TOWARDS A GREEN COMPANY THROUGH LEAN MANUFACTURING. REVIEW AND STATE-OF-THE-ART

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There is also a version in Spanish HACIA LA EMPRESA "VERDE" CON LEAN MANUFACTURING. REVISIÓN Y ESTADO ACTUAL that can be accessed by subscribers or on a pay per view basis.

1. INTRODUCTION

In 2014, a brewing company informed in the press that they had managed to reduce their water consumption and emissions of carbon dioxide within its corporate social responsibility strategy. The headline stressed that these reductions were due to the implementation of Total Productive Maintenance (TPM).

Currently, the traditional production model is considered unsustainable [1]. Companies support increasing pressures to become "green" or environmentally friendly (low levels of energy consumption, raw materials usage, hazardous usage, low levels of waste and low amounts of pollutant discharges [2]). The curious thing is that this company makes use of TPM [3, 4], a practice in the field of lean manufacturing (LM), to achieve environmental goals. The approach has some logic because LM attaches great importance to the reduction of activities without added value which are called "waste" (*muda* in Japanese) [5] and excessive usage of materials or energy and tasks of waste management are undoubtedly "waste" [6]. However, LM focuses on production, not on the environment, which leads to ask whether LM really has positive effects on the environment. Rao [7] states that making a company "green" refers to the productive system of the company, which is the main source of environmental impacts. There is a strong connection between production and the environment: modifying the production process may have environmental consequences and pursuing environmental objectives may lead to changes in the processes in order to reduce emissions, with corresponding implications for efficiency and economic performance.

A first search took us to a study [8] on synergies between the implementation of LM and being "green", the so called "lean and green" hypothesis . Within the model of resources and capabilities [9], the combination of these concepts is a valuable resource that can provide a competitive advantage, although perhaps only temporarily. This work [8] is focused on a particular sector (car manufacturers) and gets to the surprising conclusion of the existence of both positive and negative relationships depending on the type of study (quantitative questionnaires and qualitative interviews) and the variables used. That made us wonder about the evolution of research on lean and green. The following review of the literature led us to observe a wide dispersion of methods of analysis, sample sizes and conclusions. As such heterogeneity only hinders the advancement of knowledge, we found that the divergence of results justified conducting a systematic review of the literature to investigate its causes and find how far the cause-effect relationship between lean concepts and " green" has been proved; with what methods of analysis; in what circumstances (countries, types of companies): what practices or tools LM and what environmental aspects. And also, because [8] highlights the importance of the human factor, we wanted to see how this element had been taken into account in different studies and what conclusions had been derived.

Finally, we wanted to check to what extent the alleged benefits of a lean and green company impacted the bottom line.

Our work aims to contribute to the understanding of the sources of discrepancies through the answers to the above questions, to provide future research and facilitate structured information on this topic to new researchers. In addition to its academic interest, the issues raised here are of practical nature. Practitioners should be the first ones to question what works, under what circumstances, for whom and why [10], avoiding being misled by prejudices or biased opinions. Otherwise, looking for a quick solution to their problems, they can rely on texts where a certain methodology may be advised just on a limited empirical basis. When a topic is well studied from a scientific point of view, practitioners have greater guarantees.

2. MATERIAL AND METHODS

This work aims to answer the questions posed in the introduction by means of a review of the literature and its bibliometric study and content analysis, in order to achieve a better understanding of the state-of-the-art of research in this area. In its development, we have followed the phases of a model [11] which was specially conceived for the field of Operations Management: Definition of the field of study in order to set limits to the review: selection of sources of information; conducting the search; depuration of the results and, finally, analysis of results.

In this way, it is possible to identify, select and critically appraise relevant research on this subject, in an objective and systematic way, in order to get to know what is known and what is not about the issues raised here [12] so this systematic review of the literature can be considered as original research. To locate items to review, Web of Science was used. This way, we restricted our search to academic research papers published in journals that ensure methodological correction of the articles and their relevance. The search was limited to articles in journals, including editorials and revision papers.

