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Grey Systems: Theory and Application

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Abstract

Purpose – The lean production system and world class manufacturing (WCM) have been prominent in recent studies due to their conceptual synergy. However, although the number of studies is increasing, the research is immature, especially regarding the interaction between topics. Therefore, the purpose of this paper is to rank the tools of the lean production system, indicating how they help organizations achieve WCM, using the theory of grey systems.

Design/methodology/approach – Therefore, the authors conducted an initial survey to collect data to determine how the lean production tools are related to the WCM pillars. These data were analyzed by the grey relational analysis statistical method, which passes through the construction of four stages.

Findings – The results show that of the lean production tools, stream mapping, kaizen, total productive maintenance, Six Sigma, standardized work and 5S stand out for their use and implementation in the organizational environment and facilitate organizations' transitions to world-class performance through the WCM pillars.

Practical implications – The results achieved guide organizations to use the tools of the lean production system to help them reach world class status.

Originality/value – This paper stands out in the field of operations management, specifically in the research on lean production, by making use of the theory of grey correlation system in an innovative and original way. In addition, it promotes the consolidation of information on two of the main administrative strategies currently employed in the organizational environment.

Keywords Survey, Lean manufacturing, Lean tools, Grey relational analysis, World class manufacturing

Paper type Research paper

1. Introduction

The challenge generated by the competitiveness between organizations has generated a search for techniques that improve performance and, above all, increase companies' productivity. Brown *et al.* (2007) claimed that to make these changes, administrative strategies (commonly named by academics as approaches, methods, systems or philosophies) assist in the selection of appropriate tools to achieve better industrial production, ensuring the highest manufacturing performance.

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Regarding the selection of tools, Chiarini and Vagnoni (2015) pointed out that in the last ten years, many organizations have adopted administrative strategies for their development like the Toyota Production System (TPS), lean production, just-in-time (JIT), total quality control (TQC), Six Sigma and theory of constraints among others.

Among these administrative strategies, the lean production system stands out in the literature and in the organizational environment, which is the subject of extensive studies, reports and success stories. The term "lean production" is regarded as a global reference in management strategies and was coined from the production system developed by Toyota, an automotive manufacturer. One of lean production's central features is the elimination or minimization of waste based on five principles: value, value chain, continuous flow, pull production and continuous improvement (Calarge *et al.,* 2012).

The implementation of the lean production system in the organizational environment is coordinated and structured with the use of tools (Pettersen, 2009; Lucato *et al.,* 2014). These tools have been developed using scientific methods to minimize or eliminate waste, are currently employed in all large corporations and are applied by specialized consultants or by internal organizational improvement teams. The tools aim to make the organization efficient and effective in terms of quality, reliability, flexibility, innovation and cost and are chosen through the study of available resources that satisfy and accomplish the organization's objectives (Brown *et al.,* 2007).

Based on concepts and objectives similar to those of lean production, world class manufacturing (WCM) promotes best production practices through the integration of management systems, which improves processes and quality, reduces costs and promotes increased flexibility and customer expectations (Poor *et al.,* 2016).

However, achieving satisfactory goals that make an organization world-class is not straightforward because few roadmaps or drivers support organizations. In the literature, studies are visualized that determine performance indicators (Dubey *et al.*, 2015; Sukarma and Azmi, 2015; Digalwar *et al.,* 2015) that support the pillars at strategic, tactical and operational levels.

Specifically, at the operational level, organizational improvement occurs through the deployment of tools with a wide range of choice, as indicated by Sukarma *et al.* (2014), Dubey *et al.* (2015) and Vargas *et al.* (2017). At this point, it is worth noting that the tools suggested to reach world-class status are the same ones mentioned for lean production (Petrillo *et al.*, 2018).

Because of the conceptual synergies between themes, in recent studies, these two administrative strategies have been dealt with jointly (Bhamu and Sangwan, 2014; Chiarini and Vagnoni, 2015). This statement is evidenced by Goes *et al.* (2017), who identified in the literature a set of 42 publications from 2010 to 2015 that connect these two administrative strategies. The authors pointed to a growing interest in the research topic, but they identified little interaction between the topics in the studies among the researchers and in the establishment of research networks.

Understanding the importance of these two administrative strategies and the failure to advance their interaction, we aim to rank the lean production system tools according to how they help organizations reach WCM status using the theory of grey correlation system.

In this respect, this research's originality and its contribution are essential in the scientific structuring of the relationship between the WCM pillars and lean production tools, consolidating information from two of the main administrative strategies currently employed in the organizational environment. The use of the theory of grey correlation system, which is a multi-factor statistical analysis, contributes to this effort. This theory analyzes all factors of the sample data, describes the relationships' strength and feebleness and the size and order of the relationships between factors (Tie-Jun and Sha, 2008). At this point, the theory of grey correlation system will assist in the ordering of lean tools, giving organizations' implementations an orientation, and highlights the pioneering nature of this study, which demonstrates the positive impact of lean tools on the pillars because those tools do not impact the pillars in isolation.

Therefore, this research is organized in five sections beyond this introductory section. The second section provides the concepts for understanding the issues in studies of lean production and WCM. The third section outlines the survey's structure and justification for employing the theory of grey correlation system. In the fourth section, the steps involved in data analysis are presented, considering the innovation of application in this analysis of operations management. In the fifth section, we discuss the data identified in the application of the statistical method. Finally, the conclusion highlights information about how this work was conducted.

