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Integration of Ergonomics and Lean Six Sigma. A model proposal

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Abstract

Lean Six Sigma (LSS) aims to help companies continuous improvement (CI), coping with the strong business competition and gaining organizational effectiveness. Both Ergonomics and LSS are system-oriented approaches and could have a synergistic effect in CI. The integration of Ergonomics and LSS requires a new methodological framework that evolves from their single approaches, which coherently applies the principles of both and simultaneously ensuring gains in productivity and in working conditions. To help SME (99% of all businesses in EU) to realize their full potential a tool that supports the implementation of the mentioned framework is also desirable. A practical tool to fulfill this goal can assume the form of a Decision Support System (DSS). Therefore the objective of this paper is to present the model of a framework and of an associated DSS.

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Keywords: Decision Support Systems; DMAIC; Methodological framework; SME; Working conditions

1. Introduction

The continuous improvement that some companies are embracing today in order to achieve operational and service excellence are a consequence of the increase in competition, of internationalization and of an economic conjuncture that makes consumers more demanding regarding the cost of what they buy. Therefore, companies feel the need to adjust their management strategies and to continuously improve performance in all areas (e.g., operations, organization) keeping up with competitors or, if possible, overtaking them [1].

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Both Lean Management and Six Sigma philosophies have been referred to as the most promising initiatives in continuous improvement of organizations [2]. Lean focuses on eliminating the sources of waste, aiming a continuous process flow, while Six Sigma focuses on reducing the process variability. It is widely accepted that they are complementary approaches and companies tend to establish joint programs combining Lean and Six Sigma [3]. Therefore nowadays these two philosophies are being used as one approach, designated as Lean Six Sigma (LSS). The LSS concept represents a business philosophy and strategy to drive continuous improvement of production processes to reach higher customer satisfaction and profit [2]. They are very important approaches to reach good productive performance, since they focus on reducing waste, variability and costs of production [4].

What companies fail to realize is the potential for further improving the productivity gains if ergonomic principles were integrated and implemented simultaneously with LSS. The inclusion of Ergonomics in the continuous improvement process is quite important since traditional LSS interventions, while trying to maximize productivity by minimizing resources, can easily miss the limitations and needs of the human factor in the productive process.

Both Ergonomics and LSS are system-oriented approaches. However, frequently Ergonomics is not viewed by managers this way. Since Ergonomics is most often housed within the Occupational Safety and Health (OSH) department (mainly to answer legal requirements and to perform risk management), managers tend to inadvertently restrict its scope of intervention to hazards, instead of benefiting from its help to improve organizational effectiveness, business performance or costs. In fact, stovepiped approaches lead to less than optimal results. Therefore, continuous improvement processes should be performed applying simultaneously Ergonomic and LSS approaches in a coherent fashion to ensure both gains in productivity and in working conditions. For reaching this goal of integrating Ergonomics and LSS a methodological framework is required.

Contrary to multinational companies, which potentially have enough awareness, resources (money and personnel) and competences to develop continuous improvement processes tailored to their specific needs, Small and Medium-Sized Enterprises (SME) lack such capabilities. The concern with SME is relevant because of their number and because they are a key driver for economic growth, innovation, employment and social integration in European Union (EU) economy. In fact SME represent 99% of all businesses in the EU economy [5]

In order to help SME realize their full potential in today's global economy a tool that supports the implementation of the mentioned methodological framework of the continuous improvement process is also desirable. A practical tool to fulfill this goal can assume the form of a Decision Support System (DSS).

The objective of this paper is to present the model of a framework and of an associated Decision Support System conceived to help the decision making process of SME managers in the execution of an integrated implementation of Ergonomics and LSS continuous improvement processes.

This paper is organized as follows. After the Introduction, a problem domain overview section addresses core concepts regarding Lean Six Sigma, Ergonomics and Decision Support Systems. This is followed by the discussion of an Ergonomics and Lean Six Sigma integration framework and a brief presentation of a DSS model to support it. Finally some Conclusions will summarize the topics discussed in the paper.

