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A Lean Manufacturing Profile of Practices in the Metallurgical Industry: A Methodology for Multivariate Analysis

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***Abstract*—**The purpose of this project is to carry out an analysis and determine the profile of actual lean manufacturing processes in the Metropolitan Area of Bucaramanga. Through the analysis of qualitative and quantitative variables it was possible to establish how these manufacturers develop production practices that ensure their competitiveness and productivity in the market.

In this study, a random sample of metallurgic and wrought iron companies was applied, following which a quantitative focus and analysis was used to formulate a qualitative methodology for measuring the level of lean manufacturing procedures in the industry. A qualitative evaluation was also carried out through a multivariate analysis using the Numerical Taxonomy System (NTSYS) program which should allow for the determination of Lean Manufacturing profiles.

Through the results it was possible to observe how the companies in the sector are doing with respect to Lean Manufacturing Practices, as well as identify the level of management that these companies practice with respect to this topic. In addition, it was possible to ascertain that there is no one dominant profile in the sector when it comes to Lean Manufacturing.

It was established that the companies in the metallurgic and wrought iron industry show low levels of Lean Manufacturing implementation. Each one carries out diverse actions that are insufficient to consolidate a sectoral strategy for developing a competitive advantage which enables them to tie together a production strategy.

***Keywords*—**Lean manufacturing, metallurgic industry, production line management, productivity.

I. Introduction

INDUSTRY has been a great catalyst for structural change in the global economy, thanks to market liberalization, client demands and technological development. In order to stay in the competitive market, organizations must reorient their processes by implementing a diversity of models and theories. In practice, Lean manufacturing is a system whose objective is to reprogram models of production by using a diversity of tools to reduce costs through limiting variability in production as well as waste [1]. Multiple tools have resulted from implementing lean manufacturing in diverse organizations. Despite the fact that Lean Manufacturing theory is considered to be a successful business model which contributes to organizational strategies, researchers have concentrated their efforts in this theme and how its' development and application leads to increased productivity and competitiveness [2], [3]. The focus of this article is determining a profile of lean manufacturing practices in the metallurgic industry, specifically the wrought iron sub-sector, by means of a multivariate analysis which indicates if a sectoral profile of production exists and how it contributes to the competitiveness of the organizations.

Lean Manufacturing is based on the principles ensconced in the Toyota production model, whose focus is to continuously minimize waste with an eye to maximizing efficiency. The main goal of lean manufacturing is reducing costs, minimizing waste and adequate resource management [4]. According to the Toyota Model, the seven most common losses are due to overproduction, waiting times, transport, inadequate processing, unnecessary inventory, wasted movements, and defects [5], [6].

In order to achieve lean production, the solutions to these problems include: Total Productive Maintenance (TPM), Total Quality Management (TQM), Failure Mode and Effect Analysis (FMEA), 5S, Quality Function Deployment (QFD), Kaizen, Kanban, Value Stream Mapping (VSM), etc. [7], [8]

These tools have been studied and developed by many authors; especially see Howleg [9] who presents a historic overview of lean manufacturing in which the main paradigms that have given rise to the field are highlighted. Salem et al., [8] present a methodology for quantitatively evaluating the application of lean manufacturing. In this methodology six tools are evaluated, including standardized work, visual management and the 5S's. Shah and Ward [10] show the importance of a Lean tool such as Value Stream Mapping (VSM) and its relationship to operations management, and propose theoretical elements that contribute towards understanding the relationship between the central goal of production and its underlying components.

Other authors such as Black [11], have designed rules for implementing Toyota production systems. Hicks [12] proposes a series of Lean principles for improving information management and the infrastructure of information systems.

All these theories have contributed over time to the consolidation of lean manufacturing as a distinguished and successful model in production management. For the purposes of this project, six lean tools for the metallurgic sector were selected as part of the methodology based on the context and

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what have proven to be successful nationally and internationally for improving profits [13]-[15].

The tools that were selected for this study are: 5S´s, Lost Time Analysis, Standardized Work, Total Productive Maintenance, Visual Management and Kaizen [16]-[18], [11].

II. Materials and Methods

This project used a quantitative research focus of an analytical nature whereby it was hoped to achieve a detailed analysis of the application of Lean Manufacturing in the metallurgic industry, specifically the wrought iron sub-sector, in the Metropolitan Area of Bucaramanga. Production practices were studied and analyzed relative to the study variables.

