Chinese Enterprise Empirical Data Analysis: Relationship of Lean Production and Energy Consumption- A New Fuzzy Math Application

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***Abstract* — Lean production and energy consumption has become a new trend of every industrial management. For example, the traditional Chinese medicine department, lean cover overall treatments operations. If every step did not waste resource, cost down, carbon elimination, and saving energy consumption would be possible. This study attempted to explore the exactly correlation between lean production and energy consumption. After checked the data set from 288 MBA (which are managers in companies) personnel, this study offered valuable empirical data from real world. A new MIP model had been proposed and the fuzzy decision-making model was applied to validate the correlation. With the problem formulation and calculation, the results showed that lean production implementation in Chinese enterprises would raise energy consumption. Moreover, energy consumption would increase with lean production level. The results indicated that the overall level of lean production in Chinese enterprises was relative low as it needed to consume plenty of resources to implement lean production. It further suggested that enterprises in less developed countries needed more fundamental understanding of lean production and implemented lean production without increasing resource consumption.**

***Keywords* - Lean production; Energy consumption; Fuzzy math model; Health development aspect; Empirical study**

I. INTRODUCTION

Lean production and energy consumption has become a new trend of every industrial management. For example, the traditional Chinese medicine department, lean cover overall treatments operations. If every step did not waste resource, cost down, carbon elimination, and saving energy consumption would be possible. Energy issue has become an urgent subject around world due to greenhouse effects [1], sharing economics system, globalization and meager company profits. With production duplication, resource (money, energy and manpower) consuming is faster than we think. An increasing interest in energy consumption reduction and the resulting greenhouse gas emission has appeared on every sector of the economy in modern society [2], especially in health related enterprises. Cost reduction and profit increasing had been foremost focus of all companies. In their growth period, the company consumes large energy in their daily operations due to they only look at increasing number. Under today's global environment, firms encountered the increasing pressures to save energy from source and reduce carbon footprint. It means that each company needs try to lower down their energy consumption (EC). It let us generate association of ideas that lean, a powerful tool, for treating waste and how it increasing productivity in this world. As we know, there was no lean tool [3] specifically aimed at dealing with environmental issues. It's because we have possible and negative treatments for energy consumptions at the same time [4]. For human body as an example, if we raise body energy in the Chinese medicine aspect, it could be possible to increase tumors' growth concurrently. Thus previous literature indicated that the correlation between lean production and energy consumption was complicated [5]. This study focused on clarifying the correlation between lean production and energy consumption. We would adapt questionnaires survey from companies in China. Besides, fuzzy math analysis procedure would help company more precisely prediction of this complicated relationships. It would also contribute to managers facing any lean tasks or carbon elimination operations.

II. LITERATURE REVIEW

Lean production has become the integral part of manufacturing industry over the last four decades [6]. Its superior performance and ability to provide competitive advantages has been well accepted among academics and industries [7]. On the other side, China set an ambitious objective of reducing energy consumption per unit of GDP by 20% from 2006 to 2010. Most effort has been focused on how to improve energy efficiency in the industrial sectors [8]. Ray et al. [9] identified a factor model and developed a 'Lean Index' and found energy consumption was the most significant contributor to the leanness of any wood products company, and possibly the same for other industries. It demonstrated the importance of the impact of lean production on energy consumption. Seow and Rahimifard proposed a concept of 'lean energy' based on the application of the most energy efficient procedures and activities within their production plants. They adopted a innovative approach to formulate energy flows in a manufacturing system based on a product perspective. Finally, they proved that 'lean energy' were the most effective way in reducing energy consumption while ensuring the outputs. There were perfectly sufficient research and related theories of lean production and energy issues respectively. However, research on the relationship between lean production and energy issues has emerged only in recent decades.

