Work 52 (2015) 57–70
DOI 10.3233/WOR-141941
IOS Press

Review Article

Workplace ergonomics in lean production environments: A literature review

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Received 4 April 2013
Accepted 7 March 2014

Abstract.
BACKGROUND: Lean Production Systems (LPS) have become very popular among manufacturing industries, services and large commercial areas. A LPS must develop and consider a set of work features to bring compatibility with workplace ergonomics, namely at a muscular, cognitive and emotional demands level.
OBJECTIVE: Identify the most relevant impacts of the adoption of LPS from the ergonomics point of view and summarizes some possible drawbacks for workplace ergonomics due to a flawed application of the LPS. The impacts identified are focused in four dimensions: work pace, intensity and load; worker motivation, satisfaction and stress; autonomy and participation; and health outcome. This paper also discusses the influence that the work organization model has on workplace ergonomics and on the waste elimination previewed by LPS.
METHODS: Literature review focused LPS and its impact on occupational ergonomics conditions, as well as on the Health and Safety of workers. The main focus of this research is on LPS implementations in industrial environments and mainly in manufacturing industry workplaces. This is followed by a discussion including the authors' experience (and previous research).
RESULTS: From the reviewed literature it seems that there is no consensus on how Lean principles affect the workplace ergonomics since most authors found positive (advantages) and negative (disadvantages) impacts.
CONCLUSIONS: The negative impacts or disadvantages of LPS implementations reviewed may result from the misunderstanding of the Lean principles. Possibly, they also happen due to partial Lean implementations (when only one or two tools were implemented) that may be effective in a specific work context but not suitable to all possible situations as the principles of LPS should not lead, by definition, to any of the reported drawbacks in terms of workplace ergonomics.

Keywords: Lean production, ergonomics, literature review, work organization models

1. Introduction

Lean Production was the term used by Krafcik in 1988 to nominate the production organisation system used in some Japanese automotive plants installed in the U.S. during the 1980's [1]. This system, also called Toyota Production System (TPS) because of its origins in Toyota automotive plants [2], became known since the first oil crisis in 1973. Despite the crisis, Toyota results were remarkable, provoking the curiosity of other plants. Their capacity in designing and building cars in less time, with fewer people and lower inventories was notable. This crisis also motivated MIT to develop a research program entirely dedicated to this specific approach, the International Motor Vehicle Program (IMVP). One of the first of many studies that resulted from this program was the survey published in the book *"The Machine that changed the world"* from Womack et al. [3] about the differences between the Western and Japanese automotive industry practices.

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According to several publications, "Lean Thinking" [4] is focused on waste (*muda*) elimination, i.e., everything that does not directly contribute to the added value of a product, under the perspective of customers' needs and requirements. This approach is based on five main principles: i) create value for the customer; ii) map the value stream; iii) create flow; iv) the customer pulls the production, and v) pursuing perfection. To achieve these principles, it is indispensable to apply two key-concepts: JIT (Just-In-Time) production and continuous improvement (*kaizen*) [5]. The continuous improvement is linked to another lean thinking concept: the creative thinking, pointed out by Toyota Production System (TPS) as another key-concept [2,6]. This concept has to do with the will of the workers and culture promoted by the companies to extend the principles to all management activities, the Lean Production Systems (LPS).

Despite the clear gain in production, some of the so called "lean" companies were not always focused on the well-being of workers and on the issue of ergonomics, and that also applies to some of the Toyota plants, as reported in Pil and Fujimoto [7]. According to Yang et al. [8] most of the implementations of LPS emphasize the technical practices of the TPS and neglect the role of human factors in such implementations. Also Shoaf et al. [9] mentioned that lean manufacturing seems to be more focused in optimizing the process performance and, thus, ignoring the effects of these new work practices on workers.

Workers are very important and have a central role in LPS, so it is important to guarantee that they feel well and that their health and safety are assured. Nevertheless, it is possible to find in recent literature a significant number of papers addressing negative aspects of the LPS implementation regarding the workplace ergonomics (e.g., Anderson-Connolly et al. [10]; Kazmierczak et al. [11]; Winkel and Westgaard [12]; Dul and Neumann [13] and Johansson and Abrahamsson [14]). Fortunately, there are others who point out some positive aspects such as low human effort [15,16] or worker autonomy [17]. A review from Brännmark and Håkansson [18] pointed out the same conclusions, alerting for the importance of how the context and LPS implementation could influence these aspects. The context is related with work organizational model (Taylorist, Socio-Technical system,...) that was previously implemented in a company and when implement LPS, a different work organizational model [3], this must has been in account. The workplace ergonomics impact of LPS tends to be recognised as more positive when LPS are implemented in a previous Taylorist/Fordist systems [19], while when implemented in existing Socio-Technical Systems, the reactions from employees tend to be more negative [20]. The influence of work organizational model existed in the company on workplace ergonomics will be discussed later on this paper.

