

ERGONOMIC ANALYSIS OF LEAN MANUFACTURING SYSTEMS

PhD Thesis – Summary

to achieve the scientific title of doctor at

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One of the most spectacular transformations of production systems was lean manufacturing, defining the 3rd Industrial Revolution, and it is considered today one of the most successful business strategies that aims to improve the competitiveness of organizations. Lean philosophy and approach of manufacturing flow is based on methods and means of the Toyota's production system type that spread amazingly in the '90 around the world. The support of lean implementation in different production systems has been marked by two major publications (unanimously recognized as having not only theoretical but also praxiological value):

- Womack, J. P., Jones, D. T. & Roos, D. (1990). *Machine that changed the world*. Simon and Schuster;
- Ohno, T. (1988). *Toyota production system: beyond large-scale production*. CRC Press.

Those were followed by the publication of other reference books, which surprised the particularities of generalizing the application of Toyota's model (in other cultures and countries) after the year 2000, culminating with the publication of the book: Porter, M.E. (2008). *Competitive advantage: Creating and sustaining superior performance*. Simon and Schuster.

Many companies in the automotive industry which are located in the Western Region of Romania (e.g., Flextronics, Hella, Continental, Leman Industry, Takata, TRW etc.) have implemented lean manufacturing systems, identifying occupational risk phenomena among employees (as the occupational stress due to the working rhythm and requirements, fluctuation of staff, absenteeism causes by the occupational stress, increased levels of fatigue at work etc.) and that generate their dissatisfaction. The most important aspects, considered in the research conducted within the doctoral program, are those associated with occupational risks, which are covered by ergonomic research and may be diminished or eliminated from this perspective.

In the same time, psychosocial risks, which are considered to be emerging, are generated by poorly work design, organization and management of the related activities and processes, as well as by an inappropriate social context in the workplace, and can have negative psychological, physical or social effects, such as workplace stress, exhaustion or depression of workers. Among the working conditions that cause psychosocial risks can be mention: excessive workload; contradictory requirements and lack of clarity about the role the worker has to fulfill; lack of involvement in decision-making which affects the worker and lack of influence on the way in which the work is done; organizational changes inappropriately managed, job insecurity; inefficient communication, lack of support from leadership or colleagues (Boatcă and **Cirjaliu**, 2015; **Cirjaliu** and others, 2015; **Cirjaliu** and others, 2016a).

Workers are confronted with stress when workplace demands are too high, overcoming their ability to adapt. Estimates of costs incurred by businesses and society due to workplace

stress are considerable, rising to billions of euros at national level (Weinschrott et al., 2015; Cirjaliu et al., 2016a; Cirjaliu et al., 2016b).

In conclusion, in addition to the mentioned issues, were identified in the literature sporadic research (discreet concerns) of analysis, as ergonomic research developed in the context of lean manufacturing. In addition, specific needs of lean manufacturing systems have been identified, resulting from the practice of some organizations located in the West Region of Romania, which required the need to address and solve the research topic associated with this PhD thesis.

The research topic approached within the doctoral program is of high relevance and interest both from the point of view of the theoreticians of the field, but also of the practitioners (managers), who require an interdisciplinary solution, as will be demonstrated through the content of each chapter of the thesis.

Therefore, the present PhD thesis aims to present (**SCOPE**) the research carried out during 2014-2019 on the investigation of the ergonomic organization of the processes / jobs in the lean manufacturing systems (*lean manufacturing*), the results of the research having a significant impact on the performances of the human operators, in the current context of the development of production systems (industrial organizations) (the ultimate goal of researches).

The general objective of the doctoral program is related to the theoretical and experimental researches on the analysis and assessment of ergonomic aspects in manufacturing systems which had implemented lean principles, concepts and the philosophy (*lean management*).

The main objective associated with this doctoral thesis is the elaboration of an analysis - evaluation - optimization approach of the workplaces by integrating the ergonomic (principles, methods and tools) with those related to lean and the identification of improvement measures.

