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The application of fuzzy clustering to tools classification in lean management

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Abstract. In the context of the "New Normal" society, lean management is essential for the transformation of manufacturing enterprises. Therefore, the match between lean tools and lean's implementation phases is an important factor in lean management's successful application. This paper identified 21 common lean tools from management practices in 10 manufacturing enterprises and classified these tools using fuzzy clustering analysis. This classification was performed according to the 4 lean management implementation phases in enterprises: point, line, aspect, and system. The results identify the common lean tools in each implementation phase and provide guidance for scientific tool selection during lean implementation.

Key words. Manufacturing enterprises, lean management, implementation phase, tools classification.

1. Introduction

Originated by Toyota Motor Corporation, lean management has been popular among manufacturing enterprises. The success practical cases of lean management have demonstrated its great utility in improving quality, enhancing delivery and reducing costs [1]. As the economy weakens, more enterprises hope to improve their operations through lean management. However, the implementation results of lean management have thus far not been ideal. An investigation demonstrated that only 26% of American manufacturing enterprises benefitted from lean management [2, 3]. Chinese manufacturing enterprises introduced lean management later than American manufacturers. Thus, inadequate experience makes it even more difficult for Chinese enterprises to succeed in lean implementation. According to surveys conducted by lean consulting agencies, one essential reason for the failure of lean

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management is the inappropriate selection of lean tools. This means that the lean tools used do not match a given implementation phase of lean management [4]. In general, lean management implementation can be divided into 4 phases: point, line, aspect, and system. The core work and objectives of the different phases are distinct. The core work in the 4 phases are standardization of sites, manipulation, process and institution, respectively [5]. Currently, there are more than 100 types of lean management tools [6-8]. Not all these tools are suitable for every enterprise and they cannot all be applied in one enterprise. However, most mangers cannot fully understand these lean tools, which results in the inappropriate selection of lean tools during lean management implementation. This was demonstrated by Tiwari et al. (2007), who indicated that the failure of lean management was the result of managers who were incapable of choosing appropriate lean tools. Therefore, access to a summary of common lean manufacturing tools and the degree to which these tools match the aforementioned 4 phases is an urgent problem for manufacturing enterprises [9].

To solve this problem, this paper aimed to identify common lean tools in manufacturing enterprises and classify them according to the 4 phases of point, line, aspect, and system. The results of this study can improve the matching between lean tools and lean implementation, thus providing guidance for Chinese manufacturing enterprises.

2. Literature review and methodology

In the existing literature, there is relatively little research on lean tools classification. In Doolen and Hacker's research, 29 lean tools were classified into 6 bundles to measure the level of lean implementation in enterprises. The 6 bundles were manufacturing equipment and process, job-shop management, product development management, supplier management, customer management and employee management [6]. By combining development and the concept of lean production, Shah and Ward identified 10 lean tools and gave an operational definition of lean production from three dimensions: supplier, internal enterprises and customer [10]. Bortolotti and Boscari researched the relationship between lean tools and the success of lean implementation. In their study, they divided lean tools into hard and soft tools based on whether people were directly involved with their use. Soft lean tools refer to lean tools in which employees or corporate management participate, such as small group activities, staff training and continuous improvement. Above all, in the existing literature, studies of the classification of lean tools regard lean tools as brokering instruments that are used to identify the concept of lean production and measure the relationship between lean production and company performance rather than the lean tools themselves. As a result, these instruments have not focused on the nature of and application methods for lean tools.

According to the literature [6-8], there are more than 100 types of lean management tools, although not all of them can be used in practice. To facilitate this research and provide references for lean management practices, this paper primarily extracted the most common lean tools used by enterprises for lean implementation.

Because lean management happens through practice and is used in practice, the most effective way to achieve the study goals was through case studies, which can extract relevant information from practice [10-11]. Case studies can raise corporate practical experiences to the theoretical level, which is more persuasive. They can achieve the effect of "come from practice, and then apply to practice". Therefore, this paper first conducts a case study to analyze the primary lean management tools in manufacturing enterprises. Based on this summary of the most common lean management tools, the diverse tools used in different implementation phases of lean management practice are then determined.