In the academic field of lean production, most scholars believed lean production could reduce energy consumption. Independent studies estimate the energy saving potential in manufacturing industries, pointing out a great saving potential up to 30 %. Schnellbach and Reinhart [10] provided a 4-steps approach to raise energy productivity based on lean production principles (such as value steam mapping and the identification of waste). They created an energy-oriented value stream mapping and analyzed the effect of measurements on existing lean production key performance indicators, as well as identified the possible ways to reduce energy consumption. The impact network generated in this paper provided a general system dynamics model which can simulate dynamic effects on vital objectives derived from the key performance indicators in lean production systems. Then this important measure has been tested through an extended economic efficiency calculation, which could help the companies to decide whether to use this methodology or not. They found that manufacturing enterprises could increase energy productivity without doing harm to the existing manufacturing structure. Bozickovic et al. [11] used statistical analysis and simulation to present the impact of certain lean tools on achieving greater efficiency of production systems than before. It had proved that the application or integration of lean tools could definitely reduce the cost of energy resources. Lyon et al. [12] conducted a case study in a cabinet manufacturer in Virginia to examine the impact of lean thinking on the electricity consumption in the manufacturing processes. Significant reduction in energy consumption had been observed after implementing some improvement practices identified by lean thinking. Based on lean production, Riche [13] introduced a structured approach to widen the scope of sources saving in processes and operations. This approach had been proved to be able to minimum requirement, then removed non-value added energy consumption. Esfandyari et al. [14] pointed that the it was possible to achieve cost reduction in electronics manufacturing industries through reducing the energy demand in the whole manufacturing process. They presented an overview on the sustainable issues through a lean paradigm perspective in Printed Circuit Boards assembly and the scheme of alternatives for the recent green innovations and production of Printed Circuit Boards. To achieve energy saving in the assembly production, the planning stage was the most important one. The main effort in this stage is to smooth the procedures and transform the large batch production process into a continuous flow through lean tools such as Single Minute Exchange of Die, Just-in-Time, Kanban, Value Stream Mapping (to identify waste in the production flow) to achieve work in process products and waste reduction. However, they found that the energy consumption in Printed Circuit Boards assembly process is still unsettled. Arunagiri and Gnanavelbabu [15] believed that firms with successful lean production could reduce waste inside their plants and obtain practices for higher level of environmental management. To improve industrial environmental performance, enterprises needed some quality management tools focusing on products quality. Plenty of lean tools (more than 30) used commonly in regular produce processed were identified. They conducted surveys in 91 automobile companies to find which lean tools has the most influence on environment. Finally, they found the most top 5 lean tools (5S, OEE, waste elimination, Pareto analysis and 8 Step Problem Solving Methodology) in reducing environmental burden (such as energy consumption and air pollution). Alves et al. believed that lean production paradigm thinking was the base for company agile. Through an in-depth literature review, including the lean production origins, some real world case studies, the authors explored that companies could accommodate changes through waste reduction. Moreover, the lean awareness in looking for waste of both leaders and workers could lead to energy consumption reduction and gas emissions reducing, like pollution of air. Ruisheng et al. [16] proposed a Carbon-Value Efficiency model to implement lean production and environmental management simultaneously in one enterprises. For that the exiting frameworks, models and methodologies had some limitations, such as the great demand of initial resources input, difficult to realize and so on, this model proposed in this paper tried to find a practical and easy method to integrate lean and green. The authors adopted and streamlined some exiting approaches to achieve this easy-to-track metric model, which was aimed to integrate lean and green metrics from lean production and environmental management. They also demonstrate the feasibility of this introduced methodology by a case study in the production line of metal stamped parts. The Carbon-Value Efficiency had been improved by 36.3%, along with the reduction of production lead time by 64.7% and reduction in carbon emission by 29.9%. They confirmed that the proposed model did help enterprises to get over the difficulties in combining and implementing lean and green and made a profit. Duarte and Cruz-Machado [17] had conducted a comprehensive literature review and studied 12 business cases to examine the difference in various business models, reflected in awards, standards and frameworks, business models, and their contribution to model an integrated lean and green methodology for an enterprise and its supply chain. After giving definition of both lean and green practice paradigms, a series of guidelines had been proposed to relate and combine lean and green principles. Then, they proposed a lean-green transformation model based on the complete understanding of the identified models and data. They also explained that how lean and green associated with each other at the levels of strategic, tactical and operational. They found that with appropriate systematic deployment of lean and green, enterprises could achieve both improvement in environmental and economic performance, like cost reduction, energy conservation, emission reducing and so on. The key points were the fully consideration of mixed influence factors and the focus on long-term profit. Nieuwenhuis and Katsifou [18] focused on the automotive industry, which consumed large amounts of energy and generated most of the air pollution. The authors tried to perceive needs and wants in a more sustainable way. They indicated that the main problem was overproduce, and the identification of the causes was essential to the development of more environmentally friendly supply chains in the future. Through a literature review and a case study in Morgan Motor Company, the authors provided a new understanding of the determining factors in lean and green and a movement towards more environmental sustainable car production with less consumption in both resources and energy. Smith and Ball [19] indicated that sustainable society could not be achieved without more efficient manner in manufacturing industry and greener technologies provided by manufacturer. The authors found that the existing literature covered the green production principles but not the application methods. New methodologies was essential for reevaluating production processed and to identify the room for improvement. In this paper, the authors proposed a new method to define material, energy, and waste flows to systematically analyze the manufacturing processes. Their model was based on the installation case and flow maps in qualitative processes. They used the collected data to provide a guideline and applied the material, energy, and waste flow in an organization to find the improvement space. Finally, they selected some key points for improvement in CO_2 emissions and energy consumption, then to improve the organization environmental sustainability. Tiwari and Chang [20] tried to solve the vehicle routing problem, which was one of the most tough problem with lots of real-world case in logistics and transportation area. Transportation was one of the most significant influence factors of energy consumption and carbon dioxide, thus resulting in greenhouse effect and atmospheric pollution. Therefore, the authors proposed a block recombination approach to solve the green vehicle routing problem, which was the extension of the vehicle routing problem. They used this approach to minimize the energy consumption and carbon emission by various vehicles, such as truck, ships, planes and trains, during the cargo transportation from warehouse to distribution centers. Based on the calculation of carbon emission by the new model proposed in this paper, the authors attempted to arrange the weight loading in every means of transportation along with the distance travelled in such a combination, thus the total carbon emission has been minimized. Domingo and Aguado [21] provided a new metric for evaluating the achieved sustainability improvements after implementing lean and green practice. Overall Environmental Equipment Effectiveness (OEEE) was used as the final value metric to analyze the production process from both lean and sustainable perspectives. Besides availability, quality and performance measurements for each production step, OEEE in this paper incorporated the metrics of sustainability. Based on the case study in a tube fabrication company, the authors demonstrated some research questions. The new parameter OEEE allowed companies to involve sustainability in business operation decisions and confirmed the compatibility between lean and green practices. This OEEE also indicated the improvement before and after the implementation of lean and green practice, mainly in the resource and energy consumption and waste generation. Piercy and Rich [22] conducted a multi-year and multi-case studies to investigate a more comprehensive sustainability benefits obtained through lean production. The proposed model from case studies provided a method to benchmark performance and promised long-term scheduling in company. The core benefits were maintaining the same output level with less input (resources, energy and money). This would be good for the environment, as well as cost reduction for enterprise operation. Kurdve et al. [23] tried to investigate the integration method of environmental management into operation management by involving waste management along the supply chain. Through literature review on the aspect of environmental management and operational improvement tool, the authors identified waste efficiency in operational development. Then, the authors conducted a large case study using a new method named waste flow mapping (WFM) to reveal the potentials in resource waste and non-value added processes. The WFM combined lean production tools, like value stream mapping with green production to find the waste in production processes. The empirical data demonstrated that WFM was adequate for status analysis and could reflected the waste in resources and energy, thus to reduce them.