2. Theoretical foundation

2.1 World class manufacturing (WCM)

The term "WCM" was established in 1984 by two American authors, Hayes and Wheelwright (1984), who proposed a new method based on the principles of the TPS, just-in-Time and TQC. The WCM method is a synthesis of several concepts, principles, policies and tools for organizational improvement of management and operations (Đokić *et al.*, 2012; Vargas *et al.,* 2017) and is based on capabilities developed by Japanese and German companies that increase organizations' production levels and overall performance. The term "world class" came about because these organizations were associated with an overall excellent performance, which resulted in such adjectives.

The WCM method gained popularity when Schonberger (1986) reinterpreted and improved it two years later in his book *World Class Manufacturing – The Lesson of Simplicity Applied*, which described organizational management strategies focused on processes and tools to achieve high levels of performance.

To achieve world class performance, a philosophy was established based on zero waste, zero breaks, zero defects and zero-inventory concepts. This philosophy is meant to minimize the costs of an organization's activities as well as increase its excellence and, consequently, its competitiveness (Schonberger, 1986).

The WCM method consists of ten interconnections called pillars. These pillars are related to organizational processes and allow an organization to achieve a world-class order (Chiarini and Vagnoni, 2015; Gajdzik, 2013; Zimwara *et al.*, 2012; Scalera, 2011). Table I briefly describes these pillars.

Through modern approaches and the use of tools, studies point to the existence of a great competitive advantage when comparing world-class companies and companies that do not employ any specific approach. Organizations that reach a world-class order gain competitive advantages in manufacturing that stand out in the literature: costs: reduction in production costs, reasonable prices and improved profitability; flexibility: establishment of production programs, flexibility in production and supply of goods; speed: rapid reaction against competitors; credibility: improvement of training, product development and attention to customer needs; and quality: establishment of standards and quality programs, performance measurement, fundamental values and the organization's objectives (Burcher and Stevens, 1996; Gajdzik, 2013; Hosseinie *et al.*, 2012; Ng and Hung, 2001; Pałucha, 2012; Schonberger, 1986).

Authors such as Muniro *et al.* (2000), Chiarini and Vagnoni (2015), Xie (2014), Pałucha (2012) and Yamashina (2000) elucidate that the WCM method seeks organizational excellence through modern approaches, the use of tools and the elimination/minimization of process waste. The elimination of waste is one of the most relevant factors in the classification of companies as "world class" (Petrillo *et al.*, 2018). These points have a strong connection to the principles of the lean production system.

WCM pillar's	Description
Safety-hygiene and working environment	Reduce the number of accidents and it develops a culture of prevention and protection
Cost deployment	Identify the main item of loss, it quantifies the economic benefits
Focus improvement	Reduce the most important losses present in the process eliminating inefficiencies
Autonomous activities	Focus into two sub-pillars: (i) Autonomous maintenance: used to improve the overall efficiency of the production system through maintenance policies; (ii) Workplace organization: used to determinate an improvement in the workplace and to remove losses
Professional maintenance	Increase the machine efficiency using failure analysis techniques
Quality control	Ensure a quality product, it reduces non-compliance and it increases the skills of the employees
Logistics and customer service	Reduce the levels of stocks and it minimizes the material handling.
Early equipment management	Optimize the installation time and costs of the new products
People development	Ensure correct skills and abilities for each workstation.
Environment	Develop an energy, culture, and it reduces the energy costs and losses

Source: Adapted from Petrillo, Felice and Zomparelli (2018)

Table I.
The WCM pillars

2.2 Lean production system

The term "lean production" is defined by several authors as synonymous with the TPS. The TPS emerged in the late 1940s when Japan was experiencing difficulties at the end of the Second World War. To rebuild itself, Toyota needed to rethink its production model, using a pull system (demand-driven production) rather than being pushed (mass production). To that end, new strategies and tools were created, such as JIT, kanban, kaizen and TQC among others, which served to constitute the TPS that became known worldwide (Chiarini and Vagnoni, 2015; Liker, 2003; Ohno, 1988).

The lean production concept originated in the late 1980s in a research project at the Massachusetts Institute of Technology, which studied the global automotive industry, focusing primarily on Toyota's Japanese model, with the goal of mapping the best industry practices through interviews with officials, trade unionists and government officials.

The lean production system has as its philosophy the identification and minimization or progressive elimination of waste sources based on five fundamental principles: the definition of value based on the client's vision and needs and then determining the necessary activities to offer the customer the product with the lowest level of waste through the definition of the value chain. The product is then manufactured using a continuous flow; which is triggered only when the customer places the order, exemplifying pull production. These four principles lead to continuous improvement (kaizen) or radical improvements (kaikaku) to achieve the fifth fundamental principle, which is the perfection of the system (Calarge *et al.*, 2012; Lucato *et al.*, 2014).

In the literature, waste is organized into eight types: overproduction, over-processing, defects, transportation, waiting, inventory, motion and non-utilized talent, which must be constantly analyzed, as they do not add value in a productive cycle (Liker, 2003; Vinodh *et al.*, 2013; Dennis, 2015).

According to Dominici and Palumbo (2013), the lean production system has been adopted by several organizations of various segments regardless of size. Experience shows that the tools developed and assimilated by the lean system are successfully applied in all branches of service and production, including various environments such as agribusiness, health and education.

Several parts of the lean production system are interconnected in multiple ways because it is a complex model with numerous strategies to be used. However, this system's success directly consists of the company's organizational characteristics because it requires several changes (Karim and Arif-Uz-Zaman, 2013; Marvel and Standridge, 2009).

Such improvements in the organizational environment are associated with the use of tools. Womack *et al.* (1990) and Karim and Arif-Uz-Zaman (2013) state that the lean production system offers tools that can be deployed in organizations; however, each organization is unique and adopts unique forms of work. The use and choice of the types of tools depend on a choice that meets the objectives each organization aims to achieve.