The classification of lean management tools according to the proposed 4 phases of point, line, aspect, and system is a critical factor in matching lean tools with implementation processes and in the successful application of lean management within enterprises. Due to the overlap among the lean tools during different implementation phases and their ambiguous phase attributes, lean tools are not easily classified. Thus, the fuzzy cluster analysis method was adopted for this paper. This method adds fuzzy theory to cluster analysis and can be used to analyze multi-attribute objects. This soft classification without rigid standards addresses the problems inherent in the traditional clustering method: strict classification standards and the rule that that an object can belong to only one class. Fuzzy clustering analysis has been widely used in various fields as an effective classification tool. Therefore, to address the multi-phase characteristics of lean tools, this paper adopted the fuzzy cluster analysis method to match lean tools with the 4 implementation phases of point, line, aspect, and system.

3. Research design

3.1. Research sample

The representativeness of the sample has a direct impact on the credibility of the research conclusions. To make the research conclusions more universal and scientific, taking into account considerations of representation and data accessibility, this paper chose ten enterprises that have implemented lean management as the research sample. The sample enterprises and the corresponding data are shown in Table 1.

The companies are located throughout China in Anhui, Zhejiang, Shandong, Chongqing, Jilin, Hebei, and Tianjin. The companies represent home appliance manufacturing, equipment manufacturing, machinery manufacturing, the chemical industry, the rubber and plastics industry, milk products, logistics and other manufacturing enterprises. In addition, most of these enterprises rank at the top of their industries and include state-owned corporate enterprises, private enterprises and others. All these enterprises introduced lean management after 2009 and still made time-efficient gains In conclusion, a study of these sample enterprises can reveal the lean tools used in lean implementation, thus achieving the research objective.

3.2. Data collection

To obtain accurate data, this paper adopted various data collection methods including interviews with lean implementation managers, field investigations in enterprises, and telephone interviews, among others. The detailed methods are shown in Table 1.

Table 1. Research samples and data collection methods

Code	Enterprise	Industry	Introduction	Ownership	Start year	Revisit year	Case study methods
1	Hefei GREE	Household appliances	Leader in the home appliance industry	State-owned share-holding enterprise	2010	2013	Interview with implementation managers
2	Canaan	Equipment manufacturing	Top brand of medical equipment in China	Private enterprise	2009	2014	Senior manager research
3	Shandong Jingbo Petrochemical Co Ltd	Chemical industry	In top 20 of manufacturing top 500	Private enterprise	2013	2015	Departmental discussion
4	Hebei Ouya Guanye	Rubber and plastics industry	Ranks second in this industry	Private enterprise	2011	2014	On-site survey
5	Junlebao	Dairy industry	Industry top three	Private enterprise	2012	2015	On-site survey
6	Tianjin Water Group	Water industry	Regional monopolies	State-owned enterprise	2013	2015	On-site survey
7	Changchun FAW International Logistics Co. Ltd	Logistics industry	Logistics business of automobile industry corporation	State-owned enterprise	2011	2014	Departmental discussion
8	Weichai Power	Equipment manufacturing	Billions level equipment manufacturing corporation	State-owned share-holding enterprise	2009	2014	Interview with managers

4. Results

4.1. Common lean management tools extraction

Based on the data collected on the above 10 sample enterprises, combined with information about each enterprise's corporate culture and organizational structure, personnel quality, industrial characteristics, size and economic strength, this research identified 21 types of common lean management tools that are used in the lean implementation process. Their names, content, applications and corresponding enterprise information are shown in Table 2.

