Gaps between psychophysical demands and perceived workload – a framework for lean production system

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Abstract

The adoption of lean model means a systematic implementation of various management practices. Such model presents the human element as a key factor in continuous improvement efforts, influencing workers' job content and work quality. However, there are few evidences regarding researches on quantitative assessment of the work demand, either psychological or physical, in a lean production environment. Therefore, this study aims to analyse from an ergonomics perspective the psychophysical demand and worker's perceived workload within assembly cells undergoing lean implementation. The proposed method integrates complementary concepts of widely known techniques, enabling the consolidation of several assessment criteria into one particular index for both psychological and physical demands. Such method is illustrated in a case study in an auto parts industry, whose application is performed in three assembly cells. Our findings show systemic gaps between work demand and employees' profile, indicating improvement opportunities in order to provide a better work environment.

Keywords
Ergonomics, Lean system, Framework

1. Introduction

Any successful enterprise in the current global economy must possess effective and efficient organization of work at the management level (i.e., management and production methods) in order to optimize the work demands and conditions of the workforce and, subsequently, establish the best work practices conducive for maximum human health and productivity and quality of work (Oneill, 2005; Genaidy and Karwowski, 2003). The adoption of lean production model means a systematic implementation of various management methods and practices, such as just-in-time manufacture, teamwork and jidoka (Seppala and Klemola, 2004). Such model presents the human element as a key factor in continuous improvement efforts. Therefore, it directly influences workers' job content and the quality of work, since it provides increased opportunities for participation, worker control, and learning (Getty, 1999). Eklund (2000) demonstrates on its findings a clear relationship between work demand (physical and psychological demands) and quality and productivity performance.

Research into ergonomics and working conditions has for a long time focused on regular production work to a large extent (Eklund, 2000). However, Backstrand et al. (2013) comment that it is important to see ergonomics/human factors as a part of lean production practices. The lean production model differs radically from the mass production model in terms of the work demands and the work energizers acting on the workers. Theoretically, a true lean production model may tax the worker's muscular, cognitive, and emotional resources to the limit. At the same time, this model must deploy an integrated battery of work energizers to bring compatibility with the muscular, cognitive, and emotional demands. Work energizers may include, among others, task variety, employment security, financial incentives, development and utilization of skills and knowledge, and knowledge of organizational performance (Seppala and Klemola, 2004; Toralla et al., 2012).

A work demand may be either physical or psychological, although they are connected with each other and cannot be separated completely when a person is performing a particular task. Moreover, the same task may result in different levels of individual work demands because of human differences in capabilities, efforts, attitudes, cognition, skills, limitations, and states of situational awareness, complacency, fatigue, boredom, anxiety, stress, etc (Lean and Shan, 2012). Changes in human performance and behavior resulting from psychological demands are closely related to the physiological and biochemical changes in the body, which are based on nervous regulation (Zink, 2000). Furthermore, in evaluating whether a system has a proper design and a reasonable work demand, it is necessary to accumulate evidence that is both quantitative and qualitative nature. Such evidence is accrued from a variety of sources both engineering and human (Macleod, 2003).

Literature presents few evidences regarding researches on quantitative assessment of the work demand in a lean production environment. However, there are some data available – from US and Europe – to answer questions about the impact of lean production on job dimensions and health. Production work has been substantially researched in terms of work design (Eklund, 2000). However, most studies that investigated the health and safety effects of lean production model are in automotive manufacturing industry (Koukoulaki, 2014; Ulfsfalt et al., 2003; Joseph, 2003). In terms of managerial implications, Hagg (2003) discusses different corporate initiatives regarding work demands under lean environments and states that most of them are limited or present significant methodological gaps, which imply in poor analysis and practical results. In fact, few organizations study their operations in detail as long as they appear to be working satisfactorily (Beevis, 2003).