The ergonomic analysis of lean manufacturing systems, with refer to the processes and workplaces related to this organization type, was generally aimed to identify ways to improve lean management in the analyzed or investigated production systems, simultaneously with the improving of the workers' occupational health (by reducing ergonomic risks, occupational stress and increasing work satisfaction) and their safety (by eliminating wastes due to work accidents or incidents). Thus, the research approach and its associated methodology contributed to:

- The knowledge development in the areas of ergonomics, occupational health and safety, risk management, but also to the sustainable development of industrial organizations;
- The diminishing of the occupational hazards and generating workplace wellbeing in the case of the lean manufacturing systems' human operators (safety and healthy workplaces) by diagnosing occupational risks that generate stress and dissatisfaction and finally, by developing measures to considerably reduce them.

The structure of the research and the PhD thesis consists of stages related to the chapters of the thesis and which were correlated with operational objectives, derived from the general objective, as presented in Table 0.1.

Table Eroare! În document nu există text cu stilul precizat..1 **Operational research objectives related to each chapter of the PhD thesis**

No.	Chapter of the PhD thesis	Related operational objectives
-	INTRODUCTION	Description of the motivation and importance of the research topic; Definition of the general and operational objectives; Description of how the objectives were reach (structure of the thesis and synthesis of each chapter).
1	"ERGONOMY" AND "LEAN MANUFACTURING" – STATE OF THE ART	OP1 Research on bibliographic references for characterization of ergonomic and lean manufacturing concepts related to the production systems and the presentation some operating methods.
2	HUMAN RESOURCES PROBLEMS OF LEAN MANUFACTURING APPROACH AND IMPLEMENTATION	OP2 Researches on the bibliographic references to characterize the effects / problems at the level of human operators and that are generated by the approach and implementation of lean philosophy.
3	THEORETICAL AND EXPERIMENTAL RESEARCH ON THE INTEGRATION OF ERGONOMIC APPROACHES AND LEAN SIX SIGMA - THE CASE OF A MANUFACTURING LINE WITH MANUAL PROCESSES	OP3.1 Concept of a framework model and the architecture of an associated decision support system to facilitate and support business managerial processes, relative to an integrated implementation of ergonomics in Lean Six Sigma (LSS) for continuous improvement processes;
		OP3.2 Partial testing and validation of the framework model for integrating ergonomic and LSS approaches in the case of a continuous improvement implementation.
4	THEORETICAL AND EXPERIMENTAL RESEARCH ON THE INTEGRATION OF ERGONOMIC APPROACH IN THE LEAN MANUFACTURING – THE CASE OF A MANUFACTURING LINE WITH MANUAL-MECHANICAL PROCESSES	OP4.1 Identifying and characterizing the dimensions of human operator satisfaction in workplaces related to a lean manufacturing system;
		OP4.2 Developing a mathematical model for optimizing the organization of manufacturing lines through a lean ergonomic approach (the case of a production system that has a maturity level of lean management implementation).
5	CONCLUSIONS. PERSONAL CONTRIBUTIONS. FUTURE RESEARCHES	Balance of research activity and the inventory of achievements, including the original ones.

The doctoral thesis covers more than 200 pages, containing an introductory chapter, 4 chapters related to the research topics and a final chapter dedicated to conclusions, own contributions and future researches. The thesis includes 74 figures, 120 tables, 33 mathematical relations, as well as a list of 232 bibliographic titles and 6 web pages.

Fig. 0.4 shows the structure of the PhD thesis, demonstrating the planned way of achieving the proposed research objectives.

