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Product-Service Architecture (PSA): toward a Service Engineering perspective in Industry 4.0

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Abstract: Service Systems are characterized by its intense collaborative relation with the customer. In fact, the customer gives significant input also in the service providing process which anticipates the proper adaptation to a class of services - which normally appears in the design process as a *customer feedback*. That is a key issue to export the concept of service to other sector as manufacturing.

On the other hand, Cyber-Physical Systems (CPS) and Industry 4.0 extended the limits of conventional discrete manufacturing by improving discrete distribution of production components for one side and also improving collaboration between them - which also means intensify interaction. However, in spite of being an advanced concept, most implementations of CPSs are also attached to the idea of product or to a dynamic processes that can result in a product. That product-oriented approach is being questioned and new proposals emerged, based a manufacturing output that is a mix of products and services.

In this paper we revisited this new concept and propose an architecture that is an open and distributed product/service production arrangement, called PSA (Product/service architecture) relying on a cloud system of systems. This architecture could generate different manufacturing arrangements including several adaptations meant to fit a target product/service, not yet addressed by CPS manufacturing arrangement proposals. The architecture applies not just for IT infrastructure, but include hardware and human agents in order to organize product-services value units arranged to intensify the final interaction and product/service delivering.

In what follows we briefly present the Product-Service Architecture (PSA) and its basic structure, highlighting topics such as the theoretical support to derive manufacturing plans, that is, a dynamic production process over a base of manufacturing services. The focus in this short paper is towards a design discipline which points for a combination of AI methods (planning and scheduling) and a service interactive interface based on internet services, provided by a design framework called SoftDISS. The claim is that this new discipline would fit better the challenge of designing dynamic manufacturing process in Industry 4.0.

This is an on going research, and both PSA architecture and the design framework used to obtain the preliminary results shown in this paper are still in development.

Keywords: Service Engineering, System Design, Socio-technical system, Requirements analysis

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1. INTRODUCTION

Practitioners and researchers have been facing important challenges in terms of technological revolutions. In fact, smart robots and machines, Smart Factories, Big Data, virtual industrialization, Internet of Things (IoT), are creating new possible futures in terms of society (Blanchet et al., 2014; Hermann et al., 2015). A sort of fourth industrial revolution was launched introducing a whole set of new technological devices, processes and tools but not well integrated Wahlster (2012); Blanchet et al. (2014); Evans and Annunziata (2012).

Communication also played a key role and the model of virtual enterprise, depicted during 90's (Cunha et al., 2002) in Europe, was substituted by Virtual Manufacturing (VM) (Depince et al., 2004)(Bharath and Rajashekar, 2016) in the beginning of this century and finally to the current Industrial Internet (Evans and Annunziata, 2012). VM introduced the concept of simulation of the manufacturing process using special computational environments, but production design was still connected to "product" to which was added a business model(van der Aalst et al., 2003). Recent models of Industrial Internet (or Industry 4.0 a it was called in Europe) can finally integrate business and manufacturing process and express fully the concept of product/service, which implementation would be based on Cyber-physical Production Systems (Hermann et al., 2015; Brettel et al., 2014). In other words, a CPS is denoted by a proper system[1], self-contained, capable of intense

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[1] A proper system is formally defined as a dynamic discrete system having only one input and one output, that is supposed to be *alive*,

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interaction and communication between its components and with humans (Gorecky et al., 2014).

In terms of manufacturing industry service-dominant logic lead to the emergence of a formal approach in Service Engineering(Qiu, 2014), focusing on the adaptation of traditional engineering approaches to the service sector, called by some authors as a "servitization" process Schmenner (2009); Baines (2015). Today this term is also used to mean the mixed approach based on a mix of products and services.

PSA architecture PSA was proposed by Silva and Nof (2015) as a combination of a collaborative agent framework called e-work (Nof et al., 2015; Nof, 2013, 2006) and a service framework that congregates available and recent design methods and tools, called SoftDiss System [2] . It is an open and distributed architecture of product/service that support a cloud of service-product systems allowing for an adaptive plan to combine the systems into an arrangement that attends clients expectations.

PSA's perspective is attached to physical CPS agents to form a distributed architecture and derive a manufacturing service arrangement that is flexible and adaptive. In this paper we revisit the Product-Service Architecture (PSA) concept and presents its basic structure. A service design discipline is proposed to support PSA architecture modeling and design that could be applied to new manufacturing approaches.