Furthermore, the relation between the work demand and worker health is not known. Such information is vital to assess the best human performance practices that promote the optimum worker health and productivity and work quality in lean production environments. Genaidy and Karwowski (2003) affirm that research on human performance in lean production environments has been hampered by the inadequacies of prior studies both from theoretical and methodological standpoints. Beevis (2003) mentions that the concerns about commercial confidentiality and the cost of the necessary data collection and analysis effort are also disincentives to developing case studies. Therefore, the best human performance practices are yet to be established in a lean production environment.

This study aims to develop a framework that enables to identify the main gaps between the psychophysical demands and perceived workload within assembly cells undergoing a lean production implementation. The proposed method comprises the integration of complementary approaches, which provides a more robust and holistic analysis, indicating whether the identified demand gaps are systemic or punctual, thus prioritizing the improvements. Moreover, since the assessment is performed based on the existent workload balance among workers within the cells, the proposed method allows identifying the psychophysical bottlenecks created with the established standardized work, which usually does not take into account such details (Rother et al., 2001). This research is illustrated on a case study carried out in three assembly cells of a Brazilian auto parts manufacturer company, which has been implementing lean production practices for more than twenty years. Despite the fact that these cells have been continuously exposed to lean practices and improvement activities, they are the ones that manufacture the heaviest components and present the highest level of working complaints in company's medical department. Thus, with the application of the proposed method, it is expected to understand the existent demands and critical issues, so that the improvement opportunities can be addressed.

The contribution of this research is two-fold. First, academically, it provides a method that combines assessment of work demand and worker's perceived workload in a unique approach. Such combination fulfils the existent gaps identified in literature, since it integrates the psychological and physical aspects from an ergonomics standpoint. Moreover, it enables to measure the psychophysical impacts of a lean production environment, providing a better comprehension of ergonomics factors under such context. Secondly, in managerial terms, the study's outcomes allows the establishment of a psychophysical demand map along the company's workstations, indicating critical points for improvement in medium and long terms. In a short term view, this map also supports management in directing the labor force distribution according to workers' profile, in order to minimize working issues and complaints.

2. Physical and psychological risks in a lean production environment

The identification of lean and its consequences for human performance is further complicated by the fact that the possible consequences of lean will also be related to the context and its implementation (Vieira et al., 2012). It has to be expected that the context of the workplace will have an influence on the motives for introducing lean, how lean is interpreted, and what aspects of lean are emphasized. If, for instance, industrial relations are hostile with low levels of trust between management and employees, lean will be approached and shaped quite differently from a situation with high levels of trust and strong collaboration between the two parties (Hasle, 2014).

During the preparation for lean production implementation, it is important to identify MSDs (musculoskeletal disorders) and psychological risks and difficulties, since many problems can be avoided if they are known right on the first step and in order to better prepare the work environment (Maia et al., 2013). Koukoulaki (2014) examines the effects of lean production practices on MSDs, stress and associated risk factors. Work-related MSDs cover a wide range of inflammatory and degenerative diseases of the locomotor system. Examples of risk factors are repetitive handling at high frequency, awkward and static postures, force exertion, vibration, etc. Work-related psychological risks concern aspects of the design and management of work and its social and organizational contexts that have the potential for causing psychological or physical harm (Brannmark, 2013). Psychological risks are job demands, time pressure, low job control, social relations with superiors and colleagues, job insecurity, etc (Oneill, 2000).

Theoretical perspectives on the effects of lean production have evolved through the years. An analysis of trends in lean production and its effects is presented in Table 1. The analysis identifies four time periods in which studies were undertaken when there were different approaches to lean production implementation (Hines et al., 2004) and different findings about the effects of these implementations. Sparked by the superior performance achieved by lean producers over the performance of traditional mass production system designs, western manufacturers emulated the shop-floor techniques, the structural parts of lean, but often found it difficult to introduce the organizational culture and mind-set (Resnick and Zanotti, 1997). Many early lean efforts showed localized impact only, and fell short of their intended impact on the overall system's performance (Holweg and Pil, 2001). In this awareness period (up to 1990), the main weaknesses of lean production were its automotive manufacturing-based view and limited appreciation of how to handle variability in demand. The implementation was entirely tool-focused, and generally neglected the human aspects of the high-performance work system core to the lean manufacturing approach. Therefore, the majority of studies at that time report negative effects related to faster work pace, increased upper limb disorders and perceived stress (Mullarkey et al., 1995; Babson, 1993; Berggren et al., 1991; Klein, 1991).

