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Lean Application Level Appraisal and Knowledge Mining

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Abstract: In lean production application process, to appraise lean level for enterprises scientifically can point out the weak link, thus giving the direction of continuous improvement. In this study, appraisal model based on the unascertained theory is used to appraise lean application level. The index system including production improvement, process stability, financial improvement and lean culture is set up and one practical enterprise's lean level is analyzed concretely. In order to get the inner regular knowledge of lean application, Rough Set is used to analyze the appraisal data of 40 manufacturing companies. The study of this study provides one reasonable quantitative tool to appraisal lean application level for enterprises and one platform to compare lean level between enterprises, thus propelling the smooth application of lean production.

Key words: Lean application, unascertained theory, rough set, regular mining

INTRODUCTION

Lean production (LP for short) integrates diversity and low-cost, which are the advantages of traditional handicraft production and assembly line production, so it is called the third production model. After its appearance, many enterprises began to learn and apply it. In American, GE set up the first automobile joint venture company of America with Toyota. Besides GE, such as Chrysler, Du Pont, Motorola and so on, are all implementing lean production. In Europe, one standard plant operating with lean concept was set up by BMW; the Enel entered the advanced rank of European power corporations through applying lean production (Zhang, 2013). In China, FAW, Shang Hai GM and many other companies have already got certain return through lean application. However, not every company is successful in lean implementing, the whole the application situation of LP is not optimistic. In China, the existing of many misunderstandings to lean production has impeded its application. Famous IE expert QI Er-shi once said the enterprises of China doesn't seize the essence of LP, so this led to high failure rate of LP and affected the enthusiasm of applying LP. In Europe, the literature (Sim and Rogers, 2009) dictated that less than 10% of UK organizations have accomplished a successful lean implementation Bhasin (2012).

The reason leads to situation is complex but the lack of reasonable appraisal tool can not be neglected. Without appraisal tool, enterprises implementing LP can not recognize its weak link and can not know its gap compared with lean benchmarking enterprises, on the other hand, the enterprises plan to implement lean can not know the benefit brought by this advanced production model. It is disappointing that related study is very frail, which can not satisfy the need of business circles, so form the view of enterprises and the need of academic research, to study the reasonable index system and appraisal method to lean application is significant.

RELATED RESEARCH

Some researchers have done certain study to appraise LP. In China, Qi and Cheng (2009) and Zhou (2005) has set up index system of appraising LP respectively. While to appraise method, Lin (2007) put forward one model from the angle of fluid capital and Zhou (2007) applied DEA to analyze the comparative efficiency difference of enterprises implementing lean with these not.

In Europe and America, the related research is relatively rich. Huson and Nanda (1995) applied the mathematical statistic method to study the implementation effect of lean production. Manoharan (1997) analyzed the performance of implementing JIT and TOC by simulation technology. The empirical analysis was comparatively early used by Callen *et al.* (2000) to analyze the influence of LP. The cost-time profile model was firstly put forward by Rivera and Chen (2007) to study the function of LP. Using fuzzy logic, Bayou and de Korvin (2008) compared the lean degree of Ford and GE to Honda, which was treated as benchmarking enterprise implementing LP.

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Although, the extant research is meaningful to analyze LP's application effect, it is not adequate. Firstly, the analysis angle is signal. Most of the extant studys put emphasis on production and financial improvement, so the other aspects are neglected. Secondly, the analysis method needs to be mended, the extant method such as variance analysis and linear regression can prove LP's effectiveness but can not give one comprehensive index, so the unified platform of enterprises to compare lean degree is lack. Thirdly, in extant studys, researchers usually take single specific enterprise as study subject, so it is necessary to extract the inner rule by analyzing the data of group enterprises.

APPRAISAL INDEX SYSTEM

The appraisal index system should reflect LP's characters: (1) Integrity: LP's implementation is the integrative action of internal and external factors, so LP's influence not only identified in production link but also identified in financial link as well as other links. (2) Cumulativity: Favorable lean improvement is formed in long term, so enterprises should have a spirit of perseverance and put emphasis on daily improvement.