2. INDUSTRY 4.0 AND CYBER-PHYSICAL SYSTEMS

New approaches to manufacturing was inserted into a general proposal called industry 4.0(Hermann et al., 2015), based on four components: Cyber-physical systems (CPS), Internet of Things (IoT), Internet of Services (IS) and Smart Factories (SF).

According to Hermann(Hermann et al., 2015):

> Within the modular structured Smart Factories of Industry 4.0, CPSs monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPSs communicate and cooperate with each other and with humans in real time. Via the IoS, both internal and cross-organizational services are offered and utilized by participants of the value chain.

We can also add that, in order to achieve a proper degree of flexibility, CPS should rely on a distributed architecture of autonomous and intelligent agents which compose the main production process. If the general components form an open set, where it is possible to include new elements or even eliminate (or do not use) some of them, we obtain a match between a CPS network and what we proposed a PSA architecture.

Therefore, in terms of Design process, the existing approaches (related to good-oriented logic) to the modeling and design of new manufacturing process - including VM - are not sufficient to cover the demand of integration between the manufacturing process and its (cloud) supporting abstract model neither between VM and it physical counterpart. If a Service Engineering approach is used instead, based on product-service sub-systems (agents) we could achieve a more promising approach and provide a method to fit the design of production in Industry 4.0.

There is an emerging demand for design methods and technological facility tools that offer a design discipline covering the whole process of development - starting from requirements - that could be applied to service/product production systems.

3. SERVICE ENGINEERING AND SERVICE SYSTEMS

Sakao et al. (2009), defines Service Engineering as follows:

> In (Service Engineer), however, not only the functions of artifacts but also the meaning of contents must be matched to the specifications given by receivers; only then will the satisfaction level of receivers increase. (...) The critical concept in (Service Engineer) is not the function of a product, but rather the state change of the receiver.

From a manufacturing viewpoint, Service Engineering is more concerned with engineering solutions and how they could satisfy customers needs, than with infrastructure to derive production processes to deliver this solutions. In fact, the detachment between (service/product) solution and the production process could be questioned(Silva, 2014).

Service Systems are defined as systems with an intense relationship (or collaboration) with the customer. That relationship can be translated to three main features: co-design, co-production and (value) co-creation(Dutra et al., 2014, 2013). In other words, the customer provides significant inputs to the design of the delivered product/service (co-design), to the production process itself (co-production) and, most important, to the generation of value created from the coupling between the delivered product/service solution and the customer(Vargo and Lusch, 2010; Maglio, 2009).

Therefore, manufacturing should now be understood as a distributed process that delivers a product/service, were production is a dynamic process that involves the perception and prediction of value created by the final coupling solution/customer. That prediction generates feedback (co-creation) of intentions that must be attended by a production process (co-production).

A full implementation of this process is under development and relies on cognitive systems and the use of AI techniques to come out with a perception model that provide the proper predictions and expectations of all players involved.

AI approach should be used in the process of prediction, in the current work we just concentrate in the architecture and on the "planning" (still an AI based process) of the production process.

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that is, there is at least one path through which the system can evolve from the input to its output.

[2] SoftDISS is an academic tool but is implemented in a commercial platform, the Enterprise Architect.

4. PSA ARCHITECTURE

In a previous work, Silva and Nof (2015) proposed a distributed architecture where a manufacturing service environment (MaSE) was defined as an open set of value production unities that, when partially ordered in a plan, could deliver products, services, or hybrid product/services. Those artifacts could be an independent outsourced production or a commercially connected one, belonging to a corporate business.

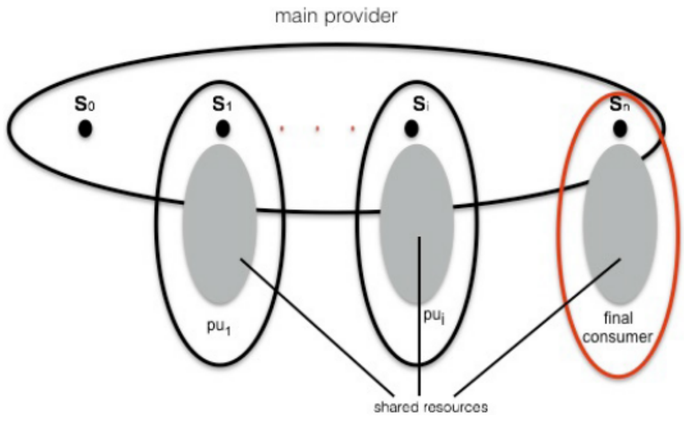
A MaSE give rise to an architecture that emerge from the combination collaborative e-work between product units (Nof et al., 2015), where other products (besides the final solution delivered), services, product/services and resources are shared.