After 1990, there was a gradual widening of focus away from the shop-floor, a trend often ignored by omission, error or design by many detractors. This process of "extension" was also accelerated by the promotion of successful western case emulation by businesses in diverse sectors that had adapted their production systems to include a new design based upon "lean principles" (Hines et al., 2004; Womack and Jones, 1996). These principles involved the identification of customer value, the management of the value stream, developing the capability to flow production, the use of "pull" mechanisms to support flow of materials at constrained operations and finally the pursuit of perfection through reducing to zero all forms of waste in the production system. Regarding risk factors and health effects, the research focus started to shift from mechanical exposure and health effects as MSDs to psychosocial risk factors and stress. The findings from these studies are mixed with some job characteristics negatively affected and others positively. The reason behind the shift from negative effects to mixed outcomes might be that the work characteristics that cause MSDs were not so extreme in these manufacturing sectors compared with the automotive industry (Christmansson et al., 1999; Parker and Sprigg, 1998; Bao et al., 1997; Jackson and Martin; 1996; Parker et al., 1995).

The comprehension evolution on lean production may be summarized as a focus on quality during the literature of the early 1990s, through quality, cost and delivery (late 1990s), to customer value from 2000 onwards, as shown in Table 1. Also, during the mid-1990s, the value stream concept evolved and was seen to extend beyond manufacturing or the single company, and stretch from customer needs right back to raw material sources (Hines and Rich, 1997; Rother and Shook, 1998). This provided the link between lean and the supply chain, as for the first time, the production "pull" was extended beyond the boundary of the single factory to include the up- and downstream partners. Thus, in the last period from 2000 to the present, studies were undertaken in a range of sectors that included service organizations that had gradually started to implement lean practices. The results include controversial both negative and mixed effects. The nature of the effects depends on two factors: (i) the sector (e.g. the automotive industry nearly always shows negative effects) and (ii) the way lean practices are implemented (e.g. management decisions on which lean practices to implement and how) (Saurin, and Ferreira, 2009; Conti et al., 2006; Leroyer et al., 2006; Karia and Asaari, 2006).

Table 1. Literature trend analysis on evolution of lean thinking and its risk factors and health effects (adapted from Koukoulaki (2014) and Hines et al. (2004)

	1980 – 1990 Awareness	1990 – mid 1990's Quality	Mid 1990's – 2000 Quality, cost and delivery	2000+ Value System
Literature theme	Dissemination of shop-floor practices	Best practice movement, benchmarking leading to emulation	Value stream thinking, lean enterprise, collaboration in the supply chain	Capability at system level
Implementation focus	JIT techniques and cost	Cost, training and promotion, TQM, process reengineering	Cost, process-based to support flow	Value and cost, tactical to strategic, integrated to supply chain
Key business process	Manufacturing shop-floor only	Manufacturing and materials management	Order fulfilment	Integrated processes such as order fulfilment and new product development
Sectors examined	Automotive – vehicle assembly	Automotive – vehicle and component assembly	Manufacturing in general – often focused on repetitive manufacturing	High and low volume manufacturing, extension into services
Lean effects theory development	Lean production brings only negative effects to workers health		Lean production has mixed effects (increased workload but better psychosocial environment)	Controversial results (negative and mixed effects). Effects are depending on the sector and lean practices implemented
Main risk factors and health effects investigated	MSD	MSD and stress	Psychosocial factors and stress	Psychosocial factors and stress

3. Research method

To attend the purpose of this paper the research method began with a demographical data collection and previous analysis of work processes. This initial assessment intends to supply practical insights from a real lean systems perspective before the framework was setup. After that, the framework setup was conducted based on three main steps (see Figure 1): (i) define proper methods for work and worker characteristics assessment, (ii) define the psychophysical demand and workers' perceived workload criteria and (iii) analyze gaps and identify improvement opportunities.