Two phases of analysis were carried out in order to meet the objective (See Fig. 1). In the first phase the 6 selected lean tools were assessed using a descriptive study, the variables that were analyzed and the data gathered in the field using a check-list of the 6 variables, 15 indicators, and 101 questions that were directly related with the evaluation model.

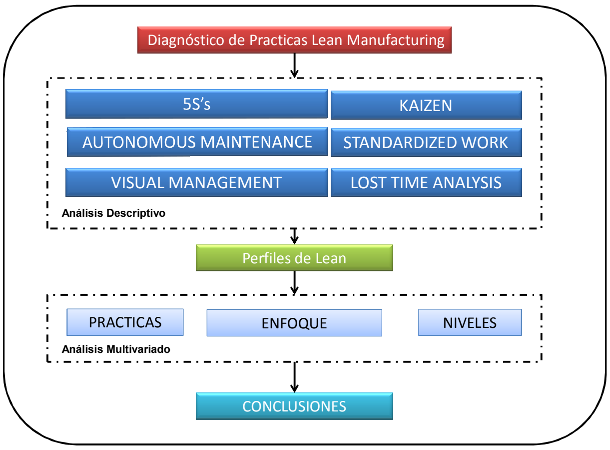

Fig. 1 Research Design

It was necessary to run a random sample for the field research. According to the Bucaramanga Chamber of Commerce there are 51 companies in the sector with current information and valid registration. Based on this information (1) was applied to the population, with a reliability quotient of 95%, a 5% margin of error, and a sampling error of 3%, which generated a sample of 40 companies.

$$n = \frac{N * Z_{\infty}^{2} * p * q}{d^{2} * (N-1) + Z_{\infty}^{2} * p * q} \quad (1)$$

N = Total statistical population
Z_{∞}^{2} = 1.96 (if reliability is 95%)
p = margen of error (in this case 5% = 0.05)
q = 1 – p (in this case 1-0.05 = 0.95)
d = sampling error (in this case we desired 3%).

The objective of the second phase was to determine what level of lean manufacturing was being achieved by each of these organizations. In the first place, a qualitative assessment of the contributions by diverse authors such as [4], [5], [8], [11], [13], [14], and [16] was carried out. A new methodology, which can be seen in Table I-VI, was built as a result of this analysis and became the prime tool for carrying out the analytical assessment.

TABLE I
Levels of Lean Manufacturing Development: 5S's

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated. The personnel are clean and wearing uniforms, no unnecessary objects are found in the workspace. Liquid and solid wastes are adequately disposed of. No unidentified parts are visible and everything is in its place.	Deficient
2	With respect to cleanliness, there are no dirt smudges on the machinery or the floor, and no leaks or residues are observable. There are no loose cables or hoses in the work area or on the floor. Any official is able to explain what the 5S's are and can demonstrate that an audit has been carried out during the last two months.	Insufficient
3	Any functionary is able to demonstrate improvements in 5S. There is evidence that a group of functionaries share the same 5S activities. A clear positive evolution can be observed over the last three audits. No dirt can be observed on the surface or the back of the machinery.	Poor
4	There are specific marked areas for tools, parts, devices, and documents. If something is out of place, any worker who notices this will return it to its rightful place. All operators can explain how the 5S's help to improve their productivity.	Average
5	The production team is in agreement as to how a tool should be used. Any functionary can convince one that the 5S's are essential for standardizing activities in any work station.	High

TABLE II
Levels of Lean Manufacturing Development: Lost Time Analysis

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated.	Deficient
2	Restricted machines and processes are identified at the work station. There is a log of bottle-necks which any functionary in the area can explain how to fill out and it is kept up to date. A poster is clearly visible with the production goals.	Insufficient
3	There are logs in other work stations, not just the ones where there are bottle-necks. The use of information contained in the logs to improve processes is evident.	Poor
4	All the functionaries can clearly explain how to fill out a log. Some functionaries can identify where time is being wasted and how to resolve the situation.	Average
5	On average, the OEE of the production line is maintained at, or superior to, 80% over two consecutive months. Improvements that result from an analysis of the logs are evident. There are minutes of meetings held to carry out a Lost Time Analysis.	High