On the base of literature research, this study sets up the appraisal index system, including the following aspects.

Production improvement: This aspect has been studied by many researchers. Till now a consistent view is basically arrived that LP can bring significant improvement to production link, such as reducing inventory level, increasing turnover rate of inventory, improving product's first time passing rate and so on.

Process stability: It is often neglected by related researchers, so there is little reference. But process stability is one vital index to assess LP's effect, without process stability the product quality can not be guaranteed and the related improvement can not be permanent.

Financial improvement: Gaining certain profit is one main goal of enterprises. But in lean implementation environment, traditional accounting method has defects in the view of LP, for it can not provide support to long-term decision and can not reflect the changing practical situation, so some new indexes should be gave out, such as turnover speed of capital, cost rate of sale and so on.

Lean culture: LP emphasizes continuous improvement which is based on lean culture. Without lean culture lean implementation will lose power source and LP can not be thoroughly implemented.

Based on the analysis above, the concrete indexes and related supporting documents are listed in Table 1.

APPRSIAL METHOD

The level of lean implementation is influenced by many factors and not all the indexes are quantitative, meanwhile, the statistical information can not be collected completely due to history factor and knowledge

Table 1: Appraisal index system of lean production

First level indexes	Second level indexes	Main supporting documents
Production improvement	New product cycle time compared to industry's average level implementation of standard operation OEE product's passing rate of first time order's completing rate punctually production cycle time to industry's average level equilibrium of production	Bhasin (2011), Gurumurthy and Kodali (2009), Doolen and Hacker (2005), Little and McKinna (2005), Gurumurthy and Kodali (2009), Doolen and Hacker (2005), Singh *et al* . (2010), Gurumurthy and Kodali (2009), Bayou and de Korvin (2008), Shah and Ward (2007), Bhasin (2012), Taj and Morosan (2011), Gurumurthy and Kodali (2009), Doolen and Hacker (2005) Shah (2002) and Todd (2000)
Process stability	Deviation of key stage's production cycle time standard deviation of key stage's setup time execution of production plan accurately deviation of product's qualified rate the rate of material supplying JIT	Deif (2012), Kojima and Kojima (2007), Shah and Ward (2007)) Deif (2012), Lander(2007), Lander(2007), Matsui (2007), Deif (2012) Zimmer (2000), Fullerton *et al* . (2003), Zhou (2005)
Financial improvement	Turnover rate of circulating fund per year sales per worker compared to industry level time of inventory turnover per year cost rate of per unit sale	Lin (2007), Kawada and Nu (2010), Huson and Nanda (1995), Bhasin (2012b), Gurumurthy and Kodali (2009) and Huson and Nanda (1995)
Lean culture	Number of suggestions every employee per year involvement rate of administration section fluency of improvement information ratio of employee participating in improvement degree of recognition to enterprise's values position of lean leading organization	Little and McKinna (2005), Shah and Ward (2007), Shah and Ward (2007), Bhasin (2012) Soriano-Meier and Forrester (2002) , Gurumurthy and Kodali (2009) Gurumurthy and Kodali (2009), Taj and Morosan (2011), Liker (2004), Cho(2003) Achanga *et al.* (2006), Little and McKinna (2005)

restriction of appraiser, so the appraisal process if full of incomplete information. Due to this, the unascertained theory is applied, which can tackle incomplete information more scientifically.

Unascertained theory is first proposed by Wang *et al.* (2013) academician of China Engineering Academy. Its main procedures of appraising lean implementation are as follow (Guo, 2011; Zhang and Sun, 2006).

Suppose S is the enterprise to be appraised, based the introduction of part 2, there are 4 first level indexes, forming the first level index space $I = \{I_1, I_2, I_3, I_4\}$. To every first level index there are m second level indexes, forming the second level index space $I_i = \{I_{i1}, I_{i2},, I_{im}\}$ and x_{ij} is the value of enterprise under index I_{ij}. There are 5 ranks in lean appraisal, so the rank space is $c = \{c_1, c_2, c_3, c_4, c_5\}$, satisfying $c_5 > c_4 > \ldots > c_1$, (">"means super to).