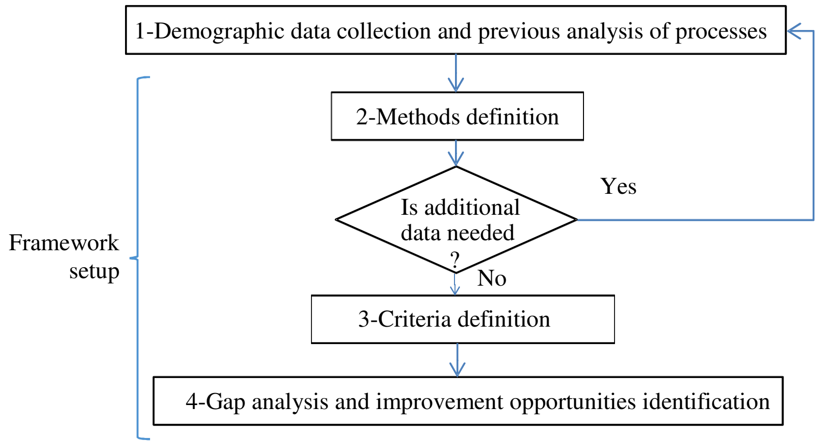

Figure 1. Proposed framework main steps

3.1. Demographic data collection and previous analysis of processes

The first step consists of collecting available data related to processes and workers. With regards to processes, several data may be quoted as fundamental for previous analysis of work demand, such as process cycle time, demand, standardized work procedures, layout, weight of manipulated components, number of shifts and employees within the cell, heights and parts handling distances, kind of packaging, existence and frequency of quality inspections and procedures, etc (Lean and Shan, 2012; Beevis, 2003; Parker and Sprigg, 1998). Regarding workers, it is recommended to gather data, such as accidents and medical records, experience and skill level, age and working complaints (Eklund, 2000; Macleod, 2003; Leroyer et al., 2006). Such demographical and process data are used as the basis for the next step of adaptation and definition of proper psychophysical criteria. Moreover, they can be further exploited in order to verify existent correlations with results obtained in the assessment and justify them.

3.2. Framework setup

The next steps comprise the definition of the methods and criteria used on the framework. The framework methods were chosen in order to accordingly meet the demands of working conditions and workers profiles. This was done by combining three different approaches: (i) the RNUR or the job-profile method of Renault (1976), which was developed with the National Control of Factories in France and intends to quantify general work demands through the analyst (ergonomist) point of view; (ii) NASA-TLX (1986), which is a multi-dimensional scale designed to obtain workload estimates from one or more operators while they are performing a task or immediately afterwards; and (iii) GHQ or General Health Questionnaire (Goldberg and Hillier, 1979), which is a screening tool to detect those likely to have or be at risk of developing psychiatric disorder.

The selection and application of these methods were performed by an ergonomist after the first direct observation of the tasks. Also, there was a meeting with some company managers (e.g. production, engineering, safety, occupational health) in order to define their applicability over the studied workplace. The proposed framework uses a simplification of the NASA-TLX and GHQ results. Its traditional point's scales were rescaled to a five point scale in order to allow the results comparison with the RNUR method.

The main worker's perceived workload was analyzed separating psychological and physical criteria. The two methods applied for both criteria were the NASA-TLX and the GHQ. Only three (out of six) NASA-TLX criteria and two (out of five) GHQ criteria were conducted by the framework. The choice for each criterion that composes the proposed framework was a consequence of applicability and workers' profile observed at the first step. The Table 2 shows the criteria source and application description.

