

Effect of Lean Production on Enterprise Performance Based on Bayesian Network

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Abstract

The market competition pressure of modern enterprise is more and more big, in order to enhance enterprise benefit, lean production model is widely adopted. How to effectively measure the effect of lean production on enterprise performance is the object of this paper. This paper will analyze the impact of different lean techniques combinations on the financial performance and non-financial performance of the enterprise, in which the four performance indicators, that is, flexibility, reliability, quality and time will be adopted, and the financial performance, non-financial performance and sustainability are determined as performance decision variables. Bayesian networks will be used to build inference model. Using the means of simulation, three different scenarios will show the impact of lean techniques promotion on enterprise performance.

Key words: Lean production; Bayesian network; Scenario analysis; Enterprise performance

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INTRODUCTION

Lean Production (Liu & Lu, 2009) (abbreviated as LP) is the recognition of Toyota's production in Japan by experts from International Motor Vehicle Program (IMVP)

which is determined by the Massachusetts Institute of Technology (MIT). In 1990, with the publication of *The Machine That Change the World: The Story of Lean Production* written by Womack and others, the idea of lean thought was gradually widely recognized. Lean production applied the just-in-time production, Kanban management, Jidoka (autonomation), TPM and other lean techniques, the goal of it is to strive for excellence, perfection, and constantly reduce costs, to achieve zero scrap, zero inventory and product variety diversification, to eliminate waste, reduce non-value-added activities, to increase value-added activities and maximize the performance of enterprises, and to increase the overall profit of the whole company. The content of lean production is more than any previously proposed techniques, the coverage involved is wider, and the problems solved is more comprehensive. In recent years, lean production is more and more valued by enterprises, and is regarded as an important strategy to enhance the competitiveness and performance of enterprises. However, there is little concern and confirmation about the positive relationship between lean production techniques and enterprise performance.

Scenario analysis can predict what might happen to the forecast object or its consequences. This approach allows enterprises to make decisions and consider changes in enterprise performance by considering a range of events that may occur in the future in the current enterprise environment. Bayesian Network, as an uncertain inference network based on probability, is considered to be one of the most effective theoretical models in the field of uncertain knowledge representation and inference, and it is an important tool for linking quantitative and qualitative methods in management decision-making. Bayesian Network is well combined with observations and expert opinions in uncertainty, and has been used to deal with uncertain information in intelligent systems, and has been successfully used in medical diagnosis, statistical

decisions, expert system and learning prediction and other fields. In lean production, only a few of Bayesian Networks have been applied to lean production: Li and Rajpal (2009) using Bayesian Network analysis to improve the sustainability of lean techniques, Li and Sawhne (2013) using Bayesian Network to evaluate Lean Six Sigma, enhance Lean Six Sigma effectiveness, Hristea and Colhon (2012) using Bayesian Network clustering knowledge in order to realize the enterprise's lean. These literatures highlight the benefits of using Bayesian Networks with limited knowledge in an uncertain environment.

The paper aims to determine the impact of lean production techniques on enterprise performance. We firstly give the lean production techniques, according to the analysis and needs of some lean production application elements of a reasonable merger, which is convenient for analysis, modeling and simulation. Secondly, we establish the "directed acyclic graph" of Bayesian Network to determine the lean factor index, give the conditional probability table and construct the Bayesian Network model. Finally, the situation is constructed, and the influence of lean production factors on enterprise performance is discussed in different situations.

1. LEAN PRODUCTION RELATED RESEARCH

The academic research on lean production practice firstly appeared in the 1970s, after that, the number of research increased continuously (Sezen et al., 2012). In various literatures, the relevant studies of lean production are carried out in different objectives and in different situations. However, in these studies, lean methods are partially evaluated or, in some cases, different name definitions are given. For example, similar lean techniques are defined as the agile manufacturing of a make-to-order factory (Narasimhan et al., 2006). Some studies prefer to use "JIT (just-in-time) production" rather than "lean manufacturing" (Callen et al., 2000). While just-in-time production is a key component of lean manufacturing, it is not sufficiently representative of the lean approach. In fact, there is a clear conceptual confusion about the definition of lean production methods in a variety of research literature (Shah & Ward, 2007).

Conceptual and semantic confusion can hinder the maintenance of content effectiveness on the model, and careful analysis and categorization of existing studies is a key prerequisite for providing support for any lean model content and related research effectiveness (Sezen et al., 2012).