We decided to do a systematic review of the literature because it is replicable and updateable. Its main drawback is that we may have skipped some papers. We removed from our research apparently unrelated areas, such as "health" (to avoid articles where the term lean refers to thin people), but this could have eliminated some work on LM in that area. However, if these discarded contributions are relevant to our field, interested researchers will surely find them though cites in other works.

LM is based on the Toyota production system [16, 17, 25] which began to develop after World War II, in order to better adapt car manufacturing to the Japanese context. The system was perfected for decades (see [13]). Other Japanese companies introduced more or less similar systems (in some cases, under the direct tutelage of Toyota). Western world was not interested in Japanese production systems until the 70s, when the oil crisis led to increased imports of Japanese vehicles. The Toyota production system became known with the name of one of the pillars of the system: "Just in Time" (JIT). When, in the 80s, some Japanese auto companies settled in North America, Western manufacturers were surprised by the higher productivity and quality of their eastern competitors. In the late 80s, during the course of a comparison among the productive systems of various car manufacturers, researchers at the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology (MIT), began to call "fragile" and “lean” the systems used in the American plants of Honda, Mazda, Nissan and Toyota, which contrasted with the "robust" systems of other manufacturers [13].

The book "The machine that changed the world" [14], which appeared in 1990, and whose authors were members of the IMVP, greatly contributed to the rapid global spread of both the term LM and its principles. Its success is due, in addition to its practical style, to the word “lean” because the term JIT looked linked to Japanese companies, while the term lean appeared as something fresh that might be applied in any country (as shown with several examples in the book), extending its reach beyond production lines [13]. For this reason, we set 1990 as the starting date of our literature search. The same justification is used in [25].

The search terms used in the fields “titles” or “topics” were "lean and green*", yielding 484 papers between 1990 and 2014. These documents belong to more than 100 research areas, so we decided to limit the search to the areas of engineering (the main contributor), environment, business economics and operations. The search was

restricted to documents in English, which is the predominant language in the references found. In total, 156 items were recovered. Other combinations were tested (for example, "lean and Sustainability" or "lean and Environment*") but either they provided the same results or they resulted in many unrelated papers. In a second phase, the 156 references first provided by the automatic review were manually validated in order to discard papers not related to our study. Finally, 61 papers were accepted.

The next step is the analysis of the selected documents. To do this, a database (it can be found on the Dyna website) was built using MS Excel. The database contains the following fields: Year; authors; journal citations; country where the empirical work was performed; sample (size and business or sector); lean practices and tools [15, 16, 17] that are cited; environmental variables used; research methodology (method of obtaining information and data analysis techniques); consideration of the human factor; observed business results; and conclusions. Since our database is unique, we can say that, although other reviews of the literature exist (see [18]), our work is not a mere reiteration because, because time span, methodology, sources or aspects analyzed do not coincide. We can consider that such revisions are complementary.

3. RESULTS AND DISCUSSION

Figure 1 shows the when 61 studies analyzed appeared. One can see that the publication rate is not constant. The lean & green hypothesis appears for the first time in 1993 in a document [19] from the IMVP written by Professor Maxwell and his assistants Rothenberg and Schenck. The thesis of that work is that when the company adopts LM, the capacity of the operations department to support innovative environmental management practices increases. This view is not shared by other researchers of that time. Thus, Hart [20] presents the LM system as an example of unsustainable production, opposite to what the "green" production should be. During the 90s, neither the pioneers of the assumption nor other followers published in refereed journals, making it easy to fall into oblivion. Thus, several studies were published in *Environmental Quality Management*, such as a valuable study of the IMVP group that shows how LM helped Honda achieve their environmental objectives [21]. From 2001 on, publishing rate in indexed journals increases. Environmental issues become very important in the field of operations management as one can realize from what is published in main journals. Research papers (on lean & green) are written by different research teams and from different countries, so that interest in the issue becomes global. In addition, many studies dealing with supply chain management appear. The moment our research ends coincides precisely with the appearance of a special number of an important journal devoted to lean & green which confirms that interest on that issue is still alive.

Table 1 shows the main indexed journals (which may be of interest to future researchers) in which the studies reviewed were published. *Journal of Cleaner Production* collects a quarter of the articles. In total, there are 33 journals devoted to production (including the most prestigious ones), the environment, logistics and journals for practitioners from several industries (most notably the health sector).