Satolo *et al.* (2018) have detected in a recent study the tools organizations commonly used in the lean production system through a literature review based on the publications of Jasti and Kodali (2014), Bhamu and Sangwan (2014) and Marodin and Saurin (2013). In this survey, a set of 25 tools was highlighted, which are cited as value stream mapping (VSM), just-in-time, total productive maintenance (TPM), lead time, Six Sigma, 5S, standardization of operations, single minute exchange of die (SMED), small lot size, cellular manufacturing, takt-time, kanban, kaizen, poka-yoke, pull production, supply chain integration, total quality management, multifunctional workforce, visual management, empowerment, group technology, production leveling, statistical process control, autonomation/jidoka and concurrent engineering.

2.3 Literature concerning organizational levels between the lean production system and WCM method

In the literature, as mentioned above, studies that cover the lean production system and the WCM method are restricted (Satolo *et al.*, 2018). It is noted in these articles that interconnection is associated with organizational levels, that is, with respect to strategic, tactical and operational levels.

At the strategic level, the interrelation occurs when a philosophy is established. The lean production system's philosophy is to identify and minimize or eliminate waste sources, that is, reducing times and tasks that do not add value (Vinodh *et al.*, 2013). The WCM method also bases its philosophy on concepts such as zero waste, zero breaks, zero defects and zero stock (Yamashina, 2000). This strategy is useful for organizations seeking to minimize their activities' costs and increase their excellence, thereby enhancing their competitiveness across sectors (Gajdzik, 2013).

At the tactical level, ways to implement the organizational philosophy are established. For the lean production system, tactical actions stem from the five principles: value, value chain, pull production, continuous flow and perfection (Liker, 2003). Regarding the WCM method, for Yamashina (2000), this process is divided into four steps: identify the problem, identify the loss, define the method that will be adopted for restoration and control the results.

Finally, at the operational level, the focus shifts to the manufacturing environment as well as the study and improvement of production processes. For the lean production system, the support is in the set of tools that helps the organization improve performance and operational efficiency, for which they need to be well-defined and -chosen (Karim and Arif-Uz-Zaman, 2013). In the WCM method, execution comprises the improvement of organizational performance according to the ten pillars that relate to the manufacturing process and that enable an organization to achieve and sustain world-class performance (Gajdzik, 2013, Zimwara *et al.*, 2012, Pałucha, 2012). The work on the WCM pillars is completed with tools, which according to Đokić *et al.* (2012) are categorized as describing the problem, identifying the cause and standardizing the results.

These strategic and tactical links are not being studied. Therefore, the purpose of this research is to establish an operational-level ranking of lean tools to provide greater access for world-class performance.

It should be noted that the literature does not present a consensus on how to implement the lean tools at the operational level to reach WCM. Pałucha (2012), Gajdzik (2013), Sukarma *et al.* (2014), Vargas *et al.* (2017) and Petrillo *et al.* (2018) report in their case studies and empirical surveys various ways to apply lean tools to each WCM pillar. Moreover, in their analyses, the authors do not describe the organizational gains that these tools present directly or indirectly to other pillars, covering only the local gains.

Pałucha (2012) warns a high volume of management tools is involved in the system's implementation, making it difficult and time-consuming. It could also potentially generate conflict in the organizational environment. Pałucha (2012) emphasizes that top-level management must decide which tool to implement and mainly understand that the tools have the potential to impact several processes.

In this aspect, the present paper contributes to the literature by complementing Pałucha's (2012) research and explaining how the lean tools generate positive impacts in the WCM pillars.

3. Research method

To achieve the objective proposed in this paper, the survey was conducted per Forza (2002). The elaborated form was validated by means of a pretest completed by three specialists in the area. This form is composed of demographic questions and a matrix that presents in its columns the WCM pillars and in its lines the tools of the lean production system. Based on judgment criteria, the respondents indicated in this matrix if they agreed that a positive relationship between existed each row and column.

To guarantee the data's validity and the respondents' knowledge, the survey population consisted of Brazilian researchers in research areas of production engineering. With the support of ABEPRO (Brazilian Association of Production Engineering), qualitative and quantitative data collection was conducted for one month (June 2016) via e-mail. A total of 774 researchers were contacted, with 107 responses collected, of which 58 were complete questionnaires (54.2 percent) and were considered for this study's analysis. The response rate is valid for the experimental planning, meeting a confidence level of 90 percent and a margin of error of 10 percent.

The majority of respondents were research doctors (86 percent) and lecturers in higher education institutions in the public sector (67 percent) with more than ten years of experience (67 percent) conducting research focused on operations and production processes.

Based on the obtained data, statistics were used for the advancement of knowledge, which is indispensable for researchers. In the present study, the collected data were analyzed through grey relational analysis (GRA).

GRA is part of the grey system theory proposed by Professor Deng in 1982 to solve multi-object problems with complicated interpellations between multiple factors and variables (Liu *et al.*, 2012). It deals with uncertain systems with information generated, excavated and extracted from what is available (Liu *et al.*, 2016). This methodology is used in several fields of science because it aims to measure the level of similarity or difference between factors (Kuo *et al.*, 2008; Zheng *et al.*, 2010; Dai *et al.*, 2014). GRA includes four steps, namely: construction of grey relational generating (GRG); definition of the ideal target sequence; calculation of grey relational coefficients (ε_{ij}); and calculation of the grey relational grade (R) (Kuo *et al.*, 2008). These steps are discussed in detail in the discussion of the results.

Based on Liu, Forrest and Yang (2012), the use of GRA is adequate in this research because it takes into account that the data collected are characterized as incomplete because the information about system behavior varies widely according to the respondent's perception and knowledge. We are also interested in determining an order regarding the importance of applying lean tools, which are structured on various conceptual types regarding the WCM pillars.

