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# DOCTORAL THESIS

## ABSTRACT

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**„LUCIAN BLAGA" UNIVERSITY OF SIBIU**
**FACULTY OF DE ENGINEERING**

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# COLLABORATIVE ENGINEERING DESIGN AND OPTIMIZATION OF COMPANY RESOURCES

## ABSTRACT

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**Sibiu**

**-2015-**

***KEYWORDS***

Collaborative platform, moldeling, conception, decomposition of value chains, business strategy.

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## *ABSTRACT*

The global race for opening new perspectives due to economic changes of the past decade, accelerated the research of innovative technologies that become strategies and drivers for quality, safety and product's sustainability for the prosperity of us all. Access to information and the new digital opportunities, form the basis of new organizational models and platforms that lead to improved working conditions and hence private lives.

Continue progresses in information technology and communication, allies partners that collaborate in sharing resources, skills and projects beyond the barriers of time, distance, culture and educational training. Companies need innovative climate, new structural initiatives, where cooperation with academia is facilitating investment decisions in accessing new markets.

Creating virtual databases with various software products, with specific modeling tools, is certainly one of future's investments. The virtual environment, which is a synthetic, integrated and collaborative medium, has the ability to predict product's quality, costs and to estimate the risks, causing the most competent alternatives.

The conceptual work of a product par excellence is an activity that generates value. During this phase, the cost of a product is determined in 75%, revealing therefore a high percentage of the definition phase in defining future product's features. But, for the success of a product, 5% can be determined. Therefore, the wrong launch of a new product, can induce an unnecessary use of resources, which has a negative influence on its success. On the other hand, an innovative design of a product, will make the initial 5% to contribute to massive cost reductions. In the current economy, efficiency is a sure way to survive and to grow in a competitive economy. So the first step towards development, is implementing new solutions adapted to this stage of actual industrial development. One of the possible solutions is the collaborative concept developed on collaborative platforms. Optimization of design, improvement of production and cost reduction are being offered as possibilities for collaborative reality.

The introduction of new perspectives into the role of architecture on the design vision, requires the abstraction of work procedures in modeling business processes, identifying new opportunities for implementing or improving software modules. The generic concept developed within the research, requires the mobility of the future. Identifying and modeling value chains, with the individualization of associated collaborative processes, lead to major benefits on interconnectivity level of the production system.

Qualitative analysis, comparison of modeling methods, comparison between the grounded architecture principles, analysis of the current situation, the evolution and impact on production systems are just some of the researches made with the purpose of implementing and integrating new elements that will lead to better management of company resources. Ensuring company competitiveness involves agility of changes in orders, rapidity in remodeling work processes, so that, they can be adapted easily to market dynamics by capitalizing the experience and know-how accumulated in easily accessible databases, which will lead to strengthening the culture and experience of the

company. Presentation of theoretical researches, were followed by experimental contributions.

**The PhD thesis is in the field of industrial engineering** and focuses on the analysis and synthesis of the current state of research, studying and following the implementation of a new concept in orchestrating the modeling collaborative design process in COMPA S.A. Sibiu.

Implementation of new industrial products or improving the existing ones, involves a process sustained by industrial researches, methods, tools, tests, exchanges of information, actually a complex collaborative process design. This is in fact the result of transition from idea, to the finished product, with all the stages involved: design, simulation, optimization, testing, validation, each with its intake side. Description of these activities in a collaborative mode and effective modeling and simulation of the design process, which certifies informed decision-making, gives the mixture of input data, the ability of prediction, which is one of the points of the research topic. The whole conception stage required for the implementation of new products, involves great efforts in planning, recognition of human errors and risks in opportune time, so the implementation of collaborative platforms will justify the investment in economic terms. Structural measures and the possibility of simulating different scenarios, ensure the development of products and processes throughout the life cycle, in a visionary approach. Visionary ideas are developing solutions to the real world, are transforming the company, where the collaborative services approach, is in fact the winning solution. I am convinced that the method presented in this thesis is useful and can be applied successfully.

Modeling the design process, separating in a collaborative way the production activities, based on BPMN (Business Process Modeling Notation) standard and on the (r)evolutionary Industry 4.0. architecture [162] [249] is creating transparency through simulation, and leads to reduced KPIs (key performance indicators), needed time to design and desired point of profit's product reflected in the final cost. The modeling, simulation and validation of this new collaborative model in the project, and the obtained results will lead to restructuring the steps in the design approaches and implementation of new products. The contributions are mainly theoretical and methodological.