Through Sezen et al. (2012), it is known that lean research mainly covers the operation practice of lean techniques. Figure 1 shows the classification of lean research in the literature. Compared with the other three

types, the research on lean techniques can be further divided into two categories. The first group consisted of case studies based on tangible factory data, and the second group includes measurement model analysis using the perceptual data. The case study of the impact of lean practice on corporate performance based on physical data is usually conducted in the automotive industry. In these studies, the suitability of the production performance and lean principle of auto parts suppliers is evaluated. The impact of lean production techniques on enterprise performance in this paper belongs to this kind of research. In addition, through the design of lean techniques compliance and the use of perceived data model to study lean production related research can be divided into two categories. The first group includes case studies using small samples size based on exploratory analysis, and the second group consisted of large sample empirical analysis. The second group can be divided into two aspects: One involves focusing on lean techniques to design a measurement model, and the other includes research on other managerial approaches, such as total quality management, human resource management, and supply chain management.

Although the concept of lean as a popular manufacturing and management concept has been accepted by global companies, it is a very complex job to successfully implement lean management. However, through the implementation of lean production, it can be found that this production and management philosophy is valuable. Ramesh and Kodali (2012) point out that the use of lean techniques is rewarded with improved operational effectiveness and cost savings. Most empirical studies show that there is a clear relationship between lean techniques and corporate performance. Enterprise performance factors are often conceptualized as operational performance, market performance and financial performance. For example, cost, inventory, production cycle, logistics, quality for operational performance indicators, sales growth and market share for market performance indicators, investment (asset, sales) rate of return, profits and market value as the index of financial performance.

Although various studies have shown that there is a clear relationship between lean technique implementation and corporate performance, it should not be overlooked that the results in different environmental conditions are different because of environmental factors. These environmental factors include factory factors (such as plant average inventory holding levels), enterprise factors (such as enterprise scale and location difference), production systems (according to make-to-order or make-to-stock), and production characteristics influence the practice of lean on enterprise performance. For example, companies with lower inventory levels are more likely to show good financial performance. Bayesian Networks have also gradually begun to use the correlation analysis of performance.

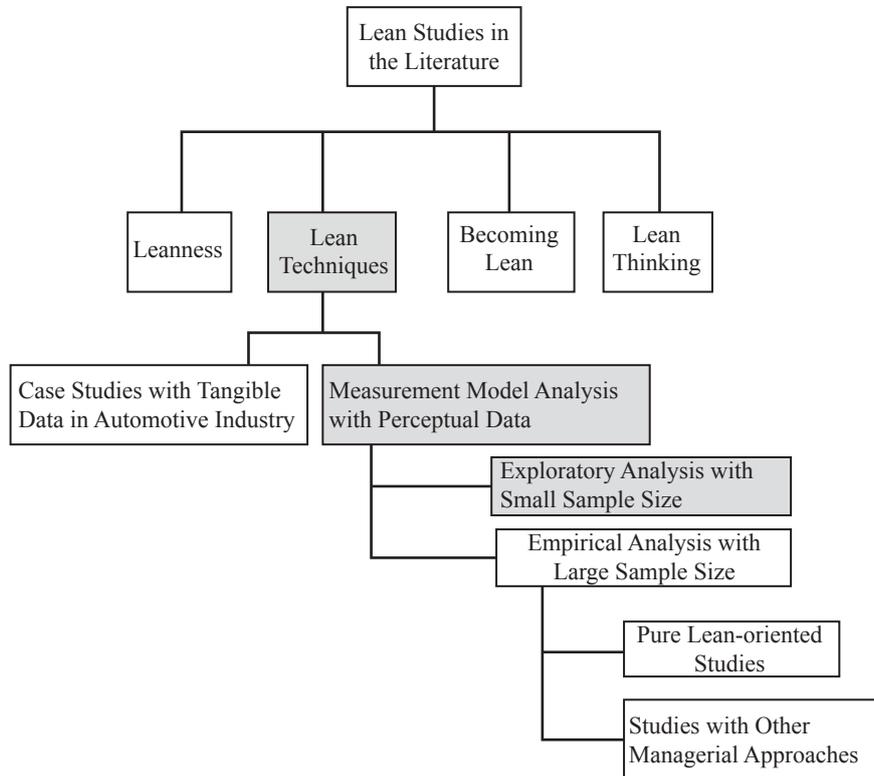


Figure 1
Conceptual Classification of the Literature on Lean Production (Sezen et al., 2012)

2. BAYESIAN NETWORK MODEL

Bayesian Network (Yang, 2007), also known as Belief Network, is the extension of Bayesian theorem, and is one of the most effective theoretical models in the field of uncertain knowledge representation and inference. Since it was put forward by Pearl in 1988, has been widely used in various fields. Bayesian Network is a probabilistic network, which is a graphical network based on probabilistic inference, and Bayesian formula is the basis of this probabilistic network. Bayesian Network is a mathematical model based on probabilistic inference, the so-called probabilistic inference is the process of obtaining other probability information through the information of some variables, Bayesian network based on probabilistic inference is proposed to solve the problem of uncertainty and completeness, and it has great advantage in solving the problems caused by the uncertainties and correlations of complex equipment.