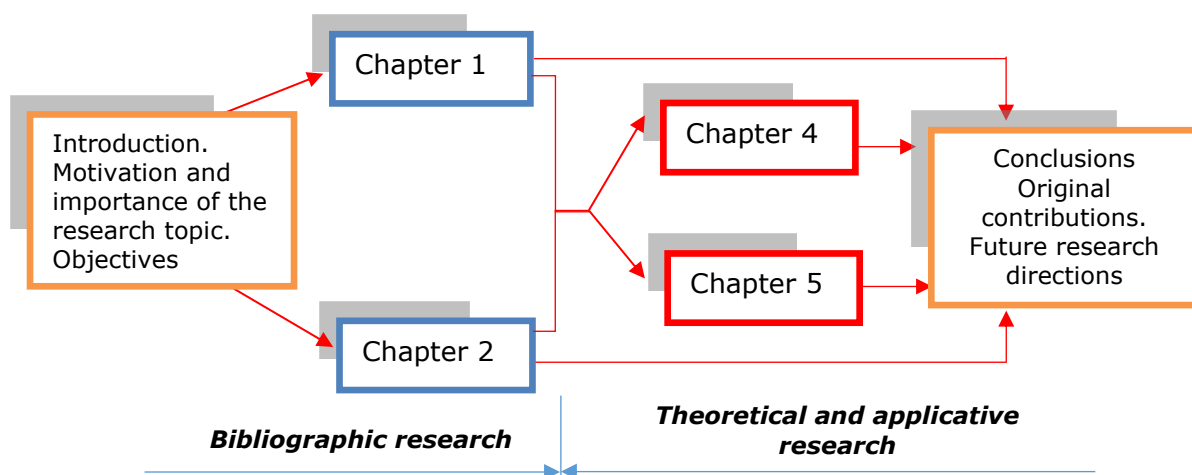


Fig. Eroare! În document nu există text cu stilul precizat..1. Structure of the PhD thesis

The treatment of the theme is logical, gradual and well structured, starting from the bibliographic reference overview on current approaches to ergonomic and lean manufacturing concepts and continuing with an inventory of human resources issues in organizations that implemented lean management. Based on the findings of the bibliographic research, the research gap (the lack of knowledge and application by integration of the ergonomic approach in the lean manufacturing systems) was defined and also theoretical and experimental researches were carried out, which proved that such an approach can significantly contribute to the improvement and optimizing lean manufacturing.

The first chapter of the thesis, "ERGONOMY" AND "LEAN MANUFACTURING" – STATE OF THE ART, contains conceptual explanations related to three priority aspects for the present research: (1) aspects regarding the development of ergonomics science; (2) aspects of ergonomic intervention in human-machine-environment systems; (3) lean manufacturing - concept and methods.

Articles with representative researches have been identified, dealing with problems of lean manufacturing, incidental to the context of the research of the PhD thesis. Conclusions of bibliographic studies sustain that the ergonomic intervention in lean manufacturing systems could have the advantage of developing and implementing more effective solutions for optimizing workplaces and workloads of workers, while simultaneously considering and integrating motivation and involvement of employees, to occupational hazards, increasing safety and health at work.

Chapter 2, HUMAN RESOURCES PROBLEMS OF LEAN MANUFACTURING APPROACH AND IMPLEMENTATION, is allocated to bibliographic research by exploring established databases, articles of interest identified by predefined keywords, and search results refined so that final articles are relevant to the topic of research approached. A first result of the bibliographic analysis and synthesis was the development of a taxonomy with the main obstacles that appear in the lean implementation.

Are being discussed aspects of human resource management in lean manufacturing (welfare or well-being of the operators at work) and significant aspects of ergonomic implications or connections with lean manufacturing systems, in the desire to continually improve the system and its performances. Research has led to the inventory of socio-technical and ergonomic practices frequently used at the management level for adopting / implementing lean manufacturing. Considering the absence of a definition of the **human dimension** in a lean context, a formulation based on the sum of the following elements was proposed: the individual

and collective characteristics of the employees; employee interactions with organizational factors; employee behavior, which can positively or negatively influence the stages of lean adoption / implementation. The definition served also to the development of a framework of human dimension in a lean context.

As regards the integration of lean principles with those of ergonomics, the bibliographic synthesis has shown that ergonomic intervention in production systems can ensure substantial improvement of workers' health and safety, interpersonal relationships of collaboration and can contribute to the success of technical cooperation, economic and financial organizations, especially for those who are implementing new technologies. It also highlighted an improvement in general working conditions in lean manufacturing systems, resulting in a decrease in the "rigidity" of the work process, with positive effects on increasing independence in adapting workers to the requirements of lean manufacturing, in line with the limits and their skills, demonstrating so that philosophies and lean and ergonomic action are not in conflict.

The bibliographic research has created the premises for the realization of convergent theoretical and experimental research on the concept of a model of integration of lean principles with those of ergonomics, in order to define an integrated framework of action for continuous improvement. This desideratum was the background of the researches in the following two chapters of the thesis.