The geographical provenance of the reviewed papers is wide (Figure 2). In the first place, studies from the United States (or United States and Canada) are prominent. That is the country where the concept first emerged and, besides, soon received official support for the Environmental Protection Agency (EPA), that disseminated the synergies between LM and environmental management [22]. According to the number of papers, then we find the UK (seven papers) in the second place. Also based on samples of European countries, we can find three papers on Portuguese companies and two papers on Swedish companies, and eight more papers about several countries. Although we know about related works on Spanish companies [23], we did not find, among the reviewed articles, any papers about Spanish companies that allow us to evaluate the synergies between lean & green in Spain. The country effect should be taken into account as many companies in the reviewed papers precisely attributed their efforts to environmental legislation in their country. In Spain, it would be interesting to study the automotive sector because it is a sector where LM is very developed, as well as other management practices [14]. Finally, we mention the four papers where samples from Asian countries (China, Japan and other Southeastern countries) have been used, to conclude that the "lean & green" topic has been studied in all continents (except Africa), but especially in the industrialized countries.

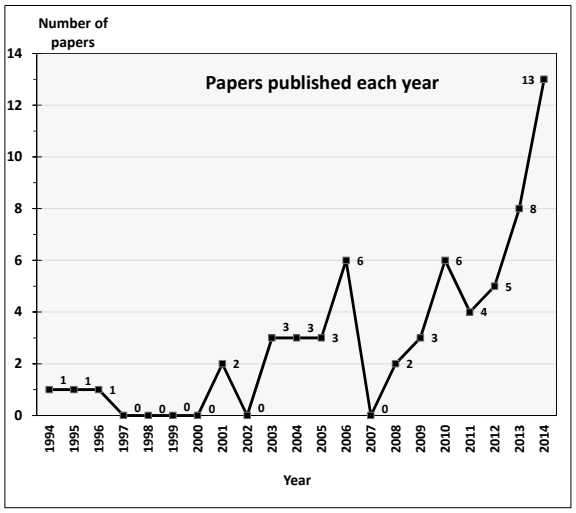

Figure 1: When the reviewed papers were published.

Journal title	Papers	%
Journal of cleaner production	15	24.6
Manufacturing engineering	5	8.2
Production and operations management	4	6.6
International journal of production economics	3	4.9
Industrial engineer	2	3.3
International journal of operations & production management	2	3.3
Journal of construction engineering and management	2	3.3
Resources conservation and recycling	2	3.3
Supply Chain Management: An International Journal	2	3.3

Table 1: Main journals where the reviewed papers were published.

The 61 studies we analyzed correspond to 139 coauthors. If we look at Table 2 which includes the most repeated authors, we see that most authors has made only one contribution on this topic. By number of publications, we can highlight, first, the seminal IMVP group (with Rothenberg), and secondly, the Canadian group formed by Klassen and Vachon (among others) and the group formed by Govindan (Denmark) and Azevedo, Carvalho and Cruz-Machado (Portugal).