Bayesian Network is used to represent the dependencies among variables and to provide a natural, efficient and concise directed acyclic graph structure for any joint probability distribution, in which each node is labeled with quantitative probabilistic information. Its topological structure satisfies: (a) A random variable set composes network node; the variable can be discrete or continuous. (b) A set of directed edges of a connection node pair. If there is a directed edge from node X to node Y , then X is a parent node of Y . (c) Each node X_i has a conditional

probability distribution $P(X_i | \text{Parents}(X_i))$, quantifying its parent node's impact on this node. (d) There is no directed cycle in the graph, so Bayesian Network is a kind of directed acyclic graph.

In probability theory, Bayesian principle is related to the conditional probability and marginal probability of two random events. Given event A and event B , and their probabilities are $P(A) \neq 0, P(B) \neq 0$, then

$$P(B | A) = \frac{P(A | B)P(B)}{P(A)}$$

Wherein $P(A)$ is a priori probability or marginal probability of event A , $P(B)$ is a priori probability or marginal probability of event B , $P(A | B)$ is the conditional probability of event B under the given event A , $P(A | B)$ is the conditional probability of event A under the given event B . More generally, for given n separate and mutually exclusive events B_1, B_2, \dots, B_j , there is $P(B_j) \neq 0$ for all j , then the Bayesian formula is:

$$P(B_j | A) = \frac{P(A | B_j)P(B_j)}{\sum_{j=1}^n P(A | B_j)P(B_j)}$$

As an extension of Bayesian theory, Bayesian Network can also be quantified using parameters. It contains the parameter $\theta_{x_i | \Pi_{x_i}} = P_B(x_i | \Pi_{x_i})$, where Π_{x_i} is a collection of parent nodes of the node X_i in the directed acyclic graph. A Bayesian Network defines

the probability of a combination of X_1, X_2, \dots, X_n are as follows:

$$P_B(X_1, X_2, \dots, X_n) = \prod_{i=1}^n P_B(x_i | \Pi_{x_i}) = \prod_{i=1}^n \theta_{x_i | \Pi_{x_i}}$$

Building a Bayesian Network requires two stages (Li & Rajpal, 2009): qualitative and quantitative phases (probabilities). In the qualitative phase, a cognitive approach is used to clarify the structure of the graph with acyclic graph. Bayesian Network is either based on knowledge of a domain or on a causal map that reflects expert opinion. An effective way is to combine expert

knowledge with existing data. In this case, prior knowledge is described by historical data, and expert advice is used to help build the connection among variables.

3. BUILDING THE MODEL

3.1 Factor Index and Enterprise Performance Indicators in Lean Production Management

Sezen et al. (2012) summarizes the lean practice techniques in 16, and gives its corresponding definition, as shown in Table 1.

Table 1
16 Kinds of Lean Techniques and Its Definition

Lean techniques	Definition
1. Setup time reduction	In order to minimize the amount of waste of line-stopping waiting, the process of shortening the setup time is to gradually remove and reduce all non-value-added operations and turn them into the process which is completed in the non-line-stopping time.
2. Pull production (Kanban)	Adhere to the internal user principle, taking the user's needs as the basis for production. A card that has the function of operating instructions and spot information that is passed between two adjacent workstations to arrive on time for production.
3. Small lot size	In the production of small and medium volume delivery, reduce online inventory, reduce the use of ineffective resources, while achieving a balanced production.
4. Inventory reduction	Although it may not be possible to meet changing market demands or risks of manufacturing disruption, there still is needed to avoid excessive inventory.
5. One piece flow	The single piece production and transmission of materials and products in the operation station, there is no waiting time between adjacent workstations.
6. Value stream mapping	In identifying the material flow and information flow of production, it can create value activities for customers to help identify waste and improve effectively.
7. Process improvement	Improve existing processes in the workshop to achieve new goals. The results of process improvements include the change to improve quality and lower costs.
8. Preventive maintenance	Routinely proactively maintain equipment to minimize the degree of machine downtime.
9. Equipment layout (Cellular manufacturing)	Allow all workers to achieve logistics exchange within the scope of one meter; Cellular manufacturing can save manpower and increase productivity.
10. 5s	A set of principles and practice of team discipline to improve the working environment, quality of work, including on-site collation, rectification, cleaning, plot and staff quality.
11. Order and cleanliness in the plant	Neatly place and identify parts and tools for easy use and cleaning.
12. Root cause analysis (5 Why)	Find out the source of the problem in production, take effective countermeasures to the occurrence source, and solve the problem effectively.
13. Employee suggestion system	Encourage employees to bring production-related issues to problem-solving teams to define and resolve issues.
14. Continuous improvement (Kaizen)	The system is designed to improve product quality, improve operational efficiency, reduce waste, and improve facility layout.
15. Error Proofing (Poka-Yoke)	A procedure that is used to prevent errors or to indicate errors immediately when a flaw occurs. An error-proofing device is a device that prevents incorrect parts from being manufactured or assembled, or is easy to identify defects/errors.
16. Waste elimination	It is about eliminating all waste without added-value of the production system, to achieve the lowest cost of production objectives.