Chapter 3, THEORETICAL AND EXPERIMENTAL RESEARCH ON INTEGRATION OF ERGONOMIC APPROACHES AND LEAN SIX SIGMA - THE CASE OF A MANUFACTURE WITH MANUAL PROCESSES, is dedicated to theoretical and experimental research. The chapter is structured into two parts: (1) theoretical research to design a general framework for integrating ergonomic knowledge into the Lean Six Sigma (LSS) approach; (2) experimental research on the partial testing and validation of the framework model for the integration of ergonomic and LSS approaches in the case of a car wiring manufacturing line.

In the first part, the theoretical research led to the elaboration of:

1. The framework model for integrating ergonomic approaches and LSS. This is based on the continuous improvement approach associated with the DMAIC cycle. The proposed framework is associated with the LSS procedures, methods and tools used in each phase of the DMAIC cycle, but which have been combined with an ergonomic approach designed to diminish or eliminate the disadvantages and negative aspects of human operators when addressing and implements lean organization;
2. A possible architecture of a decision support system to facilitate the implementation of the framework model (without its applicative development).

The second part of the chapter presents the experimental research and its results, through which it was partially tested and validated (only stages D, M and A - stages I and C would involve investments from the company to implement the proposed improvements and control or monitor the evolution of performance parameters of the new optimized system). The study was conducted in a medium sized automotive enterprise that is a significant employer on the local market from the Western Region of Romania. The studied subsystem, the wiring harness line, has 300 employees working in three exchanges and carrying out their tasks on 76 different workstations related to the assembly process of the product.

The overall equipment efficiency indicator (OEE) was used in the preliminary research conducted to monitor the day-to-day operation of the equipment, the frequency of failures and the quality of the final products. Research has been backed by data and information from the company so that the pointer can be calculated as accurately as possible.

Subsequently, a series of *in situ* observations and informal discussions with key managers and employees were carried out to compare the level of lean philosophy implementation with the effects of eliminating losses as the company had a low performance in

terms of diminishing and eliminating losses and achieving real continuous improvements. The study focused on the 5S, SMED, TPM, Hoshin Kanri, Kaizen and Kanban methods, and comparative analysis (deployment level versus loss elimination) allowed to demonstrate that lean implemented means and methods do not eliminate certain losses (or more precisely all losses) as assumed in the initial stage of implementation planning. It has also been shown that the implementation plan for certain methods and means does not fully apply in practice due to existing constraints of time, space or resources in the organization of processes.

Following the observations and discussions with the manager's department, it was pointed out that the main omission in approaching and implementing the principles of lean manufacturing was related to the treatment and solving of the many problems invoked by human resources during the changes, but also to the actual exploitation of the new conditions of the manufacturing system. These considerations have motivated the continuation of research and the identification of new ways to improve processes and the working environment. Thus, it was estimated that the ergonomic knowledge base should be integrated in the lean implementation approach to resolve the misunderstandings or contradictions between the theoretical aspects relative to the lean philosophy and the actual implementation that is determined by the context of the enterprise (such an approach has not yet been still adopted by the company).

As a result, experimental research continued through the design of an approach that utilized various methods and means (including ISO 9241 and ISO 13407, which regulate aspects of the use of a technical system and introduce the notion of ergonomic usability) through which they had interventions in the reorganization of the assembly line and the creation of a training point for the staff, even within the production department.

From a practical point of view, the research scenario suggested by the DMAIC Framework Model embracing ergonomic approaches was supported by a survey on the user-friendliness of employees of an automotive industrial system with the support of workers' users. Thus, a questionnaire was developed inspired by the **System Usability Scale (SUS)** described by research in ergonomics of software products (Brooke, 1996; Harvey et al., 2014; Lewis, 2018). The attributes for evaluating-usability measurement were: E - Efficiency, including by avoiding errors and losses; O - effectiveness, including by avoiding errors and losses; L - Learning; S - Satisfaction; M - Memorability.

The proposed approach has been developed, tested and validated in the case of the assembly line of the car wiring in which various ergonomic interventions have been carried out:

- Horizontal reorientation of the control and test panels (height adjustment of the assembly panels);
- Ergonomic organization of workplaces for orthopedic joints, with the implementation of visual management elements;
- Designing a space for training programs.

