identify what type of data they could get from the viable smart product. Regarding Systems 5, 4, and 2, they found that information more relevant to the implementors of the solution. We found that System 2 was transparent to them (more important to integrate the smart product IoT system by technical staff), System 5 was a representation of their own vision and regulations (more important to third party), and System 4 was, in this case, mostly developed by the research team, who identified the future opportunities and needs for adaptation. This case revealed that the interest of each systems in VSM can vary according to each stakeholder. Additional research is necessary to understand how the VSM representation can improve its communication capabilities according to multiple viewpoints of smart products development.

6 Conclusions

We presented a Viable Product Model artifact based on VSM theory to the design of smart products. The results are attained from (1) a DSR project aiming to introduce smart technologies for safety in construction, and (2) a structured literature review focusing on VSM for BITA at the product-level of analysis, contrasting to the usual adoption of VSM for business units and departments. Digitalization is changing products in all sectors of the economy, requiring new models to capture the alignment between business needs and pervasive IT. The multiplication of IoT systems creates challenges to align synergies within these systems and the (internal and external) social realms of the organization. One central conclusion in our work is that VSM theory can be adopted to model viable smart products in the emerging fourth industrial revolution.

Some limitations must be stated. The first stems from the literature review, namely, the restriction of the source database and the selected keywords. We decided to use Google Scholar, which is the most comprehensive search engine [16], but other databases can be used. Secondly, to our knowledge this is the first attempt to adopt VSM for smart product developments, focusing on the product-level of alignment in a single organization. A more in-depth evaluation of the pros and cons of the VPM is necessary, and other cases may follow to improve the approach. More field work is necessary since current results are mainly supported in the literature review and the preliminary findings of one case. Thirdly, although the model results were positive for the company managers, there are risks of the Hawthorn effect in social studies, suggesting that the observed participants' behavior could be "*related only to the special social situation and social treatment they received*" [34]. Finally, we did not yet explore the full potential of VSM for detailing the relations between specific sensors and actuators in System 1, the integration in System 2, and the detailed information flows with the environment and other

Systems (3-4-5). The model that we present in this paper can be improved, including, for example, sensor specifications and detailed data models.

Future research opportunities are promising. First, looking to the possibility to adopt VSM to other types of interactive products. Another possibility is to align the VPM with VSM for the same organization, for example, aligning viability of the product with other levels (recursions) of viable systems such as departments. We also found an opportunity to explore VSM in the entrepreneurship context, namely, its potential to model minimum viable products that are popular in start-ups. Finally, it is possible to develop different VPM representations (viewpoints) to improve its utility to BITA with enhanced communication capabilities according to the needs of each stakeholder.

We plan to test the proposed model in our information systems course, to evaluate the potential of the tool for training smart product specification aligned with the company strategies. Additionally, the next step of our DSR will adopt VPM to a smart tower crane. One of the companies belonging to the construction group rents tower cranes and wants to use IoT to improve safety (e.g. prevent collision with the building during hoisting processes; alert the user in critical weather conditions), maintenance (monitor the equipment use and alert the supplier for maintenance procedures), and other smart capabilities to improve their tower crane rental business.

References

1. Kohli, R., Melville, N.P.: Digital innovation: A review and synthesis. Inf. Syst. J. 29, 200–223 (2019).
2. Hendler, S.: Digital-physical product development: a qualitative analysis. Eur. J. Innov. Manag. 22, (2018).
3. Yoo, Y., Henfridsson, O., Lyytinen, K.: The New Organizing Logic of Digital Innovation : An Agenda for Information Systems Research. Inf. Syst. Res. 21, 724–735 (2010).
4. Luftman, J., Brier, T.: Achieving and sustaining business-IT alignment. Calif. Manage. Rev. 42, 109–122 (1999).
5. Mintzberg, H.: Patterns in Strategy Formation. Manage. Sci. 24, 934–948 (1978).
6. Zhang, M., Chen, H., Li, X., Lyytinen, K.: Evolvement of Business-IT Alignment: A Conceptual Model and Intervening Changes from Resource Allocation. IEEE Access. 6, 9160–9172 (2018).
7. Luftman, J., Lyytinen, K., Zvi, T. Ben: Enhancing the measurement of information technology (IT) business alignment and its influence on company performance. J. Inf. Technol. 32, 26–46 (2017).
8. Beer, S.: The heart of enterprise. Wiley (1979).
9. Schwaninger, M., Scheef, C.: A Test of the Viable System Model: Theoretical Claim vs. Empirical Evidence. Cybern. Syst. 47, 544–569 (2016).
10. Espejo, R.: The viable system model. Syst. Pract. Action Res. 3, 219–221 (1990).
11. Porter, M.E., Heppelmann, J.E.: How smart, connected products are transforming companies. Harv. Bus. Rev. 2015, (2015).
12. Hevner, A.R., March, S.T., Park, J.: Design Science in Information Systems Research. MIS Q. 28, 75–105 (2004).
13. Simon, H.: The sciences of the artificial, (third edition). MIT Press (1996).
14. Barata, J., Cunha, P.R.: Safety Is the New Black: The Increasing Role of Wearables in Occupational Health and Safety in Construction. In: Lecture Notes in Business Information

