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Procedia CIRP 00 (2016) 000–000
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Product-Service Systems across Life Cycle

Towards a Reference Procedure for Designing and Modelling a PSS in the Automotive Industry

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Abstract

Nowadays, PSS lifecycle models are a crucial issue. The management of both the product and the service lifecycle together is recent: to date, there is no evidence of an accepted and operational combined lifecycle model. Furthermore, PSS lifecycle models are based on top-down approach, which are not always suitable from an engineering point of view. The aim of this paper is to propose a reference procedure, built on a bottom-up methodology, for the designing and modeling of PSSs and its lifecycles, applied to the automotive sector.

Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle.

Keywords: product-service systems; PSS; bottom-up methodology; reference procedure; design and modeling; automotive industry.

1. Introduction

The Manutelligence project [1] aims to develop sustainable innovative Product-Service Systems (PSS) efficiently addressing customer needs. The main objectives of the projects are:

(i) To create a cross-disciplinary collaborative management environment for Product-Service engineering, able to increase the efficiency in the design process, with a potential for wide market adoption;

(ii) To support completely product lifecycle and service lifecycle, using methodologies and tools to support cross development;

(iii) To develop a platform for Product-Service Design and Manufacturing Intelligence;

(iv) To involve all the key partakers in the value chain, including customers;

(v) To extend and improve the use of simulation and optimize it through use of field data;

(vi) To improve precise and quick measures and simulations of cost and Sustainability issues, through Life Cycle Cost (LCC), Life Cycle Analysis (LCA) and CO2 footprint.

One of the key innovation point is reached providing a lifecycle transversal infrastructure, able to provide to the different involved actors (designers, engineers, manufacturing managers, testing, maintenance, users and service team, represented in the bottom part of the picture) a coherent, secure and content driven access to information. Furthermore, one of the objective is to integrate completely the product life cycle and the service life cycle, using methodologies and tools to support cross development. The management of both the product and the service life cycle together is recent: to date, there is no evidence of an accepted and operational combined life cycle model. Furthermore, PSS life cycle models are based on top-down approach, which are not always suitable from an engineering point of view. Thus, a reference model that describes PSS in a structured and complete manner is still lacking. The aim of this paper is to a reference procedure for the description and creation of PSSs and its lifecycles within the automotive sector. Section 2 presents an overview about PSS and lifecycle, highlighting the lacks, while section 3 presents the PSS in the automotive sector. Section 4 shows the application of the bottom-up methodology and the selection of the common language. Section 5 presents the reference procedure, while Section 6 concerns the application of the

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Peer-review under responsibility of the scientific committee of the 8th Product-Service Systems across Life Cycle.

procedure to a real case. Finally, Section 7 shows remarks of the procedure.

2. State of the art

The aim of the state of the art of this paper is to understand how academics faced the PSS life cycle. Thus, product lifecycle, service lifecycle and product-service lifecycle models have been analyzed. Life cycle models are a way to describe, in a simplified way, important steps a product or service has to pass while it exists. From an engineering perspective, lifecycle models provide system boundaries for management tasks. In particular, a life cycle can be defined as consecutive and interlinked stages of a product or service system, from raw material acquisition or analysis of customer requirements to the final disposal.

Concerning product lifecycle models, generally it starts from the first idea and concept and ends with recycling and disposal phases [2]. In literature there are many product lifecycle models; however, the majority is based on the three main life cycle phases, Beginning of Life – design and manufacturing of the product, Middle of Life – use of the product, and End of Life – disposal or recycling of the product. The majority of models include processes, while only few include processes and stakeholders. Concerning the geometry of the lifecycle models, the majority of the models are a linear type not featuring closed-loop characteristics. Circular models contain different feedback flows or directly arrange processes/stakeholders in a circular way to indicate that the product and its components circulate.

Concerning service lifecycle models and product-service lifecycle models, they are still quite unexplored, compared to product lifecycle ones. The research conducted by [3] has been taken into account, due to it presents an extensive and complete list of phases along the life cycle, which has been elicited by merging different models proposals.

The most relevant phases investigated by these models are mainly related to the Beginning of Life, with a great emphasis on all the requirement activities. Phases, such as Use, Maintenance and End of Life, have been considered only by recent publications, showing their increasing relevance in the development process [4, 5, and 6]. An important observation is that activities related to the end of life are not or only briefly covered by the majority of the process models, especially monitoring and evaluation is barely considered.