The main psychophysical work demands were analyzed separating psychological and physical criteria. The main method applied for both criteria was the RNUR. Out of the thirty existent criteria in the Renault's method, only six were applicable for our study: (i) supply-removal, (ii) level of alertness, (iii) repetitiveness of cycle, (iv) work effort, (v) heavy objects handling and (vi) potential. Table 3 shows the criteria source and an application commentary. The quantitative application of these criteria was inverted in relation to the original RNUR methodology. In our framework, values were change to make the possible comparisons and gap analysis. In the original methodology a greater value represents a worst work demand. In this framework, the greater the value the better work demand is.

Table 2. Physical and psychological perceived workload criteria

Physical perceived workload criteria		
Source	Criteria	Description
NASA-TLX	Performance	It represents how successful the worker feels in accomplishing the goals of the task considering lean production characteristics such as standardized work
	Effort	It represents how hard the worker have to work to accomplish his level of performance
Psychological perceived workload criteria		
Source	Criteria	Description
NASA-TLX	Frustration	It represents how insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did the worker feel during task
GHQ	Psychic stress	It represents evidences of tension, irritation, impatience, fatigue and overload, that make the worker life a constant, exhausting and unhappy fight
	Performance suspicion	Expresses the awareness of being able to play or perform daily tasks satisfactorily

Table 3. Physical and psychological demand criteria

Physical demand criteria		
Source	Criteria	Description
RNUR	Heavy objects handling	The compatibility between the height of heavy objects handling during the task and the worker height
	Supply-removal	The compatibility between the dimensional characteristics of feeding and evacuation devices and the normal worker postures
	Thermal environment	The risk of thermal discomfort considering air temperature e the dynamic workload on a workstation
Psychological demand criteria		
Source	Criteria	Description
RNUR	Initiative	The possibility of the worker vary its work rhythm without perturbing production
	Thoroughness	The level of worker skills needed to maintain satisfactorily the task
	Identification	Elements of motivation and satisfaction linked to the task of compliance

Finally a comparison between each criterion occurs, quantifying the gaps magnitude and revealing improvement opportunities. The gap comes from the difference between the criteria and represents an ergonomics indicator of that working situation. The resultant gaps should address improvement actions. However, these improvement opportunities need to consider not only the gaps, but also the initial information of step 1 and all qualitative information that was gathered trough the framework application. Table 4 shows the relationship between criteria and their specific meanings.

Table 4. Relations between framework criteria

		Psychophysical demands	Profile	Comments about the gap
Physical	1	Heavy objects handling	Effort	The height of heavy objects handling should be adapted to anthropometric characteristics of the workers in order to reduce effort
	2	Supply-removal	Performance	The workstation' physical design and/or work organization should be facilitated to improve workers performance
	3	Thermal environment	Effort	The thermal environment should be controlled avoiding extreme heat or cold temperatures to reduce influence on workers effort
Psychological	4	Initiative	Psychic stress	Task and work organization must allow that workers leave their workstations whenever is needed so the psychic stress is reduced to a minimum level
	5	Thoroughness	Frustration	The level of worker skills needed should consider psychosocial characteristics of the workers so the level of frustration on the job does not get uninteresting
	6	Identification	Performance suspicion	The tasks and the products should motivate and bring satisfaction to workers so they perform their job without suspicion

4. Case study

4.1. Framework application

The case study was developed in a southern Brazilian large auto parts manufacturer. Its facilities consist of six manufacturing units, with different processes such as machining, punching, forming, tempering, painting and assembly, totaling approximately 1,500 employees. This company started its lean production implementation in 2003 and has widely trained and implemented several lean practices along the site. Many continuous improvement activities were developed and stimulated by senior management, especially at the assembly unit, which is the final unit before parts expedition and the one that presents the highest level of manual tasks within the cells. This unit also presents the highest level of absenteeism and labor complaints due to MSDs at company's medical department. Therefore, among the 21 existent assembly cells, our case study took place at the three assembly cells with the highest level of employees' complaints. These cells present specific characteristics, as shown in Table 5. Cells A and C are the ones that present the heaviest parts assembled in the whole assembly unit, while cell B is the one with the fastest demand pace, around 20 seconds per part, which implies in the highest frequency of the performed tasks within the cell. Moreover, these three cells have been through an extensive amount of lean training and demonstrate to be sustaining such lean practices in a cell level along time, which carves the scenario of this research.