The basic element of PSA is the production unit (*pu*), which are different from a classic production unit in the sense it is not just specialized on a sequence of tasks that transforms input material into a target product output. Eventually this *pu* could have only people or just machines or any combination of those.

Suppose now that there is a general (finite) production process that interacts in a specific moment with one or more *pu*'s, and that in the final state delivers a new product, a service or a product/server. We would call this process a service provider and the generic *pu*'s, its components, sub-services. Once the final consumer is identified, it is possible to plan the pu's arrangements, actions, inputs and outputs to deliver the proper product/service. Therefore, the service provider has also the need to have a final state that ensures value co-creation offering a service, a product or a product/service.

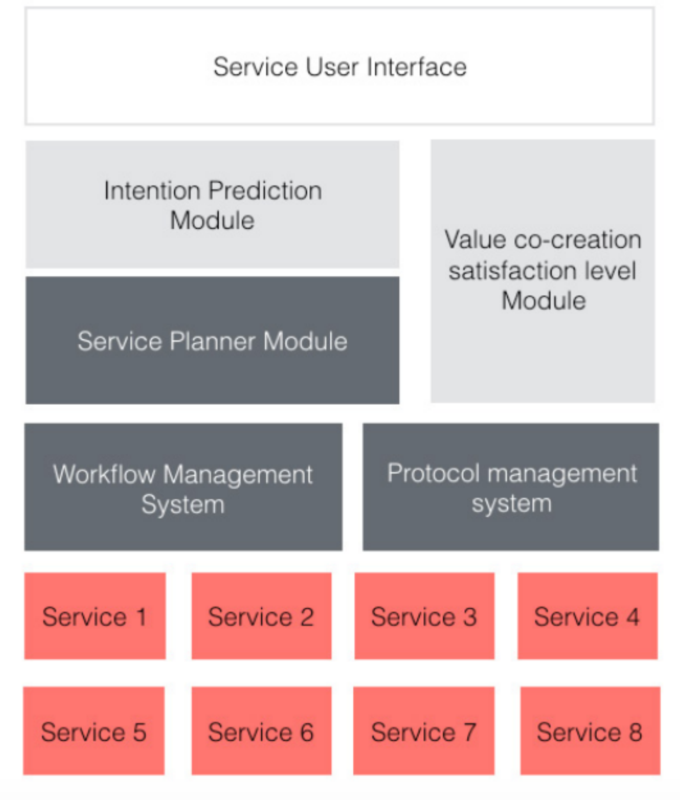
Comparing with the basic consumer-provider interaction proposed in Qiu (2014) (chapter 1, pg. 3) we provide an extended relationship between a PSA arrangement and a final consumer as depicted in Fig. 1. This figure shows how a PSA architecture can couple with a final user to provide product/service also interacting and sharing its resources.

Fig. 1. Interaction between a PSA provider and a final consumer



In fact, the architecture proposes a service model of agents which can be attached to physical CPS agents. Those CPS agents could be arranged in an adaptive planing to offer a final product/service that meets client's expectations.

Fig. 2. Product-Service Architecture



The PSA representation in Fig.2 is denoted by a cloud of production unities (red boxes in the bottom of the picture) that will form a production arrangement and could provide a product/service deliver - to the costumer - following a a planned workflow defined by the main service provider. Such workflow also defines resource sharing and the exchange of information between sub-services, or a combination of them up to the final consumer delivering. Production actions are partially ordered (planned) or follow a time schedule to provide the deliverable product/service. Communication between elements should be managed by the Protocol Management System. Actions and sub-services calling are arranged by the Service Planner Module, which can also decide about message sending or broadcasting.