Unascertained measurement of bottom indexes: The unascertained measurement matrix of second level index is determined by unascertained function based on appraisal rank. The membership degree of I_{ij} is denoted by μ_{ijk}, which means the degree that I_{ij} makes the enterprise belong to rank c_k. Multiplying related classification weight of second level index with this matrix, the unascertained measurement vector of I_i can be got:

$$u_i = (w_{i1}, w_{i2}, w_{im}) \begin{bmatrix} \mu_{i11} & \mu_{i12} & \cdots & \mu_{i15} \\ \mu_{i21} & \mu_{i22} & \cdots & \mu_{i25} \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{ik1} & \mu_{ik2} & \cdots & \mu_{ik5} \end{bmatrix} = (u_{i1}, u_{i2}, \cdots, u_{i5}) \quad (1)$$

where, in i = 1, 2, …, 4. w_{ij} is the classification weight of I_{ij} got by entropy theory.

The fixation of index's weight: Based on the unascertained theory, there are two kinds of weights-classification weight and importance weight. Classification weight is fixed by entropy theory and this weight identifies the classification ability of index, which depends on the measured value of index. Importance weight fixed by AHP identifies the importance of index, which depends on the preference of decision maker and the attribute of index.

The second level indexes all have measured values and their weights are classification weights based on the unascertained theory. The computation procedure is as follow. Suppose:

$$w_{ij} \ (0 \le w_{ij} \le \sum_{j=1}^{m} w_{ij} = 1)$$

is the classification weight of I_{ij}, w_{ij} is fixed by entropy theory, that is:

$$v_{ij} = 1 + \frac{1}{\lg 5} \sum_{k=1}^{5} \mu_{ijk} \lg \mu_{ijk}, \ w_{ij} = v_{ij} \Big/ \sum_{j=1}^{m} v_{ij} \quad (i = 1, 2, 3, 4; j = 1, 2, \cdots, m)$$

Comprehensive unascertained measurement to first level index: The importance weight vector of first level index got by AHP is denoted by $w = \{w_1, w_2, w_3, w_4\}$. Multiplying this vector with the unascertained matrix of first level indexes, get the final lean degree of enterprise:

$$u = (w_1, w_2, w_3, w_4) \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{15} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{25} \\ \cdots & \cdots & \cdots & \cdots \\ \mu_{41} & \mu_{42} & \cdots & \mu_{45} \end{bmatrix} = (u_1, u_2, \cdots, u_5) \quad (2)$$

where, in u is the membership vector of enterprise belonging to every rank.

Appraisal level identification: Usually there are two methods to do identification, maximum membership degree method and confidence criterion. Because the lean level rank satisfies $c_5 > c_4 > \ldots > c_1$, which means the ranks are ordered, so the confidence criterion is better. Suppose λ is the confidence, usually $\lambda = 0.7$ and:

$$k_0 = \min\left(k : \sum_{1=5}^{1} \mu_{i1} \ge \lambda, 1 \le 1 \le 5 \right)$$

then the lean level of the enterprise belongs to rank c_{k0}.

CASE STUDY

In this study, one enterprise manufacturing shock absorber in China's Tian Jin is chosen as appraisal subject. As one manufacturer integrating develop, design and manufacturing of shock absorber, in order to upgrade product's quality and economic benefit, this enterprise began to implement LP at 2001, till now 12 year has gone. As one key supplier of FAW of China, this enterprise wants to recognize its weak link in lean application and do further improvement. In the analysis process, the examining group is made up of 5 experts, 2 are from lean department of this enterprise and 3 are lean researchers. To the qualitative indexes, the values are got by taking mean of expert scoring. In scoring process, every expert grade from 0-100, higher grade means higher performance. To quantitative index, the index value is got by practical data of the enterprise. The specific segmentation point of ranks and practical measurement value of appraisal is listed in Table 2. In order to make the appraisal more scientific, the rank segmentation is got by referring the performance of Toyota Motor Corporation and other enterprises, which are leading ones in lean application.