Based on this scenario, this study aims at reviewing the most recent literature and at identifying the most relevant impacts of the implementation of LPS in industrial manufacturing context, regarding ergonomics working conditions and discussing some possible drawbacks about a flawed or partial application of LPS. The impacts discussed are focused in four dimensions: work pace, intensity and load; worker motivation, satisfaction and stress; autonomy and participation; and health outcome.

2. Research design

This paper is based on an extensive literature review about the proposed subject and comprises two of the most comprehensive and large available publications databases, namely the ISI Web of Knowledge, from Thomson Reuters, and Scopus, from Elsevier.

As a literature review, the current paper intended to discuss the relevant published information on the considered domains and within a certain time period. Thus, this literature review has focused on the LPS and its impact on occupational ergonomics conditions, as well as on the Health and Safety of workers. The context is LPS implementations in industrial environments and mainly in manufacturing industry workplaces.

Considering that some previous works focused on similar literature reviews and included all the relevant literature during the 1980's and 1990's, it was decided that the current study would focus on the review of the more recent publications, i.e., documents published from the year 2000 onwards.

The first step of the analysis consisted in a search for relevant papers/studies within the defined topics. The search was limited by the publication date and to academic journals, thesis and other published documents available online. Therefore, all the unpublished works, including personal communications, were excluded from this analysis.

As an example of a (non-exhaustive) list of the used keywords, it is possible to mention "Lean Production", "Lean Manufacturing", "Lean Management Systems", "Lean Thinking", "Lean Management", "Ergonomics", "Health and Safety", "Workplace conditions".

According to the mentioned procedure, the current literature review included empirical and theoretical, quantitative and qualitative studies, written in English, which focused on the topic of LPS and its relationship with the working conditions.

3. Brief review of work organization models

A brief review of work organizational models is presented to contextualize Lean Production Systems and to support the discussion that work organization models influence workplaces ergonomic.

3.1. Fordist and socio-technical systems

Henry Ford adopted Taylor's *Principles of Scientific Management* (1911) to his automobile factory to improve productivity. These principles were simple and, mainly, consisted of dividing the operations in elementary tasks that anyone could do. Each operator stayed permanently in one workstation doing his simple and monotonous task with a previously estimated standard time. Tasks like product or process design, production planning and control, quality control or decision-making tasks were carried out by management. Operators had no relevant responsibilities and were excluded from any active participation regarding the improvement of processes and products.

This work organization model emphasizes the individual and the individual specialization for executing one task at some point in the moving assembling line. Accordingly, it restricts the mobility of operators between tasks, as well as their participation in solving problems and their creativity. For these reasons, this model imposes severe and hard work conditions, considering that each worker is only a gear of the "big machine" and is totally dependent on the equipment, reason for referring to this system as a techno centric system.

The workers' promotion is limited because the possibility to learn and develop other tasks is denied. Other effects, such as aggressiveness, anger and overall stress may also be found in workers' behaviour.

Contrasting with this techno centric system is the Socio-Technical, or also called anthropocentric production system, defined as a system based on the utilization of skilled human resources and flexible technology adapted to the needs of a flexible and participative organization [21]. The STS totally breaks away with the Fordist system, by promoting the operators' qualification, teamwork and giving power and autonomy to the team operators. The multi-skilling, empowerment and job rotation, enlargement, and enrichment are strategies adopted with that aim in mind. For example, multi-skilling is the opposite of job specialization; the operator is capable of doing several different tasks. These could be obtained through training and maintaining job rotation in the workplace. The job rotation plans have been used by the companies and is largely recommended in the literature [22] as a strategy to avoid the workers' boredom and the injuries caused by repetitive tasks. For example, in the case studied in Oliveira and Alves [23], the operators rotate after two hours doing one task. This workers' mobility is promoted by working in a dynamic standing posture that simultaneously reduces their fatigue [24]. This could also be a way to avoid monotony, demotivation and absenteeism on the job.

Job enlargement means to join tasks previously fragmented and executed by different operators. It is mainly a horizontal enlargement because the basis of the tasks is the same, as opposed to job enrichment that includes different task contents like tasks preparation, quality control and machine maintenance. Job enlargement permits more work variety and diversification, longer cycle duration and more flexibility and work organization.

Job enrichment goes beyond these advantages and looks to promote the operator's initiative, giving him complex and responsibility tasks and, ultimately, giving him power, authority and responsibility (the empowered operator) to decide the work to be done.