In literature, there is evidence of PSS life cycle models, even if they are very rare and not actually adopted or considered as a reference. For instance, [7] proposed a PSS life cycle model, which is a very complex model, as it was aggregated with the goal of getting an appropriate basis for further analyses concerning a life cycle, oriented planning of PSS.

The analysis conducted points out that there is a lack in the product-service lifecycle modelling studies. From a modelling point of view, the product side had been widely investigated, while there is not such a deep and complete understanding of the service side. This also leads to a lack in modelling a combined lifecycle.

More precisely, it has been argued that a "reference" product-service lifecycle model, within the scientific or the industry community, does not exist yet.

3. PSS in the automotive industry

The automotive industry is one of the world's most important economic sectors by revenue and it is a very dynamic environment: technologies are continuously shaping and challenging the firms within the market. Furthermore, to revolutionize the automotive industry and to achieve challenging goals, the Product-service system business model offers an interesting perspective.

In order to investigate the industry from a PSS point of view, a survey on the services that carmakers are currently offering has been conducted. Furthermore, different types of PSS in the automotive sector have been identified, analyzing the literature. PSS is a fundamental shift in the relationship between the producers and the consumers of a product or service, which is no more depicted as a "traditional" form of sale ownership, consumption and disposal of products. PSS concept, instead, focuses on the delivery of a "function" to the customer that might mean the provision of combinations of products and services that are capable of ‘‘jointly fulfilling users needs’’ [8].

In literature, [8] identifies different types of PSS in the automotive sector. First, the so called product-oriented services: (i) product related services, in which products or services needed are sold during the use phase, such as extended warranties on new cars; (ii) advice and consultancy, in which providers give advice to use the product in an efficient way, such as provision of energy-efficiency information.

Second, the so called use-oriented services: (i) car leasing, (ii) car sharing, and (iii) carpooling.

Third, the so called result-oriented services: (i) activity management/outsourcing, in which providers charge a third party to outsource part of the process, such as car parts outsourcing; (ii) pay per service unit, in which users buy outputs of product according to level of use, such as cars "pay per Km"; and (iii) functional result, in which providers and users agree on an end result, such as integrated mobility.

The survey has been conducted on premium sector, due to unique characteristics of services offered by this kind of carmakers, which cannot be found in the big and mainstream companies. Customers of these cars do not want only a mere system of transport, but they want an outstanding experience of driving and the offering of exclusive services contribute in achieving this need.

Analyzing services offered by different premium sector carmakers, they provide services such as car configurator, dealer locator, and test drive, which are provided also by general brands.

Furthermore, premium sector carmakers offers more added value services, such as: (i) genuine parts, in which customer can customize his product with many different accessories, in order to build his unique sport/premium car; (ii) service program, in which the vehicle will be subject to regular inspections by the mother company trained personnel using factory-approved dedicated diagnostic equipment, in order to maintain the car originality and value; (iii) driving experience, in which customers can attend driving courses in order to improve their driving ability; (iv) owners club, in order to join exclusive clubs, numerous events, track days, gala dinners, brand meeting, etc.

Lastly, even if it does not perfectly fit with the service definition, marketing is consider as service as well. Indeed, it can be considered as a way through which companies earn extra incomes using their brands to sell products, not, or low related with the car. It is not a service that directly enhances the car value. However, considering the premium sector, this practice represents a remarkable share of the companies' profits, thus marketing can be considered as service.

4. The bottom up methodology

Summarizing section 2, PSS models are very different and present various shapes and steps. They are mostly created trying to be as general as possible, covering a wide range of different industries and sectors, and they are using a top-down approach. A top-down approach tries to get the big picture of a system, specifying but not detailing any subsystems that create the upper one; each subsystem can then be more detailed until the entire specification is reduced to base elements.

Considering, for instance, the model proposed by [7] some questions like the following arose: (i) How does each specific phase work internally? (ii) Which stakeholders are involved? In which phase are they involved? How are they related to each other? (iii) How does the communication work? (iv) Are there information or material flows? How are they connected to each phase? (v) If a company wants to create a product-service system, how does it approach using the models analyzed in the state of the art?