2. Problem domain overview

2.1. Lean Six Sigma

Lean Six Sigma results from two different but complementary management philosophies: Lean Management and Six Sigma. Lean Management is a production philosophy that evolved from the Toyota Production System (TPS) and appeared after the 2nd World War [6]. Its objective is to help companies achieve on time the delivery of the right product quality and quantity to satisfy customer demand. It is based on the following five principles [7]:

- Specify Value – it is necessary to specify what adds value from the end customer's perspective, so that all the non value activities can be identified and removed; in fact for most production processes only a small part of the total production time and effort adds value for the end customer;
- Identify the Value stream – identify all activities that don't aggregate any value to the final product;
- Create Flow - promote continuous flow in the process by eliminating wastes;

Fig. 1. Eight different types of waste.

- Customer Pull – respond to customer demand; produce what customers want at the right time;
- Pursue Perfection – continually remove wastes, striving for a perfect process.

As implied from the above principles, Lean Management focuses on the elimination of the non-value added activities or wastes. As presented in Figure 1 there are eight different types of wastes: transportation, excessive inventory, unnecessary movements, over production, over processing, waiting time, quality/defects and intellect underuse.

To support the Lean Management philosophy implementation in reducing lead and set up times, inventories, equipment downtime, scrap, rework and other wastes there are many tools and techniques. Some examples are: 5S, Kaizen, Value Stream Mapping, Kanban and SMED.

The Six Sigma methodology is a management program developed by Motorola Company, in the 80s, in response to an increase of the international market competitiveness created by Japanese companies. To cope with this situation, Motorola felt the need to improve the process quality, due to an excessive amount of defective production parts [8]. Six Sigma seeks to achieve high levels of quality and low levels of variability [3], by detecting and removing defects causes. As a consequence of this philosophy, the waste of organizations decreases and the production variability is reduced as well improving production control and forecasts [9, 10]. Its application is based on the structured approach DMAIC (Define, Measure, Analyze, Improve and Control) cycle. In each phase a set of tools and methodologies are applied, for example: Brainstorming, Cause-and-effect diagram and Control charts.

As mention before Lean Six Sigma (LSS) results from the combination of Lean Management and Six Sigma methodologies. As describe in [11] these methodologies were first integrated in 1986 in the US-based George Group, however the term Lean Six Sigma only appear in literature after the year 2000, when a marked increase in LSS popularity and deployment in the industrial world occur, especially in large western organizations such as Motorola, Honeywell and General and in some SME. The objective of the implementation of LSS is to improve performance of production processes by reducing waste, variability, costs and satisfying customers [3, 4]. LSS started to use the DMAIC cycle as support structure for problem solving and to integrate tools from both philosophies [2]. Using both methodologies simultaneously, so that their synergy can be leveraged, makes it more effective and most beneficial. Furthermore, the use of both simultaneously is also more effective to identify root causes of problems rather than focusing on the processes where the problems appear [3].

2.2. Ergonomics

Ergonomics is the science that focuses on systems where the interaction between people and their environment occur in order to optimize well-being and overall performance [12]. Therefore Ergonomics can be characterized by (1) having a system approach; (2) being design driven and (3) focuses on performance and well-being [13].

According to these authors the potential of Ergonomics is under-exploited, being one of the reasons that managers are not aware of the value of Ergonomics. Ergonomics is mainly associated with the workers well-being, being most often housed within the Occupational Safety and Health (OSH) department, therefore managers tend to inadvertently restrict its scope of intervention to OSH hazards, instead of benefiting from its help to organizational effectiveness, business performance or costs. In fact, the value of Ergonomics is beyond health and safety since Ergonomics can add value to a company' business strategy to reach the ultimate business goal of profit, or intermediate business goals related to profit drivers like cost minimization, productivity, quality, delivery reliability, responsiveness to customer demands, or flexibility [4]. Therefore it is necessary a paradigm shift, which requires a re-positioning from a primary health ergonomics approach to a more business-oriented ergonomics approach [4]. The integration of Ergonomics in LSS matches this paradigm.