In addition to the lean techniques in 16 given in Sezen et al. (2012), other lean techniques are also deserved to give attention to. In fact, in recent years, with the development of lean production, lean technique is also being summarized and developed, which includes Single Minute Exchange of Die (SMED), leveling production, standard work, TPM, visual management, employee multi-work, and the core content of lean production Just-in-time (JIT) and Jidoka (autonomation). These lean techniques are linked and may overlap or contain each other, and they are important technologies and practices that form the lean production system.

According to Büyüközkan and Kayakutlu (2015), the lean performance indicators of enterprise lean model is established as quality, flexibility, time and reliability, and according to previous research, three kinds of main performance measurements are selected: financial performance, non-financial performance and sustainability, and are determined as the decision nodes of Bayesian network.

3.2 Construct Bayesian Networks

The construction of Bayesian network model includes network structure learning and network parameter

learning. In order to determine the Bayesian network structure, three experts from related fields judged lean techniques, four lean performance indicators and three performance decision variables mentioned in 3.1. We

can get the Bayesian network by analyzing the relation between variables, excluding and merging the variables which have similar attributes and relations, as shown in Figure 2.

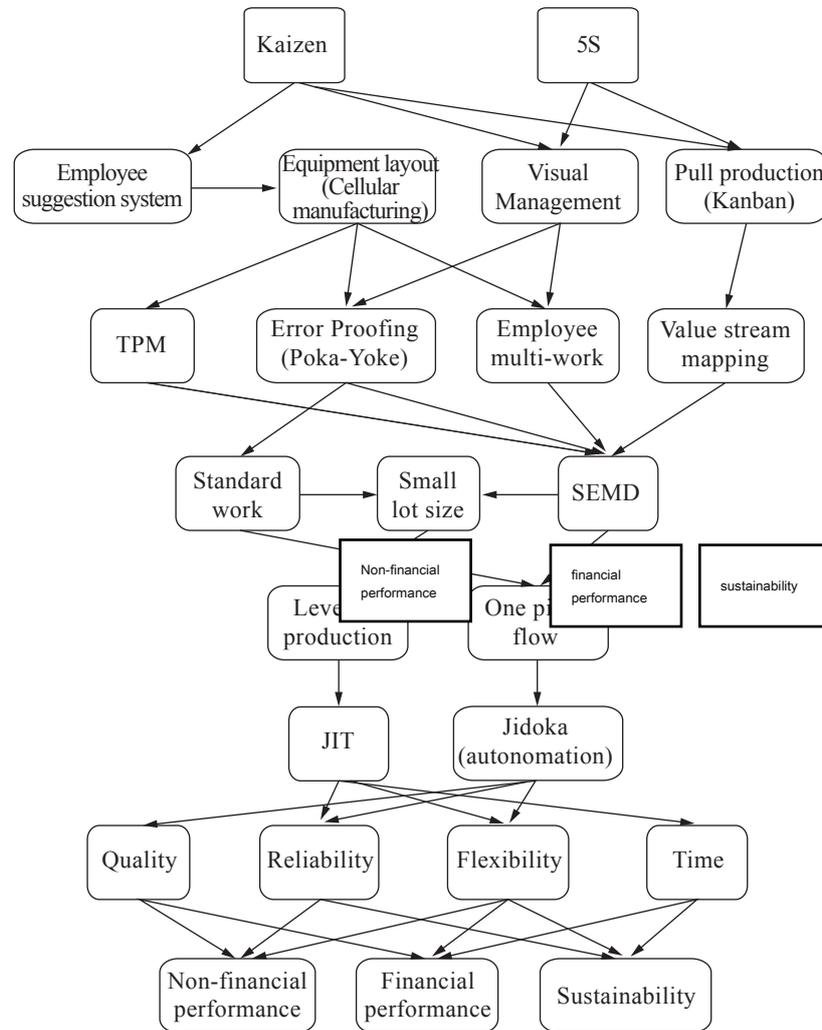


Figure 2
Bayesian Network

In the choice of the prior probability and conditional probability of the lean practice, different enterprises have different situation conditions in the implementation of lean production, the prior probability of lean practice can be judged by the enterprise evaluation, but the conditional probability in different enterprises is difficult to unify. In order to make the model universality, the text uses expert judgment to assume the conditional probabilities between the various lean practices. Although conditional probability is hypothetical, the synergy between lean practice is fully considered in the process of value-taking.