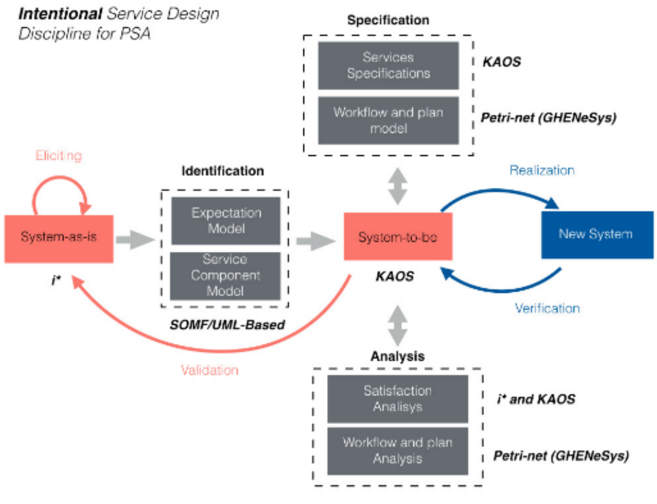
However, to reach the intended value co-creation it is necessary to predict costumer satisfaction derived from the co-created value. An interface that capture some client inputs and predicts clients intentions. As the plan is executed, a satisfaction module should measure or anticipate clients reaction and adapt the plan if value co-creation do not reach the required level. This feature, called value co-creation supervisor is a key issue in modern manufacturing architecture, and its verification follows the same approach used in a post-design proposal for artificial intelligence planning. This model is being adapted from a previous proposal for some of the authors(Vaquero et al., 2013).

As mentioned before the success of the proper and selection of *pus* the construction of the right arrangement and production plan - and identification of costumer intentions, not included in the present work - depends on the elicitation of the proper requirements from stakeholder and costumers. This process is done by using Goal Oriented Requirements Engineering (GORE), where user intentions are treated in a natural way. Next section will show briefly how to relate this early phase with PSA, including all these phases in a unique design discipline.

5. SERVICE DESIGN DISCIPLINE FOR PSA

A Service Design Discipline for PSA is a sequence of design steps starting with the modeling of the System-as-is, that is, integrating all previous knowledge about the production system. Based on this model, intentions and expectations about a prospective System-to-be with will be added using a goal oriented requirements approach. Fig. 3 depicts the main steps of the process.

Fig. 3. Service Design Discipline

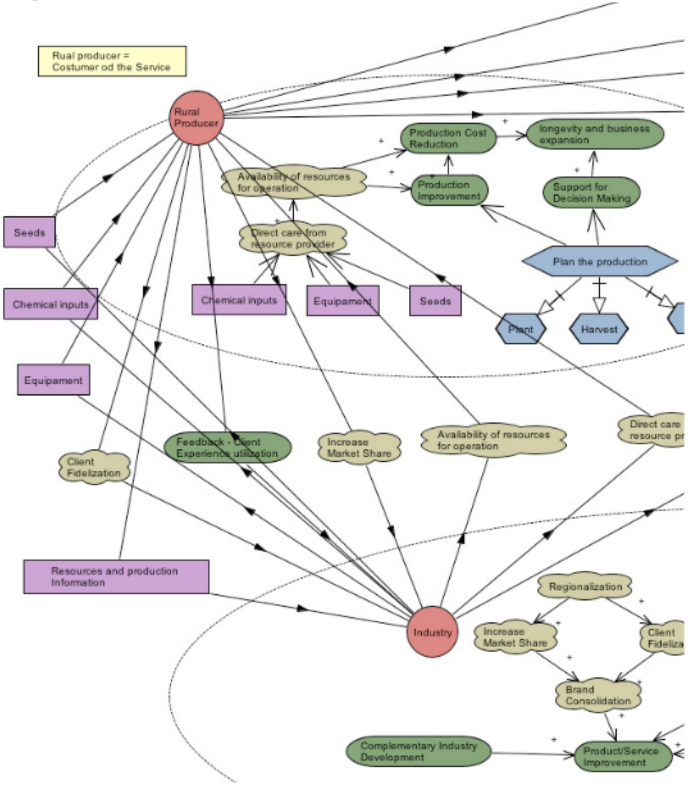


A key issue in the service design discipline is the eliciting of the intentions and expectations of the final costumer which will be based on a intentional models using i* (Yu, 2001). Expectations would be used in another goal oriented representation: KAOS (Keep All Objects Satisfied)(Lamsweerde, 2009). KAOS diagrams will be automatically transformed in a Petri Net(Silva and Silva, 2015) where requirements could be analyzed and validated to start the modeling of the production process. Models resulting from this approach will be the basic input for the prediction, adaptation and satisfaction measurement modules of PSA.