The operators in the Socio-Technical System were organized in semi-autonomous work groups (SAWG) or self-directed (or self-managed) work teams (SDWT) [25] where the democratization is the work basis. In self-management teams, all members participate in the local decision-making, previous function of supervisors and managers [26]. Self-management is defined as autonomous decision-making about the tasks to be done and how to do them, organizing the transformation processes to achieve the objectives of the team [27]. Additionally, giving power and responsibility to the team present other advantages, such as the reduction of hierarchic levels of management and the promotion of cooperation and creativity [28]. Examples of the most discussed of these kinds of teams were implemented in the Kalmar and Uddevalla Volvo automobile factories in the 1970's and

1980's [29]. This organization model was also known as the *Volvoísm* model. Each team is responsible for the whole automobile assembling process.

3.2. Lean production system

Many authors see work organization in LPS as an evolution with some deviations from the *Taylorism/Fordist* system, job rotation and team-work being two of these deviations. Other authors, like Forza [19], considers that workers were structurally stimulated to move to a different dimension of responsibility that combines its own with the companies' responsibility in a manner of obtaining the greatest employee willingness. In his research, he concludes that LPS uses more teams for problem solving, schemes for employee's suggestion and quality feedback, production documents procedures and task variety. On the other hand, van Amelsvoort and Benders [25], discussing the Toyota "team", consider that those teams do not have autonomy, only a set of duties and responsibilities. Björkman [30] also refers that the team work in LPS is restricted to Quality Circles and to cleaning and housekeeping activities. Quality Control Circles (QCC) [2], comes from TPS and consisted in small groups of workers that discuss quality control issues or improvement methods for production. However, the purpose of the circle is beyond the housekeeping activities and, as an ultimate goal, the circle is seen as a continuous way to improve the quality of work. The mentors of TPS believed that when properly stimulated operators could improve, better than anyone, the process they were working on. The unused operators' creativity is the additional type of waste that is frequently referred to, besides the well-known and discussed LPS seven wastes [31]. The new shop-floor management, as Suzaki [32] names the TPS, only has meaning with the workers intervening and participating in the operating, planning, designing, coaching, self-managing, measuring, training and controlling involved in problem-solving, meeting, suggesting and improving processes. Spear and Bowen [33] referred that all organizations managed by TPS they studied *"…share an overarching belief that people are the most significant corporate asset and that investments in their knowledge and skills are necessary to build competitiveness."* and *"…a work environment that is safe physically, emotionally and professionally for every employee"*. Work organization practices in LPS are deeply related with workers' participation, empowerment, continuous training, learning and team working, as pointed out by Olivella et al. [34].

This leads to a different concept of teams – *Lean Teams* – that emerges as something different from the socio-technical teams. According to the study of MacDuffie and Pil [35], workers had more influence on the job to be done and who should do the job than on the selection of the team leader or the amount and the work pace. Working in teams shows how important teamwork is, although the teams have different levels of influence in the work they do. The characteristics of Lean Teams were, according to Delbridge et al. [36], the presence of a formally recognized, hierarchically distinct team leader who is part of the team and whose duties include some element of direct work; a clearly defined and relatively fixed membership; a span of control for team leaders that does not typically exceed 20 workers; the teams are constituted around specific, on-line production activities within clearly recognizable areas of the plant. These characteristics are based on the works of Cutcher-Gershenfeld et al. [37] and Mueller [38]. This last author also refers that *"a team shall be understood as a group of people that has between 8 and 15 members, is responsible for producing a well-defined output within a recognizable territory, where members rotate from job to job with some regularity, under a flexible allocation of tasks"*. Normally, this team works in a U shaped cell layout with all machines necessary to produce a product or a family of products [39]. U-shaped layout is preferred because it contributes to less monotony in terms of work [40,41]. Working on this cell arrangement, the team members could adopt different and flexible work patterns or cell operating modes, i.e. an internal organization and distribution of the operators by the workstations (related to how people work and how they flow inside a cell).

4. Literature review results

Generically, and as pointed out by many authors, such as Saurin and Ferreira [42], Wong [43] and Gnoni et al. [44], ergonomics and occupational safety can be impacted by the implemented lean production systems, thus the identification of the possible advantages and disadvantages related to this implementation is highly dependent on the discussed contexts and also on the type of production shift observed at the time of the LPS implementation.

Despite some dispute about the positive and negative outputs of the implementation of a LPS, it seems that there are arguments for both "sides". Overall, almost a half of the analyzed papers and topics referred to positive impacts, or opportunities, and the other half to negative impacts, even though, many of these studies indicated that both impacts occurred simultaneously.

Accordingly, it was decided that some transversal issues regarding the impact on workplace ergonomics of the LPS would be presented and, in the last part of this section, a compilation of some of the cited positive and negative points resulting from the adoption of a LPS. This review will be focused on 4 dimensions: work pace, intensity and load; worker motivation, satisfaction and stress; autonomy and participation; and lastly, health outcome.