Other scholars did argue that there were certain blind spots, or even contradictions between lean production and environmental issues based on real companies' case studies [24]. Based on the criteria in G4 Sustainability Reporting Guideline, Aminuddin et al. [25] demonstrated that the green manufacturing is more sustainable than lean manufacturing. The main contradictions lied on more energy consumption resulted from JIT and Jidoka [26,27]. Mollenkopf et al. [26] conducted an in-depth and comprehensive literature review to check the relationship, especially the concurrent implementation of green, lean and worldwide supply chain strategies. Although separate literature reviews had arisen to conduct the research issues in green, lean, and global supply chain strategies, but scholars had neglected the interactive relationship among these 3 issues. Therefore, as the first synthetical literature review of the green, lean and global supply chains strategies, they revealed drivers, barriers, combination and conflict points involving in these 3 supply chain strategies, as well as proposed a research agenda for future research. Finally, they found that the main contradiction between lean production and environmental management is energy consumption result from multi-frequency and low-volume delivery in JIT. Venkat and Wakeland [28] took greenhouse gases emission as key performance indicators to study the environmental performance in lean supply chain management. Traditionally, time compression could reveal hidden quality problems and the solution of these problems would result in more efficient and effective production processes. Thus, lean processes was believed to be greener than other processes with less pollution emissions. The authors used simulation model of different supply chains to examine the relationship between lean production and energy consumption. They indicated that emissions in supply chain were highly sensitive to the transportation frequency and mode, as well as the inventory amount and type, which meant that when a supply chain is geographically wide-spread and long, the lean supply chain would possibly increase the amount of CO_2 emissions from transport, which meant more energy consumption. Similarly, Dues et al. [29] indicated that lean production did not necessarily reduce carbon emissions. Based on JIT delivery and pull system of small batches, lean production increased the replenishment frequency, which meant that transport requirement had also been raised, resulting in more energy consumption and carbon emission. Therefore, they stated that the major conflict between lean production and environmental management was CO_2 emission. Therefore, the tradeoff between lean and green was essential in the aspect of energy consumption. Bergenwall et al. [27] investigated the different Toyota Production System processed designed by American auto manufacturer and their effects from interactive viewpoint on the triple bottom line sustainability. They conducted 2 case studies using semi-structured interviews with logistics executives and first-line managers in two major American auto manufacturer's assembly plants. They found that these two plants had implemented different lean production principles. The results showed supplementary energy was required to meet the need of more frequent trips for delivery of materials in lean production, which resulted in the increasing in greenhouse gas. However, they also pointed that based on the lean production (or TPS) principles, the manufacturing industries could achieve sustainability in all of the triple bottom lines. Moreira et al. [30] found some examples showed that lean was negatively related to environmental performance, such as the greenhouse gas emissions and the use of fossil fuels. They believed that JIT delivery caused energy waste and atmospheric contamination. Moreover, computer information systems and robots used in Jidoka would also aggravate energy depletion. Because the requirement of reduce inventory in lean production would increase the transport frequency, which could lead to the energy augment.