From an engineering point of view, the models discussed in literature are more guidelines to be followed or steps to go through, rather than actual usable modelling tools. They can be considered as a checklist that draws attention to what activities have to be done. These models are not properly engineering models, namely they do not give indications on manner to use in performing an activity, and thus it seems that they are not really "operational". The mentioned issues are especially problematic from the PSS point of view as it is usually a very complex matter and there are many elements involved in these systems. Therefore, to have a useful and operational tool it is necessary to model all these elements and all the relationships between them.

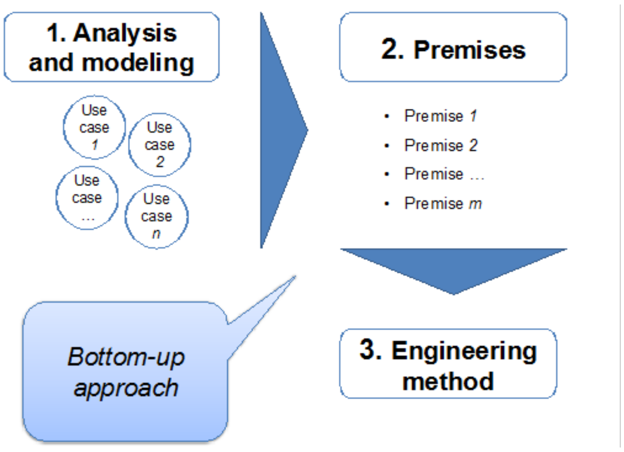

Fig. 1. The bottom-up approach

Since lifecycle models approach (top-down approach) is not always suitable from an engineering point of view, a bottom-up approach is proposed. This approach begins at a low level and proceeds to grow upwards, combining the basic subsystems together. Fig. 1 shows the bottom up approach scheme.

The result of this approach applied in the PSS context should be a formal method to describe assets, activities and relations along the lifecycle.

Starting with the analysis and modelling of a several numbers of use cases, the approach goes on with the premises deduction and ends with the development of a formal engineering method that allows describing and creating a PSS and its life cycle.

In this work, the first step is the analysis and the modelling of a use case in the automotive industry to start finding out some premises towards an Engineering method. Further steps will be to model other use cases from the same sector, finding out more premises to build the method and finally scaling up applying the same methodology in other sectors.

In order to describe every single use case in the same way, where everyone is able to understand all the models and then to create his own one, a common language is needed.

This work is meant to be the first step towards a reference model of PSS lifecycle engineering. In order to create a solid and widespread basis a common language is needed. The language is the vehicle through which it will be possible to describe every single use case in the same way. Everyone will be able to understand all the models and then to create his own one. It is the foundation of the project. For this reason the choice of the best and most suitable language is an essential decision.

In this work Lifecycle Modeling Language (LML) [9], IDEF0 and the Service Blueprinting have been compared. In detail, LML language is an open-standard modelling language designed with a systems engineering approach, based on UML language.

The three different languages have been tested and compared on a simple case, based on car maintenance. At the end of this comparison, the perspectives and the user features and modelling capabilities of the languages have been overviewed.

Concerning the perspectives, the proposal of [10] of four common perspectives in modelling business process is followed. The authors identified four main perspectives: (i) functional perspective, where a model represent which process elements are performed; (ii) behavioral perspective, where a model represents when process elements are allocated (for instance sequencing), and how related actions are performed; (iii) organizational perspective, where a model represents where and by whom in the organization process elements are performed; (iv) informational perspective, where a model represents the informational entities produced by a process, such as data, documents, etc.

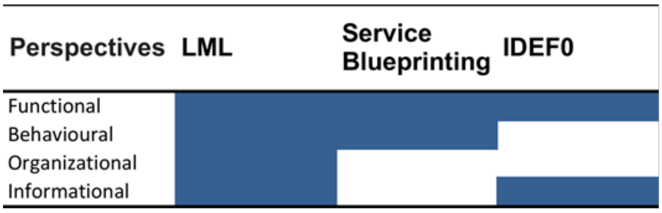

Fig. 2. Languages perspectives

These four modelling perspectives cover the essence of business processes, such as what, when, where and by whom the process elements are performed and how related actions are executed. The three languages have been analyzed through this perspective, and results are reported in Fig. 2.