4.1. Work pace, intensity and load

Some of the main characteristics of the LPS, such as the standardization of cycle time, which prevents workers from managing their own work pace [45], the need to be multi-skilled [17,46], which often implies job enlargement and work intensification, by the unlimited demands on performance, the willingness to frequently work overtime and on very short notice and a close individual surveillance and pressure [42,47] are also associated to some of the main cited drawbacks of this production system.

In terms of workload and regarding its content, it can be assumed that the need to reduce the work cycle will imply that the work will tend to be more repetitive and intense [42]. The reduction of the work cycle to small values (often less than 60 seconds), which are sometimes cited by some authors as being linked with the Toyota Production Systems [46,48], is considered as one important risk factor for work-related injuries and may have a negative impact on workers' well-being. In contrast to this, other authors, such [15], mentioned that LPS use less human effort.

Angelis et al. [49] emphasized that in some activities there is a need to maintain a certain high level of work pace during long periods. According to those authors, these activities are, most likely, very highly demanding, hence they need to be designed for an execution at a maximum of 80% of the total possible work pace, including the participation of the workers in the planning of their activities. However, the adoption of a "self-definition" of the work pace, also viewed as a sort of autonomy, may imply, for example, the need to preview the availability of intermediate points for product storage. Additionally, some studies [17,45,46] also described other previous studies where it was assumed that the LPS principle of reducing all the inactivity periods may also result in an increase of the intensity of the work.

4.2. Worker motivation, satisfaction and stress

One of the most cited negative effects of the LPS is the stress level registered among workers. Although the effect that can result from a LPS implementation may be seen as contradictory throughout the various studies found in the literature, it seems that there is some consensus in the potential for an increase level on the stress observed among workers [10,49–51].

As pointed out by Dul and Neumann [13], Lean production and business process re-engineering are focused on improvements of business processes in order to cut costs and serve customers better, which are likely to involve the need to downsize. Some of these strategies have been linked to the decrease of the wellbeing of employees. For example, the individual's perception of the downsizing process itself also appears to affect health [52,53]. In this respect, Parker [54], based on a longitudinal study, showed that the implementation of a LPS results in job depression and reductions in job control and skill utilization although the same author referred that this study could not be generalized because of the applied methodology (only one plant was studied). Moreover, the author also pointed out that the analyzed plant adopted a mixture of mass production and lean production principles, which is typically found in non-Japanese companies introducing lean production. Conti et al. [51], in a study of 21 different companies, found that the stress in lean implementations was related to implementation and operational decisions, rather than inherent problems with the LPS, concluding that workers' well-being in lean production is not deterministic.

Some authors, like Dul and Neuman [13,55], refer that despite the fact that new forms of work (including LPS) are seen as improvements in working conditions, at the same time, a long series of negative tendencies are visible in working life, such as the increased number of people on long-term sick leave and with work related injuries, burned out personnel, stressed people, and overburdened people [56].

Carayon and Smith [56] also referred that various theories of job design can help in the definition of the positive and negative characteristics of the work system. For instance, theories of occupational stress have defined work stressors that are negative characteristics, such as high workload, shift work, low job control, high role ambiguity and role conflict. Theories of job design have also specified some positive characteristics, such as high task variety, feedback, opportunities for learning and autonomy.

Some of the possible positive outputs of the LPS implementation are related to work aspects that can improve workers' motivation and satisfaction. These include job stability, a hierarchical level decrease, as most of the employees enjoy a similar status, and the high qualification of the workforce [42].

Taking into consideration the workers' opinion, Eklund and Berglund [45] have also reported that after the introduction of LPS in two manufacturing companies, production operators were more positive than negative to the new production system, identifying also both positive and negative aspects of the production concept.

The concept of *Lean Teams* implemented in many lean environments improves the working conditions for operators and stimulates satisfaction in the work. For instance, training and job rotation had been strategies adopted to familiarize the workers with a range of tasks. Accordingly, workers will be able to understand the scheduling problems and that the workload balance may prevent ergonomic problems associated to repetitive operations and avoid monotony.

4.3. Autonomy and participation

Two of the most important requirements for an effective implementation of the LPS are the workers' commitment with the company performance and job enrichment (sometimes also called job enlargement), considering the workers' skills and activities. This enrichment assumes that workers will need to identify and control work variations, that they reorganize and improve production within their jobs.

There are some studies (e.g. Olivella et al. [34]) referring that a LPS is also characterized by a significant decentralisation of the authority and the attribution of a great degree of autonomy to each worker. This involvement of workers seems to be positively reflected in the improvement of working conditions, as long as it is assumed that a large diversity of activities, skills and responsibilities tend to enrich the job content. Thus minimizing work monotony and isolation [50], and also seen as having beneficial ergonomic effects [15]. However, other authors [49,57] also consider that the same characteristics may result in a more stressful job. A few authors, for example Johansson and Abrahamsson [14] and NIOSH [58], consider that workers' power and autonomy to decide is relatively modest, as it is often 'overlooked' due to the need to increase the work intensity and pace.