It is worth noting that different scholars hold conflicting view about the relationship between lean production and energy consumption. Thus far, although some researches have discussed and investigated lean production or energy consumption, there were few studies discussing on the relationship between lean production and energy consumption, especially in the fuzzy math approach to evaluate. Fuzzy math model is suitable for the analysis of complexity, especially to clarify the indeterminate relationship among things and make them into describable by other mathematical methodologies. Therefore, this study attempts to apply a new fuzzy math model [31] to analyze the impact of lean production on energy consumption more humanization. In addition, this study focused on the certain context of Chinese enterprises.

III. PROBLEM FORMULATION

This study adopted a fuzzy decision-making model, with a new application into energy issues, finding the minimal penalty of the distance between the empirical company before and after implementing lean production. Based on the previous research[32], this study tried to construct a more precise problem formulation.

In this study, N denotes the set of sample enterprises, while n denotes the number of sample questionnaire; i, j denote sample number, $i \neq j$; t denotes the trials, $t = 1, 2, ..., n$, also an information process loop. Let **Error! Reference source not found.** denote a fuzzy calculation function (**Error! Reference source not found.**= 1, 2, ..., or n), at **Error! Reference source not found.** information process loop. Let **Error! Reference source not found.** denote an answer of different sample questionnaire, at **Error! Reference source not found.** information process loop. Let C denote a penalty cost, a distance between historical choice and a new choice adding to this evaluation. Let **Error! Reference source not found.** denote the vector of input choices, a list of binary variable, at **Error! Reference source not found.** information process loop.

Let **Error! Reference source not found.** denote cumulative weight of level k of questionnaire, increasing or descending degree real number, is also a variable, $k = 1, 2, ..., 5$. The model was shown as follows:

N : the set of sample enterprises

n : the number of sample questionnaire, **Error! Reference source not found.**

i, j : sample number, $i \neq j$

t : the trials, $t = 1, 2, ..., n$

Error! Reference source not found.: a fuzzy calculation function (**Error! Reference source not found.**=1, 2, ..., or n), at **Error! Reference source not found.** information process loop

Error! Reference source not found.: is an answer of different sample questionnaires, at **Error! Reference source not found.** information process loop

c: a penalty cost, a distance between historical choice and a new choice adding to this evaluation.

$$c = \sum_{t=1}^{n} (y_t - a_t)^2$$

Besides,

Error! Reference source not found.: is the vector of input choices, a list of binary variable, at **Error! Reference source not found.** information process loop, belongs to decision variable

$$V_t = [v_1, v_2, \dots, v_n]_t, \text{ and } \sum_{j=1}^{n} v_j = 1 \quad \forall t$$

Error! Reference source not found.: cumulative weight of level k of questionnaire, increasing or descending degree real number, is also a variable, $k = 1, 2, ..., 5$, belongs to decision variable

$$\gamma = \frac{\sum_{k \in N} \sum_{j=1}^{n} w_k \, v_j}{\sum_{k \in N} \max\{w_k\}}$$

$$x_t = \begin{cases} 1, & 0 \le \gamma < 0.25 \\ 2, & 0.25 \le \gamma < 0.5 \\ 3, & 0.5 \le \gamma < 0.75 \\ 4, & 0.75 \le \gamma < 1 \\ 5, & \gamma = 1 \end{cases}$$

$$y_t = x_t V_t$$

Error! Reference source not found. would be a choice
The MIP model is to minimize the penalty, the objective is as follows:

Min C (1)

s.t.

Error! Reference source not found. (2)

$v_j \in \{0, 1\}$ (3)

The objective equation (1) is to find a minimal penalty. In equation (2), in a **Error! Reference source not found.** trials, there is only one choice that would be selected. Equation (3) declares artificial binary decision variable constraints.

Through this fuzzy decision making model, a different sample questionnaire is regarded as a different training sample. A five Likert scale, $k = 1,2,...,5$, represents ranging from "lowest level" to "highest level", which would also be fuzzy processed, forming a new fuzzy decision model regarding this sample questionnaire of the enterprise's opinions. The computer process flow chart has been showed in Figure (1).