For Bayesian networks, there are three types of nodes, one is lean techniques elements, one is lean performance indicators, the other is the enterprise performance decision variable. To reduce the complexity of the model and

increase the recognition of the results, we defined the application level of technical factors as two states - “good” and “bad”, and the states of performance indicators also use “good” and “bad” two states, at the same time, we define the decision of enterprise performance. The decision state is “high”, “medium” and “low”. For example, for lean techniques, the “good” state means that the lean technique or lean practice is fully applied, with a probability of 100%, the “bad” state means lean technique or lean practice has not been applied, with a probability of 0%. For performance indicators and performance decision variable, there are similar explanations. Tables 2, 3, and 4 give the conditional probability distribution of Bayesian networks.

In Tables 2, 3, 4, using T to indicate lean practice application or performance indicator as “good”

state, using F to indicate lean practice application or performance indicator as “bad” state. For example, under the condition probability of the two factors in Table 2, the “Visual management” in the first line, “TTT” indicates the two of lean technique of the Kaizen and 5S are in “good”

state, the application state of visual management is “good” probability. Table 3 shows the conditional probability under the action of four factors, Table 4 shows the conditional probability under the action of single factor, and its corresponding expression is similar to Table 2.

Table 2
Conditional Probabilities Under the Action of Two Factors

			TTT	TTF	FTT	TFF	FTF	FFT	FFF	
Visual management	Kaizen	5S	0.9	0.7	0.6	0.1	0.1	0.3	0.4	0.9
Kanban	Kaizen	5S	0.8	0.7	0.7	0.15	0.2	0.3	0.3	0.85
Poka-Yoke	Equipment layout	Visual management	0.85	0.6	0.75	0.2	0.15	0.4	0.25	0.8
Employee multi-work	Equipment layout	Visual management	0.8	0.65	0.6	0.3	0.2	0.35	0.4	0.7
Small lot size	Standard work	SMED	0.95	0.65	0.3	0	0.05	0.35	0.7	1
A flow	Standard work	SMED	0.9	0.6	0.45	0	0.1	0.4	0.55	1
Reliability	JIT	Jidoka	0.85	0.35	0.45	0.2	0.15	0.65	0.55	0.8
Flexibility	JIT	Jidoka	0.95	0.65	0.5	0.15	0.05	0.35	0.5	0.85

Table 3
Conditional Probabilities Under the Action of Four Factors

SMED	TPM	Poka-Yoke	Employee multi-work	Value stream mapping	TTTT	TTTF	TTFT	TTF	TFTT	TFTF	TFFT	TFFF
T					0.95	0.8	0.75	0.55	0.8	0.55	0.4	0.05
F					0.05	0.2	0.25	0.45	0.2	0.45	0.6	0.95
SMED	TPM	Poka-Yoke	Employee multi-work	Value stream mapping	FTTT	FTTF	FTF	FTFF	FFTT	FFTF	FFFT	FFFF
T					0.85	0.65	0.5	0.1	0.55	0.1	0.05	0
F					0.15	0.35	0.5	0.9	0.45	0.9	0.95	1

Table 4
Conditional Probabilities Under the Action of Single Factor

			TT	TF	FT	FF
Employee suggestion system		Kaizen	0.8	0.25	0.2	0.75
Equipment layout		Employee suggestion system	0.9	0.4	0.1	0.6
TPM		Equipment layout	0.85	0.4	0.15	0.6
Value stream mapping		Kanban	0.8	0.25	0.2	0.75
Standard work		Poka-Yoke	0.9	0.5	0.1	0.5
Leveling production		Small lot size	0.9	0	0.1	1
JIT		Leveling production	0.9	0	0.1	1
Jidoka		One piece flow	0.85	0	0.15	1
Time		JIT	0.85	0.45	0.15	0.55
Quality		Jidoka	0.9	0.55	0.1	0.45

Finally, the conditional probability tables of three performance decision variables are given in Table 5. Similarly, we use T to indicate the performance indicator as a “good” state, using F to indicate the performance

indicator as “bad” state. For performance decision variables, H is used to indicate the state of the decision indicator as “high”, with M to indicate the state as “medium”, and a “low” state is indicated by L.