Table 2.Twenty-one common lean management tools

Tool	Enterprise	Contents of tool	Level
5S	1	Seiri, Seiton, Seiso, Seiketsu, Shitsuke	Enterprise Lean activities
	3,8		Factory Lean activities
	4,6,10		Team Lean activities
LCIA	1	Solution for efficiency and quality issues with low cost	Workshop Lean activities
	10	Independent design of semi-automatic tools that prevent human error and improve equipment efficiency and product quality	
TPM	1	Optimize the operations process based on study of operation sequence	Team Lean activities
	2		Workshop Lean activities
	3	Total involvement in equipment efficiency promotion activities	
	5		Factory Lean activities
	10		Enterprise Lean activities
Andon	5,7	Mechanism for rapid response to production failure	Workshop Lean activities
Standard Operation	5,6,8,10	Study of operation and repair processes	Post Lean activities
	7		Factory Lean activities
Multi-skill	3	Study of operation process, optimizes the operation process	Post Lean activities
	5	Summarize and report improvement on a piece of paper	Factory Lean activities
	8	Operators with multiple job skills	Team Lean activities
Hoshin Kanri	2	Total involvement in management and manufacturing process	Enterprise Lean activities
	5,6	Staff activities based on plant objectives	Factory Lean activities
	9		Department Lean activities
Rationalization proposal	3,6	Propose suggestions for production process and management	Staff Lean activities
VSM	1,7,8,9,10	Document the time flow of material and information, improve the efficiency of the process	Factory Lean activities

4.2. Clustering analysis of common lean management tools

After extracting the 21 types of lean management tools, we classified them according to the 4 implementation phases of point, line, aspect, and system to match the tools with the implementation phases. In this process, we determined the scope attributes of lean tools. The coverage scope of a tool determines its application phase. Then, we further analyzed the excitability of each tool in its corresponding phase. We also determined the investment characteristics of the lean management tools. The subordinate phase of each tool was determined by the phase that benefitted directly and by the phase in which staff were highly involved (pay cost). The range and investment attributes must be taken into consideration when matching lean tools and implementation phases.

In the specific operation, lean tools were assessed based on their characteristic coefficients of range and their investment attributes, which were the premise and key for classifying lean tools according to the lean management implementation phases. Scoring was performed by an expert team that included scholars in related areas and practiced technicians. This study invited 3 experts from a research center at Tianjin University and from Chusanren Japan who have engaged in the research and practice of lean management for a long time, as well as 2 middle managers of lean management implementation. In the evaluation process, after fully reviewing the 10 cases, these 5 experts scored the character coefficient of range and the investment attributes of 21 lean tools according to the 4 implementation phases of point, line, aspect, and system. Based on the results, the 21 common lean tools were classified by the fuzzy clustering method. Common fuzzy clustering algorithms can be divided into 2 types: the transitive closure method and the maximum tree method. This paper adopted the transitive closure method. Using the score results of the point phase as an example, the specific analytical procedures were as follows:

(**??**)1) Build fuzzy similarity analysis matrix R of lean management tools.

A: Hypothesis $X = x_1 \ldots x_n$??denotes the set of lean tools; xi denotes each lean tool (as shown in Table 1); (xi1, xi2) denotes the character coefficients of range and investment attributes of lean tool i. The lean tools suited to the point phase were analyzed first. The character coefficients of lean tools were scored from 0 to 1. Based on the investment attributes and scope of application, a higher score represents a better degree of match between a tool and the point phase. The character coefficient of each lean tool is shown in Table 3.

Table 3.Symbols and character coefficients of lean management tools

Symbol	Lean tool	Character coefficient		Symbol	Lean tool	Character coefficient	
		xi1	xi2			xi1	xi2
x1	5S activity	0.9	0.9	x12	ANDON	0.3	0.3
x2	Rationalization proposal	0.9	0.8	x13	Emergency stop	0.9	0.8
x3	Hoshin Kanri	0.2	0.3	x14	Time study	0.8	0.9
x4	Proposal improvement	0.3	0.2	x15	Multi-skill	0.8	0.9
x5	TPM	0.3	0.1	x16	One worker multiple machines	0.3	0.5
x6	Proposal management	0.5	0.2	x17	Value flow	0.5	0.2
x7	Project management	0.2	0.4	x18	LCIA	0.4	0.3
x8	Total improvement	0.2	0.2	x19	Just-in-time	0.2	0.2
x9	Exception management	0.3	0.1	x20	Jidoka	0.1	0.3
x10	Small-group activities	0.9	0.9	x21	Standard operation	0.5	0.2
x11	Exception engineering	0.4	0.2				

B: Based on the characteristics coefficient of the lean management tools, a lean management tools similar analysis matrix R was calculated using the absolute value subtrahend method, as shown in Table 4.