LML seems to be the most complete modelling language, according to the classification proposed by Curtis et al. [10]. It covers all the four perspectives as it answer to the questions "what", "when", "where and by whom the process elements are performed" and "how related actions are executed".
Service Blueprinting works well especially on the functional and behavioral perspectives, while IDEF0 is targeted mostly toward the functional modelling perspective.
Concerning features and capabilities, LML offers more opportunities, even if it is not completely user friendly or ease to model. More information are reported in the Fig. 3.

5. The reference procedure

The process of selecting the right technique and the right tool to model a life cycle has become more and more complex not only because of the number of approaches available, but also due to the lack of a guide that explains and describes the concepts involved [11].

Having a reference modelling procedure is necessary in designing the sequence of forming and elaborating components of a target process. Following the bottom-up approach presented above, a simple/basic case has been modeled, using three different methods (LML, Service Blueprinting and IDEF0) to compare them and choose the most suitable one for a PSS. After a series of analysis, LML proved to be the best one for our purposes. Thus, considering the state of the art, the automotive sector, the bottom-up methodology and the Lifecycle Modeling Language, all the elements to propose a reference procedure for designing and modelling a PSS in the automotive industry are available.

The procedure is a sequence of steps to go through while modelling a PSS life cycle with the LML.

The procedure developed is composed of 4 main phases: (i) Phase zero – identification of company's purposes, (ii) Preliminary phase – PSS identification, (iii) Mapping phase – modelling the single Product-Service System, (iv) Validation phase – accuracy verification.

First, the phase zero enables the identification of company's purposes (e.g. to design a new PSS, to manage an existent PSS, etc.). The following step is the preliminary phase, where the user work within the PSS life cycle environment. This phase prepares for the process of mapping the PSS. It also gives the user the big picture on the PSS he/she is working on. In this phase: (i) the reference industry is identified; (ii) the target of PSS is selected; (iii) all the PSS elements are identified and analyzed; (iv) the system boundaries are defined; (v) product and service components are analyzed; (vi) PSS life cycle is characterized.

In the following phase, the user maps and models the PSS, identifying the logic flow and the information and physical flow. The last phase concerns the validation of the model and the verification of its accuracy. In particular, the semantic and the syntactic accuracy of the model are verified. Concerning the semantic accuracy, the model should be meaningful and significant, and it should clearly represent the PSS life cycle and be as comprehensible to everyone as possible (without losing its accuracy). Concerning the syntactic accuracy, the model has to respect the set of rules, principles, and processes that govern the structure of the chosen language.

	Characteristic	LML	Service Blueprinting	IDEF0
User features	User friendly	Average	Yes	Yes
	Special features	Possibility to represent a lot of different entities in the spider diagram	Customers journey	Different levels of detail (A-0, A0, A1,...)
Modelling capabilities	Goal centered	Yes	Not clear	Yes
	Roles	Yes	Only the customer's	Not clear
	Front-end analysis	Yes	No	No
	Ease of modelling	Average - it is not always easy to understand which entity and relationship is the most suitable to model the reality	Very good	Good
	Level of detail	The more in detail the model goes, the more complicated the model gets	The more in detail the model goes, the more complicated the model gets	In general as good as the user wants. Good for inputs-outputs
	Object-orientation	Yes	No	Yes
	Customisation of blocks	No	Yes	No
	Time	Yes	Only sequencing	No
	Cost	Yes	No	No
	Discrete event modelling	Yes	No	Yes

Fig. 3. Features and capabilities

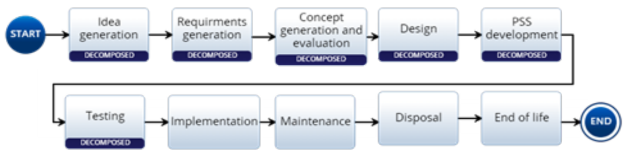

Fig. 4. LML language applied to reference case

6. Reference case and preliminary results

The procedure presented in the previous paper has been tested on a reference case. An Italian company that engineers and produces luxury and high performance cars has provided the case, within the Manutelligence project. The PSS analyzed is basically composed by the pleasure of riding a car and the thrill of drive that the car can provide. It is not a simple test drive, but it consists in a two years project in which the most loyal customers of the brand have the opportunity to take part in dedicated and exclusive race sessions. During these events, the client has the opportunity to drive a limited edition of a car. Unfettered by homologation and racing regulations, the car will never be used in official competitions apart from the programme. It is, indeed, developed to be completely uncompromising, incorporating technological innovations that