Table 5
 Condition Probability of Enterprise Performance

				H T T T	H T T F	H T F T	H T F F	H F T T	H F T F	H F F T	H F F F
Non-financial performance	Quality	Reliability	Flexible	0.9	0.6	0.7	0	0	0	0	0
Financial performance	Quality	Flexible	Time	0.9	0.7	0.7	0.4	0.6	0.3	0.4	0
Sustainability	Reliability	Flexible	Time	0.9	0.3	0.05	0	0	0	0	0
				M T T T	M T T F	M T F T	M T F F	M F T T	M F T F	M F F T	M F F F
Non-financial performance	Quality	Reliability	Flexible	0.1	0.4	0.3	0.3	0.8	0.2	0.4	0.1
Financial performance	Quality	Flexible	Time	0.1	0	0.1	0.2	0.2	0.1	0.2	0.2
Sustainability	Reliability	Flexible	Time	0.1	0.6	0.8	0.55	0.9	0.3	0.2	0.1
				L T T T	L T T F	L T F T	L T F F	L F T T	L F T F	L F F T	L F F F
Non-financial performance	Quality	Reliability	Flexible	0	0	0	0.7	0.2	0.8	0.6	0.9
Financial performance	Quality	Flexible	Time	0	0.3	0.2	0.4	0.2	0.6	0.4	0.8
Sustainability	Reliability	Flexible	Time	0	0.1	0.15	0.45	0.1	0.7	0.8	0.9

3.3 Simulation and Scenario Analysis

The purpose of simulation and scenario analysis is to observe the impact of lean technique or lean practice on performance indicators such as quality, reliability, flexibility and time, so that performance decisions have some reliability. In this paper, we design three scenarios and use *Netica* for simulation.

In Scenario 1, we define the worst case, that is, the probability that both “Kaizen” and “5S” lean techniques “good” are set for 0%, no lean technique has been used

most effectively. The simulation results are shown in Figure 3. It can be seen that the four lean factors-“Employee suggestion system”, “Equipment layout”, “Visual management”, “Kanban” - are not entirely dependent on two fundamental factors of node, even the application of probability of “Visual management” is still 10%. In this case, in the four performance indicators, the “good” state of “quality” and “time” still maintain a higher probability of more than 60%.

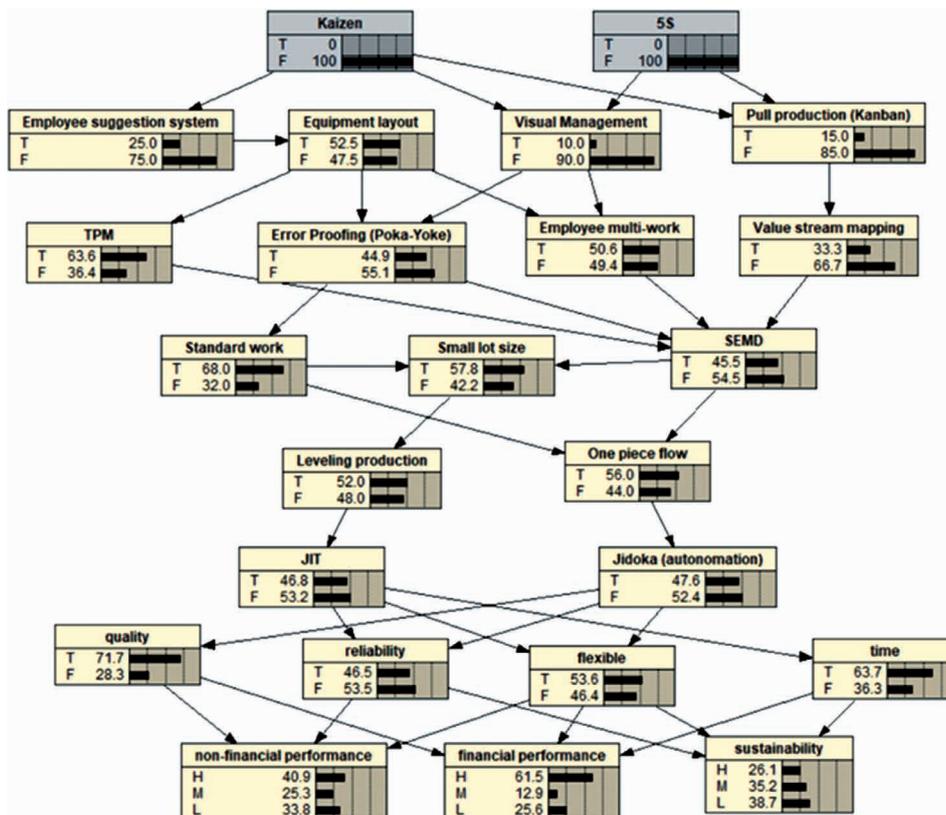


Figure 3
 The Bayesian Network Analysis of Scenario 1

In Scenario 2, we define a medium scenario in which the probability of “good” and “bad” for both “Kaizen” and “5S” two lean techniques are set to 50%, it means the effectiveness of lean techniques is half, as shown in Figure 4. It can be seen that compared with Scenario