Table 4.Similar analysis matrix R

xi1	2	3	4	5	6	7	8	9	10	11	12
11.0	1.0	0.4	0.4	0.3	0.5	0.4	0.3	0.3	1.0	0.4	0.4
21.0	1.0	0.4	0.4	0.4	0.5	0.5	0.4	0.4	1.0	0.5	0.5
30.4	0.4	1.0	0.9	0.9	0.8	1.0	1.0	0.9	0.4	0.9	1.0
40.4	0.4	0.9	1.0	1.0	0.9	0.9	1.0	1.0	0.4	1.0	0.9
50.3	0.4	0.9	1.0	1.0	0.9	0.8	0.9	1.0	0.3	0.9	1.0
60.5	0.5	0.8	0.9	0.9	1.0	0.8	0.9	0.9	0.5	1.0	0.8
70.4	0.5	1.0	0.9	0.8	0.8	1.0	0.9	0.9	0.4	0.8	0.9
80.3	0.4	1.0	1.0	0.9	0.9	0.9	1.0	0.9	0.3	0.9	0.9
90.3	0.4	0.9	1.0	1.0	0.9	0.9	0.9	1.0	0.3	0.9	0.9
101.0	1.0	0.4	0.4	0.3	0.5	0.4	0.3	0.3	1.0	0.4	0.4
110.4	0.5	0.9	1.0	0.9	1.0	0.8	0.9	0.9	0.4	1.0	0.9
120.4	0.5	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.4	0.9	1.0
131.0	1.0	0.4	0.4	0.4	0.5	0.5	0.4	0.4	1.0	0.5	0.5
141.0	0.9	0.4	0.4	0.4	0.5	0.5	0.4	0.4	1.0	0.5	0.5
151.0	0.9	0.4	0.4	0.4	0.5	0.5	0.4	0.4	1.0	0.5	0.5
160.5	0.6	0.9	0.9	0.8	0.8	0.9	0.8	0.8	0.5	0.8	0.9
170.5	0.5	0.8	0.9	0.9	1.0	0.8	0.9	0.9	0.5	1.0	0.9
180.5	0.5	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.5	1.0	1.0
190.3	0.4	1.0	1.0	0.9	0.9	0.9	1.0	0.9	0.3	0.9	0.9
200.3	0.4	1.0	0.9	0.8	0.8	0.9	0.9	0.8	0.3	0.8	0.9
210.5	0.5	0.8	0.9	0.9	1.0	0.8	0.9	0.9	0.5	1.0	0.9

(??)2)The transitive closure of the fuzzy similar matrix t(R)

According to the method of transitive closure, the transitive closure of similar matrix t(R) of lean management tools was calculated.

Choose the appropriate level in which to classify the lean tools

λ=0.8, {x1,x2,x10,x13,x14,x15} belonged to a single category, which meant that the 5S activity, reasonable proposal, small-group activities, emergency stop, time study and multi-skill tools match the point phase of implementation.

4.3. Clustering results

The clustering process was repeated until all the lean tools were classified according to the implementation phases of point, line, aspect, and system. Thus, we matched the lean tools with their corresponding implementation phases. The detail clustering results are shown in Table 5.

Table 5.Classification results for lean management tools

	Point	line	aspect	system
	working team	workshop	factory (department)	enterprise
1	5s	5s	5s	5s
2	Reasonable proposal	Proposal improvement	Proposal management	Total improvement
3	Small-group activities	TPM	Project management	Hoshin Kanri
4	Emergency stop	Andon	Exception engineering	Exception management
5	Time study	Standard operation	VSM	JIT
6	Multi-skill	One worker multiple machines	LCIA	Jidoka

As shown in table 5, the 5s tool is applicable to all 4 phases of lean implementation. However, the emphasis placed on 5S is not same in each of the 4 phases. In the point phase, 5S is an action request for a working group. In the line phase, 5S is the basis for production management of a workshop. In the aspect phase, 5S is the standardization and visual management of materials and operations in an entire factory. In the system phase, 5s is an important tool for promoting overall improvement at the enterprise level (as shown in Figure1). 5S is a simple and efficient lean management tool that plays a large role in standardizing operations, reducing costs, ensuring on-time delivery, adhering to safety procedures, creating a coordinated workplace and improving corporate image. Therefore, 5S is an important driving force of lean management implementation.