4. Survey results

The data collected were tabulated using Microsoft Excel® software. Table II presents the proportion of the research respondents' judgment who agree positively about the

Table II. Proportion of the research respondents' judgment relative to the positive relationship between lean production tools and WCM pillars

Lean production tools	WCM pillar's: Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
5S	69.0	29.3	46.6	37.9	25.9	51.7	24.1	29.3	43.1	55.2
Autonomation/Jidoka	24.1	27.6	24.1	29.3	19.0	27.6	17.2	22.4	15.5	36.2
Cellular manufacturing	22.4	41.4	46.6	36.2	25.9	44.8	41.4	27.6	12.1	31.0
Concurrent engineering	17.2	36.2	22.4	19.0	17.2	24.1	31.0	29.3	20.7	29.3
Empowerment	27.6	22.4	34.5	34.5	24.1	31.0	24.1	25.9	24.1	60.3
Group Technology	12.1	27.6	19.0	17.2	15.5	20.7	25.9	13.8	8.6	22.4
Just in time	15.5	51.7	46.6	22.4	20.7	44.8	70.7	34.5	19.0	27.6
Kaizen	32.8	51.7	51.7	41.4	36.2	55.2	37.9	39.7	32.8	48.3
Kanban	13.8	46.6	34.5	24.1	22.4	37.9	55.2	31.0	12.1	25.9
Lead Time	15.5	44.8	41.4	17.2	13.8	34.5	51.7	36.2	6.9	12.1
Multifunctional workforce	29.3	22.4	20.7	29.3	15.5	19.0	19.0	15.5	8.6	51.7
Poka Yoke	37.9	27.6	36.2	31.0	13.8	51.7	20.7	20.7	19.0	29.3
Production Leveling	6.9	29.3	17.2	6.9	12.1	20.7	34.5	24.1	5.2	12.1
Pull Production	10.3	41.4	24.1	24.1	17.2	32.8	56.9	27.6	10.3	19
Single minute exchange of die (SMED)	27.6	37.9	53.5	29.3	32.8	27.6	25.9	29.3	6.9	32.8
Six Sigma	27.6	48.3	55.2	17.2	22.4	72.4	25.9	31	19	43.1
Small lot size	5.2	62.1	63.8	17.2	10.3	27.6	55.2	19	8.6	15.5
Standardization of operations	56.9	44.8	55.2	34.5	25.9	55.2	36.2	24.1	13.8	50
Statistical process control	12.1	31	22.4	12.1	10.3	53.5	20.7	25.9	13.8	20.7
Supply chain integration	8.6	41.4	20.7	8.6	6.9	32.8	58.6	24.1	12.1	19
Takt-time	15.5	46.6	34.5	24.1	15.5	31	55.2	31	8.6	20.7
Total productive maintenance	53.5	48.3	46.6	34.5	55.2	44.8	29.3	46.6	27.6	36.2
Total quality management	12.1	32.8	17.2	12.1	12.1	56.9	19	15.5	10.3	19
Value stream mapping	34.5	56.9	62.1	32.8	22.4	50	53.5	36.2	37.9	37.9
Visual management	34.5	24.1	29.3	19	15.5	34.5	24.1	36.2	19	27.6

relationship between the WCM pillars and the lean production system's tools. For example, in the relationship between the safety-hygiene and working pillar and the VSM tool, of the 58 questionnaires considered, 34.5 percent perceived a positive relationship between them, that is, the use of VSM rises in connection with the pillar of safety-hygiene and working.

In addition, Table II highlights in gray the five lean production tools with the largest percentages for each WCM pillar. These data are used as input for the GRA test.

4.1 Application of the GRA

The application of the GRA test in the areas of industrial engineering is restricted, lacking details in the application procedure that would permit replication and technical exploitation by researchers in studies like this one. Therefore, the next section highlights each stage and its results in the statistical application.

4.1.1 Construction of GRG. The GRG calculation performs the performance translation of all factors and is performed in a sequence of comparability in a process analogous to normalization (Kuo *et al.*, 2008). Huang and Liao (2003) point out that this process is necessary when the sequence range is large enough to cause the influence of some factors to be neglected. This calculation is made in reference to the WCM Pillars. Its value is determined by dividing a tool's average value by the highest average value between the pillars under analysis (Equation (1)). In this way, the normalization of the WCM pillar is based on the lean tool with the highest percentage (which gives the result of 1.000). The other lean tools' values indicate their representativeness as a function of the tool with the highest average value:

$$\mathrm{GRG}_{(ij)} = \frac{\text{Average value of the tool } (i)}{\text{Highest average value between pillar tools } (j)} \tag{1}$$

For example, the relationship between the cost development pillar and the 5S tool has an average of 29.3 percent (Table II), and the highest average value among all the cost development pillar tools is 62.1 percent. The calculation of the GRG (5S tool, cost development pillar) is 0.472. The other results of this step are presented in Table III.

4.1.2 Definition of ideal target sequence. From the matrix resulting from Table III, the absolute difference (Δ) of the elements for optimal performance, ($X0j = 1$) is calculated according to the following equation:

$$\Delta_{ij} = \left| X_{0j} - X_{ij} \right| \tag{2}$$

In the previous example, $\Delta_{(5S,\text{Cost Development})} = |1\text{-}0.472| = 0.528$. The remaining results of this step are described in Table IV.