1, the application of lean techniques has not been fully effective, but the probability of “good” in lean practice has been significantly improved. In performance indicators, “reliability” and “flexibility” have a significant increase of 6%-7%.

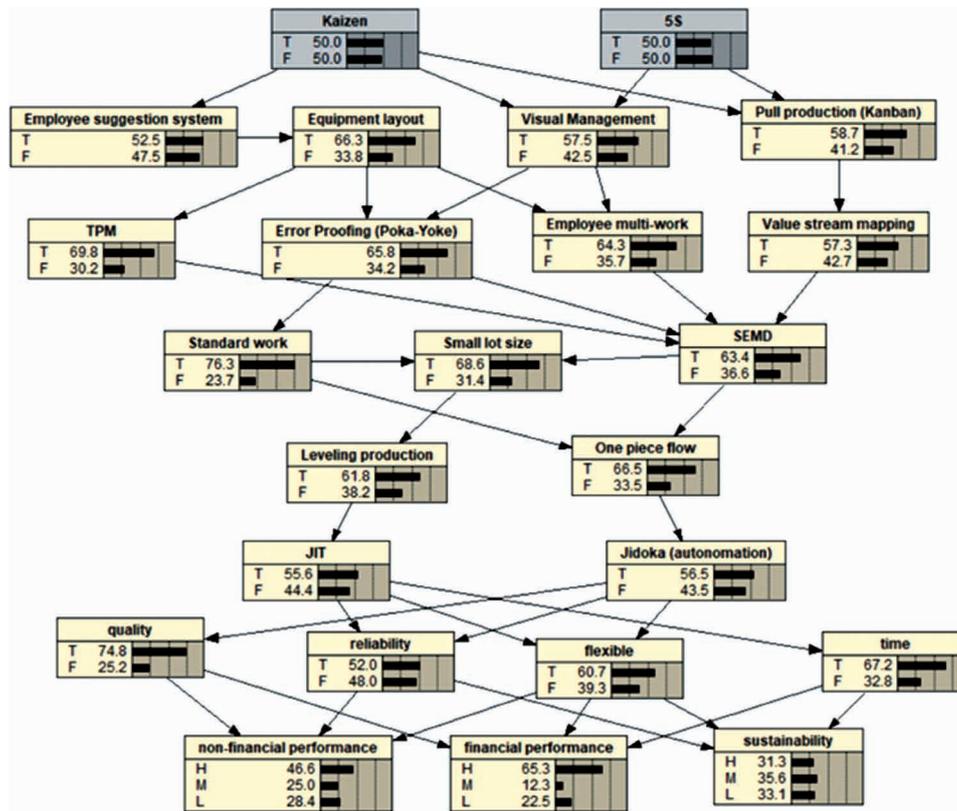


Figure 4
The Bayesian Network Analysis of Scenario 2

Finally, in Scenario 3, we define the most ideal situations-the probability of “Kaizen” and “5S” two lean techniques “good” are set to 100%, the lean techniques are most effectively applied, the result is shown in Figure 5. Obviously, affected by the change of the root node, the probability of “good” state of the “Employee suggestion system”, “Equipment layout”, “Visual management” and “Kanban” is significantly improved, which increases the probability of about 20%-30%. But further down the line, compared with above-mentioned four lean techniques, the probability lifting limit of the “good” state of the “One piece flow”, “Leveling production”, “Jidoka” and “JIT” is smaller. As a result, the improvement of the “good” state of four performance indicators has not increased by more than 5%.

To sum up, in the three cases, if we observe the performance decision indicators of the three scenarios, we can find that with the improvement of “Kaizen” and “5S” application effectiveness, the state of the three performances will also improve. In the three kinds of performance, the probability of the “high” state of financial performance is the highest, followed by non-financial performance,

while the probability of the “high” state of sustainable is the smallest. At the same time, you can see that when the situation from Scenario 1 to 2, the lifting range of the probability of the “high” state of three performance is from 4% to 6%, but from Scenario 2 to 3, the lifting range of the probability of the “high” state of them is only from 2% to 3%. In this case, the following hypothetical explanations can be made: For enterprises with no effective use of lean techniques, after the initial introduction of lean techniques or lean practice, there are many parts which the enterprises can improve, the role of lean technology in the production process may be significantly improved, and the enterprises are easy to achieve a certain degree of results. However, with the deep application of lean techniques and practice, the later minor improvement adjustments need more effort, which is equivalent to one thing that the “marginal benefit” of its promotion continues to decrease. Therefore, in order to make lean technology to bring better performance status, we need to continuously refine the lean practice application, step by step, make each lean technique integration as a whole and maximize the effectiveness at the “system level”.