After those implementations, the questionnaire for evaluating the usability of ergonomic interventions was applied to the affected human operators (including managers). Research findings have highlighted that human operators, the users, have appreciated the concept of usability and operating mode for its assessment / measurement, and new developments and implementations in the field of continuous improvement have to affect more, and in a positive sense, the attributes of Learning, Satisfaction and Efficiency. As a general remark, the overall increase in ergonomic usability score was achieved through minimum investment.

In conclusion, the research is an original one, and integrates the ergonomic approach within the DMAIC cycle, more precisely partially, the DMA.

Chapter 4, THEORETICAL AND EXPERIMENTAL RESEARCH ON THE INTEGRATION OF ERGONOMIC APPROACH IN THE LEAN MANUFACTURING – THE CASE OF A MANUFACTURING LINE WITH MANUAL-MECHANICAL

PROCESSES, includes theoretical and experimental research extended in duration and scope, using other integrated ergonomic means in the case of a lean manufacturing system that has had an effect in optimizing its organization. The aspects considered in the adopted and implemented approach was the succession of workstations, the costs and the consumption of energy as well as the reduction of ergonomic risks.

Research has been approached into **three-steps**:

(I) Study of the research context, by describing FLEXTRONICS ROMANIA, the Infrastructure Department and the SSY assembly line, as well as relevant aspects for the research (the company management, organizational culture, and concern for the human resource). At the end of this part, the research scenario was adopted and approved by the department's management;

(II) The realization of research on operators' satisfaction at work in a mature production system in the implementation of lean principles, methods, and means. *At this stage the main objective of the research was to highlight the link between the motivation and the satisfaction of the work of human operators in a lean manufacturing system, considered mature at SC FLEXTRONICS ROMANIA Ltd. Timisoara.* To achieve the research objective, there have been developed:

1. *A qualitative research using **the fundamental theory on data (Grounded Theory)**, which provided a series of interdependencies on the dimensions associated with the behavior of employees and managers within the analyzed production system. The application of the theory has gone through the coding steps (open, axial and selective) to characterize the semantic categories identified and their interdependencies (**March - October 2017**). The specific objective pursued was to understand the socio-professional behavior of human operators (workers and managers) to the work situation imposed by the context of management and lean manufacturing, in terms of motivation and satisfaction. The application of the research approach led to the elaboration of a theoretical, conceptual model, characterizing the socio-professional behavior in a lean context, in terms of motivation and satisfaction at the workplace. The model consists of 11 interrelated semantic categories and characterizes the investigated social phenomenon (supra demand of human operators in the lean manufacturing system). The model has a high degree of generality, allowing the development of quantitative research, more precisely the questionnaire used in it;*
2. *A quantitative research based on an **investigation through questionnaire**, attended by human operators on the SSY manufacturing line at SC FLEXTRONICS ROMANIA Ltd. Timisoara (**February - July 2018**). The design and application of the questionnaire aimed to investigate issues related to motivation, motivation and job satisfaction:*
 - A. The importance of needs and their satisfaction;
 - B. Motivation and salary satisfaction;
 - C. Conditions and working climate;
 - D. Positioning and career management;
 - E. Workplace dissatisfaction.

The research findings have contributed to the development of measures to improve human operator activity by increasing motivation, motivation, and satisfaction at the workplace and whose implementation will require sustained efforts by human resources specialists and department managers.

The conclusions of the research on the satisfaction of human operators within the SSY assembly line required a deepening of the research on the technical system, on how to organize the processes related to the line, but in relation to the perception of the human operators, in order to achieve better working conditions.

(III) Theoretical and experimental research to optimize a manufacturing line with manual and mechanical processes, by developing a mathematical model and validating it. Thus, a possible approach to redesigning the assembly lines with heterogeneous processes (manual-mechanical and automatic) has been conceived, which simultaneously considers the principles of lean production and the ergonomic requirements in the case of safe working processes and assemblies. The proposed mathematical model, developed on the basis of the bi-objective linear programming method (having two objective functions), has led to the provision of a set of optimal reorganization sequences for the manufacturing line.