Another call to involvement of workers in a lean environment are the continuous improvement (Kaizen) initiatives that are seen as a natural fit and complementary with ergonomics initiatives by Monroe et al. [59] and Vieira et al. [60]. According to them, improved ergonomics and working conditions of the job were achieved by the employees when involved in these initiatives. Even so, other authors like Toralla et al. [61] and Silva and Bento [62] alert for the need to clarify the effects of continuous improvement initiatives and improve ways of how work and activities are conceived and designed, otherwise this could leads to an *"increased pace of work and to the definition of rigid standards"* ([61, p. 2710]).

In terms of autonomy, some authors [50,63] consider that workers' autonomy in LPS is also modest, as most of the workers follow some imposed rigid work patterns, which tend to limit their freedom to decide on their work.

Treville and Antonakis [64] argue that autonomy is a necessary condition for workers' intrinsic motivation. Since LPS is more about process standardization, it reduces workers' autonomy. Therefore LPS cannot be intrinsically motivating. Nevertheless, they suggest that motivation is theoretically possible in LPS since other job-factors may compensate the lack of autonomy. They concluded that LPS may also lead to workers' intrinsic motivation.

Zink [65], considered that the observed "Lean Management wave" has weakened the ergonomics structure within companies, by reducing costs with Health and Safety (H&S) and Ergonomics staff. In this respect, some studies reported that some changes were observed in terms of the companies' safety culture [66].

According to Saurin and Ferreira [42], some studies mentioned that top management's commitment to H&S issues had increased due to LPS and this subject was no longer considered to be a specific concern of the H&S staff. However, Li [66], in a literature review regarding lean practices and experiences, also noted that employees reported quite different experiences of work effort, health and safety and relations with management.

4.4. Health outcome

As aforementioned, the major cited workers' health outcome related to LPS is the increase in stress levels. However, there are other possible health outcomes that are related to LPS and mentioned in the literature. For example, Genaidy and Karwowski [17], pointed out that, at least from a theoretical point of view, a true LPS may imply a demand of the workers' muscular, cognitive and emotional resources to the limit. Other authors, such as Colombini and Ochipinti [67] referred that it is still unknown to what extent the organizational changes are helping to reduce musculoskeletal problems of assembly and other routine tasks of manufacturing or if, in turn, they are initiating new occupational risks.

Although the impact of lean practices in workers' safety can be an important issue, according to Wilson-Donnelly et al. [47], this impact has been neglected. There are also recent examples of the analysis of the relationship between safety and LPS, for example Cournoyer et al. [68] reported that the use of some Lean tools in a nuclear facility implied some statistically significant variations in the injury/illness reports. Also Rozenfeld et al. [69] reported the development of a method within the framework of research toward a Lean approach to safety management in construction, which, according to them, is able to predict fluctuating safety risk levels in order to support safety planning and, ultimately, carrying out a more effective safety management.

Brown and O'Rourke [70] mentioned that lean manufacturing establishes small production cells, which complete an entire product from raw material processing through to final assembly and, according to these authors, it will increase health and safety hazards by mixing exposure to previously separated hazards. However, it seems that these authors did not take into account that the same systems could also decrease the time of exposure to the same risk factors.

It is also possible to find a frequent reference to the relationship between the LPS and the appearance of high rates of Work-related Musculoskeletal Disorders (WMSD). For example, Eklund and Berglund [45] mentioned that in jobs with ergonomic stressors, intensification appears to result in an increase in the WMSD. The same authors referred that the main criticism of LPS is that the lean working conditions are very demanding and that the risk of stress-related disorders (including musculoskeletal disorders) is high.

Other critics claimed that LPS by principle did not differ from Taylorism. Kazmierczak et al. [11] went further and referred that some ergonomics problems have been associated to Lean environments, and also referred that it is possible that the problems were a consequence of the rationalisation of the production system. In accordance, LPS and Total Quality Management (TQM) have been claimed to contribute to poor ergonomics and to the increasing appearance of musculoskeletal disorders.

Assuming the adoption of some typical Lean practices, Johansson and Abrahamsson [14] reported that the return of the assembly line also creates problems at the level of working conditions mentioning that, in general, a Lean environment tends to represent an increasing risk for one-sided work movements and physical over exertions, contributing to the potential development of WMSD.

Surprisingly or not, a set of papers argument exactly the opposite point of view, i.e., that the implementation of LPS tend to increase workers' quality of life by introducing some improvements in their occupational environments.