**The research, follows the four stages** perfectly defined by the conceptual model presented by Blessing and Chakrabarti (2009) in "DRM, a Design Research Methodology". So in the first stage, it was studied and recognized the main results so far, in a critical analysis of solutions and models, which has set the goals for future research. In the second phase, the objectives already outlined, will determine the factors that will be further studied by reviewing the existing literature. After understanding the goal of research in the prescriptive study, was developed a synthesis of analysis and evaluation, and in the last stage was made the passing from the stage of vision to the viable one in the real world by testing, modeling and simulations.

The doctoral thesis was developed within the doctoral school of the University "Lucian Blaga", co-funded project by European Social Fund Operational Programme Human Resources Development 2007-2013. Priority axes: no. 1: "Education and training in support of growth and development of a knowledge based society" Key Area of Intervention 1.5.: "Doctoral and post-doctoral research support Project Title: "Compliance of the Romanian academic valences with the European Community ones" Contract Code: HRD / CPP107 / DMI1.5 / S / 76 851.

**The thesis is divided into seven chapters. Chapter one** presents the research topic, the main objectives and the approach applied. **In chapter two**, studying technical literature, scientific papers and theses, it is presented the current stage in the evolution of manufacturing systems with precise references to the stages of the technical, informational, organizational and management development (section 2.1). Competitiveness as a sure path to development, required studying the dynamics of development strategies (section 2.2). Implementing a system of good manufacturing may cause remaining or not in market of a business, and therefore are made relevant analysis and classification of manufacturing systems, which was undertaken in section 2.3. Simultaneous engineering in organization and using of resources research is part of the thesis topic and were studied in section 2.4. The next step, the integration of data in new technologies like CIM, PLM and the benefits analysis of their implementation were studied in Section 2.5. Following the evolutionary line, the next step, that of collaborative mechanisms, has been studied in chapter 2.6, along with their use in the allocation of resources. The chapter ends with conclusions definition in subsection 2.7.

**In chapter three**, are treated the most relevant main aspects of modeling architectures (section 3.1), paying attention on the main standards, which provides protocols and reference models (section 3.2). ERP, one of collaborative models with maximum efficiency, will have allocated an ample documentation (section 3.3), which will treat the contribution brought by virtual models (section 3.3.1) by the most important features and functionality (section 3.3.2 ), customer relationship management in (section 3.3.3) it's deployment in a real environment (section 3.3.4) with the implementation of risk analysis (section 3.3.5). A SWOT analysis of implementation will study trends future (section 3.3.6) and research on future ERP (section 3.3.7). The research thread leads into SAP (section 3.3.8), where a complete set of agile solutions covers the relevant functionalities. Emerging technologies like SOA (section 3.4.1), support group decision (section 3.4.2), Cloud Computing (section 3.4.3), and Industry 4.0 in (section 3.4.4), followed by an analysis of modeling capabilities are presented in (section 3.5). Modeling languages will be treated and analyzed (section 3.6) followed by the multi-criteria analysis for modeling language (section 3.7). The findings of this chapter will be presented in (section 3.8).

Throughout **chapter four**, there will be presented topics related to methods of modeling and production systems simulation (section 4.1), which will include classifications of the types of models (section 4.1.1), stages for building a model (section 4.1.2) studying computer-assisted modeling and simulation and presenting of software (section 4.1.3). Petri Modeling (section 4.1.4) requires presentation of the main types of networks. In the paragraph about waiting theory (section 4.1.5) can be found an application that supports the adjustment and optimization of waiting theory in a production system. Plant Simulation modeling is presented in (section 4.1.6). With particular interest I treated modeling with Adonis (section 4.1.7), which allows the interpretation of collaborative value chains. Neuro Solutions, studied (section 4.1.8), become an important facility because the interpretation of the results. Mathematically speaking, it is possible to model any production system, so there were studied mathematical concepts and functions involved in optimization process (section 4.2), using genetic algorithms (section 4.3).

In **chapter five**, the first phase in the implementation of a platform explain how to identify and model I40 value chains with the aim of defining new business models that take advantage of the growing interaction between different subsystems of manufacturing system. This step will be detailed in (section 5.1) on the principles of engineering collaboration. The following sections exemplified decomposition of value chains in collaborative processes, specifically for product development (section 5.2) and manufacturing capabilities (section 5.3). The interaction of various collaborative processes within value chains is illustrated in section 5.4. The chapter ends with a summary of the main ideas resulting from analysis and modeling of collaborative processes within value chains I4.0 reference architecture and the personal contributions of this part of the paper (section 5.5).