2.3. Decision Support Systems

A Decision Support System (DSS) is an information system developed to support a specific decision-making process to deal with semi-structured problems [14]. Semi-structured problems are problems that cannot be solved by a mathematical or logic formulation, or by standard operating procedures (the continuous improvement process addressed by the integration of Ergonomics and LSS is an example of a semi-structured problem). The purpose of DSS is to achieve the same level of accuracy of a human expert in solving problems in specific domain of expertise.

A DSS is composed by 4 components:

- Knowledge base – contains the specialized knowledge about the expertise domain;
- Inference engine – offers the reasoning capacity of the DSS;
- Database – is the working memory of the DSS, where the analyzed problem data are stored;
- Interface – allows the interaction of the user with the DSS.

The main advantages of the use of DSS are that knowledge is more widely available and can help translating knowledge into practical useful results. In fact, the use of a DSS allows non specialists to take high quality decisions in the domain of expertise of the DSS even when human experts are not available.

In the current context the support of a DSS offers SME the opportunity to overcome the lack of competences required for implementing a continuous improvement process, which integrates Ergonomics and LSS.

3. Ergonomics and Lean Six Sigma integration framework

Much has being written about the negative consequences in the working conditions due to the interventions perform during a Lean Management implementation. These interventions often lead to an increased work pace, workload and work intensification [15, 16, 17] which may affect the health and well-being of the workers, namely originating fatigue, stress, tension and work-related disorders [18]. However there are also studies showing positive effects in the working conditions, therefore the outcome depends on the technical and organizational context in the company [17]. This raises the question that a more comprehensive approach is required incorporating a human factors oriented approach, since higher productivity is expected with fewer resources, which can compromise the workers well-being and performance.

LSS is mainly focused on external (i.e., company) productivity but leaves internal (i.e., human) productivity virtually ignored [19, 20]. Internal productivity regards the ability of workers to produce more output with no increase in risk of injury or errors, which is a core concern of Ergonomics. Conversely unwary ergonomic interventions can result in unwanted effects in production performance [21]. Therefore, a solution that maximizes performance combining the internal productivity concern in the overall external productivity goal is one that requires the integrating Ergonomics and LSS.

The integration of Ergonomics in continuous improvement activities give an added perspective of recognizing ergonomic issues and a whole new dimension to the improvement activities [15, 22]. Despite a search on the web can lead to blogs and consulting companies mentioning this topic, to the best of the author knowledge there is a lack of scientific literature and studies addressing how the integration Ergonomics and LSS can, in fact, be performed.

As Snee refers improvement approaches are steps along the way in evolution of business improvement methodology, being each approach build up on previous approaches and adopting the effective aspects of previous approaches and adding, for instance, new concepts or methods [23].

Based on this idea a framework is proposed to help the integration of Ergonomics and LSS based on the DMAIC cycle, which was originated in Six Sigma. In fact, DMAIC is very convenient since it was generalized as an overall framework for process improvement [3]. This generalization can go further; encompassing an integrated approach that incorporates Ergonomic principles, tools and methods. Figure 2 shows the corresponding framework.

The proposed framework associates to the LSS procedures used in each phase of the DMAIC cycle an additional ergonomic perspective, as follows:

- Define - ergonomic tools (e.g., checklists) and data from existing records (e.g., injuries, accidents) is used to characterize the initial situation of the working conditions and to identify new improvement opportunities;
- Measure - to complement the establishment of the baseline, ergonomic methodologies are used to evaluate the status of performance metrics in the beginning of the improvement process. These data will be compared to the performance metrics at the end of the process to evaluate the gain resulting from the improvement process;
- Analyze - ergonomic tools and methodologies are used to pin-point root causes affecting the working conditions. These root causes have to be prioritized and selected for elimination on the subsequent step;
- Improve - the selection and implementation of solutions which eliminate or, at least, mitigate the effect of root causes incorporates ergonomic tools and methodologies which help to identify cost-effective solutions, test such solutions (e.g., using Human CAD modeling), and plan their implementation and deployment;
- Control - to sustain the gains achieved during the process, a continued monitoring process and training are required, which includes ergonomic tools and methodologies, as well as interventions to raise awareness.