According to Hunter [15,16], the proper adoption of LPS may result in positive health effects, including the reduction of chronic and traumatic work injuries. This author, for example, referred that one typical goal of the LPS cell designer is to promote job enlargement, and not job simplification. Accordingly, job enlargement will result in better ergonomics, for example, by including additional time to do the additional work it will allow the human body to "heal micro injuries", which, according to the author, are related to chronic WMSD. Besides, and based on a RULA analysis approach, the author concluded that a substantially lower risk, in postural terms, is present when using the cellular manufacturing design rather than the functional job shop design. Spear [71] also reported a case where a number of parts racks were reconfigured to present materials to the operators more comfortably and a handle on a machine was repositioned to reduce wrist strain and improve ergonomic safety.

Womack et al. [48] have also analyzed the relationship between LPS and WMSD in 56 similar jobs in the automobile industry. They referred that, in the analyzed cases, a greater repetition exposure was detected in Lean systems. However, when they combined repetition and force, they noticed that a lean system does not necessarily increase workers' risk for WMSD.

In LPS it is also usual to find workers with a variety of tasks, implying and requiring that workers stand and walk. According to Hunter [15,16], walking can be beneficial to the workers' wellbeing, as the walking benefits include the reduction of risk for deep-vein thrombosis, increased bone strength, reduced cholesterol and blood vessel plaque, and healthier hearts. Additionally, Balasubramanian et al. [24] referred that working in a dynamic standing posture reduces fatigue and promotes the workers' mobility, this being important to work in lean cells.

Saurin and Ferreira [42] also reported that, when comparing LPS and other production paradigms, some authors revealed that lean production cell was superior concerning some ergonomic aspects, such as posture adoption and manual materials handling. However, in their study carried out in a harvester assembly line, they also referred that they did not identify a particular focus on the prevention of cumulative trauma injuries, despite the strong emphasis on accident prevention. Acharya [72], for example, refers a lean manufacturing implementation that lead to a reduction on manpower use for material handling.

4.5. *Synthesis of advantages/disadvantages of LPS*

After the previous summary of the literature review, it is possible to briefly present the main results regarding the advantages, or positive points, related to LPS and also the main disadvantages, with the indication of the authors who cited some of these points. These advantages and disadvantages could be classified inside each dimension referred to in Table 1, being related to specific sections in this paper.

Tables 1 and 2 were obtained through the literature review carried out and by combining the diversity of factors cited in the literature.

It should be noted that the indication of a specific combination author(s)/advantage or disadvantage in Table 2 does not necessarily means that the indicated author(s) argue for this advantage/disadvantage, but only that the indicated paper refers the particular cited aspect of LPS.

5. Discussion

The main objective of this paper was the identification of the most relevant impacts of LPS implementations from the ergonomic point of view and was based on the literature review. Additionally, it was also intended to include the authors' experience (and previous research) along the following discussion. This discussion will be based in the influence that the work organization model has on workplace ergonomics and on the waste elimination previewed by LPS.

5.1. *Influence of work organization models on workplace ergonomics*

Workplace ergonomics is deeply related to work organization models and many authors had addressed this relationship, for example Angelis et al. [49], Seppälä and Klemola [50] and Carayon and Smith [56]. The relationship between ergonomics and the type of production strategies is clearly recognized by Dul and Neumann [13].

A brief review about the work organization models showed how those models can influence workplace conditions in different ways. Therefore, it is important to contextualize the (positive/negative) aspects presented in Tables 1 and 2 within the specific work organization models, since it is very different moving from a Fordist system to a LPS or from a Socio-Technical System (STS) to a LPS.

Most of the dimensions appear on both sides of Table 2, i.e., most dimensions are identified as advantages by some authors and as disadvantages by other authors, regarding LPS implementation. This fact shows that there is no consensus among the referred authors about the impact of LPS implementations. The reasons may be several, but one possible reason may result from the work organization model in place before the LPS implementation. One example is the workers' autonomy that appears on both sides of Table 2. In a LPS this autonomy may decrease when compared to the STS, because this autonomy is seen as a goal to be achieved by the balance between the social and technical sub-system [37]. Also, some authors like Kuipers et al. [73], see lean production assembly line introduction as a move backwards regarding performance and employees' involvement compared to a ST system. However, it is possible to have a hybridization of the two models, STS and LPS, in order to retain some advantages from both [74]. Seppälä and Klemola [50] referred that a combination of socio-technical and lean thinking ideas in Finnish companies resulted, in most cases, in more challenging and enlarged jobs. Additionally, they pointed out that Finnish companies "...did not reveal signs of the comeback of Fordism as predicted by some critics of lean production". Similar ideas were shared by Eklund and Berglund [45] but related with the Swedish companies that integrated concepts from the Scandinavian tradition of work design (STS) with concepts from Japanese production systems (LPS). Pil and Fujimoto [7] had noticed a convergence between the practices and policies on multiple fronts of Toyota and Volvo, representing the two main work organization models, respectively LPS and STS. Paez et al. [75] goes beyond that and considered Lean Enterprise as socio-technological construct because it is based on the combination of human and technological subsystems.