In **chapter six**, are presented the collaborative simulation and analysis processes previously modeled for company COMPA SA Sibiu where, through its participation in FP7 research project the company implemented Virtual Factory Framework partially on previously developed models. In this way the simulation results have been validated against real data obtained in the project. So after analysis of value added flow in the company (section 6.1) are simulated and analyzed collaborative processes related to product development (section 6.2) establishing the manufacturing capabilities (section 6.3). The chapter ends with a summary of the main ideas from the simulation results of collaborative processes and the personal contributions of this part of the paper (section 6.4).

The **main purpose, from chapter seven** of this study was to develop a collaborative platform, incorporating the principles of collaborative engineering for optimizing a company's resources. Research has complied well defined stages, starting from analyzing the current state of the manufacturing process to the implementation of specific value chains in I4.0. Developing of a new methodological model was based on the concept of collaborative engineering, as well as basic information on process integration and transfer of information between systems, while respecting the principles of data compatibility and using of standardized languages.

The **personal contributions** were mainly theoretical-conceptual and methodological. A stage of major personal involvement, implied analysis of production stages plans and the conditions in the COMPA SA Sibiu company. There were presented technologies and tools based on collaborative environment that improve the design activities, prototyping and products manufacturing. Reducing time and costs together with increasing quality and flexibility, these days are probably the most important targets to be achieved within companies, thus leading to the conclusion that collaborative processes, are actually a strategy for the future. The study proved to be benefic, for revealing new methods, easily applicable in the company for optimizing decision-making process in the moment of introducing a new product into production.

The major interest of resources suppliers and consumers, is to build a collaborative mechanisms, making possible an efficient allocation of resources and to obtain benefits and maximum satisfaction through a direct confrontation between the participants, based on the duality of "cooperation-competition" that exist in decentralized systems. An effective collaborative model ensures optimal communication between participants, while providing the necessary mechanisms to meet the requirements of

communication, coordination and cooperation with the ultimate goal of optimizing the use of resources.

Collaborative engineering is an approach way for process that adds value by default. It is a mindset (towards increased productivity and customer satisfaction), a way of working (design strategies allowing participants to solve tasks collaboratively), a modeling way (addresses design artifacts that can be developed, represented and documented by a collaborative process) and a control way (referring to methods of measuring the quality aspects of collaborative process). Collaborative design processes, certainly is a success factor. This doctoral thesis, aimed to discuss issues of conception (definition and design of modules) in terms of collaborative production system with focus on company resources. The collaborative engineering, did not study an isolated collaborative technology, but rather practices that support collaborative platforms that allow an easy access to designers and design modeling techniques. The emergence of collaborative intelligence is influenced by factors that contribute decisively to differentiate products made in mass production compared to traditional collaborative. Implementation of engineering and designing new models, such as platforms, as solutions of manufacturing processes is the only one viable in the current industrial context.

Permanent access to all database systems requires an excellent cooperation between participants. The contribution of this collaboration is the major phase during the development and implementation of new products or services by that the virtual organization will work virtually identical to the real one, having also the opportunity to monitor and improve any process. Key findings lead in the direction of developing a methodological design model based on collaborative engineering, using the value chains of I4.0, which would allow all those who participate in the process to collaborate. In order to integrate all necessary information and standards, data compatibility is useful, so, the possibilities of the BPML modeling and modeling languages are helpful. All study has enabled the progressive transition from general to specific modeling of manufacturing processes. In this way, it became easy to identify the steps in developing a collaborative platform methodology. Modeling and simulation of production systems methods have been studied and ranked. After classifying and comparison of modeling principles of the most relevant methods for simulation and modeling specific tools, I chose the ADONIS modeling application for the specific case investigated. Starting from flows of added value well defined in reference architecture I4.0 and from the principles of analysis and design of specific cooperation between decision-support systems engineering group, there were modeled several of the most relevant collaborative processes with major impact in enterprise resource optimization. Due to the complexity and particularity analysis of collaborative processes within enterprises, it is primarily a methodological approach.

In addition, each company, along value chains analyzed, maintain specific value chains. Due to various economic objectives of enterprises, or of the adoption of different business models and production strategies, inevitably are resulting different structures of collaborative processes. They differ not only in the selection of value-added steps involved, but in the manner of their control and management. It is essential for any enterprise, that collaborative processes can be modeled, stored and reused when they have technological infrastructure specific for collaborative work environments. Therefore to improve modeling the collaborative activity, was used ADONIS instrument, that

allows implicit definition of model of interaction or Think Let. In addition it is developed on cloud-computing technology, allowing sharing, interaction and reuse of collaborative models within the enterprise.