The tasks performed on these cells were mainly manual operated with drive shaft components assemble. The framework was conducted among eighteen cell workers, which are allocated on three different work shifts. The researchers, specialists (ergonomics and lean expertise) and the managers performed six meetings to conduct and discuss the ongoing research. The researchers visited the company several times to perform application of the proposed framework and record some general data. These data included the age, height, weight and the period of work of each worker. Also, the medical department was contacted to collect workers' physical claims, absenteeism index and their main medical records (see Table 6).

Table 5. Main characteristics of assembly cells included in the case study

Assembly cell	Employees per shift	Working shifts per day	Parts demand per shift	Assembled parts average weigh (kg)	Absenteeism level (%)
A	4	1	840	8.45	8.3%
B	3	3	1,260	4.02	9.4%
C	3	1	910	8.09	9.8%

Table 6. General data of participants

Data	Mean	Std. Dev.
Age	29.21	6.48
Height (cm)	175	6
Weight (Kg)	78.93	12.87
Working Time (months)	60.06	65.79
Physical claims	1.79	1.65
Absenteeism (days)	13	10.71
Medical records	Hearing loss, musculoskeletal pain (shoulders, elbows, wrists, hands, knees, hips, low back)	

4.2. Perceived workload and psychophysical demands

For the perceived workload, workers after their working shift were invited to answer questions on mental, physical, temporal, performance, effort and frustration aspects. The results showed in Figure 2, present that, for physical profile, effort aspects are the main perceived components of their workload (mostly between levels 3 and 5). Further, for psychological profile, results show a low level of workers' capability, which is mostly scored between levels 1 and 3.

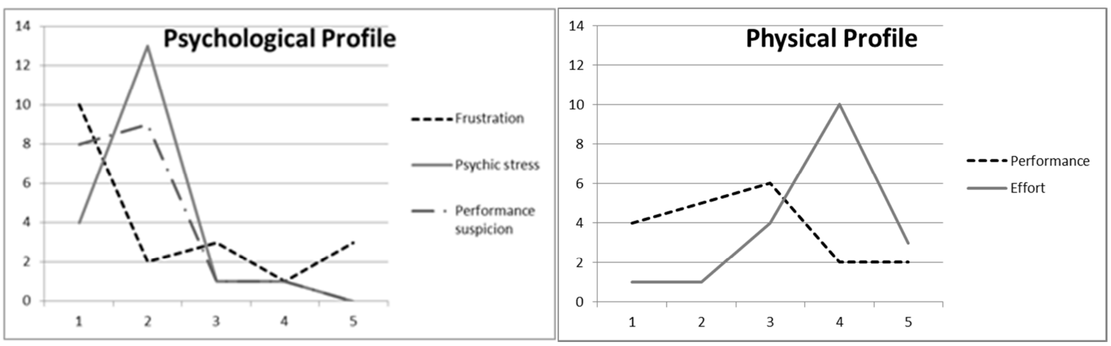

Figure 2. Physical and psychological profiles of the perceived workload

For psychophysical demand evaluation, researchers assessed each operation of the tree cells included in the study. The demand's results are presented in the Table 7. The numbers on the table reefers to the inverted five point scale of the method, attributed by the specialists after several technical observations. These observations were made during different work shifts and used video records to facilitate the process.

Table 7. Psychophysical demands of each operation. Inverted values of RNUR considering that greater is better

Criteria	Cell A				Cell B			Cell C		
	Op. 1	Op. 2	Op. 3	Op. 4	Op. 1	Op. 2	Op. 3	Op. 1	Op. 2	Op. 3
Heavy objects handling	5	4	1	1	5	3	2	5	3	1
Supply-removal	4	4	4	5	4	3	5	4	3	5
Thermal environment	1	1	1	1	1	1	1	1	1	1
Initiative	2	2	2	2.5	2	2	2.5	2	2	2.5
Thoroughness	4	4	4	5	4	4	5	4	4	5
Identification	2.5	2.5	2.5	1.5	2.5	2.5	1.5	2.5	2.5	1.5

4.3. Gap analysis

All perceived workload and psychophysical demands' results were compared regarding each cell's operation. The difference between them is showed in Table 8. These values may vary from -4 to 4 and indicate the level of work adaptation to its workers' profile. The lowest values in one criteria (e.g. Heavy objects handling/Effort) shows the specific needs of improvement of each cell operation (e.g. cell A/operation 4, or A4).