4.1.3 Calculation of grey relational coefficient (ε). In Table III, the values of Δ (max) and Δ (min) are identified in the matrix, which is used to calculate the correlation coefficient (Equation (3)). The coefficient of distinction ρ, which commonly varies from 0 to 1, is attributed to the participating members' knowledge and experience, 1 being the highest, 0.5 the average and 0 the lowest (Zheng *et al.*, 2010). This research will follow the commonly adopted value of ρ as 0.5 (Kuo *et al.*, 2008; Dai *et al.*, 2014; Zheng *et al.*, 2010) because although a majority of researchers work in the study area, it is not valid for the entire population, and we had no control over the responses:

$$\varepsilon_{ij} = \frac{\Delta\min + \rho \times \Delta\max}{\Delta ij + \rho \times \Delta\max} \tag{3}$$

Table III. Calculation of grey relational generating (GRG)

	WCM pillar's									
Lean production tools	Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
5S	1.000	0.472	0.730	0.917	0.469	0.714	0.341	0.63	1.000	0.914
Autonomation/Jidoka	0.350	0.444	0.378	0.708	0.344	0.381	0.244	0.481	0.360	0.600
Cellular manufacturing	0.325	0.667	0.730	0.875	0.469	0.619	0.585	0.593	0.280	0.514
Concurrent engineering	0.250	0.583	0.351	0.458	0.313	0.333	0.439	0.630	0.480	0.486
Empowerment	0.400	0.361	0.541	0.833	0.438	0.429	0.341	0.556	0.560	1.000
Group technology	0.175	0.444	0.297	0.417	0.281	0.286	0.366	0.296	0.200	0.371
Just in time	0.225	0.833	0.730	0.542	0.375	0.619	1.000	0.741	0.440	0.457
Kaizen	0.475	0.833	0.811	1.000	0.656	0.762	0.537	0.852	0.760	0.800
Kanban	0.200	0.750	0.541	0.583	0.406	0.524	0.78	0.667	0.280	0.429
Lead time	0.225	0.722	0.649	0.417	0.250	0.476	0.732	0.778	0.160	0.200
Multifunctional workforce	0.425	0.361	0.324	0.708	0.281	0.262	0.268	0.333	0.200	0.857
Poka Yoke	0.550	0.444	0.568	0.750	0.250	0.714	0.293	0.444	0.440	0.486
Production leveling	0.100	0.472	0.270	0.167	0.219	0.286	0.488	0.519	0.120	0.200
Pull production	0.150	0.667	0.378	0.583	0.313	0.452	0.805	0.593	0.240	0.314
Single minute exchange of die (SMED)	0.400	0.611	0.838	0.708	0.594	0.381	0.366	0.630	0.160	0.543
Six Sigma	0.400	0.778	0.865	0.417	0.406	1.000	0.366	0.667	0.440	0.714
Small lot size	0.075	1.000	1.000	0.417	0.188	0.381	0.780	0.407	0.200	0.257
Standardization of operations	0.825	0.722	0.865	0.833	0.469	0.762	0.512	0.519	0.320	0.829
Statistical process control	0.175	0.500	0.351	0.292	0.188	0.738	0.293	0.556	0.320	0.343
Supply chain integration	0.125	0.667	0.324	0.208	0.125	0.452	0.829	0.519	0.280	0.314
Takt-time	0.225	0.750	0.541	0.583	0.281	0.429	0.78	0.667	0.200	0.343

(*continued*)

Table III.

Lean production tools	WCM pillar's: Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
Total productive maintenance	0.775	0.778	0.730	0.833	1.000	0.619	0.415	1.000	0.640	0.600
Total quality management	0.175	0.528	0.270	0.292	0.219	0.786	0.268	0.333	0.240	0.314
Value stream mapping	0.500	0.917	0.973	0.792	0.406	0.69	0.756	0.778	0.880	0.629
Visual management	0.500	0.389	0.459	0.458	0.281	0.476	0.341	0.778	0.440	0.457

Table IV. Results of the calculation of Ideal target sequence

Lean production tools	WCM pillar´s Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
5S	0.000	0.528	0.270	0.083	0.531	0.286	0.659	0.370	0.000	0.086
Autonomation/Jidoka	0.650	0.556	0.622	0.292	0.656	0.619	0.756	0.519	0.640	0.400
Cellular manufacturing	0.675	0.333	0.270	0.125	0.531	0.381	0.415	0.407	0.720	0.486
Concurrent engineering	0.750	0.417	0.649	0.542	0.688	0.667	0.561	0.370	0.520	0.514
Empowerment	0.600	0.639	0.459	0.167	0.562	0.571	0.659	0.444	0.440	0.000
Group technology	0.825	0.556	0.703	0.583	0.719	0.714	0.634	0.704	0.800	0.629
Just in time	0.775	0.167	0.270	0.458	0.625	0.381	0.000	0.259	0.560	0.543
Kaizen	0.525	0.167	0.189	0.000	0.344	0.238	0.463	0.148	0.240	0.200
Kanban	0.800	0.250	0.459	0.417	0.594	0.476	0.220	0.333	0.720	0.571
Lead Time	0.775	0.278	0.351	0.583	0.750	0.524	0.268	0.222	0.840	0.800
Multifunctional workforce	0.575	0.639	0.676	0.292	0.719	0.738	0.732	0.667	0.800	0.143
Poka Yoke	0.450	0.556	0.432	0.250	0.750	0.286	0.707	0.556	0.560	0.514
Production leveling	0.900	0.528	0.730	0.833	0.781	0.714	0.512	0.481	0.880	0.800
Pull production	0.850	0.333	0.622	0.417	0.688	0.548	0.195	0.407	0.760	0.686
Single minute exchange of die (SMED)	0.600	0.389	0.162	0.292	0.406	0.619	0.634	0.370	0.840	0.457
Six Sigma	0.600	0.222	0.135	0.583	0.594	0.000	0.634	0.333	0.560	0.286
Small lot size	0.925	0.000	0.000	0.583	0.813	0.619	0.220	0.593	0.800	0.743
Standardization of operations	0.175	0.278	0.135	0.167	0.531	0.238	0.488	0.481	0.680	0.171
Statistical process control	0.825	0.500	0.649	0.708	0.813	0.262	0.707	0.444	0.680	0.657

(continued)

Table IV.