The validity of this framework is supported by several successful continuous improvement preliminary studies which were performed including Ergonomics and using the DMAIC cycle (e.g., [24, 25]). Besides the validation of the framework, based on the empirical knowledge collected during these studies it is possible to conclude that the integration of Ergonomics and Lean Six Sigma during continuous improvement initiatives is possible and beneficial both for the production process and the workers.

4. DSS

The objective of the DSS, whose model is presented, is to assist managers in the activities required by each phase of the DMAIC cycle. The objective is to help choosing and applying the tools and methods used by Ergonomics and LSS paradigms, in the implementation of the integrated continuous improvement framework discussed above.

The proposed DSS functionalities will be based on the DMAIC cycle phases, and will support or guide managers to identify improvement opportunities and implement recommended courses of action. The DSS conducts data collection, analysis and decision support activities, with different granularity, depending if the main purpose of the current stage is to support the assessment of potential for improvement, to identify and deploy improvement solutions or to monitor and respond to the degradation of process performance. Table 1 provides a generic view of such DSS functionalities associated with each phase of the DMAIC cycle.

Table 1. Continuous improvement DSS functionalities characterization in relation with the DMAIC cycle.

Phase	Granularity		Activity			Purpose		
	Coarse	Fine	Data collection	Analysis	Decision Support	Assess	Improve	Sustain
Define	x		x	x	x	x		
Measure		x	x				x	
Analyze		x		x			x	
Improve		x			x		x	
Control	x		x	x	x			x