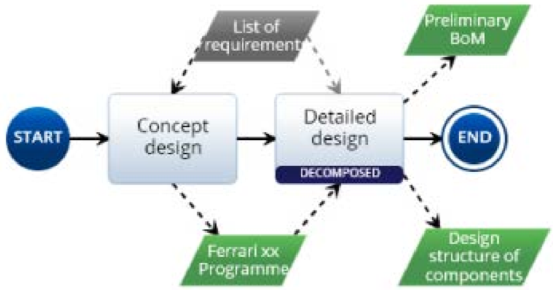

Fig. 5. LML language –design phase

will guarantee an unprecedented driving experience to the exclusive of selected clients. The company offers to them a team of experienced technicians to manage every mechanical request and dedicated driving courses are provided. During the sessions, the accommodations are represented by the most luxurious hotels on earth. The same goes for the catering and the entertainment features.

Following the previous procedure, it is possible to map in a simple way this PSS. Starting from the company purpose, different objectives have been identified:

- To achieve a large integration between the working groups in order to reduce the number of loops
- To achieve the project objectives with less time in order to offer a product-service at low costs and high quality
- To reduce largely the prototypes and design faults mainly on the customer side
- To define and implement a virtual and physical design validation supported by the platform, considering retrieving data from field from the early prototype to the final product the possibility.

Continuing with the PSS identification, it involves the following elements:

- Car: it is a limited edition super car; it is developed to be completely uncompromising, incorporating technological innovations that guarantee an unprecedented driving experience to the exclusive of selected clients.
- Dedicated driving courses during the events: the clients have the possibility to enhance their driving abilities thanks to the presence of professional driving instructors during the events.
- Most luxurious accommodation solutions: during the events, the clients stay at the best hotels that can be booked in the surrounding areas of the tracks.
- Outstanding catering service: the best and most remarkable catering companies provide all the meals offered in the sessions.
- Tailored mechanical support: the car and the driver, during the sessions, receive technical support by experienced technicians from Ferrari, in order to figure out every request or issue connected with the car.
- Real-time data monitoring: the car is provided by sensors to capture any performance and technical data. These data can be analyzed by the client and also by the company to improve potential car weaknesses.

Concerning the boundaries, they are very extended towards the customer side. The heart of the PSS is to let the client experience the “thrill of driving” a super car. For this reason, customers have to be deeply involved in the development of the project starting from the car production.

Within this PSS, the product part is represented by the car, whereas all the other elements, like the technicians or the catering, are services.

After the PSS identification, it is possible to maps the PSS, using the LML. Fig. 4 shows only the macro-activities, while Fig. 5 and 6 show some of the phases (Fig. 5 the design phase, Fig. 6 the PSS development)

Finally, the validation phase has not been performed yet, because the project is going on.

7. Conclusions

The aim of this paper is to a reference procedure for the description and creation of PSSs and its lifecycles within the automotive sector. Section 2 introduces the state of the art concerning product lifecycle, service lifecycle and product-service lifecycle models, identifying lacks. The main lack is that a “reference” product-service lifecycle model, within the

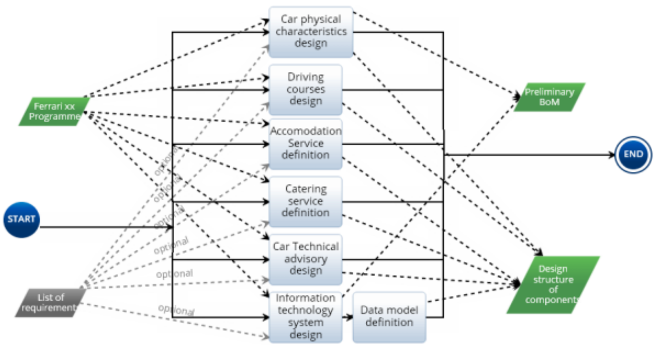

Fig. 6. LML language – PSS development

scientific or the industry community, does not exist yet. Section 3, instead, identifies the PSS in the automotive sector. Section 4 aim is to cover the lack identifying, proposing a bottom-up methodology, instead of the more used top-down approach. In particular, a common language to model different PSSs within the automotive sector has been identified in the LML language. Finally, Section 5 presents the reference procedures, while Section 6 shows a first application of the procedure within a company that engineers and produces luxury and high performance cars.