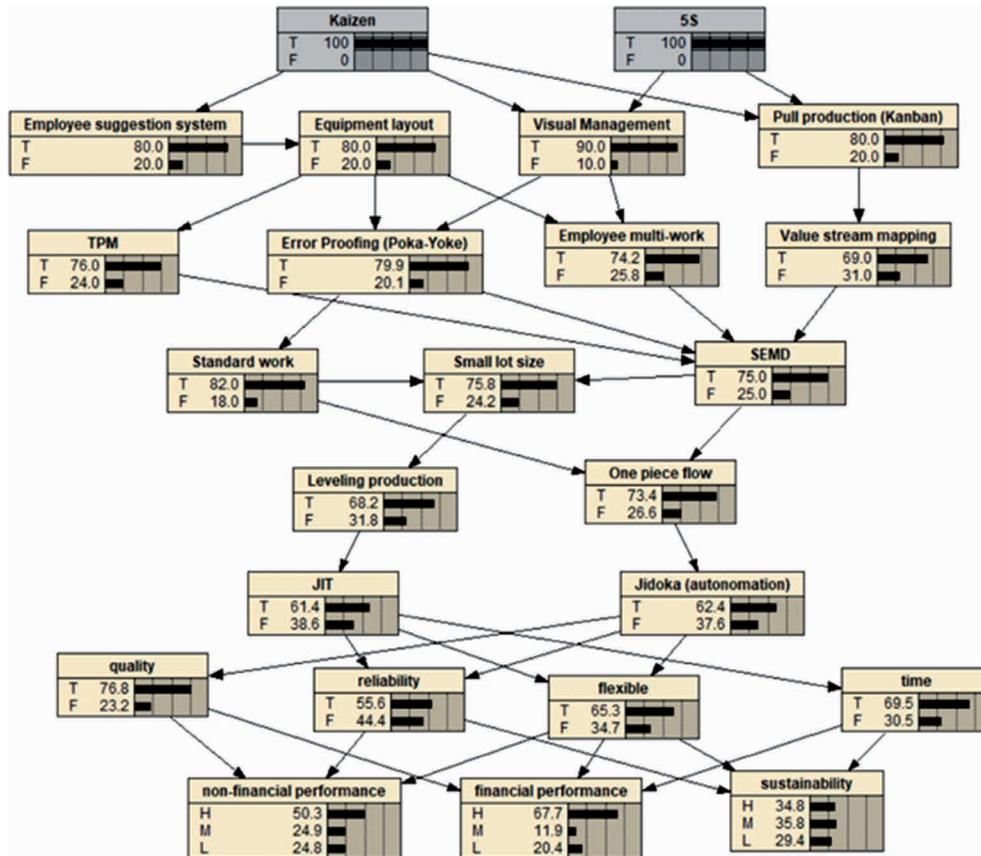


Figure 5
The Bayesian Network Analysis of Scenario 3

CONCLUSION AND PROSPECT

Through the design and application of Bayesian network model, this paper attempts to analyze and verify the impact of lean technique or lean practice in the enterprise on enterprise performance. The core of enterprises using lean production is to enhance the productivity, competitiveness and efficiency of enterprises, and finally to increase the profits of enterprises. How to effectively implement lean techniques and measure the impact of it on the actual situation in the enterprise and enterprise itself, related research is not very much in recent years. Scenarios analysis can be used to predict the future situation of enterprises to a certain extent. The application of Bayesian network can well establish the relation between the lean practice in the enterprise, make probabilistic forecast and diagnosis, understand the interaction relationship between lean practice and the effect of lean practice on enterprise performance.

This paper uses Bayesian network to analyze the impact of lean production on enterprise performance, but there are still some problems and some aspects need further research in the future: When building Bayesian network structure, this paper lacks a certain degree of rigor, we only use some expert opinions, this may not be representative, besides, there is a need for further

discussion on how to establish a reasonable Bayesian network structure between lean techniques. Secondly, we use the simulation method to make scenario analysis, it is the lack of validity, if the real data collected by the enterprise can be analyzed, the feasibility of the result will be improved significantly.

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