Table 2: Segmentation point of ranks and measurement value

Ranks	I_{11} (%)	I_{12} (score)	I_{13} (%)	I_{14} (%)	I_{15} (%)	I_{16} (%)	I_{17} (score)	I_{21} (%)	I_{22} (%)	I_{23} (%)	I_{24} (%)	I_{25} (%)	I_{31} (days)	I_{32} (score)	I_{33} (times)	I_{34} (%)	I_{41} (No.)	I_{42} (%)	I_{43} (score)	I_{44} (%)	I_{45} (score)	I_{46} (score)
Segmentation point																						
1	85-100	0-50	0-65.0	60-80	50-70	85-100	0-50	>20	>20	<75	>10	<90	180-360	85-100	0-15	>90	0-2.0	0-50	0-50	<50	0-50	0-50
2	70-85	50-65	65-75.0	80-85	70-80	70-85	50-65	15-20	15-20	75-80	5-10	90-93	180-120	70-85	15-30	80-90	2-5.0	50-60	50-65	50-60	50-65	50-65
3	55-70	65-75	75-85.0	85-90	80-90	55-70	65-75	10-15	10-15	85-80	3-5	93-96	120-60	55-70	30-45	70-80	5-9.0	60-70	65-75	60-70	65-75	65-75
4	40-55	75-85	85-95.0	90-95	90-95	40-55	75-85	5-10	5-10	90-95	1-3	96-99	60-30	40-55	45-60	60-70	9-15.0	70-80	75-85	70-80	75-85	75-85
5	<40	85-100	>95.0	>95	>95	<40	85-100	<5	<5	>95	<1	>99	<30	<40	>60	<60	15-20.0	>80	85-100	>80	85-100	85-100
Measurement value		75	80	91.5	93	90	70	82	15	10	90	5	95	90	80	30	70	2.5	58	75	68	76	65

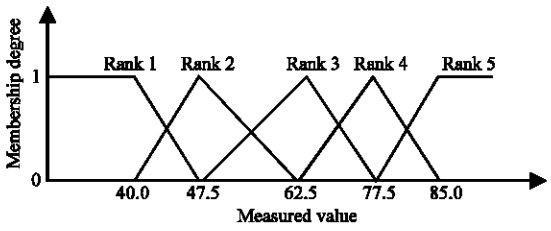

Fig. 1: Membership degree function of I_{11}

In this study, I_{11} is taken as an example to show the computation process of unascertained theory. Based on the logic of unascertained theory, the member function of I_{11} is got, showed by Fig. 1.

Substituting 75 the measured value of I_{11} in to the function the membership degree vector of I_{11} is got, r_{11} = (0, 0.8571, 0.1429, 0, 0). By the same way, the membership degree vectors of other indexes under I_1 are got, so the membership matrix of I_1 is got:

$$R_1 = \begin{pmatrix} 0 & 0.857 & 0.143 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0.7 & 0.3 \\ 0 & 0 & 0 & 0.8 & 0.2 \\ 0 & 0 & 0.333 & 0.667 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 \\ 0 & 0 & 0 & 0.6 & 0.4 \end{pmatrix}$$

According to part 3, the classification weights of second level indexes under I_1 are got by entropy theory, which is w_1 = [0.115, 0.208, 0.129, 0.143, 0.126, 0.118, 0121], then multiplying w_i with R_i, the membership degree vector of I_1 is got, $\mu_1 = w_1 . R_1$ = (0, 0.133, 0.123, 0.628, 0.116).