TABLE III
LEVELS OF LEAN MANUFACTURING DEVELOPMENT: AUTONOMOUS MAINTENANCE

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated.	Deficient
2	Restricted machines and processes are identified at the work station. There is a table for Autonomous Maintenance at bottle-necks, which any functionary can explain how to use and it is kept up to date. Improvements are communicated to maintenance for 5S aspects.	Insufficient
3	Some unsafe condition related to equipment maintenance can be observed that was noted more than a week ago but has not been corrected and the equipment is still in use. Some area functionary cleary identifies their responsibility in the table of Autonomous Maintenance Activities at their work station. Every functionary along the line is able to explain Autonomous Maintenance activities in the table for which they have received training.	Poor
4	There is a complete Autonomous Maintenance table for every machine. Any functionary can talk about a meeting that they attended where maintenance activities were discussed with maintenance, manufacturing and process technical staff. Some line functionary can speak about training that they received related to special maintenance skills.	Average
5	There is a matrix of capabilities related to maintenance activities carried out by production operators for the line. Any line functionary can demonstrate a plan to improve their maintenance capabilities.	High

TABLE IV
LEVELS OF LEAN MANUFACTURING DEVELOPMENT: STANDARDIZED WORK

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated.	Deficient
2	There is evidence of clear work standards in the area and any functionary is able to show and explain a document in which they have participated that standardizes work. All line functionaries can explain what standardization is. There are minutes of work meetings in which work procedures and methods are reviewed.	Insufficient
3	All the line functionaries can explain all the instructions and work procedures related to the line, as well as show the Time Cycle for it. All the functionaries work according to the instructions and procedures. The work instructions include some diagram or schematic which facilitates comprehension.	Poor
4	The area functionary can identify 7 types of waste. In addition, they can explain how standardized work instructions contribute towards eliminating one of the 7 types of waste.	Average
5	It is evident that line functionaries are involved in developing standardized work for new manufacturing processes. No area functionary routinely waits longer than 1/5 of a “Takt” for a machine to complete its operation.	High

TABLE V
LEVELS OF LEAN MANUFACTURING DEVELOPMENT: VISUAL MANAGEMENT

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated.	Deficient
2	Performance measurements are visible in the workspace. At least 3 comuniques are seen in the workspace over a period of one month. Any functionary is able to epxlain what Visual Management is. There are notices clearly indicating the entry, exit and storage of materials. No notice obstructs the visibility of any other notice.	Insufficient
3	At bottle-necks, there are visual indicators for stoppages and for when no productions occurs which are visible to everyone. Every functionary can show a Visual indicator related to maintenance and/or quality. There is evidence of descision-making based on Visual Management.	Poor
4	Limits are clearly marked on measurement devices such as thermometers, pressure guages, etc. All functionaries are able to explain the visual management indicators, and the indicators are sufficiently clear so as to avoid confusion.	Average
5	Functionaries are capable of explaining what Visual Management is and in what ways it contributes towards improved working conditions.	High

TABLE VI
LEVELS OF LEAN MANUFACTURING DEVELOPMENT: KAIZEN

Level	Description	Qualitative Assessment
1	The work station is clearly demarcated.	Deficient
2	Any functionry is able to explain what a Kaizen is and how to develop one for their work station. There is a record of Kaizen that have been implemented.	Insufficient
3	It can be seen that work standards have been modified as a result of applying a Kaizen. There is a structured process for developing Kaizen.	Poor
4	There is evidence of implementing Kaizen events that include a minimum of 30% of the personnel. Improvements in OEE can be seen as a result of implementing Kaizen events. The Kaizen events have contributed to a reduction in some of the 7 types of waste.	Average
5	It can be seen that implementing successive Kaizen events has contributed to the reduction of the 7 types of waste. The organization promotes the recognition of people who participate in and propose Kaizen events.	High

Following this, a quantitative analysis was run using SPSS Statistics in order to establish the main statistical measures, as well as determine the relationship between different companies for the purpose of establishing trends that could be used to define profiles of Lean Manufacturing for these companies. The results produced through the use of the checklist were run through a multivariate analysis devised with the use of the Numerical Taxonomy System (NTSYS) program [19].