One of the result achieved is the reference procedure and its application on a real use case; indeed, the procedure for designing and modelling a PSS life cycle in the automotive industry is defined. Starting from the state of the art, the automotive sector analysis, the bottom-up methodology and the Lifecycle Modeling Language, all the elements to propose a reference model are found.

Furthermore, the bottom-up approach has been used, in order to fill the main lack identified in literature concerning PSS lifecycle models.

A first step towards a reference model of PSS lifecycle engineering has been moved identifying a common language, the LML, in order to create a solid and widespread basis.

The main benefit provided by this research is an engineering procedure, instead of a guideline procedure, giving an answer to questions reported in Section 4. Furthermore, it is possible to save time for mapping PSS; indeed, the model allows a company to reduce the time needed to turn an idea into a final product. Moreover, it helps in being quicker to integrate new technical solutions into products and be first to market. These time reductions derives from the effort that the company make in modelling its PSSs.

The main criticism is the limitation to the automotive industry; indeed, a non-conventional approach has been implemented, thus it is not possible to assure that the same is applicable in other industries rather than the automotive one. Furthermore, the procedure has not to be considered definitive, because it is a work in progress that should be integrated and completed every time with new information or with insights come from the modelling of other use cases. Moreover, LML presents two limitations: one concerns the difficulty to implement a loop circle with a logic connector, the other one concerns the management of the relationships between asset and resources.

Further researches will compare more languages or methods to model lifecycles, in order to strength the LML proficiency. Furthermore, it will complete the work-in-progress procedure, modeling more use cases. Even if the structure might remain the same, some steps should be reconsidered in case new modelling issues may come up. Finally, the procedure will be extended to more industries.

Acknowledgements

This work was partly funded by the European Commission through Manutelligence (GA_636951) Project. The authors wish to acknowledge their gratitude to all the partners for their contributions during the development of concepts presented in this paper. Moreover, the authors wish to thank Eleonora Borando and Marco de Bon for his valuable support in the research.

References

[1] http://www.manutelligence.eu (last visit 12-03-2016)

[2] Wiesner, S., Freitag, M., Westphal, I., Thoben, K.D., 2015. Interactions between Service and Product Lifecycle Management, Procedia CIRP 30, pp. 36-41.

[3] Cavalieri, S., Pezzotta, G., 2012. Product–Service Systems Engineering: State of the art and research challenges, Computers in Industry 63 (4), pp. 278–288.

[4] Aurich, J., Fuchs, C., Wagenknecht, C., 2006. Life cycle oriented design of technical Product-Service Systems, Journal of Cleaner Production 14, pp. 1480-1494.

[5] Erik, S., Lindahl, M., Öhrwall Rönnbäck, A., Ölundh Sandström, G., Östlin, J., 2006. Integrated product and service engineering methodology, Proceedings of 11th International Conference of Sustainable Innovation

[6] Lindahl, M., Sundin, E., Sakao, T., Shimomura, Y., 2004. Integrated product and service engineering versus design for environment – a comparison and evaluation of advantages and disadvantages, 14th CIRP Conference on Life Cycle Engineering, pp. 137-142

[7] Hepperle, C., Orawski, R., Nolte, B.D., Mörtl, M., Lindemann, U., 2010. An integrated lifecycle model of product-service-systems, 2nd CIRP Industrial Product-Service Systems Conference, pp. 159-166

[8] Williams, A., 2007. Product service systems in the automobile industry: contribution to system innovation?, Journal of Cleaner Production 15, pp. 1093-1103.

[9] http://www.lifecyclemodeling.org/ (last visit 29-02-2016)

[10] Curtis, B., Kellner, M.I., Over, J., 1992. Process Modeling, Communications of the ACM 35(9), pp. 75-90

[11] Aguilar-Savén, R.S., 2004. Business process modelling: Review and framework, Int. J. Production Economics 90, pp. 129-149