By the same logic, the membership degree vectors of other first level indexes are got, consisting first level indexes' membership matrix R:

$$R = \begin{pmatrix} 0 & 0.133 & 0.123 & 0.628 & 0.116 \\ 0 & 0.147 & 0.568 & 0.285 & 0 \\ 0.094 & 0.251 & 0.592 & 0.063 & 0 \\ 0.113 & 0.242 & 0.415 & 0.230 & 0 \end{pmatrix}$$

Multiplying the importance weight vector of first level index w with R, the membership degree vector of appraisal subject is got μ = (0.051, 0.192, 0.423, 0.307, 0.027). To the first level index's importance weight vector, it is got by AHP with the help of AHP software developed by Tian Jin University. According to the calculation result, the weight vector of first level index is w = [0.235, 0.277, 0.195, 0.293], CI = 0.001, RI 0.900, CR = 0.001, CR<0.1 satisfying consistency test.

According to the first level indexes' matrix R and the membership degree vector μ, let λ = 0.7, we can know that although this enterprise has implemented LP for nearly 12 years, its comprehensive lean level is not optimistic, only belonging to rank 3 with confidence degree 0.757. To the 4 first level indexes, the performance of production improvement is the best, which reaches rank 4 with confidence 0.744. Next is process stability reaches rank 3 with confidence 0.853. The other two indexes financial improvement and lean culture performed worst, only reaching rank 2 with confidence 0.906 and 0.887, respectively. In general, through 12 years' implementation this enterprise has achieved certain outcome, the lean level of production link as well as the production process has got great improvement but because the performance of financial improvement and lean culture perform not ideal, so the general lean level of the enterprise is not satisfying. The appraisal result shows that the enterprise should do much more to cultivate lean culture in future, because lean culture is power source of lean implementation. Secondly, to the financial respect the enterprise should do some change, because traditional accounting can not reflect the character of lean, this demand the enterprise to change traditional performance appraisal method and give more emphasis on financial indexes reflecting essence of LP.

RULE EXTRACTED BY ROUGH SET

The formation and upgrading of lean implementation level is not irregular, so to extract the inner rule and get the common knowledge from the data of group corporate will be more valuable to LP's smooth development. For this reason, the rough set is used to extract to inner rule. The data processing is realized by rough set software Rosetta, which was developed by Aleksander Ohm, scholar of Norwegian University of Science and Technology. This software owns the table tool based on frame of rough set, which not only can do several kinds of data pretreatment but also provides common algorithms about reduction and rule extracting, so it is an ideal software of Rough Set (Gong *et al*., 2008). In this study the data inputted to Rosetta is got by unascertained appraisal and the sample size is 40.

Importing lean appraisal data of the 40 manufacturing enterprises into software Rosetta, the decision table is got (Table 3).

Do analysis to this decision table following the procedure of Rough Set, including completing missing value data, data reduction by genetic algorithm and rules generation, then getting the rules (Table 4).

Table 3: Decision table of lean implementation

No.	Index 1	Index 2	Index 3	Index 4	Lean lavel
1	3	5	3	5	5
2	2	2	2	3	3
3	4	1	2	1	1
4	4	1	1	1	1
5	2	1	2	2	2
6	4	1	2	1	1
7	4	2	3	3	3
8	4	5	3	4	4
9	4	1	1	1	1
10	2	1	1	1	1
11	2	2	3	2	2
12	2	1	3	2	2
13	3	2	3	3	3
14	3	2	3	2	2
15	2	1	1	2	2
16	2	1	2	1	1
17	2	2	3	2	2
18	3	1	3	2	2
19	2	1	1	2	2
20	3	1	3	2	2
21	3	3	3	3	3
22	2	2	1	1	1
23	4	2	2	3	3
24	3	3	3	3	3
25	3	3	4	4	4
26	4	2	3	3	3
27	4	2	2	3	3
28	3	5	3	5	5
29	4	4	4	5	5
30	2	1	2	1	1
31	4	2	1	3	3
32	5	3	2	3	3
33	4	4	3	3	4
34	5	3	2	4	4
35	4	5	2	4	4
36	3	3	4	5	5
37	3	1	2	3	2
38	4	3	3	5	5
39	4	3	4	4	4
40	3	4	3	5	5