III. Results

A. Diagnostic of Lean Manufacturing Processes

1. 5S´S

For this analysis tool it was possible to establish that 75% of the companies in the metallurgic sector have clearly demarcated work stations. In addition, they embody a culture of cleanliness and tidiness as reflected by 67,5% of the companies which adequately dispose of solid and liquid waste. With respect to tidiness, there is still some way to go since tools can be seen with no clear storage location.

With regards to standardization, there are tools and sites that are clearly identified, although 70% report that there are parts in the work area that are either not used or people don't know that they are used for.

Most of the time the staff is clean. On some occasions 45% observe loose cables and hoses in the work area.

On the other hand, although the company is aware of the importance of the 5 S´s, not all the employees know what they are, or they do not apply them, the consequence being that not everyone is following the same work standard, as evidenced by a frequency of 50%.

On the whole the implementation level is poor, indicating a need for more training, discipline and practice for personnel on this topic.

2. Lost Time Analysis

With respect to Lost Time Analysis, which is a fundamental variable in increasing productivity, only 40% of the companies have identified bottle-necks, and of these only 50% keep logs of them, which represents only 20% of the whole sample.

Of the sample, 22.5% also keep logs at other work stations which show a weak management of reliable information for carrying out lost time analyses. Not one case exceeds 40% with respect to the other aspects measured under this heading indicating that the tool is seldom used.

3. Autonomous Maintenance

Using the lean maintenance thermometer it was found that a frequency of 65% of companies have identified restrictions at the stations. Although not all the companies have an autonomous maintenance table, 80% do have a register of machine parts. No more than 30% can demonstrate the other aspects for improvement such as a maintenance table, the relationship between maintenance and the 5 S's and the other aspects. This indicates a lack of dynamism and discipline in applying this lean tool.

4. Standardized Work

With respect to Standardized Work, the majority of companies, 90%, have work standards that have to do with documentation, control plans and other standardized work requirements, which any functionary can explain and handle. However, a weakness is that only 35% of the companies use graphs, although when it comes to production goals they do use them but without including them in the control scheme.

5. Visual Management

As a consequence of the level of implementation of the previous tool, this tool shows a low implementation rate. It was found that only 40% of the companies have performance goals that are visually represented, while 37.5% update their visual communication on a monthly basis. Only 30% carry out periodic evaluations of their production areas and have an evaluation system. All the other aspects of visual management do not exceed a 30% implementation rate.

6. Kaizen

While evaluating the application of Kaizen it was found that a culture of continuous improvement is lacking in the metallurgical sector. Not one of the Kaizen aspects evaluated exceeds 30%, which hints that a culture of quality is also lacking. This is coherent with why these companies have great problems competing in terms of quality and costs.

After analyzing each of the 6 tools, a qualitative assessment was carried out in accordance with the methodology outlined, showing the level achieved at a sector level. This is clearly shown in Table VII.

TABLE VII
Assessment of the Rate of Implementation of Lean Manufacturing Tools in the Metallurgy and Wrought Iron Companies of Bucaramanga

Tool	Level	Assessment
5S´S	Level 2	Insufficient
LOST TIME ANALYSIS	Level 2	Insufficient
AUTONOMOUS MAINTENANCE	Level 2	Insufficient
STANDARDIZED WORK	Level 3	Poor
VISUAL MANAGEMENT	Level 1	Deficient
KAIZEN	Nivel 1	Deficiente

Source: Authors.

After carrying out the analysis in Fig. 2 which shows the average implementation level for each of these tools, it can clearly be seen that it is consistent with what is suggested by the analytical assessment.