Lean production tools	WCM pillar´s: Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
Supply chain integration	0.875	0.333	0.676	0.792	0.875	0.548	0.171	0.481	0.720	0.686
Takt-time	0.775	0.250	0.459	0.417	0.719	0.571	0.220	0.333	0.800	0.657
Total productive maintenance	0.225	0.222	0.270	0.167	0.000	0.381	0.585	0.000	0.360	0.400
Total quality management	0.825	0.472	0.730	0.708	0.781	0.214	0.732	0.667	0.760	0.686
Value stream mapping	0.500	0.083	0.027	0.208	0.594	0.310	0.244	0.222	0.120	0.371
Visual management	0.500	0.611	0.541	0.542	0.719	0.524	0.659	0.222	0.560	0.543

Source: Prepared by the authors

In the case of the data sample, the maximum value (Δmax) of 0.925 and the minimum value (Δmin) of 0 were identified.

For the example in use (Equation 4):

$$\varepsilon_{(5s,\text{Cost Development})} = \frac{0+0.5\times 1}{0.528+0.5\times 1} = 0.467 \tag{4}$$

The results obtained from Equation (3) are in Table V.

4.1.4 Calculation of gray relational grade (R). Once the grey relational coefficients (ε) are established, the correlation calculus is performed (Equation (5)). At this point, the variables under analysis are influenced by relative weights (ω) to weigh criteria of importance for the analysis in question. These weights receive real values between 0 and 1, and the sum of the weights is equal to 1:

$$r_{ij} = \left(\omega_j \times \varepsilon_{ij}\right) \tag{5}$$

For the present research, the relative weight of the WCM pillar was determined by dividing the pillar's general average by the average for all the pillars. The result of the calculation is presented in Table VI.

The established relative weights were applied in Equation 5. For the example in use, $r_{(5S,\text{ Cost Development})} = 0.467\times 0.131 = 0.061$. The other values are expressed in Table VII.

Finally, to obtain a tool's gray relational grade (R) result, the values of the columns (Equation (6)) are added together:

$$R_i = \sum_{i=1}^{24}\left(\omega_j \times \varepsilon_{ij}\right). \tag{6}$$

Therefore, to obtain the 5S tool's grey relational grade (R), for example, we sum the results of the ten WCM pillars, obtaining a total of 0.407.

The tools' sums were ranked in decreasing order, showing, in the experts' opinion, which of the lean production system's tools has the greatest impact on the WCM pillars, as shown in Table VIII.

Table VIII shows the column frequency among the most indicated tools, which reflects the number of times a lean production tool was among the five largest percentages presented in Table I.

5. Discussion of the results

The results obtained from the use of GRA present an important coherence and logic to conduct the application of lean tools in an organizational environment.

The VSM tool that obtained the highest index (0.6816) stood out according to the expert respondents when we determined the indicator of greatest impact among the tools evaluated based on the WCM pillars. The VSM is an important tool in the lean philosophy because the symbols visually represent the flow of materials and information in the organization and enables the calculation of several performance indicators associated with cost, time, quality and flexibility, such as cycle time, setup time, availability, number of operators, scrap rate, and lead time of activities that add value and do not add value. This characteristic of the VSM tool makes it possible to positively leverage several WCM pillars, allowing for the study of process improvements. In literature reviews conducted by

Table V.
Grey relational coefficient calculation results (ε_{ij})

Lean production tools	WCM pillar's									
	Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
5S	1.000	0.467	0.631	0.847	0.465	0.618	0.413	0.555	1.000	0.844
Autonomation/ Jidoka	0.416	0.454	0.427	0.613	0.413	0.428	0.380	0.471	0.420	0.536
Cellular manufacturing	0.407	0.581	0.631	0.787	0.465	0.548	0.527	0.532	0.391	0.488
Concurrent engineering	0.381	0.526	0.416	0.461	0.402	0.41	0.452	0.555	0.471	0.473
Empowerment	0.435	0.42	0.502	0.735	0.451	0.447	0.413	0.51	0.512	1.000
Group technology	0.359	0.454	0.397	0.442	0.392	0.393	0.422	0.397	0.366	0.424
Just in time	0.374	0.735	0.631	0.502	0.425	0.548	1.000	0.641	0.452	0.460
Kaizen	0.468	0.735	0.710	1.000	0.574	0.66	0.500	0.757	0.658	0.698
Kanban	0.366	0.649	0.502	0.526	0.438	0.493	0.678	0.581	0.391	0.447
Lead time	0.374	0.625	0.568	0.442	0.381	0.469	0.633	0.675	0.355	0.366
Multifunctional workforce	0.446	0.420	0.406	0.613	0.392	0.385	0.387	0.41	0.366	0.764
Poka Yoke	0.507	0.454	0.517	0.649	0.381	0.618	0.395	0.454	0.452	0.473
Production leveling	0.339	0.467	0.388	0.357	0.372	0.393	0.475	0.49	0.345	0.366
Pull production	0.352	0.581	0.427	0.526	0.402	0.458	0.703	0.532	0.378	0.403
Single minute exchange of die (SMED)	0.435	0.543	0.74	0.613	0.532	0.428	0.422	0.555	0.355	0.503
Six Sigma	0.435	0.675	0.774	0.442	0.438	1.000	0.422	0.581	0.452	0.618
Small lot size	0.333	1.000	1.000	0.442	0.363	0.428	0.678	0.438	0.366	0.384
Standardization of operations	0.725	0.625	0.774	0.735	0.465	0.66	0.487	0.49	0.405	0.730
Statistical process control	0.359	0.481	0.416	0.395	0.363	0.638	0.395	0.51	0.405	0.413

(*continued*)

Table V.