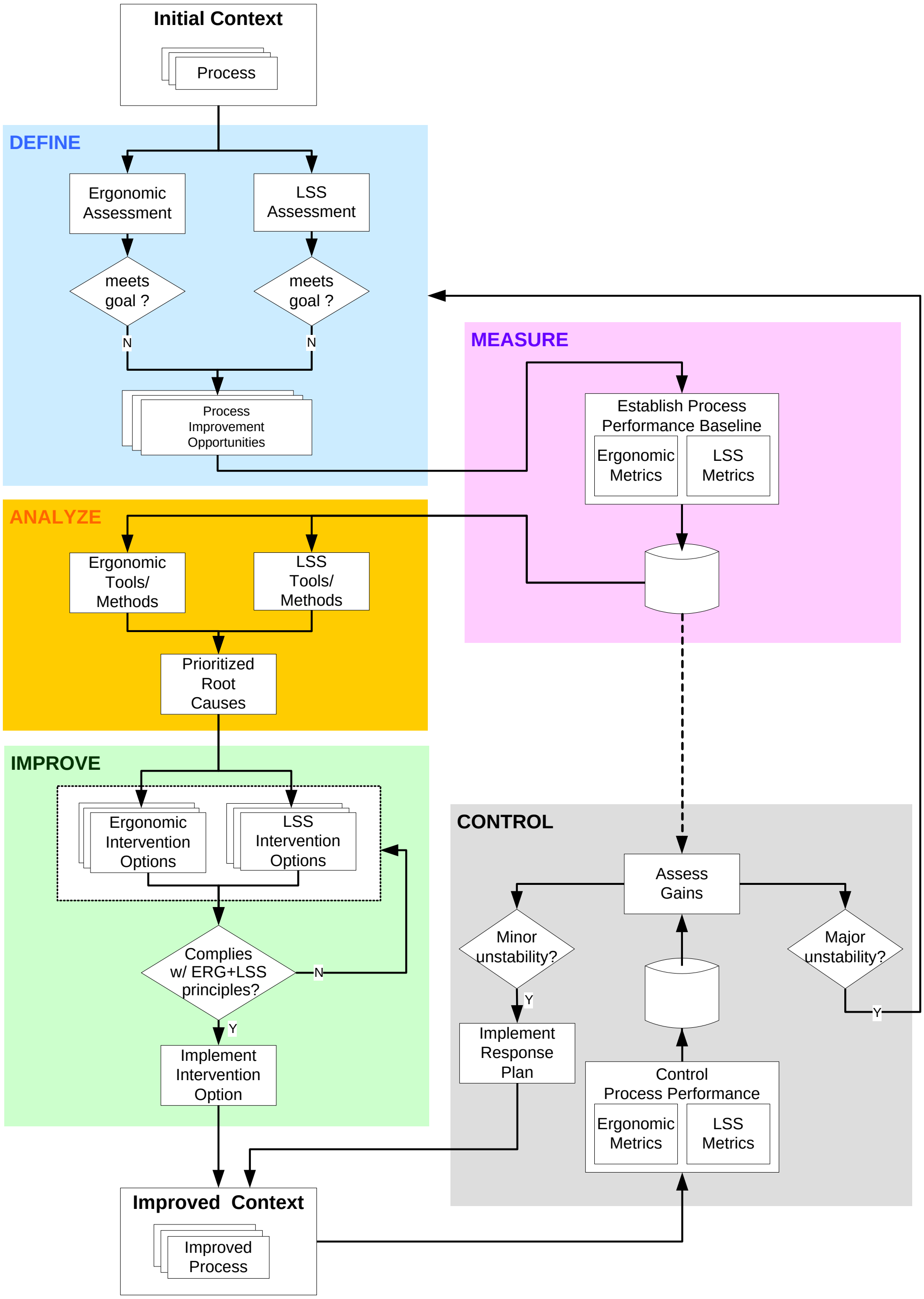

Fig. 2. Ergonomics and LSS integration framework.

The implementation of the DSS is illustrated in Figure 3. The knowledge base has to be initialized with Ergonomic and LSS domain knowledge, gathered through a knowledge acquisition process from experts and from explicit sources of knowledge. A deeper discussion on the process involved in the building of knowledge bases can be found in [26]. Data regarding the processes to improve has to be gathered and stored in the database. The inference process will conduct the execution of the framework presented in Figure 2, interacting with the DSS user (by means of the interface) providing orientation to the data collection stages, analyzing such data and providing results and advice, or help and guidance regarding the continuous improvement process. Due to the limitations on the extension of this paper it is not possible to discuss the details on the reasoning process required for the inference engine; nevertheless we note that such reasoning can be based in fuzzy IF-THEN rules or in other heuristic approaches. Examples and the discussion of the application of this AI approach developed by the author in the domain of Ergonomics can be found in [27].

An example of rule which can be used in the Improve phase to identify options for improvement, considering the root causes found in the Analyze phase is the following (adapted from [24]):

IF $cause_{1j}$ OR … OR $cause_{mj}$
THEN $recommendation_j$

where:

- $cause_{ij}$ – corresponds to the *i-th* root cause to process j
- $recommendation_j$ – corresponds to the set of alternative solutions to implement for improving process j

note that the both cause typology (i.e., rule conditions) and response options (i.e., rule conclusions) have to be elicited in the knowledge acquisition phase of the development of the DSS. The use of fuzzy logics allows the combination of quantitative and qualitative data and an easier generation of the rating of the conclusions, providing a coherent means for prioritizing the options [28].

5. Conclusions

Companies are embracing continuous improvement as a means to increase competitiveness while facing the increasing markets internationalization and an adverse economic conjuncture.