Processing. 22nd BIS. pp. 1–12. , Seville, Spain (2019).
15. Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S.: A Design Science Research Methodology for Information Systems Research. J. Manag. Inf. Syst. 24, 45–78 (2007).
16. Martín-martín, A., Orduna-malea, E., López-cózar, E.D., Martín-martín, A.: Google Scholar, Web of Science, and Scopus: a systematic comparison of citations in 252 subject categories. J. Informetr. 12, 1160–1177 (2019).
17. Grabis, J., Kirikova, M., Zdravkovic, J., Stirna, J.: The Practice of Enterprise Modeling. 6th IFIPWG 8.1Working Conference, PoEM . (2013).
18. Zimmermann, E., Bril, H., Haouzi, E.L., Thomas, P., Thomas, A., Noyel, M.: A hybrid manufacturing control based on smart lots in a disrupted industrial context. In: 20th IFAC World Congress. pp. 9585–9589 (2017).
19. Cardin, O., Trentesaux, D., Thomas, A., Castagna, P., Berger, T., Bril, H., El-Haouzi: Coupling predictive scheduling and reactive control in manufacturing hybrid control architectures: state of the art and future challenges. J. Intell. Manuf. 28, 1503-1517. (2017).
20. Batista, L., Davis-Poynter, S., Ng, I., Maull, R.: Servitization through outcome-based contract – A systems perspective from the defence industry. Int. J. Prod. Econ. 192, 133–143 (2017).
21. Pickering, A.: The science of the unknowable: Stafford Beer’s cybernetic informatics. Kybernetes. 33, 499–521 (2004).
22. Ashby, W.R.: Design for a brain: The origin of adaptive behaviour. Wiley, New York (1952).
23. Espejo, R.: Aspects of identity, cohesion, citizenship and performance in recursive organisations. Kybernetes. 28, 640–658 (2002).
24. Espejo, R., Dominici, G.: Cybernetics of Value Cocreation for Product Development. Syst. Res. Behav. Sci. 34, 24–40 (2017).
25. Huygh, T., De Haes, S.: Using the Viable System Model to Study IT Governance Dynamics: Evidence from a Single Case Study. Proc. 51st HICSS. 9, (2018).
26. Coertze, J., Von Solms, R.: Towards a cybernetics-based communication framework for IT governance. Proc. 48th HICSS. 4595–4606 (2015).
27. Schwaninger, M.: Design for viable organizations. Kybernetes. 35, 955–966 (2006).
28. Buckl, S., Matthes, F., Schweda., C.M.: Towards a method framework for enterprise architecture management–a literature analysis from a viable system perspective. In: CAiSE 2010 Workshop. Business/IT Alignment and Interoperability. pp. 46–60 (2010).
29. Kandjani, H., Tavana, M., Bernus, P., Nielsen, S.: Co-evolution Path Model (CePM): Sustaining enterprises as complex systems on the edge of chaos. Cybern. Syst. 45, 547–567 (2014).
30. Herrera, C., Thomas, A., Belmokhtar, S., Pannequin, R.: A viable system model for product-driven systems. In: Proceedings of the IESM. pp. 1–10 (2011).
31. Shaw, D.R., Snowdon, B., Holland, C.P., Kawalek, P., Warboys, B.: The viable systems model applied to a smart network: The case of the UK electricity market. J. Inf. Technol. 19, 270–280 (2004).
32. Hildbr, S., Bodhanya, S.: Guidance on applying the viable system model. Kybernetes. 44, 186–201 (2015).
33. Badri, A., Boudreau-trudel, B., Saâdeddine, A.: Occupational health and safety in the industry 4.0 era : A cause for major concern? Saf. Sci. 109, 403–411 (2018).
34. French, J.: Experiments in field settings. In: Festinger, L. and Katz, D. (eds.) Research methods in behavioral sciences. Dryden Press, 101 (1953).