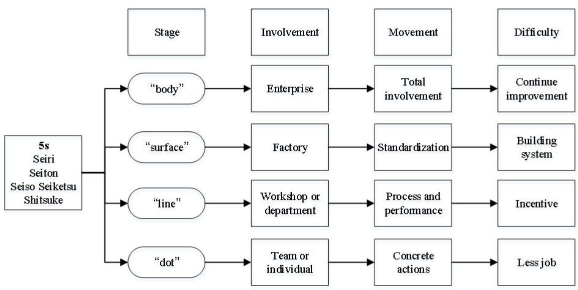

Fig. 1. Representation of 5s in different levels of lean implementation

As shown in Figure 1, the relationship between lean tools and lean management implementation is not a one-to-one correlation but a many-to-many relationship instead. Some lean tools can be used in different implementation phases (levels), while others can be used only in one implementation level. The same lean tool may have different content and a different application in different phases. Therefore, matching lean tools with the different implementation phases cannot be undertaken mechanically. Enterprises should choose the optimal lean tools to match the different implementation phases according to their own practical situations to increase the efficiency and success rate of lean management in enterprises.

5. Discussion

This paper offers important theoretical and practical contributions to the field through multiple case studies.First, this paper defined 21 common lean tools that are currently used by Chinese enterprises according to their range and investment attributes. The definition of lean tools has been ambiguous in the past. In this sense, the paper provided a new perspective on defining lean tools.

Second, by addressing the vague classification of lean tools, this paper provided a new classification mode according to the lean implementation phases of point, line, aspect, and system. This new mode can help managers clarify the logical sequence and application levels of these lean tools, thus ensuring the proper application of the tools and improving operational efficiency.

Third, this paper deduced the matching status, which was multiple-to-multiple, between lean tools and implementation phases in enterprises. This meant that multiple lean tools could be needed in one phase, while some lean tools such as 5S could match multiple phases. When involved in a lean implementation phase, enterprises would typically activate certain ranges and staff for the phase. By using the proposed matching structure, enterprises could find the appropriate lean tools (with consistent range and investment attributes) that match a given phase. Thus, lean tools could be fully effective, allowing the maximization of improvement effects and preventing the abuse of lean tools.

Fourth, this paper revealed that some lean tools have a progressive relationship with the different phases of point, line, aspect, and system. These lean tools could be updated in step with progress made in a phase, while the updates to the tool in the next phase must be based on how the tool was applied in the previous phase. The updated tools would have more functionality, match a larger range and solve a greater scope of problems. The definitive classification and continuity of application of lean tools are the foundations of the sustainable and efficient implementation of lean management.

As discussed above, the essence of lean implementation is to continually absorb more staff and involve them in lean activities, while the involved staff absorb more lean tools and implement effective improvements in their work areas. The core goal is the continuous improvement of an enterprise's overall capacity to improve.

6. Conclusion

Based on case studies of 10 sample enterprises, this paper extracted 21 common lean tools used by most manufacturing enterprises by conducting an analysis of the sample data. We then invited experts to score the range and investment attributes of these lean tools. Finally, we classified the 21 lean tools according to the lean implementation phases of point, line, aspect and system using fuzzy clustering. Thus, a suitable match between the lean tools and the implementation phases could be achieved. The hierarchical classification of lean tools clarified the relationships among these tools and made these lean tools easy to understand. It could also help enterprises train more internal specialists, meaning that total staff involvement would be easier to achieve. As employees improve their executive abilities and communication costs decrease, passive resistance could be effectively avoided. All these changes could improve enterprises' implementation efficiency and success rates. Additionally, it could become a reference for manufacturing enterprises that are implementing lean management. However, because few enterprises implement lean management, the selection of sample enterprises for the study was rather difficult. Although this paper conducted an adequate investigation, the number of sample enterprises was limited, which might result in some deviations between the research results and practice. This limitation can be further addressed in the future.

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