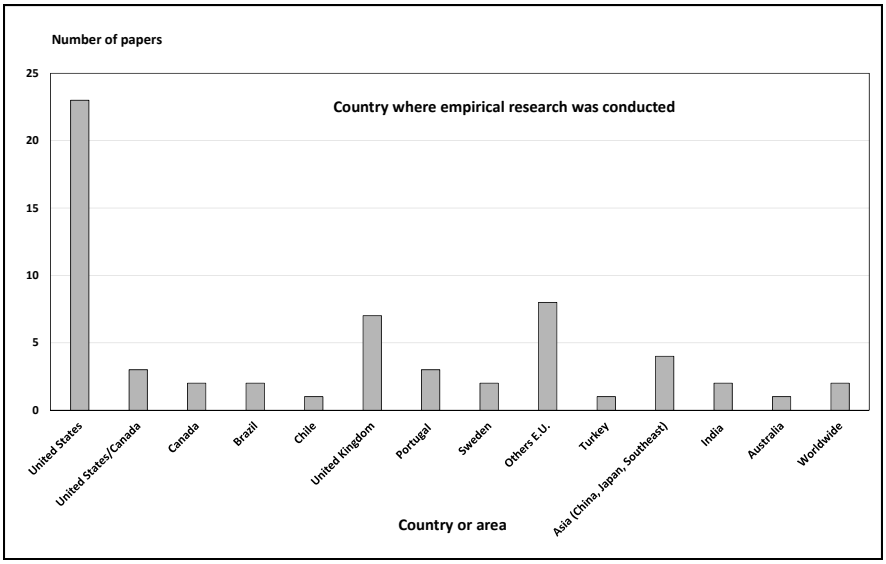

Figure 2: Countries or geographic areas where studies included in our reviewed papers were made.

Author	Papers
Cruz-Machado V.	3
Klassen R.D.	3
Rothenberg S.	3
Vachon S.	3
Azevedo S.G.	2
Carvalho H.	2
Govindan K.	2
Pil F.K.	2

Table 2: Authors with greater number of papers.

Multiple methods of study have been followed (Table 3) in the papers we have reviewed. Most of them are case studies (or sometimes simply examples). For practitioners, a case study may be the most attractive type of work because it illustrates success stories and helps to understand how a company manages lean manufacturing and environmental aspects. For academics, it may be the weakest method because the findings are not generalizable. Next in the ranking come the theoretical papers (without empirical support) and reviews of the literature. Next, we find works where correlation and regression methods or structural equations have been used. It may be surprising not to find these type of papers at top of the ranking because they are commonly used in research because they are the most formal methods that attempt to see if the relationships between variables, in a sufficiently large sample, are statistically significant. The main drawback is that their results do not explain causal relationships [24], which can be perfectly complemented by case studies. Finally, there are some other works where other techniques such as simulation or design of experiments have been used.

Research approach	Papers	%
Case studies and examples	18	29.5
Theoretical, Editorial	15	24.6
Review of the literature	6	9.8
Correlation / Regression	6	9.8
Structural Equations	4	6.6
Interviews and questionnaires	4	6.6
Simulation	3	4.9
Design of experiments	1	1.6
Hierarchical analysis	1	1.6
Others	3	4.9

Table 3: Main research methods.

Very different sample sizes can be found in the retrieved articles. In the case studies, samples are very small, while in statistical studies larger samples are used (from 21 to 522 companies). Sometimes papers study the global activity of a company, sometimes they focus on specific projects, or they even include suppliers, etc. In some papers, research focuses on a specific sector, while others consider equally companies from different sectors. The lack of uniformity in the units of analysis impedes the comparison between papers and the generalization of results.

Shah and Ward [16] warn that there is no unanimity when defining what comprises LM and, of course, when we want to measure it. In the studies reviewed, to justify that a company applies LM or to assess the degree of leanness of a company, researchers have turned to assess the extent of the lean practices (such as just-in-time production, TPM or total quality) and lean tools (5 S, Value Stream Mapping, ...) used in the companies (see Table 4 for the practices and tools that have been considered most of the times in the reviewed studies). Since there is no "right" way to measure LM (although we have found some ways at least arguable) in each of the studies we analyzed different variables ae considered and this diversity does not allow comparison between the items, what would be especially desirable in studies using statistical methods (correlation, structural equations ...). In case studies, usually only those practices or tools whose contribution is intended to describe are mentioned. In

statistical studies, it is usual to consider a selection of practices and tools, defining LM as a construct (a not directly measurable variable). Each work decides what variables are necessary (in some cases a single variable) and even the application of the principles of LM [25] is considered as a variable. Thus, most of the paper simply consider the minimization of waste. In the second place in Table 4, we find quality. Although quality management does not imply the existence of LM, LM in some papers is identified with a quality management system [34]. Also present in Table 4, logistics and supply chain extend the subject to supply chain management. We can find several terms related to the human factor as the capacity to take decisions (empowerment), multidisciplinary teams or continuous improvement (kaizen) so we conclude that the importance of employee involvement receives much attention. Finally, we would like to mention that different authors set forth using the Value Stream Map (VSM) (e.g. [26]), even changes in its original formulation, to identify opportunities for environmental improvement. TPM, which gave rise to our study, instead, although it is mentioned in 8 articles as an important practice in LM, is reserved to improve environmental aspects of the machinery (e.g. [27]).