As it can be seen on the results, the gaps of the same operation of each cell tend to be similar. The gap for criterion 5 ("thoroughness/frustration") of cell A/operation 1 is 2.11 as well as operation 1 of cells B and C. This occurs due to its similarities in terms of working conditions and workers' profile. The Heavy objects handling/Effort (criteria 1) has received higher levels mainly on end operations (3 and 4) of each cell. This was expected given the parts assembly nature of these tasks. Any improvement action that could reduce this heavy objects demand will impact positively in the gap and can reduce as well the effort perceived.

Table 8. Gaps values for each operation. The head line numbers represents the mean values of the six criteria used

Criteria	Cell A				Cell B			Cell C		
	Op. 1	Op. 2	Op. 3	Op. 4	Op. 1	Op. 2	Op. 3	Op. 1	Op. 2	Op. 3
1	1.32	0.32	-2.68	-2.68	1.32	-0.68	-1.68	1.32	-0.68	-2.68
2	1.37	1.37	1.37	2.37	1.37	0.37	2.37	1.37	0.37	2.37
3	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68	-2.68
4	0.05	0.05	0.05	0.55	0.05	0.05	0.55	0.05	0.05	0.55
5	2.11	2.11	2.11	3.11	2.11	2.11	3.11	2.11	2.11	3.11
6	0.76	0.76	0.76	-0.24	0.76	0.76	-0.24	0.76	0.76	-0.24

Table 9. Gaps analysis

	Criteria	Comment about the gap
Physical	1	The height of heavy objects handling should be adapted to anthropometric characteristics of the workers in order to reduce effort. Operations A3, A4, B3 and C3 should be prioritized on this behalf.
	2	The workstation' physical design and/or work organization should be facilitated to improve some workers performance on operations B2 and C2.
	3	The thermal environment should be controlled avoiding extreme heat or cold temperatures to reduce influence on effort of almost all workers and all the operations.
Psychological	4	Task and work organization must allow that workers leave their workstations whenever is needed so the psychic stress is reduce to a minimum. There is no specificity of operations on this criterion because the work organization evaluated affects all cells.
	5	The level of worker skills needed should consider psychosocial characteristics of the workers so the level of frustration on the job doesn't get uninteresting. Considering the low time cycle this is not a great concern but could be improved on operations A1, A2, A3, B1, B2, C1 and C2.
	6	The tasks and the products should motivate and bring satisfaction to workers so they perform their job without suspicion. Three quality related operations are critical on this criterion: A4, B3 and C3.

5. Conclusion

The main findings on this case study suggest that the gaps analysis between psychophysical demands and perceived workload could be a helpful approach to lean systems. The psychophysical demands results show inconformity with the workload perceived by these cell workers. This result indicates that, despite the fact the standardized work techniques were already applied in these cells, traditional lean practice is not sufficient to define workers tasks and a broader approach should be used. Further, a traditional approach would bring the work demand analysis over several characteristics. The proposed framework confronts that type of analysis with the workers perception highlighting the gaps between demands and workload on lean cells operation.

Despite the contribution of our study, further researches are necessary to improve the comprehension around the subject. In our study, despite the existence of several criteria for assessment of psychophysical demands, only six criteria were elected. This was a consequence of the case study that was used to illustrate the proposed method. However, our results applicability in other companies is limited due to this scenario. Therefore, an approach that is supported by complementary criteria, providing a general overview about the problem is fundamental for companies' real life problems.

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