Lean Six Sigma is a very powerful continuous improvement methodology. The integration of Ergonomics during the LSS implementation has the potential to obtain substantial gains in productivity and to simultaneously improve the working conditions.

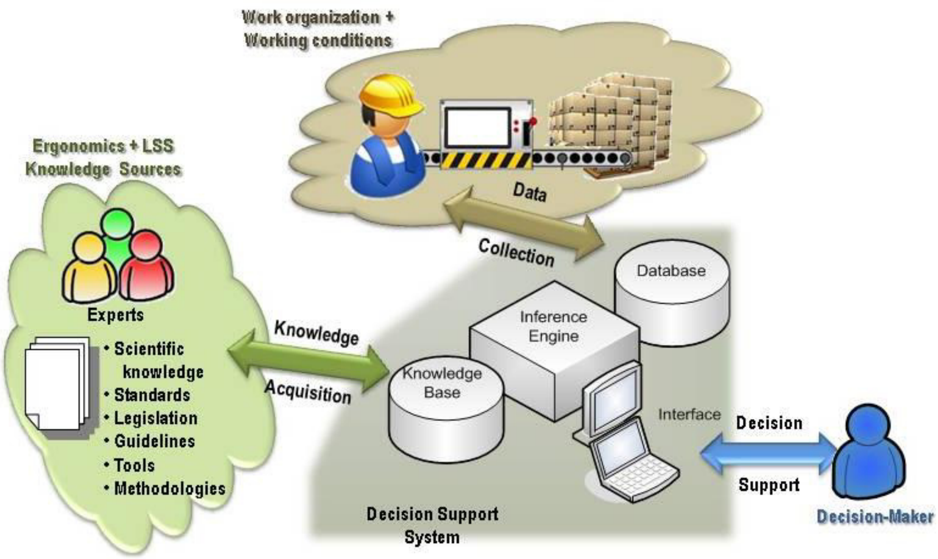

Fig. 3. Decision Support System model.

The model of a framework regarding the integration of Ergonomics and LSS based on the DMAIC cycle was presented. The proposed framework associates to the LSS procedures used in each phase of the DMAIC cycle ergonomic tools and methodologies introducing an additional ergonomic perspective.

Also a DSS model conceived to help the decision making process in the execution of the integrated implementation of Ergonomics and LSS continuous improvement processes was presented. This DSS is useful both to experts in continuous improvement and to SME managers which may have the awareness but usually lack the means to develop the required steps to implement continuous improvement.

References

[1] T. Melton, The Benefits of Lean Manufacturing: What Lean Thinking has to Offer the Process Industries. Chemical Engineering Research and Design 83 (2005) 662-673.

[2] S. Taghizadegan, Essentials of Lean Six Sigma, Butterworth–Heinemann, Massachusetts, 2006

[3] S. Salah, A. Rahim, J.A. Carretero, The integration of Six Sigma and lean management, Int. Journal of Lean Six Sigma, 1 (2010) 249-274.

[4] J. Dul, W. Neumann, Ergonomics Contributions to Company Strategies, Applied Ergonomics, 40 (2009) 745-752.

[5] EU, Small and medium-sized enterprises (SMEs), http://ec.europa.eu/enterprise/policies/sme/index_en.htm. Retrieved Jan22, 2015

[6] J. Womack, D. Jones, D. Roos, The machine that changed the world. New York: Macmillan, 1990.

[7] J. Womack, D. Jones, Lean Thinking: Banish Waste and Create Wealth in Your Corporation. 2nd Edition. New York: Free Press 2003.

[8] E.D. Arnheiter, J. Maleyeff, The integration of lean management and Six Sigma, The TQM Magazine, 17 (2005) 5-18.

[9] D.C. Montgomery, W.H. Woodall, An Overview of Six Sigma, International Statistical Review, 76 (2008) 329-346.

[10] S.Vinodh, S.G. Gautham, R. Anesh Ramiya, Implementing lean sigma framework in an indian automotive valves manufacturing organisation: a case study. Production Planning & Control, 22 (2011) 708-722.