To help in the process of extracting stakeholders expectations of the system-to-be the framework SoftDISS was used. SoftDISS is a framework developed inside the package Enterprise Architect to design services in general(Dutra et al., 2014) and acts as a software support to design services.

Preliminary results were obtained using different tools, but the development of a unified software tool to implement the discipline would be done in further steps. For the present work we select a case study about the potential introduction of services and PSA in agribusiness. In this case, the production and costumer relation would be distributed to better attend rural producers.

Fig. 4. Intentional model



Each requirement block were converted into an i* Early Requirement's model, supported by TAOM4E tool (an i* modeling tool) 4. The expectation identification phase transform i* goal statements into expectations statements on a Requirement Model in SoftDISS. Those expectations were analyzed an decomposed into sub-expectations reaching a more detailed expectation composition.

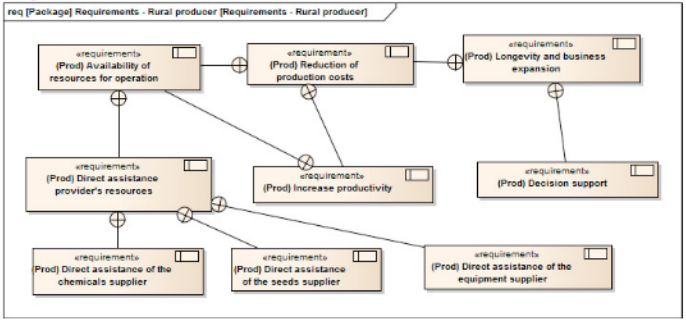
A set of expectations can form a viewpoint once all requirements in this set is associated with the same agent. A viewpoint can be linked to a stakeholder's (agent) expectation and to the correspondent i* model and can also be classified according to some design objective - included in KAOS model - such as a set of security expectations.

Fig. 5 shows an illustrative example with the representation of viewpoints from rural producers in the design of agriservices, using SoftDIss (Oliveira and Silva, 2015).

In the next phase, after the service identification phase, different service possibilities were listed on a service model frame in SoftDISS. Through a matching process, services were linked to requirements and expectations aiming to get the simplest service model matching the requirement model.

Using SoftDISS' for service identification we found - for the same agriservice application - the best service to fit the demand (or at least the one that better fit all viewpoints and achieve highest costumer satisfaction). Actually, the producer wants to have a service that make available au-

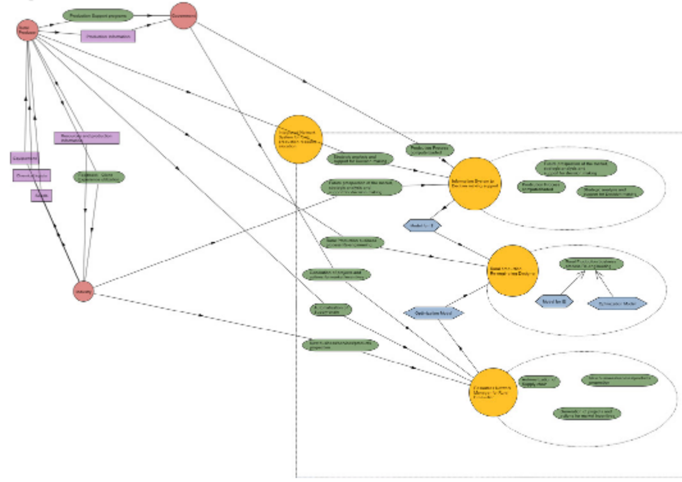
Fig. 5. Requirements Model in SoftDiss



tomated machines instead of purchasing it. Manufacturers would have to adapt their business, participating in a collaborative network to offer machines for a short amount of time. In this example, production could be planned and modeled as a real-time system to maximize profit using a distributed network of agricultural services.

After identifying services and how it would be traced to agents, the design discipline recommend to build an objective model of requirements using KAOS (see Fig.6) which advances one step towards the formal specification of the System-to-be.

Fig. 6. KAOS Model



This process sets off the next phase of the discipline, the specification phase, which will be detailed on a future work. Internal agents and sub-services are conceived according to the possibilities and boundaries of the context. Following the specification phase, from KAOS, a mapping process to petri-nets is conceived using GHENesys(Silva and Nof, 2015) Petri Nets environment. Validated specification of the production can be submitted to the software itSimple(Vaquero et al., 2013), which can deliver a production arrangement plan. Petri net representation can also be used in the analysis phase to consolidate the system-to-be Salmon et al. (2011, 20014).