Applied research aimed at analyzing and reorganizing the manual-mechanical assembly process for the SSY assembly line of electronic circuit boards for the automotive industry at SC FLEXTRONICS ROMANIA Ltd. Timisoara. Thus, the proposed mathematical modeling approach has resulted in a set of solutions that provide an optimal way of organizing the manufacturing line, these being defined by manual-mechanical and automatic work-ordering sequences, in which the working pace of the machines is harmonized with that of human operators. In addition, each optimal assembly line solution provides an ergonomically acceptable level of risk for human operators performing repetitive movements with upper limbs and has a high musculoskeletal risk according to the OCRA method considered (ISO 11228-3 / 2007). In conclusion, the research confirmed the usefulness of the approach and the mathematical model proposed for the optimization of the production lines with heterogeneous processes.

At the same time, the theoretical and experimental researches made it possible to exploit and integrate other ergonomic methods and ergonomic means related to manufacturing, lean management, other than those used and presented in the researches in Chapter 3, which made it possible to extend the area of knowledge related to the research topic.

Chapter 5, entitled CONCLUSIONS. PERSONAL CONTRIBUTIONS. FUTURE RESEARCHES, presents a brief overview of the bibliographic, theoretical and experimental researches, emphasizes the original own contributions in the field of integrating the ergonomic and lean approach to the production systems' continuous improvement of (and not only). In addition, research directions with potential for further development are presented.

The results of the researches were disseminated in 12 papers / scientific papers published in journals and proceedings of international events in the country and abroad, out of which: 6 papers ISI Thomson Reuters indexed / Clarivate Analytics (Web of Science), from which 1 paper was published in an ISI Journal; 4 papers BDI indexed (Springer, ECONPaper), 1 article published in an international conference proceeding (published abroad and unindexed) and 1 paper published in a national (non-indexed) conference proceeding. These define the journalistic activity of the author of this PhD thesis, but also the way of involvement in different research groups.

At the end of the thesis, there is a list of bibliographical references, two Annexes containing the questionnaires used in the experimental researches described in Chapter 4, an Annex with the PhD student's CV and the list of the scientific papers published during the period of doctoral studies.

Selective Reference List:

1. Boatca, M. E., **Cirjaliu, B.** (2015). A proposed approach for an efficient ergonomics intervention in organizations. *Procedia economics and finance*, 23, 54-62.
2. **Cirjaliu, B.**, Boatca, E. M., Gaureanu, A., & Weinschrott, H. (2015). Application of Occupational Risk Assessment Methods in the Organization. In *Proceedings of the MakeLearn and TIIM Joint International Conference* (pp. 1069-1076).
3. **Cirjaliu, B.**, Draghici, A. (2016). Ergonomic issues in lean manufacturing. *Procedia-Social and Behavioral Sciences*, 221, 105-110.
4. **Cirjaliu, B.**, Draghici, A., & Jitarei, A. (2016a). A proposal approach for stress management. In *Managing Innovation and Diversity in Knowledge Society Through Turbulent Time: Proceedings of the MakeLearn and TIIM Joint International Conference 2016* (pp. 475-480). ToKnowPress.
5. **Cirjaliu, B.**, Weinschrott, H., Gaureanu, A., & Boatca, E. M. (2016b). A Proposal for a Risk Assessment Management in a Transport Company. *Procedia Economics and Finance*, 39, 229-234.
6. **Cirjaliu, B.**, Mocan, A., Boatca, M. E., & Draghici, A. (2019). A propose approach for continuous improvement using ergonomics and quality management knowledge and methodologies. *Quality Access to Success*, 20(S1), 135.
7. Ivascu, V. L., **Cirjaliu, B.**, & Draghici, A. (2015). Operationalization Of The Professional Risks Assessment Activity. *ACTA Universitatis Cibiniensis*, 66(1), 73-78.
8. Ivascu, L., **Cirjaliu, B.**, & Draghici, A. (2016). Business model for the university-industry collaboration in open innovation. *Procedia Economics and Finance*, 39, 674-678.
9. Ohno, T. (1988). *Toyota production system: beyond large-scale production*. CRC Press
10. Porter, M. E. (2008). *Competitive advantage: Creating and sustaining superior performance*. Simon and Schuster
11. Womack, J. P., Jones, D. T. & Roos, D. (1990). *Machine that changed the world*. Simon and Schuster;