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AN EVALUATION OF FACTORY PERFORMANCE UTILIZED KPI/KAI WITH DATA ENVELOPMENT ANALYSIS

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Abstract In this paper, based on Key Performance Indicator (KPI) and Key Activity Indicator (KAI) as the fundamental data for calculating defined factory performance function, evaluation system of factory performance is discussed by following four phases. 1) Designing framework for evaluation system of factory performance, 2) Constructing structure of KPI/KAI database, 3) Formulating evaluation of factory performance with proposed model utilized Data Envelopment Analysis (DEA) and 4) Classifying analyzed factories based on established factory performance values.

Keywords: DEA, performance evaluation, KPI, KAI, kaizen, manufacturing

1. Introduction

These decades, Japanese manufacturers have been recognized for their strength over the world through their strategy based on development and application of Kaizen scheme. For instance, strength points of manufacturing workers' ability in Japan are higher than other Asian regions such as on TPM activity, Quality Management and Teamwork between production and R&D sectors [15].

On the other hand, amazing decrease of number of incoming employees over the decade, who graduate from school and join manufacturing industries, is occurred. Rate of this figure to total graduate students came down from 29.5% in 1990, 24.4% in 1995, and to 17.3% in 2000 [14].

Under the existing conditions, it is necessary to develop more systematic approach of Kaizen activity than ever. One relevant way to realize effective Kaizen activity is clarification of relationship between a result of improvement project and a process for achieving purpose of improvement project. An indicator of the former is called Key Performance Indicator (KPI) and the latter is called Key Activity Indicator (KAI) within Total Productive Maintenance (TPM) that is regarded as one of the most relevant improvement management systems.

In this paper, development of evaluation system of factory performance utilized KPI and KAI with Data Envelopment Analysis (DEA) is discussed. This paper is divided into the following sections. Several related literatures are reviewed in next section. A research procedure to building an evaluation system of factory performance is proposed in third section. Preliminary experimentation is performed in forth section, followed by proposed procedure in third section, and conclusions are made in the final section.

2. Literature Review

2.1. Key performance indicator/Key activity indicator

There are some reports and practical guides about Key Performance Indicator (KPI) and Key Activity Indicator (KAI) in TPM.

KPI represents a result of improvement project, e.g. sales, profit, productivity of labor, performance rate of equipment, quality product rate, Mean Time to Failure (MTBF) and Mean Time to Repair (MTTR) [11, 17, 19]. KAI represents a process for achieving a purpose of improvement project, e.g. a total number of education times for employees who tackle performance improvement projects, a total number of employees who pass a public certification examination and an accumulative number of Kaizen cases [11].

Shirose [17] explained two indicators, which are an overall management indicator and KPI for measuring the effect of TPM activities, in fabrication and assembly industries. Aims of measuring two indicators are following four reasons [17]:

- To learn if activities of individual echelons lead to positive results
- To learn if propriety tasks can be detected from the results

  Priority tasks to be attained, if the targets are not achieved.

  Priority tasks for further improvement, if the targets are achieved.
- To allow evaluation as to how echelon-based results are connected to profitability improvement and cost reduction for the entire plant

Achievement indicators for individual echelons (circle, assistant section manager, section or department manager, plant manager levels) are consistently systemized.

- To learn priority problems for individual echelons.

Also, 53 indicators of KPI are divided into six groups, i.e. productivity group, quality group, cost group, delivery group, safety group and moral group.

JIPM [11] tackled with classification of 97 indicators utilized factories/offices received TPM Awards based on some outline reports of TPM Awards. Procedure for classifying 97 indicators consists of two steps. For the first step, 97 indicators are divided into three groups, i.e. overall management indicator group, KPI group and KAI group.

For the second step, each three group derived in the first step is divided into several sub-groups. Overall management indicator group consists of two sub-groups, i.e. sales indicator group and profit indicator group. KPI group consists of seven sub-groups, i.e. quality indicator group, cost indicator group, delivery indicator group, productivity indicator group, safety and healthy indicator group, environment indicator group and moral indicator group. KAI group is classified by eight principles in TPM development [7], i.e. 1) Focused improvement (kaizen) to make equipment more efficient, 2) Autonomous maintenance activities, 3) Planned maintenance for the maintenance department, 4) Technical training in equipment maintenance and operation, 5) An early equipment management problem, 6) Quality maintenance activities, 7) A system for increasing the efficiency of administrative and support function (office TPM) and 8) A system for management of safety and environmental issues.

Three kinds of group in the first step of classification as shown in JIPM [11] are referred to in this paper. It is A) overall management indicator group, B) KPI group and C) KAI group. KPI that represents a result of improvement project is considered as A and B. And KAI that represents a process for achieving a purpose of improvement project is considered as C. Proposed evaluation system of factory performance in third section and a preliminary experimentation in forth section are tackled with followed by this classification.

2.2. Data envelopment analysis

Data Envelopment Analysis (DEA) is originally introduced by Charnes et al. [4]. This analytical model regards each enterprise ("decision making unit" or DMU in DEA terminology) as a transformation function of input resources to output attainments and its ratio as its performance. For example, sales revenue is usually considered as a relevant business output value and cost such as total manufacturing cost is considered as an input value. Based on this scheme, a set of specific linear programming problem solving is performed to classify high-efficient and low-efficient units.