Volatile requirements and software maintenance could be done just positioning the current system-to-be as a new system-as-is, using the symmetry of the proposed design discipline.

The final phases of the design discipline involve realization and verification of services measuring and comparing costumer satisfaction and the matching with the system-to-be specifications. The new service system can be a piece of software, a cyber-physical systems, or a combination of both also including human agents. Each service package remains on a library in PSA format, consolidating a cloud of manufacturing services. In the case study a cloud of services that can make automated projects to agribusiness, select the proper machine and have it available at the proper time.

The planner and workflow module, organize production units to start execution. Once the service is implemented user expectations-satisfaction's measure is performed, by the satisfaction module. The execution of the *production plan* can be interrupted if an expected satisfaction is not achieved.

Therefore with PSA is possible to make the design of a production system-of-systems based on a collaborative e-work of sub-services (or cyber-pysical systems) that could be combined to fit intentions belonging to viewpoints derived from all player in the service network and also to check the convergence to a main production process that deliver product/service to the final costumer.

6. CONCLUSION

Industry 4.0 and Cyber-Physical Systems points to new new production arrangements where the same distributed architecture can be instantiated either to a system of indoor systems, belonging to the same business corporation up to an open completely outsourced arrangements, including several levels in between. Independently of the point we choose on this production arrangement scale, the flexibility of the architecture would allow a multitude of different solutions raising the need to treat more formally the design of such production systems, specially in what concerns the early requirement phase. Production processes, would now be based on production units that are at the same time independent, collaborative, and capable of intense communication. Also, the arrangement should be rapidly tested and engaged in a production arrangement, which fits with an open architecture. This new concept will be constructed base on services or a hybrid of product and services, following a new paradigm. Thus, Service Design and its derived methods should be used to approach this problem.

That was exactly the proposal presented in this paper: a new approach based on Service Design - even if the final delivering also use products and resources - to fit the generic architecture we call PSA.

PSA proposes a distributed architecture to product/service production arrangement based on a cloud system of systems. For these characteristics, this architecture could be a formal base to generate different manufacturing arrangements including several adaptations meant to fit a target product/service. As the CPS is a proper system, self-contained with a great capacity of communication, it could fit well as an element of this cloud element of manufacturing systems on PSA.

PSA architecture and the proposed design discipline are still in development, However, these join proposal is already present in a realistic case study were we analyze the reconfiguration of an important shoes manufacturer using a distributed and partially outsourced set of production units. Another application is related to a general process of low voltage energy distribution in being prepared as well as another case where the general provider is related to the automotive industry. This practical examples would give more confidence in the proposal while we develop further the theoretical aspects and tools that would give a clear vision of the architecture.

REFERENCES

Baines, T. (2015). Exploring Service Innovation and the Servitization of the Manufacturing Firm. *Research-Technology Management*, 58(5), 9–11.

Bharath, V. and Rajashekar, P. (2016). Virtual Manufaturing: A Review. *Int. Journal of Eng. Research & Technology.*

Blanchet, M., Rinn, T., Von Thaden, G., and Georges, D.T. (2014). Industry 4.0 The new industrial revolution How Europe will succeed. Technical report, Roland Berger Strategy Consultants. doi:10.1007/s00287-014-0809-1.

Brettel, M., Fridesrichen, N., Keller, M., and Rosenberg, M. (2014). How Virtualization, Descentralization and Netwok Building Change the Manufacturing Landscape: An Industry 4.0 Perspective. *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering*, 8(1), 37–44.

Cunha, M.M., Putnik, G., Carvalho, J., and Avila, P. (2002). A review on environments supporting virtual enterprise integration. In V. Marik and H.A. L.M. Camarinha-Matos (eds.), *Knowledge and Technology Integration in Production and Service*, chapter 14, 133–140. Springer, New York.

Depince, P., Chablat, D., and Woelk, P. (2004). Virtual Manufacturing: Tools for Improving Design and Produtivity. In *Proceedings of 14th. CIRP Design Seminar.*

Dutra, D., de Oliveira, V.C., and Silva, J.R. (2013). Manufacturing as Service : the challenge of Intelligent Manufacturing. In *11th IFAC Workshop on Intelligent Manufacturing Systems (IMS13)*, 7–15. São Paulo, SP, Brasil.