[11] S. Albliwi, J. Antony, Implementation of a lean six sigma approach in the manufacturing Sector: a systematic literature review, in: Proceedings of the 11th International Conference on Manufacturing Research (ICMR2013) (2013)

[12] IEA, The Discipline of Ergonomics. International Ergonomics Association, Available from: www.iea.cc [Accessed 11 April 2015], 2000.

[13] J. Dul, R. Bruder, P. Buckle, P. Carayon, W.S. Marras, J.R. Wilson, B. van der Doelen, P. Falzon, A strategy for human factors/ergonomics: developing the discipline and profession, Ergonomics 55 (2012) 377-395.

[14] E. Turban, J. Aronson, T.-P. Liang, Decision Support Systems and Intelligent Systems. 7th ed., New Jersey, USA: Prentice-Hal, 2005.

[15] R. Wilson, Guarding the LINE, Industrial Engineer 37 (2005) 46-49

[16] Nunes, I.L., V. Cruz Machado.2007. "Merging Ergonomic Principles into Lean Manufacturing." In Proc. of the 2007 IERC "Industrial Engineering's Critical Role in a Flat World", Bayraksan G et al. (ed), Nashville, Tennessee-EUA, 836-841

[17] P. Hasle, A. Bojesen, P.L. Jensen, P. Bramming, Lean and the working environment: a review of the literature, International Journal of Operations & Production Management 32 (2012) 829-849

[18] P.A. Landsbergis, J. Cahill, P. Schnall, The impact of lean production and related new systems of work organization on worker health, Journal of Occupational Health Psychology 4 (1999) 108-130

[19] Kelby Ergo Design, How Much Waste Are You Still Missing By Doing Lean Without Ergonomics?, http://www.kelbyergodesign.com, [Accessed 31 March 2015].

[20] B. Zavitz, S. Smith, Application of New Ergonomic Tools and Methods to Lean, Ergonomics and Six Sigma (LESS), in: Applied Ergonomics Conference 2012.

[21] S. Caroly, F. Coutarel, A. Landry, I. Mary-Cheray, Sustainable MSD prevention: management for continuous improvement between prevention and production. Ergonomic intervention in two assembly line companies. Applied Ergonomics, 41 (2010), 591-599

[22] K. Monroe, F. Fick, M. Joshi, Successful integration of ergonomics into continuous improvement initiatives, Work 41 (2012) 1622-1624.

[23] R.D. Snee, Lean Six Sigma – getting better all the time, International Journal of Lean Six Sigma 1(2010) 9-29

[24] I.L. Nunes, N. Gouveia, S. Figueira, V. Cruz-Machado, Integração da Ergonomia e da Segurança na Implementação Lean Six Sigma (Integration of Ergonomics and Safety during Lean Six Sigma Implementation), in: G. Soares et al. (Eds.), Riscos, Segurança e Sustentabilidade, 2012, pp. 965 – 984

[25] D. Freitas, V. Nunes, I.L. Nunes Integrating Lean Six Sigma and Ergonomics – a case study, in: Arezes, P. et al. (Eds), Occupational Safety and Hygiene III - Selected Extended and Revised Contributions from the International Symposium Occupational Safety and Hygiene (SHO 2015), CRC Press/Balkema, 2015, pp. 441-446.

[26] I.L. Nunes, M. Simões-Marques, Contributions to the Design of Knowledge Base Development Tools for Intelligent Systems, in: M. Soares, F. Rebelo (Eds.), Ergonomics and Usability in Design, CRC Press, 2015 (to be published)

[27] I.L. Nunes, FAST ERGO_X–a tool for ergonomic auditing and work-related musculoskeletal disorders prevention, Work 34 (2009) 133-148

[28] I.L. Nunes, Fuzzy systems to support Industrial Engineering Management, Journal of Applied Engineering Science 10 (2012) 143 - 146