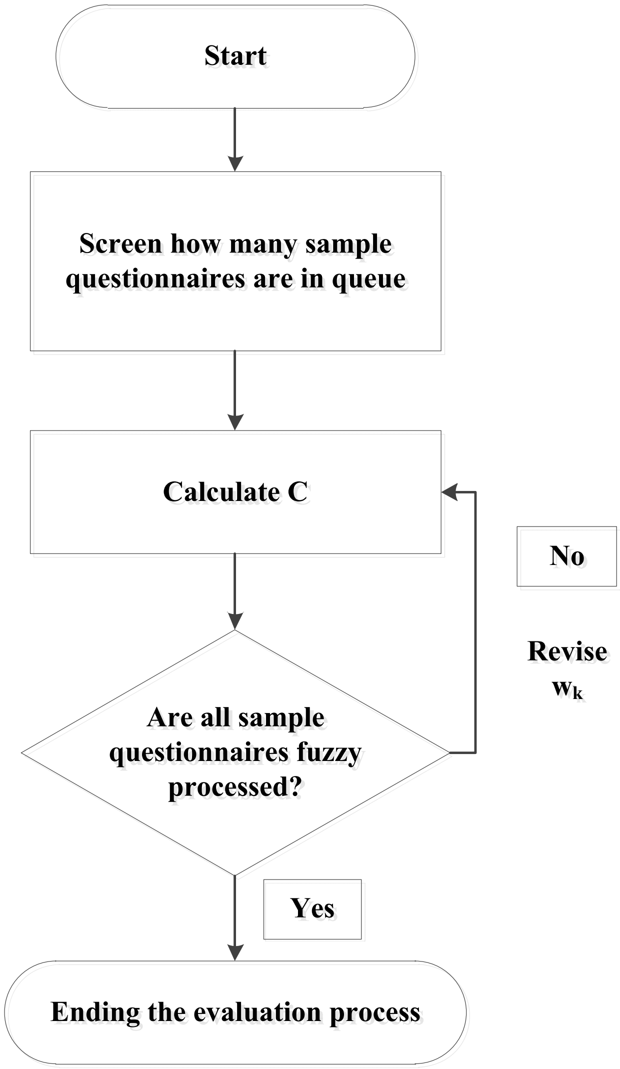

Fig. 1 A process diagram of the proposed approach

IV. DATA COLLECTION

The experiment of the proposed approach was proceeded with on the basis of empirical data analysis. The data set came from 288 Chinese enterprises. As MBA are practitioners in their enterprises and observe the enterprise in detail, so we sent 500 questionnaires to MBA from Tianjin University. Only 288 questionnaires had passed the validation. The response rate was 57.6%. The male and female proportion of respondents was almost the same (Figure (2)). There were 205 respondents coming from manufacturing industry, 37 from service industry, 16 from education sector and 30 from other industry. The data collected period was from Dec 3rd 2014 to Dec 7th 2014.