Lean production tools	WCM pillar's									
	Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
Supply chain integration	0.346	0.581	0.406	0.369	0.346	0.458	0.73	0.49	0.391	0.403
Takt-time	0.374	0.649	0.502	0.526	0.392	0.447	0.678	0.581	0.366	0.413
Total productive maintenance	0.673	0.675	0.631	0.735	1.000	0.548	0.441	1.000	0.562	0.536
Total quality management	0.359	0.495	0.388	0.395	0.372	0.683	0.387	0.41	0.378	0.403
Value stream mapping	0.481	0.847	0.945	0.689	0.438	0.599	0.655	0.675	0.794	0.555
Visual management	0.481	0.431	0.461	0.461	0.392	0.469	0.413	0.675	0.452	0.46

Source: Prepared by the authors

Table VI. Relative weight distribution calculation result (ω) by pillars

WCM pillar's	Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development	Total
General average for the pillar	24.90	38.97	37.03	24.48	20.34	39.31	36.55	27.86	16.62	31.31	297.3
Relative pillar weight (ω_j)	0.084	0.131	0.125	0.082	0.068	0.132	0.123	0.094	0.056	0.105	1.000

Source: Prepared by the authors

Table VII. Results of the calculation with the relative weight of grey relational grade (r)

Lean production tools	WCM pillar's: Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
5S	0.084	0.061	0.079	0.069	0.032	0.082	0.051	0.052	0.056	0.089
Autonomation/Jidoka	0.035	0.060	0.053	0.050	0.028	0.056	0.047	0.044	0.023	0.056
Cellular manufacturing	0.034	0.076	0.079	0.065	0.032	0.072	0.065	0.050	0.022	0.051
Concurrent engineering	0.032	0.069	0.052	0.038	0.027	0.054	0.056	0.052	0.026	0.050
Empowerment	0.037	0.055	0.063	0.060	0.031	0.059	0.051	0.048	0.029	0.105
Group technology	0.030	0.060	0.050	0.036	0.027	0.052	0.052	0.037	0.021	0.045
Just in time	0.031	0.096	0.079	0.041	0.029	0.072	0.123	0.060	0.025	0.048
Kaizen	0.039	0.096	0.089	0.082	0.039	0.087	0.061	0.071	0.037	0.073
Kanban	0.031	0.085	0.063	0.043	0.030	0.065	0.083	0.055	0.022	0.047
Lead time	0.031	0.082	0.071	0.036	0.026	0.062	0.078	0.063	0.020	0.038
Multifunctional workforce	0.037	0.055	0.051	0.050	0.027	0.051	0.048	0.039	0.021	0.080
Poka Yoke	0.043	0.060	0.065	0.053	0.026	0.082	0.049	0.043	0.025	0.050
Production leveling	0.029	0.061	0.048	0.029	0.025	0.052	0.058	0.046	0.019	0.038
Pull production	0.030	0.076	0.053	0.043	0.027	0.060	0.087	0.050	0.021	0.042
Single minute exchange of die (SMED)	0.037	0.071	0.093	0.050	0.036	0.056	0.052	0.052	0.020	0.053
Six Sigma	0.037	0.088	0.097	0.036	0.03	0.132	0.052	0.055	0.025	0.065
Small lot size	0.028	0.131	0.125	0.036	0.025	0.056	0.083	0.041	0.021	0.04
Standardization of operations	0.061	0.082	0.097	0.060	0.032	0.087	0.060	0.046	0.023	0.077
Statistical process control	0.030	0.063	0.052	0.032	0.025	0.084	0.049	0.048	0.023	0.043

(*continued*)

Table VII.

Lean production tools	WCM pillar's: Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
Supply chain integration	0.029	0.076	0.051	0.030	0.024	0.060	0.090	0.046	0.022	0.042
Takt-time	0.031	0.085	0.063	0.043	0.027	0.059	0.083	0.055	0.021	0.043
Total productive maintenance	0.057	0.088	0.079	0.060	0.068	0.072	0.054	0.094	0.031	0.056
Total quality management	0.030	0.065	0.048	0.032	0.025	0.090	0.048	0.039	0.021	0.042
Value stream mapping	0.040	0.111	0.118	0.057	0.030	0.079	0.081	0.063	0.044	0.058
Visual management	0.040	0.056	0.058	0.038	0.027	0.062	0.051	0.063	0.025	0.048

Source: Prepared by the authors

Rank	Lean production tools	R	Frequency among the most indicated
1	Value stream mapping	0.6816	8
2	Kaizen	0.4325	8
3	Total productive maintenance	0.4245	7
4	Six Sigma	0.4198	6
5	Standardization of operations	0.4186	6
6	5S	0.4068	7
7	Small lot size	0.4014	3
8	Cellular manufacturing	0.3578	3
9	Just in time	0.3491	5
10	Single minute exchange of die (SMED)	0.3432	2
11	Poka Yoke	0.3274	2
12	Kanban	0.3165	3
13	Lead time	0.3084	1
14	Takt-time	0.3079	3
15	Empowerment	0.3043	4
16	Total quality management	0.2914	1
17	Pull production	0.2900	1
18	Statistical process control	0.2865	1
19	Autonomation/Jidoka	0.2826	0
20	Visual management	0.2807	2
21	Concurrent engineering	0.2722	1
22	Multifunctional workforce	0.2710	1
23	Supply chain integration	0.2702	1
24	Group technology	0.2541	0
25	Production leveling	0.2446	0

Source: Prepared by the authors

Table VIII. Ranking of the lean production system tools resulting of GRA calculation

Bhamu and Sangwan (2014) and Jasti and Kodali (2014), the VSM stands out, respectively, as the 1st and 2nd lean tools of higher implementation frequency. This fact corroborates the results of the expert judgment and emphasizes that although the use of the tool is focused on the solution of a problem by the organization, it obtains positive impacts on other factors that are not considered.