Since the involvement of employees in an atmosphere of cooperation and trust with their supervisors is a pillar of LM, we assessed whether the reviewed papers include the human factor and we observed that this topic appears in 35 of the 61 papers but it is not included in the remaining 26. We can highlight 13 works where the importance of involving employees (and even suppliers) to get results is stated and 9 more papers that explicitly mention improvement groups and kaizen. In order to achieve results, papers mention the importance of training, staff satisfaction, initiative and creativity, the motivating role of management and leadership style, and the effect of a proper organization and the management of human resources. In [28], the relevance of the human factor is very clear. Shetlar *et al.* show how, after implantation of LM, lean mindset to identify and reduce "waste" is extended to the environmental field thanks to the will of committed people, without resort to any specific methodology, while even achieving measurable results in economic terms. Similarly, [29] shows in detail the commitment of staff, from the operations area, in projects with environmental implications.

Lean practices and tools	Papers
Minimizing waste (7 *muda*)	14
Total Quality Management (TQM)	13
Just in Time manufacturing	10
Logistics and supply chain management	9
Empowerment, multiskilled teams, kaizen	8
Total Productive Maintenance (TPM)	8
Reducing inventories and batch size	8
Reducing process time	7
Staff (HR management)	6
Layout, cellular manufacturing	5
Lean design	5
5 S program (housekeeping)	5
Continuous improvement	5
Quick setup (SMED)	5
Value stream map (VSM)	5
Supplier management	3
People involvement	3
"A3", "5 Why" and "go to gemba" methods	3
Kanban	3
Quality management system (ISO 9000 standards)	2
Six Sigma	2
Quality circles	1
Process standardization	1

Table 4: Lean tools and practices in the retrieved papers.

On the other hand, many studies try to show how much "green" (see definition in [20]) a company is. This is necessary, for example, to study the correlation between being lean and being green or to measure the importance of the environmental improvements (in order to justify that lean practices are green). To do so, articles resort to identifying activities (environmental certification, eco-design, recycling, use of cleaner processes)

and environmental performance (waste, emissions, energy savings, resource consumption). Different papers use a list, more or less extensive, of these indicators. In some cases they also uses monetary terms, such as the amount of certain investments. Each study uses a different indicators and many times these depend on the industrial process involved. Table 5 shows that the indicator which more often appears is energy consumption. The second indicator is the production of waste and, in other positions, we find water consumption, materials, toxic products and companies that compute their carbon footprint [30]. Below them, we found polluting emissions, detailing in some papers the names of the chemical compounds. The relationship that exist between consumptions or emissions and industrial processes make it complex to attempt studies including firms from different sectors, as their consumptions or emissions can be very different. As an added difficulty, we may think that environmental improvements experienced in a company are not necessarily related to LM.

In the 1990s the hypothesis that being green increases the competitiveness of companies [31] arises. That is, to be green eventually yields economic results. If this is so, a company which is both lean (in the studies we reviewed, often this just means being an efficient or a low cost firm) and green must show the benefits achieved by its improvement efforts in its profit. 21 of the papers we analyzed do not include this aspect. In three studies, it is stated that projects become more expensive (due to training, investments, new materials), although one such papers concludes that LM can offset the cost increase. Finally, the remaining 31 papers admit that companies experience reduction in prevention costs, reduction in material costs, lower energy costs, less inventories, less penalties for breaches of legal obligations, etc. However, although there is evidence that better environmental management leads to better business results, these results may also be due to the fact that the company has a better overall management [32], and thus good results cannot be attributed to a single reason.