In all the examples modeled is highlighted the possibility of reuse of collaborative processes in the context of different value chains. This is essential for the assimilation of collaborative working environments within the enterprise where decision-makers involved are often reluctant in using new technologies. Even if these processes are addressed in particular, the bearing business, I4.0 emphasizes the need for the use of specific processes in manufacturing machinery where operators may contribute with information and knowledge to optimize enterprise resources. The models presented are examples of some of the most important collaborative processes where technology can have a significant impact. Due to the complexity and specificity of each enterprise, models must be identified and continually improved. Their introduction should be gradual as a positive practice in assimilating existing collaborative technology. Starting from flows of added value defined in reference architecture I4.0 and the actual results of the implementation of FP7 collaborative processes within the Virtual Factory Framework project, were validated and simulated scenarios on an extensive set of the most representative collaborative processes within value streams I4.0. for the real company COMPA S.A. Sibiu .The conclusions of these simulations are summarized in sections 6.2.3 and 6.3.3.

Because of the generic nature of collaborative processes modeled and the need for reuse, simulation results can be extrapolated easily in the context of all value chains. For instance the collaborative process manufacturing configuration capabilities is different only because of the use of a different instrument, of that which is establishing production facilities. Although COMPA used in the project VFF, the GIOVE tool for layout optimization, the simulation of the collaborative process is irrelevant in relation to the use of NeuroSolutions, an instrument much more complex.
Stages of research performed by NeuroSolutions software, with the scope of optimizing the decision-making process were described punctual, and were presented by screenshots during investigations. Comparisons and graphs results, accurately reveals that the introduction of additional predictions, and the simulation of several variants depends of a great set of constraints, and led to minor deviations.

It is well known that the classical phenomenological modeling highlights the difficulties in mathematical modeling of industrial processes. These difficulties are related to the creation and use of the model in optimization and automated management of these processes. This circumstances are proved to be useful alternatives methods of empirical character or techniques based on soft-computing instruments belonging to artificial intelligence. Their use has required the development of a specific methodology that involves the collection and analysis of experimental data available, accurate inputs and outputs, the development of the most suitable model, and the use of it, by making predictions.

Improving the performance of neural models was achieved by various methods:
- aggregation of neuronal networks in stacks by summing the weighted outputs;
- a sensitivity analysis on the influence of the input parameters considering the process output.

Neural networks have been used in direct modeling applications. They also have proven

to be effective tools in modeling and optimizing decision-making processes, their predictions were representing useful information for the engineering practice, particularly by allowing the substitution of experiments. There were made models that need to be implemented to simulate the functionality of a decision making process with the aim of non- traditional modeling and optimization using special methods. Substitution of experiments means avoiding practical test which requires time and resources, that lead to desired results from all points of view, for the idea of maximizing process.

As personal contributions can be included:

- Extended research of PLM concept, following idea of reconsidering initiatives and future trends. Based on these researches showing how early in PLM was included collaborative work, the collaborative model developed the idea of introducing the concepts of virtual and augmented reality in the production system. They were disseminated through the work [38] Dobrin, C., *Product life cycle analysis, a selection tool in measurement environmental performances and management*. Article published UGAL MAT Conference, Galati 2011;
- The concept of virtual collaboration was analyzed by synthesizing the literature which allowed the shift towards knowledge-based environments, which require the easy sharing of know-how information, with the aim to adopt the best solutions for implementing new products. These are contained in the paper [37] Dobrin, C., Cioca, M., *Intelligent Collaborative Platform for testing the product by virtual prototyping*. Advanced Materials Research Vol 837 pp 77-83 Trans Tech Publications, Switzerland- 2014;
- A summary of research on virtual teams of specialists diversity explains the different perspectives of the new platform, based on open architectures were involved in [39] Dobrin, C., *Virtual Reality Perspectives in the Design Environment*. ARTCAST Conference, Galati 2012 ISSN 1453-083x 2012, pp 163;
- Study and analysis of the duality of cooperation-competition from collaborative processes together with synthesis of collaborative technologies during the development and implementation phase of new products, have been addressed in [40] Dobrin, C., Bondrea, I., *Collaborative Engineering in the Management of Business Implementing Initiatives.* International Conference on Engineering Education Innovation and Entrepreneurship and Business, Sibiu, 2012 Conference proceedings 978-606-12-0369-7 ISBN, ISSN 1843-6730;
- Undertake a SWOT analysis of the implementation of an ERP system (section 3.3.6);
- At the same time, comparative and critical analysis studies of attributes and technologies for organizations with or without the implementation I4.0 were undertaken in (section 3.4);
- Were synthesized relevant information I4.0. (section 3.4.4);
- Were studied and completed analysis and synthesis referring to architecture and communication techniques between modules or systems (section 3.5);
- Were analyzed and completed multi-criteria analysis of modeling languages (section 3.7);
- The applicability of genetic algorithms in modeling the company's resources, was the source for paper [42] Dobrin, C., Bondrea, I., *The Power of Genetic Algorithm*