Some of the dimensions analyzed in Table 2 only appeared on one side of the table. One example of

Table 1
Main cited advantages and disadvantages of LPS

Dimension	Advantages		Disadvantages		Section of this paper
Human effort (work intensification; work pace)	low	A1	high	D1	4.1
Qualification of the workforce (job enrichment) multi-skills requirements	high	A2	low	D2	4.2
Job enlargement	good	A3	bad	D3	
Stress	decrease	A4	increase	D4	
Workforce perceived as central element	clear	A5	not clear	D5	
Hierarchical levels	decrease	A6	increase	D6	4.3
Workers' autonomy	increase	A7	decrease	D7	
Workers' participation and engagement	high	A8	low	D8	
Work pattern	flexible	A9	inflexible	D9	
Teamwork	increase	A10	decrease	D10	
Risk of WMSD development	low	A11	high	D11	4.4

Table 2
References with citations of the considered advantages and disadvantages of LPS

	Advantages*											Disadvantages*										
References	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
Zink [65]																						
Carayon & Smith [56]																						
Hunter [15]																						
NIOSH [58]																						
Anderson-Connolly et al. [10]																						
Genaidy and Karwowski [17]																						
Parker [54]																						
Seppälä & Klemola [50]																						
Kazmierczak et al. [11]																						
Conti et al. [51]																						
Colombini and Ochipinti [67]																						
Li [66]																						
Eklund and Berglund [45]																						
Brown and O'Rourke [70]																						
Pil and Fujimoto [79]																						
Hunter [16]																						
Winkel and Westgaard [12]																						
Womack et al. [48]																						
Dul and Neumann [13]																						
Johansson and Abrahamsson [14]																						
Saurin and Ferreira [42]																						
Monroe et al. [59]																						
Vieira et al. [60]																						

*See Table 1 for the meaning of each advantage and disadvantage.

that is the dimension "stress", since this dimension is never mentioned by any author as an advantage (stress decreasing). The other examples are the dimensions "Hierarchical levels" and "Teamwork", since they are never mentioned as disadvantages of the LPS implementation.

It is unquestionable that working in teams is an important requisite for the current work organization models. Johansson and Abrahamsson [14] discussing the criteria for "the good work", pointed out that "…an assembly line can be organized around a group-based organization…", which is something already done in "truly" lean companies. Production teams, like the cell layout teams, problem-solving teams, and the Quality Circles are in the heart of these companies and, most of the time and for most people, they promote a better workplace through an increasing work satisfaction. Nevertheless, in some cases, teamwork may provoke stress to some workers, mainly if they enjoy working on their own or if they see more duties and responsibilities as a sign to work more without being paid for it. The solution to this may be to train the workers for teamwork and problem-solving issues.

5.2. *Influence of waste elimination: Muda, Mura and Muri*

If looking at the basic principles of LPS it is possible to find concepts like the continuous pursue of waste elimination, called elimination of *Muda*, as well as the elimination of *Muri*. Since this paper is also about human factors, special attention should be paid to the concept of *Muri* elimination. The Japanese word *Muri* means physical strain or overburdening. Any actions such as "bending to work", "pushing hard", "lifting heavy weights", "repeating tiring actions", and "wasteful walk" are considered *Muri* and consequently they must be eliminated according to the LPS principles. Any implementation of LPS that does not reduce *Muri,* or even worse, if increasing it, as reported in some publications, should not be considered as fully representing the *'true spirit'* of the LPS implementation. If we look at the very first publication in English about TPS [6] we find that TPS is based on two main concepts. The first one is the reduction of cost through the elimination of waste and the second is "to make full use of workers' capabilities". This second concept is referred "in short" by the authors as "treat the workers as human beings and with consideration". Any practical implementation that contradicts this concept cannot be considered as a truly lean implementation.

One of the techniques that, at the beginning, may lead to some discomfort among workers is the Standard Work technique. This technique is strongly related to "all work shall be highly specified as to content, sequence, timing, and outcome," which is the first out of the four TPS rules presented by Spear and Bowen [33]. The operations must be followed exactly as it is defined and there is no margin for improvisation (referred as inflexible work pattern). According to the same authors, "Toyota managers recognise that the devil is in the details" and therefore every task must be specified in detail to avoid unexpected results. In other words, this rule prevents the generation of *Mura* (variability), improving quality, effectiveness of the planning, safety, as well as helping preventing WMSD. The reasons why improvements in safety and health are expected is because when a standard is created, more attention is given to the design of the operations and therefore the issues of safety and prevention of WMSD are naturally taken into account. When a worker follows the pre-defined and tested job detailed instructions, he or she is preventing work hazards and decreasing the risk of WMSD development.