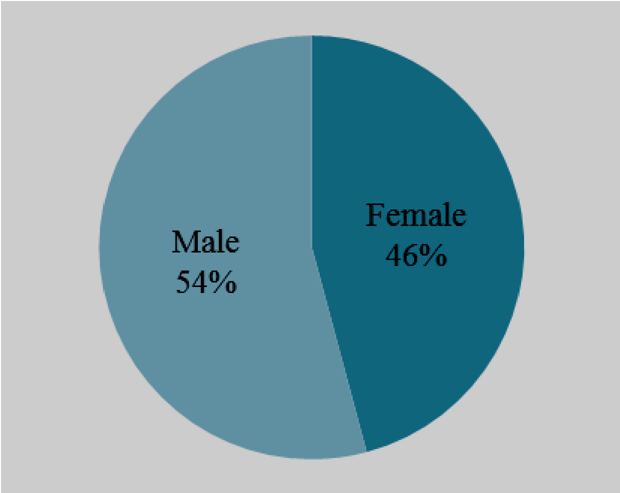

Fig.2 The male and female proportion of respondents

V. RESULTS AND DISCUSSION

A. Data results

A five point Likert scale perceptual measures (1 refers to the lowest level; and 5 refers to the highest) was applied in this study. At first, the measurable indicator of lean production should be determined. In the last two decades, lean production (LP) had been defined by many scholars. Cua et al. [33] identified 3 dimensions in lean production: Just-in-time (JIT), Total quality management (TQM), and Total productive maintenance (TPM). Schonberger [34] considered lean production as principles of world class manufacturing, which could be realized through JIT, TQM, TPM and employee involvement (EI). The same did Zhou and Xu [35], who made the same conclusion by literature review and analyzed the correlation among these dimensions through case study. Sarkis et al. [36] pointed out that lean production should not been measured by inventory. It must cover all the production process. Schloetzer et al. [37] selected JIT, TQM, TPM, HRM, and EI as metrics of lean production to analyze the relationship between management practice and lean production program. Shah and Ward [6] distinguished a series of measurements of lean production and summarized them into 3 dimensions: supply chain relationship (suppliers' feedback, JIT delivery, and supplier development), customer involvement and interior management (pull system, continuous flow, set-up time reduction, TPM, TQM and EI). Based on this, Yu et al. [38] divided lean production into supply chain relationship, custom relationship and internal lean production implementation. On the basis of previous research and plus the purpose of this research, lean production is conceptualized as a first-order construct with 4 sub-dimensions: Just in Time (JIT), Total Quality Management (TQM), Total Productive Maintenance (TPM), Employee Involvement (EI). Also, this research used a single item to measure energy consumption (EC).

The basic descriptive statistics, reliability statistics and Chi-squire test statistics are shown in table Ⅰ, table Ⅱ and table Ⅲ respectively.

The Cronbach's Alpha was greater than 0.7 (reliability coefficient threshold by Nunnally and Bernstein [39], representing an acceptable reliability of the questionnaire. Meanwhile, as all the progressive significance was under 0.01, so different enterprises had different levels of all these 5 categories in the significant level 0.01.

We also checked the correlation coefficient matrix of all these 5 terms (table IV.). The 4 terms of lean production (JIT, TQM, TPM, EI) showed a greater correlation (>0.5) in each pairs, while all these 4 terms showed lower correlation with EC. However, all the correlation were greater than 0, representing a positive relationship among all these terms. Therefore, we could preliminary deduct that enterprises would consume more energy if they had a high level of lean production.

B. Objective calculations

In the situation of global warming, energy issues has become a new challenge for enterprises, especially in developing countries like China. Thus this study followed the proposed approach of solving applied mathematics research topic. In this section, the algorithm was coded in PHP computer language with Intel (R) Core(TM) i5-5200U CPU at 2.20 GHz and 4GB of RAM memory. The MIP model proposed in this study is a strong NP-hard problem [40]. As the proposed model is a new problem in the energy consumption and lean production field, there is no literatures' solution usage and can not be comparison. Hence, this study has conducted as a pioneer study.

TABLE I. DESCRIPTIVE STATISTICS

Categories	Mean	S. D.	Max	Min
JIT	3.6	0.95	5	1
TQM	3.7	0.91	5	1
TPM	3.7	0.85	5	2
EI	3.7	0.88	5	1
EC	3.8	0.77	5	2

TABLE II. RELIABILITY STATISTICS

Cronbach's Alpha	Cronbach's Alpha based on the standard terms	Number of terms
0.788	0.782	5

TABLE III. CHI-SQUIRE

	JIT	TQM	TPM	EI	EC
Chi-square test	146.965	150.993	98.111	176.444	136.528
Degrees of freedom (df)	4	4	3	4	3
Progressive significance	0.000	0.000	0.000	0.000	0.000

TABLE IV. THE CORRELATION COEFFICIENT MATRIX

	1	2	3	4	5
1. JIT	1				
2. TQM	0.576	1			
3. TPM	.596	.534	1		
4. EI	.533	.510	.556	1	
5. EC	.181	.204	.255	0.228	1

The flowchart of the proposed approach (Figure (1)) indicated that in the beginning, the software screened and showed how many sample questionnaires were in the queue. Next, based on the model in section 4, the process as shown in Figure (2) was used to calculate *C*. The detail fuzzy decision process, and putting data into the proposed formula, referenced Hou et al. [41]. If all sample questionnaires were fuzzy processed, evaluation process should be ended; otherwise, the process went back to previous step and revised **Error! Reference source not found.**. The dynamic decision making model can be solved in the proposed mathematical formula exactly.

For the purpose of reducing calculation complexity and identifying the difference between high level and low level of lean production (calculated by the weighted average of JIT, TQM,TPM and EI), we only selected questionnaires of highest level (24 questionnaires) and lowest level (29 questionnaires) respectively for further analyzing. Since this research is a pioneer one, the calculation process had to check each respondent's data manually. Then we review the accuracy of program automatic process.

Each questionnaire has been evaluated by 5-point Likert scale, allowing the respondents to evaluate each question from 1 to 5, ranging from "lowest level" to "highest level". This research focused on the energy issues in lean enterprises. Other energy issues or lean production issues would not be discussed here for the purpose of this study.