Green indicators	Papers
Energy consumption (electricity, fuel oil)	23
Waste	16
Water consumption	15
Carbon footprint, CO_2	12
Material Consumption/Squandering	10
Toxic/Chemical products used	9
Polluting emissions	9
VOCs, NOx, ozone, SOx, CO, formaldehyde, metals	5
Environmental management system (ISO 14001)	8
Recycling	7
Ecodesign	6
Prevention and control technologies (clean processes)	3
Life cycle	2

Table 5: Indicators related to environmental impact or environmental commitment in the assessed papers

In the reviewed studies, we have found a disparity of approaches and therefore the conclusions reached are also very different. Although the initial intention was to show that LM helps to be green, sometimes we find that the objectives of LM are contrary to being a green company. For example, a company may decide to use more water to achieve higher product quality [8]. In [5], it is suggested that the success of environmental initiatives may depend on the support provided by the operations area. Thus, it is stated that LM alone will not help to achieve better environmental results. However, other studies [8] conclude that, although LM focuses on operational efficiency, it also promotes environmental objectives. In [33], it is stated that LM does not influence environmental results but environmental practices and these are responsible for environmental performance: what has been learned through LM is then applied to environmental management. Conversely, there are studies that show that trying to be green leads to improving production processes in order to reduce emissions, achieving in turn savings in resources [24]. Finally, some authors argue that success might not be caused by a synergistic effect of two factors, but to the existence of a third factor (for example, the innovative capacity of the company [34]).

4. CONCLUSIONS, RESEARCH LIMITATIONS AND FUTURE DIRECTIONS

The interest in studying the positive effects of LM on the environmental objectives of the company started at MIT in the 90s. Afterwards, it became international and jumped to most important journals and researchers. It has attracted many authors and several industries have been analyzed. Several research methods have been used - ranging from case studies to structural equations- to validate the existence of relationships between LM and the environment and even its impact on business results. The object of study has surpassed the company and has been extended to the supply chain. A great disparity in results is observed, making it difficult to draw conclusions.

Production processes affect the environment because they consume resources and create waste. Therefore, it seems logic that processes improvement contribute to avoid these undesirable effects. However, while LM is aimed at reducing "waste" and this may be seen as related to environmental management, the objective of LM is not the environment and it may even be harmful to the environment (for example, it seeks to improve quality, even if this requires more resources), so it cannot be said that lean production is greener than other systems.

The inverse relationship can also be true: Changes, sometimes spurred by legislation, in processes, trying to improve their environmental impact, can lead to a greater productive efficiency (and this without applying any lean technique).

Papers that state that the correlation between LM and environmental impact is proved can be qualified as too optimistic. Research based on large samples that might allow generalized conclusions showed either positive or negative correlations depending on the indicators used. Furthermore, this type of studies is based on synthetic indicators, which cannot show the effect of each tool. Therefore, the contradictory results seem to be caused by the fact that each study uses different variables to express what is LM and different variables to measure how green companies are. These environmental variables are also closely linked to the production process so it is difficult to compare different sectors. The apparent synergies between the two systems can also be due to the existence of other factors: for example, larger plants are usually the ones with the largest investments in R & D, advanced management tools and better performance in many aspects.

If anything can be generalized from the case studies, it is that staff motivation appears in all them. For example, we can see how a lean transformation in a hospital takes staff to lead an environmental transformation. We reach the conclusion that staff involvement and a continuous improvement culture can facilitate the adoption of environmental management practices. Therefore, the human factor should be considered a moderating factor in any model that anyone may want to analyze. It also follows that success does not depend on any specific lean technique, but on the will to seek and eliminate environmental "waste", although there are lean practices and tools that stand out for their usefulness, such as VSM.

In conclusion, there is no direct and immediate link between production and the environment, but it is mandatory that they have a good relationship, under a multidimensional and contingent approach. As many studies show, synergies are possible, but a specific solution is necessary for each case. The company culture largely explains the achieved results.

Readers should notice that the main limitations of this study are due to the way information was gathered (some important works might have gone unnoticed) and to analysis methodology, which is basically narrative and descriptive. The articles analyzed are so different that it is difficult not to draw biased conclusions.

Some directions for future research: research on lean & green in Spanish companies should be undertaken, especially in relevant sectors (each sector has its own indicators and values); longitudinal studies can be conducted and research can be extended from the environment to the broader concept of sustainability. More studies are needed to find synergies, tool by tool. New models should take into account the human factor as a central variable. Business performance should be included as a dependent variable.

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