*in Resource Modeling of Company Scheduling*. International Conference of unconventional Technologies, Sibiu, 2013;

- Literature study on modeling with ADONIS, led to comparisons between ADONIS and UML (section 4.1.7) and between the latest two versions used: Cloud and Process Portal;
- Was justified the need for the implementation of the principles of engineering principles in the context of implementing workflows with added value in the reference architecture I4.0 (section 5.1);
- Identification of a methodological framework (section 5.1.3) was analyzed and modeled in collaborative processes necessary to optimize enterprise resources were defined in (section 5.2 and 5.3);
- Was emphasized the necessity of modeling, reuse and interaction of collaborative processes in the real context of actual implementation (section 5.4);
- Were created models and data streams regarding enterprise resources, from the activities and interactions of the system;
- Value flows of the company SC COMPA S.A. were analyzed according to reference architecture I4.0 meanwhile given their optimization through new collaborative model (section 6.1);
- There were simulated and analyzed collaborative processes used by SC COMPA S.A. in VFF project (section 6.2)
- Was implemented and experienced a neuronal model for optimizing manufacturing capabilities in SC COMPA S.A. (section 6.3.1);
- Was simulated and analyzed the use of the neural model collaborative processes within SC COMPA S.A. (section 6.3.2);
- Were performed extensive research on decision-making using NeuroSolutions that were developed and disseminated through the work [45] Dobrin, C., Bondrea, I., & oth *Hybrid Approach Based on Genetic Algorithms and Neural Networks in Decision Making within a Virtual Factory*. International Conference on Materials Science & Engineering, Bramat, Braşov, 2015.

Research made so far creates the **perspectives** for development in the following areas:

- ✓ industrial environment validation using collaborative platform design in the automotive industry;
- ✓ database development by integrating several constraints and a set of criteria for choosing constraints;
- ✓ development platform for tracking production;
- ✓ transfer of data, from the collaborative platform into the real factory .

Cloud solutions will certainly be the next step. This will allow users to work anytime, from anywhere in the world via a simple Internet connection. Whether it is a cable into a desktop system, or a wireless connection on a laptop, or a 3G mobile applications dedicated, all are available anytime, anywhere. If it's a tight deadline, a user can work in the office, directly at home or even on the road, from taxi. Cloud solutions are available directly from the web browser. According to studies, over 58% of US companies that are already using such solutions say they enjoyed the mobility offered by the cloud. This is facilitated by the proliferation of mobile devices (such as tablets or

smart phones) that can be used by all company personnel and may contribute actively and effectively in collective decision making.

One of the main advantages of the cloud is that companies using such data solutions are safe and their integrity is protected. Security enjoyed by users is one of the most important advantages offered by cloud technology and it is designed on many levels. On a physical level, data center is hosting servers always guarded and the access to servers is limited exclusively to security expert.

Cloud solutions eliminates the problem of costs generated by an internal network in a company and does not involve the existence of an IT department. Using online solutions, and the costs with the own servers are no longer needed, advanced equipment whose parts need to be changed constantly will always give the return that is required for working in the company. More, it eliminates unforeseen costs. Meanwhile, the cloud technologies do not involve installing any additional software, eliminating in the mean time the cost needed for each so expensive licenses. At the same time, it is not necessary to purchase the software updates. In the mean time, it is not necessary physical archiving of documents. Costs are always predictable and flexible. Thus, a user can opt to quit or, conversely, others may be added, as needed, which means a perfect optimization of expenditures and predictability. Excellent integration is offered by these solutions.

The major difference between traditional software suites and cloud services online is that solutions can be integrated so as to work together without the need to apply computer processor. Collaboration is possible anywhere, anytime, directly from your computer, Smartphone or tablet. Besides the ease use and the advantage of being intuitive, cloud solutions enable flexibility. Cloud enables the possibility to choose exactly the solutions it is needed by every employee. Also, customized packages solutions can be created for each company. Thus, are eliminated unnecessary expenses, and costs are kept under control.

Any scientific discovery is based on her invention, which is actually finding a fair solution to the issue researched. To discover means to reveal something that may already exist, but was not sought or found. Inventing, however, means to produce something new. Scientific discovery is the ultimate research, while the invention is the ultimate conception. So in conclusion, there is no invention without conception, and this is the only modality that transforms invention into innovation.