In many Standard Work implementations it is possible to observe workers' disapproval, since they may feel some loss of flexibility and autonomy. In many cases, after some time, they may see the benefits of such implementations and the initial stress gradually disappears. It should be pointed out that in real lean environments workers are encouraged to propose new standards to be applied if they find better ways of performing the same task. The improvements must follow the fourth rule, which indicates that "any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest level in the organization" [33].

The same issue is referred by Jayaram [76] stating that, apart from product, equipment and methods, people are also one of the main causes of variation due to lack of motivation, fatigue and improper training. According to the author, the lean solution (taken seriously by Toyota) is the culture of problem solving decentralization and of empowering workers to make decisions. The workers are encouraged to treat the problems as they arise and to develop suggestions for improvements in a way that they feel playing a significant role in the production success.

To show that the ergonomic issues were taken very seriously by Toyota, which is known to be one of the main sources of the lean production approach, the new ergonomic assessment method was created to be followed in new assembly lines called "Toyota Verification of Assembly Line". In this method several ways are identified to improve the physical work environment [77]. Also, Eswaramoorthi et al. [78] redesigned Lean assembly lines with ergonomics concern in order to eliminate wastes related with unreasonable mental or physical burden.

The repetition of the same movements for long periods, increasing the risk of WMSD, is reported in many publications as one of the drawbacks of lean implementations. Any solution that results in these types of disorders is considered as *Muri* and, accordingly, it is not acceptable under Lean principles. When short cycle times are present, some solutions, such as the "rabbit chase" or forcing the workplace rotation among workers, should be implemented. In some cases, workers show some resistance in the beginning but normally the success is achieved after a short period.

As a result of lean implementations, some authors pointed out that workers need to be multi-skilled, often implying job enlargement and work intensification. On the other hand some other authors reported, as results of lean implementations, a reduction in the cycle time. Those two effects cannot coexist at the same time since they are conflicting conditions.

The reported negative impacts of lean implementations, namely the work pace, increase and the work intensification perceived by workers may also be a real issue. Lean implementation also implies a better use of the workforce. Solutions are developed to use the workforce in adding value during most of their working time. During Lean implementations it is necessary to eliminate non-value adding activities, such as people waiting for material, waiting for orders, or searching for tools, transport equipment, walking, transporting materials, monitoring equipment, etc. The final result will be a greater 'use' of people in value-adding activities.

Good lean solutions must be the ones that, although increasing the efficiency in the use of the workforce, also improve the working conditions resulting in an increase of team spirit and motivation among workers. In this respect, Brown and O'Rourke [70] refer that in Lean production a key to worker safety is the development of informed, empowered and active workers with the knowledge and opportunity to act in the workplace to eliminate or reduce hazards.

As already mentioned, the LPS principles are focused on improving working environments by creating appropriate workplaces, team spirit, challenges, motivation, flexibility, cross skills, responsibility and autonomy. From the literature review and authors' experience, if some of those goals are not achieved it is likely that the developed LPS solutions are not based on a real Lean approach. As reported in Womack et al. [48], lean manufacturing seeks to define a minimum number of resources, therefore all the people involved will have mutual interest that the work is safe, the workers have high morale and low injuries prevalence occur. These authors suspected that negative consequences of lean production in past studies happened because lean tools were used in traditional companies, i.e., without the broader philosophy implementation. This is also the authors' belief.

6. Concluding remarks

This study comprised a comprehensive literature review of the last decade regarding the possible impact, both positive and negative, of Lean Production Systems on the occupational ergonomics.

The core principles of LPS, being the same as the ones followed by TPS (Toyota Production System), assume a constant concern with the ergonomic aspects of the workplaces through the elimination of sources of physical strain or overburdening. Moreover, the motivation and welfare issues play a key role in the development of an effective and sustainable environment for continuous improvement, required under the LPS approaches. Nevertheless, many publications on LPS implementations reported negative consequences for the working conditions.

From this literature review we ended up recognizing that there is no consensus on the impact of LPS implementations on the working conditions. Some authors referred to negative impacts on dimensions, such as human effort, workers' autonomy, risk of WMSD development, job enrichment, and workers' participation and engagement, while other authors reported exactly the opposite. On the one hand, it is possible to notice that no author has yet reported any improvements on stress reduction through LPS implementation. On the other hand, there were no reports on negative impacts on teamwork or on hierarchical level increase.

As aforementioned, the principles of LPS should not lead, by definition, to any of the reported drawbacks in terms of workplace ergonomics. The reported disadvantages of LPS implementations may result from the misunderstanding of the Lean principles and possibly by implementing similar solutions that may be effective in a specific work context but not suitable to all possible situations.

Acknowledgement

This work was financed by National Funds – Portuguese Foundation for Science and Technology, under Project Pest-OE/EME/UI0252/2011.

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