Pay more attention to lean culture and process stability: In the earlier stage of lean implementation, many enterprises put emphasis on the applying lean tools, hoping get significant production improvement. While with further application of LP, this way must be adjusted, otherwise the LP can not be implemented deeply and thoroughly. According to Table 4, lean culture and process stability are the critical factors, deciding the lean level to a great degree. If enterprises want to reach level 5, its lean culture must reach at least level 4 and its process stability must above level 3. Concretely, lean culture is the essence of LP, so to strengthen the building of lean culture is an inevitable choice to upgrade lean application level and keep strategic advantage. Process stability is the accumulation result of long-term lean implementation; it is the underlined effect of LP, so only when this dimension reaches high level, can lean implementation reaches high level.

Deal with the relation of long term and short term improvement effect: In lean implementation process, some

Table 4: Rules extracted by rough set

No	Rule	LHS support	RHS support	RHS accuracy	LHS coverage	RHS coverage	RHS stability	LHS length	RHS length
1	Index 2(1) and index 4(1) ⇒ lean level (1)	7	7	1.0	0.175	0.875000	1.0	2	1
2	Index 2(2) and index 4(1) ⇒ lean level (1)	1	1	1.0	0.025	0.125000	1.0	2	1
3	Index 2(2) and index 4(2) ⇒ lean level (2)	3	3	1.0	0.075	0.300000	1.0	2	1
4	Index 2(1) and index 4(2) ⇒ lean level (2)	6	6	1.0	0.150	0.600000	1.0	2	1
5	Index 2(1) and index 4(3) ⇒ lean level (2)	1	1	1.0	0.025	0.100000	1.0	2	1
6	Index 2(3) and index 4(3) ⇒ lean level (3)	4	4	1.0	0.100	0.363636	1.0	2	1
7	Index 2(2) and index 4(3) ⇒ lean level (3)	7	7	1.0	0.175	0.636364	1.0	2	1
8	Index 2(4) and index 4(3) ⇒ lean level (4)	1	1	1.0	0.025	0.200000	1.0	2	1
9	Index 2(3) and index 4(4) ⇒ lean level (4)	2	2	1.0	0.050	0.400000	1.0	2	1
10	Index 2(5) and index 4(4) ⇒ lean level (4)	2	2	1.0	0.050	0.400000	1.0	2	1
11	Index 2(3) and index 4(5) ⇒ lean level (5)	2	2	1.0	0.050	0.333333	1.0	2	1
12	Index 2(4) and index 4(5) ⇒ lean level (5)	2	2	1.0	0.050	0.333333	1.0	2	1
13	Index 2(5) and index 4(5) ⇒ lean level (5)	2	2	1.0	0.050	0.333333	1.0	2	1

Through the analysis by Rough Set, some revelations are got

enterprises hope to get effect instantly, so they put much attention on the application of lean tools and want to get improvement in traditional financial index, which is called near-sightedness of short-term benefit by lean scholars. We can see from Table 3 and 4, production improvement and financial improvement are not the decisive factors of lean level, so the upgrading of lean application level is a long-term strategic engineering, it is unreasonable to measure its effect by financial or production indexes simply and the enterprises should pay much more attention to long-term effect.

CONCLUSION

The analysis and appraisal method of lean implementation put forward by this study provides one tool to analyze itself lean level for enterprises and can points out the weakness and the direction to take action for further improvement. On other hand, the study of this study provides one platform for enterprises to compare the difference in lean level, which identifies the thought of benchmarking management. Fatherly, this study does certain work to extract the inner rule and common knowledge of lean implementation, related conclusions offer certain reference for enterprises to implement lean production smoothly and thoroughly. But the implementation of lean production is a complex system engineering, different industries have different traits, different type of enterprises have different demands, all these need lean researchers to rich and deepen related study.

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