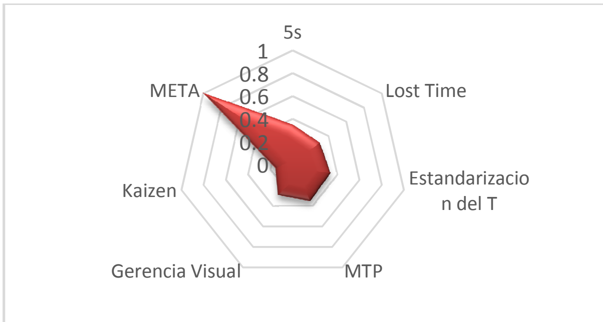

Fig. 2 Level of implementation for Lean Manufacturing practices

B. Lean Manufacturing Profiles in the Metallurgic and Wrought Iron Sector

The Lean Manufacturing profiles were determined using a multivariate analysis which allows for quantitatively assessing the links with the actions of the metallurgical sector. The component programs of the NTSYS system permit different kinds of calculations based on matrices, calculating coefficients and obtaining similarity matrices, ranking and classification methods such as principle components analysis, and graphing the results [20]. They were used to establish if there is a dominant profile in each of the different lean manufacturing practices, analyze if there are some which share similar practices or if, on the contrary, each one functions in a different way with respect to their production models.

Fig 3 shows the concurrency analysis of the results provided by the research based on a multivariate analysis. The 40 participating companies are shown, and as can be inferred, there is no conglomeration despite a cloud of points representing 17.5% of all the companies shown. This is consistent with the levels of implementation found. With respect to the other companies there is no clear tendency in lean manufacturing although some coincide but in different spheres.

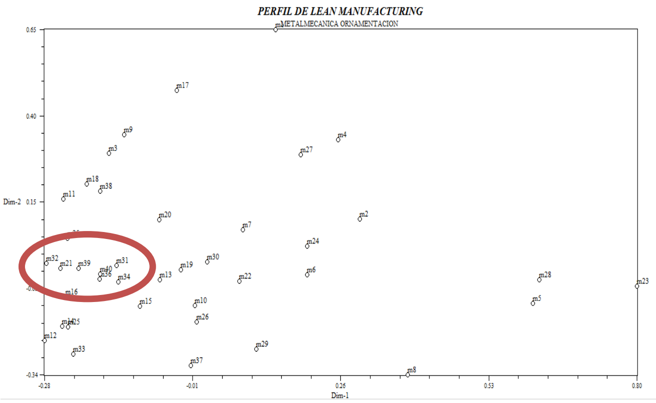

Fig. 3 Lean Manufacturing profiles in the metallurgical industry

Given the above, it is possible to conclude that a Lean Manufacturing Profile does not exist since none of the companies adhere to a trend, either because each has an independent trend or because they deal with special dynamics.

The other companies that were analyzed deviate from the central trend due to creating their own trend, or dealing with unique dynamics, or because their actions do not converge with the sectoral dynamic. Firstly, the results of the analysis show that alternative trends do exist for a group representing 17.5% of the sample, while their individual actions show a differentiated dynamic with respect to key variables for each dimension, which are analysed later. The concurrency of actions analyzed from the companies' point of view is shown in Fig. 3. As can be seen in Fig. 3, there are no clear profiles for the sector, but when looking at each lean manufacturing variable it is possible to see that some trends do exist.

IV. Conclusions

Lean Manufacturing is a successful production model which leads to increased productivity and competitiveness for a company because it allows for cost reduction and increased profits through establishing discipline and rigor in carrying out the company's activities. Within the metallurgical sector, only a very few companies have understood this model as one that can create competitive advantage, and which enables the sector to consolidate itself as one which makes a significant contribution to GDP.

None of the companies demonstrate optimum levels of implementation. On the contrary, for a large majority there are many aspects of the six tools that need to be improved. If one of these aspects fails, all the others are affected. A lack of discipline and commitment can be observed with respect to the tools.

The tool with the highest level of implementation is the one known as the 5S's. All the others have very low implementation levels that do not exceed 30%. What this indicates is that in large part the production problems faced by the industry are due to internal and corporate factors, as opposed to macroeconomic variables.

Upon realizing the multivariate analysis in order to identify a sectoral lean manufacturing profile, it was found that one does not exist. Only a small group of companies, which is not representative, are developing lean manufacturing practices. The others are highly dispersed. This leads to the conclusion that there are no production standards that allow for consolidating production and competitiveness in the sector.

An opportunity for developing lean manufacturing practices exists since investment proposed by developing countries for infrastructure development is very high, and it requires the involvement of this sector. It is projected that 20% of the Colombian GDP over the next decade will be spent on infrastructure. This study shows that the companies are unable to compete with Chilean, Mexican or Brazilian companies when it comes to production, and that possibly this is a factor in costs which clearly undermine competitiveness in this sector.

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