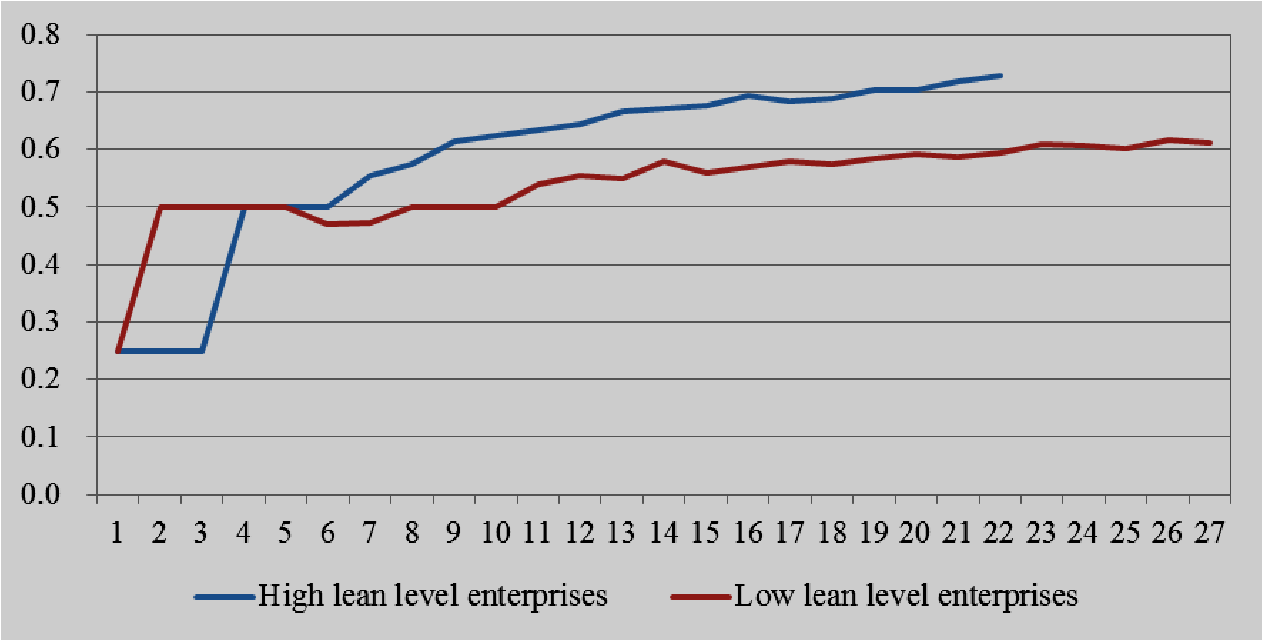

Fig. 3 An increasing trend of lean production and energy consumption

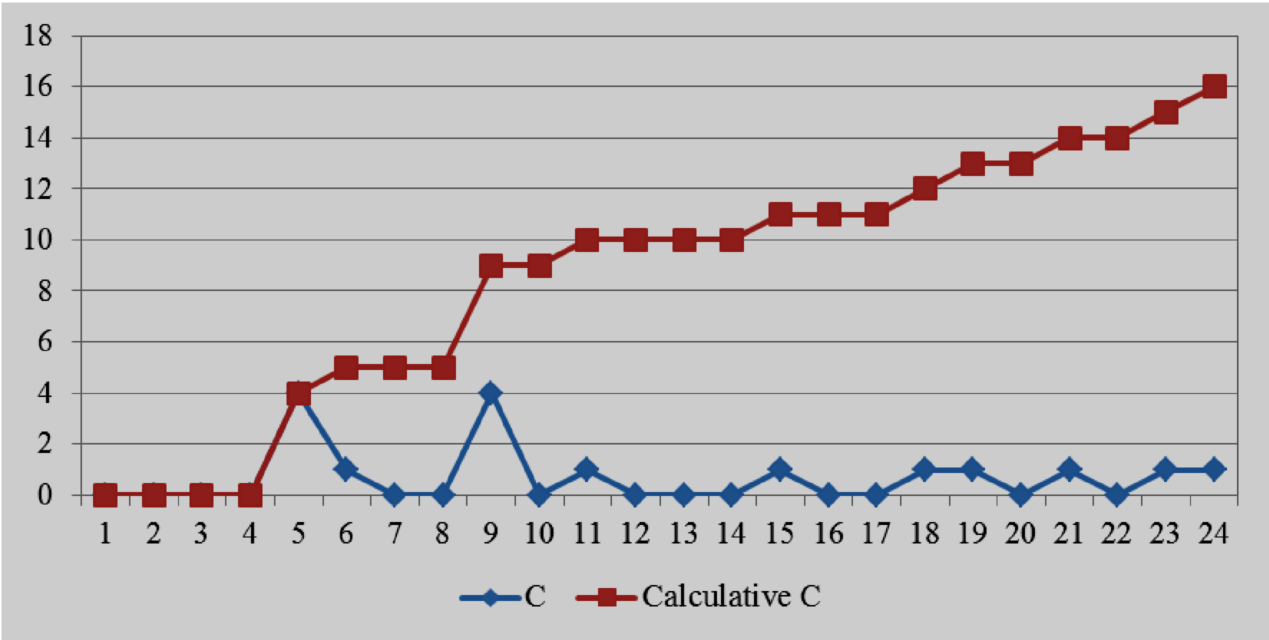

Fig. 4 A variation of objective *C* in high lean production level enterprises

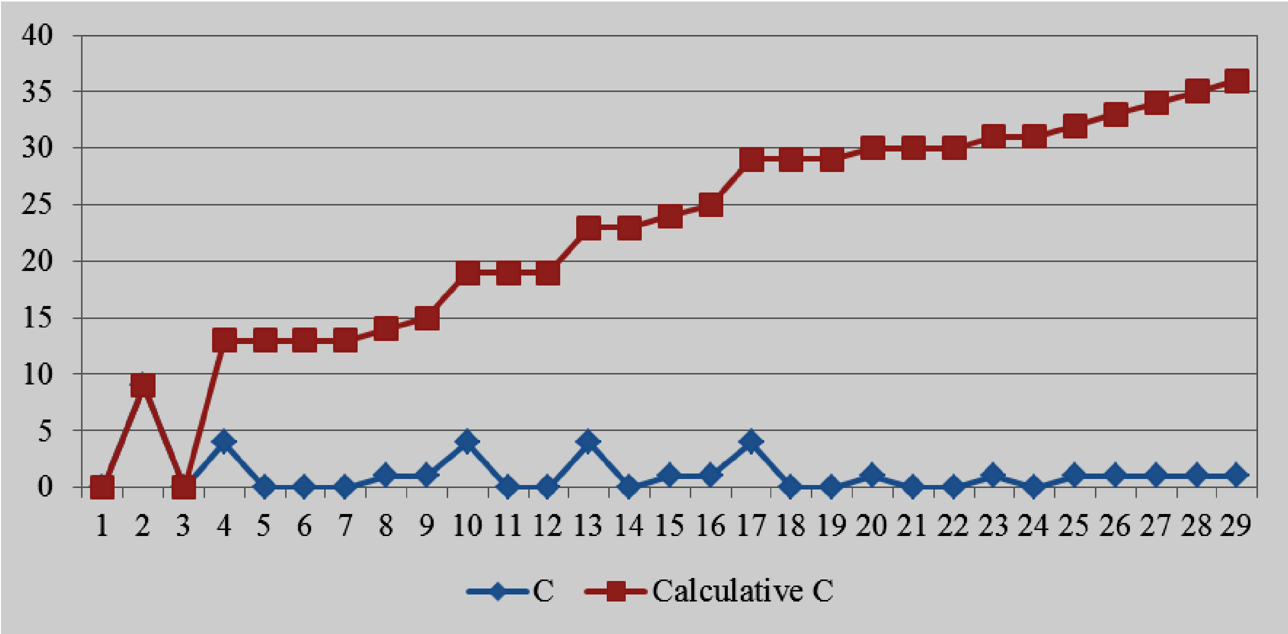

Fig. 5 A variation of objective *C* in low lean production level enterprises

In brief statement, enterprises should implement lean production to raise their productivity and competitiveness. Meanwhile, enterprises should not simply increase transportation frequency to assure delivery and reduce inventories, or purchase automation equipment for labor saving. Chinese enterprises must pay more attention to the essence of lean production, such as preventive maintenance and flexible manufacturing system.

VI. CONCLUSION

Energy conservation and emission reduction is vital to enterprises, especially in the developing countries, such as China. Managers hope to know factors influencing energy consumption in their enterprises. This study examined data from 288 MBA (which were managers in companies) to find the difference between different level enterprises of lean production. In this research, a new MIP model had been proposed to validate the correlation. The fuzzy decision-making model was applied into the lean production field. Sample questionnaires were classified into high level and low level of lean production according to the weighted average of JIT, TQM, TPM and EI. Thus the number of samples had been concentrated to 24 and 29 and regarded as different training samples in this study. With the problem formulation and calculation, the results showed that lean production implementation in Chinese enterprises would raise energy consumption. Moreover, energy consumption would increase with lean production level. Although this result was contrary to researches in developed countries, it presented valuable empirical data for researches in the context of China.

Further study would apply this fuzzy math approach to evaluate enterprises energy issues in other developing countries to enrich the researches in certain context. It further suggests that enterprises in less developed countries need more fundamental understanding of lean production and implement lean production without increasing resource consumption.

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