These process improvements, through the lean philosophy, can be carried out with the kaizen tool, which took the 2nd position (kaizen) as a tool that makes it possible to leverage the WCM pillars. Comparison with literature reviews on lean tools reveals the use of kaizen with various frequencies (and hence, importance). In Jasti and Kodali's (2014) study, kaizen is the 3rd most frequently used tool, but in the surveys conducted by Bhamu and Sangwan (2014) and Marodin and Saurin (2013), it falls into the intermediate range of use. Kaizen is focused on and includes action-oriented events to solve a problem or implement an improvement, driven by a logical structure. From the knowledge of a process's current state established by the VSM, kaizen emerges as an important tool for proposing and implementing improvements in the future state.

TPM is the third tool of the lean production system that impacts the seven WCM pillars. The TPM allows organizations to improve their global efficiency indicators through actions to prevent failures, which allow for the improvement of equipment effectiveness and the empowerment of employees. In studies by Bhamu and Sangwan (2014) and Marodin and Saurin (2013), the TPM is the 4th tool and 3rd tool, respectively, and for Jasti and Kodali, it is the tool with the thirteenth highest frequency of use.

With equipment presenting smaller failures and fewer stops, a positive scenario emerges for the use of Six Sigma because it can eliminate variations and defects in the process (Lameijer *et al.*, 2016), helping reduce the number of defects and increase the financial benefit

(Habidin and Yusof, 2013). It is therefore important to highlight that Six Sigma is theoretically considered an administrative strategy and not a lean tool (Drohomeretski *et al.*, 2014). In the lean tool survey studies used here as a comparative basis, the use of Six Sigma was not included.

The elimination of process variations involves the establishment of work standards (5th tool), which give employees easy access to the production stages, tools and parts needed to produce the desired good or service (Liker, 2003). The knowledge gathered from all the chain's stages allows for the process's stabilization (fundamental to the success of Six Sigma) and action on the flow, proposing improvements.

5S emerges as a sixth highlight. Although it has a positive impact on a larger number of pillars (seven) than Six Sigma and standardized work (six pillars), its impact is considered inferior to those from the GRA calculation. 5S is a tool that emphasizes awareness of the importance of organization and cleanliness in the workplace and positively impacts the success of the tools listed above.

Table IX presents the six best performing (1st quartile) lean production tools from the GRA calculation. The gray-top relationships between tool × pillar previously presented in Table II are presented in gray. It is noteworthy that the use of these six lean tools broadly serves WCM pillars, contributing in a meaningful way to the organizational performance. Each of the pillars, except for logistics and quality control, would have a positive impact on at least four of the six main tools highlighted by the GRA calculation.

The quality control pillar is impacted by three of the six main tools, and the logistics pillar is positively impacted by the two main tools highlighted by the GRA calculation.

It should be noted that important tools of lean production, such as kanban, autonomation/jidoka, simultaneous engineering, group technology and production leveling were not present in this research from the respondents' point of view and by the statistics employed in their calculation. However, their absence should not result in their exclusion of their use; rather, they are merely of less significance than the others. Sundar *et al.* (2014) pointed out that in practice, the organization focuses on only a few aspects of lean elements such as cellular manufacturing, pull system, production leveling and others for their contributions to manufacturing system success. This finding contributes to a restricted view of the use of lean tools and gains in other areas of the organization. We surpassed this fact by conducting an analysis of lean tools' impact on the various WCM pillars, allowing researchers to reflect beyond the point of use.

6. Conclusion

This research stands out in the field of operations management and specifically in the research on lean production by making use of the theory of the grey correlation system in an innovative and original way. This theory proved to be adequate to analyze the data resulting from a survey conducted with Brazilian researchers that work on the research theme and allowed us to connect two administrative strategies (lean production and WCM) that stand out in the literature, which was important because joint theoretical studies are scarce.

The VSM, kaizen, TPM, Six Sigma, standardization of operations and 5S tools stood out in the analysis conducted by obtaining high (R) indicators and by positively and jointly impacting a large number of WCM pillars.

Finally, it should be pointed out that although this work provides guidance on which lean production tools result in a greater impact on the WCM pillars, it is up to each organization, as Karim and Arif-Uz-Zaman (2013) point out, to determine which tool will be used because this factor depends on each organization's specific manufacturing process, and not all of them can or do fit all types of organizational environments.

Table IX. Main lean production tools by GRA calculation and impacted WCM pillars

Lean production tools	WCM pillar's									
	Safety-hygiene and working environment	Cost deployment	Focus improvement	Autonomous activities	Professional maintenance	Quality control	Logistic and customer service	Early equipment and product management	Environment	People development
Value stream mapping	■	■	■	■			■	■	■	■
Kaizen		■	■	■	■		■	■	■	■
Total productive maintenance	■	■	■	■	■			■	■	
Six Sigma		■	■			■		■	■	■
Standardization of operations	■		■	■	■	■				■
5S	■		■	■	■	■			■	■

Source: Prepared by the authors

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