Dutra, D., Oliveira, V., and reinaldo Silva, J. (2014). A Service-oriented Approach to Technology Based Industry. In *IEEE Congress on Industrial Informatics.* Porto Alegre, Brazil.

Evans, P.C. and Annunziata, M. (2012). Industrial Internet: Pushing the Boundaries of Minds and Machines. *General Electric*, 37.

Gorecky, D., Schmitt, M., Loskyll, M., and Zuhlke, D. (2014). Human-machine-interaction in the industry 4.0 era. *Proceedings - 2014 12th IEEE International Conference on Industrial Informatics, INDIN 2014*, 289–294. doi:10.1109/INDIN.2014.6945523.

Hermann, M., Pentek, T., and Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios: A Literature Review. doi:10.1109/HICSS.2016.488.

Lamsweerde, A. (2009). *Requirements Engineering: From systems goals to UML models to Software Specifications.* Wiley.

Maglio, P.P. (2009). Toward a Science of Service Systems.

Nof, S.Y. (2006). Robotics, Agents, and e-Work: The Emerging Future Of Production. doi:10.1016/B978-008044654-7/50139-4.

Nof, S.Y., Ceroni, J., Jeong, W., and Moghaddam, M. (2015). *Revolutionizing Collaboration through e-Work, e-Business, and e-Service.* Springer Heidelberg New York Dordrencht London, New York, New York, USA, 2nd edition.

Nof, S. (2013). Research Advances in Manufacturing with Service-Oriented E-Work and Production.

Oliveira, V. and Silva, J. (2015). A Service-oriented Framework to the Design of Information Systems Service. *Journal of Service Science Research*, 7(2), 55–96.

Qiu, R.G. (2014). *Service Science: The Foundations of Service Engineering and Management.* John Wiley & Sons.

Sakao, T., Shimomura, Y., Sundin, E., and Comstock, M. (2009). Modeling design objects in CAD system for Service/Product Engineering. *Computer Aided Design*, 41(3), 197–213. doi:10.1016/j.cad.2008.06.006.

Salmon, A., Miralles, J., del Foyo, P., and Silva, R. (2011). Towards a Unified View of Modeling and Design with GHENeSys. *21st International Congress of Mechanical Engineering.*

Salmon, A.O., del Foyo, P.M., and Silva, J.R. (20014). Scheduling Real-Time Systems with Periodic Tasks Using a Model-checking Approach. *Proc. of IEEE-INDIN.*

Schmenner, R.W. (2009). Manufacturing, service, and their integration: some history and theory. *International Journal of Operations & Production Management*, 29(5), 431–443.

Silva, J.M. and Silva, J.R. (2015). Combining KAOS and GHENeSys in the requirement and analysis of service manufacturing. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, 48(3), 1634–1639. doi: 10.1016/j.ifacol.2015.06.320.

Silva, J.R. (2014). New Trends in Manufacturing : Converging to Service and Intelligent Systems. In *IFAC World Congress 2014.* Elsevier, Cape Town, South Africa.

Silva, J.R. and Nof, S.Y. (2015). Manufacturing service: From e-work and service-oriented approach towards a product-service architecture. *IFAC Proceedings Volumes (IFAC-PapersOnline)*, 48(3), 1628–1633. doi: 10.1016/j.ifacol.2015.06.319.

van der Aalst, W., ter Hofstede, A., and Weske, M. (2003). Business Process Management: A Survey. In W. van der Aalst, A. ter Hofstede, and M. Weske (eds.), *Business Process Management*, 1–12. Springer, Berlin.

Vaquero, T., Silva, J., and Beck, J. (2013). Post-design analysis for building and refining AI planning systems. *Engineering Applications of Artificial Intelligence*, 26(8), 1967–1979. doi:10.1016/j.engappai.2013.04.006.

Vargo, S.L. and Lusch, R.F. (2010). Advancing Service Science with Service-Dominant Logic. In P. Maglio, C. Kieliszewski, and J. Spohrer (eds.), *Handbook of service science.* New York.

Wahlster, W. (2012). Industry 4.0: From Smart Factories to Smart Products.

Yu, E. (2001). Agent orientation as a modelling paradigm. *Wirtschaftsinformatik*, 43(April), 123–132.