There are many classes of DEA sub models depending on supposed assumptions [1, 3, 5]. Also Tone [20–24] introduced a concept of DEA, its techniques and some case studies with DEA in Japan. Charnes Cooper Rhodes (CCR) model [4] is the simplest model among DEA models. Mathematical representation is given as the following formula.

$$\max \frac{\sum_{r=1}^{s} u_r y_{rj_o}}{\sum_{i=1}^{m} v_i x_{ij_o}} \tag{2.1}$$

subject to

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \qquad (j = 1, \ldots, n) \tag{2.2}$$

$$u_r \geq 0 \qquad (r = 1, \ldots, s) \tag{2.3}$$

$$v_i \geq 0 \qquad (i = 1, \ldots, m) \tag{2.4}$$

Where j_o is DMU, which is to be evaluated, y_{rj} is a value of the output r of DMU j, x_{ij} is a value of the input i of DMU j, u_r is a weighting coefficient for output r, v_i is a weighting coefficient for input i, n is a number of DMU, s is a number of output, m is a number of input, j is a suffix of DMU, r is a suffix of output and i is a suffix of input.

The technological essence of this model is to obtain the optimal weighting coefficient values of input and output linear functions of the target DMU, which enable to accomplish maximum ratio of these functions defined mentioned above. As the constraints introduced in Equation (2.2), this maximum value cannot exceed 1 and each variable as well as coefficient is non-negative. Therefore, measured performance of the target DMU, i.e. maximum ratio, is between 1 and 0. The same calculation described in Equation (2.1) - Equation (2.4) is performed for all decision making units (DMUs). Then, maximum ratios of all DMUs are obtained as their position among the considered DMUs.

3. Procedure of Building Evaluation System of Factory Performance

Proposed procedure for realizing an evaluation system of factory performance consists of four phases as shown in Figure 1. Phase 1 is designing a framework for an evaluation system of factory performance. Phase 2 is constructing a structure of KPI/KAI database that comprises three data categories, i.e. factory performance category, KPI category and KAI category. Phase 3 is formulating an evaluation of factory performance with DEA. And Phase 4 is classifying multiple factories based on factory performance values derived in Phase 3. Detailed explanation of each phase is described in following four chapters of this section.

3.1. Designing framework for evaluation system of factory performance (Phase 1)

It is important to perform PDS Cycle (or PDCA Cycle) effectively for a success of performance improvement project for high productivity organization, skilled manager and fine

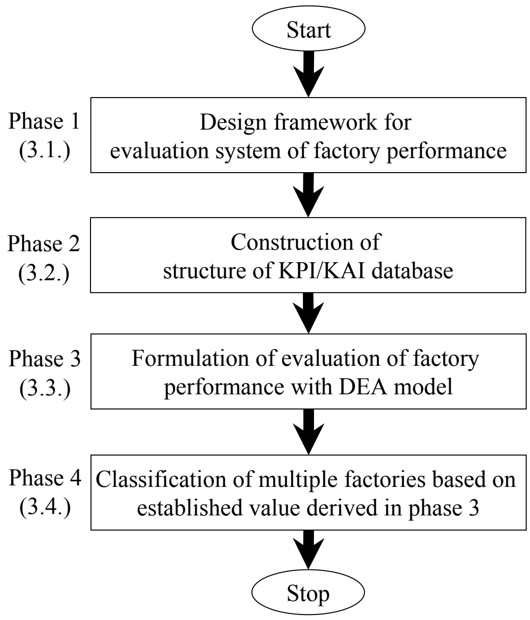

Figure 1: Procedure for building proposed evaluation system of factory performance

product and service. KPI/KAI database, which is the center of proposed evaluation system of factory performance, is useful for supporting See step and Plan step in PDS Cycle (Figure 2). KAI data are accumulated to KPI/KAI database on the way to practicing improvement project. KPI data are registered to KPI/KAI database after finishing improvement project. Based on supplied two categories' data in KPI/KAI database, defined factory performance value is calculated.

In See step, three categories' data, i.e. KPI data, KAI data and factory performance value, is useful for evaluating results of improvement project. Also a gap between target value and obtained actual data is analyzed. In Plan step, three categories' data is useful for investigating past improvement projects and setting target value of next improvement project. These operations in See step and Plan step are considered as benchmarking process.

It is noticed from Figure 2 that there is Kaizen case-base [16] in Do step. Compact and useful Kaizen technologies, e.g. Visual Management (VM) technology, POKAYOKE, KARAKURI, are accumulated to Kaizen case-base. Kaizen case-base supplies suitable Kaizen technologies to improvement project. Owing to using two tools, i.e. KPI/KAI database and Kaizen case-base, supporting a total of PDS Cycle effectively can be realized.

Moreover, if KPI data and KAI data are registered to KPI/KAI database from multiple manufacturing factories, KPI/KAI database will be useful for comparing among registered manufacturing factories. Three ways to compare among manufacturing factories are illustrated from Figure 3.

For the first way, "Measurement" is a ranking of manufacturing factories based on factory performance value. For the second way, "Action" is a setup of target manufacturing factory that is aimed for better factory performance. For the third way, "Evaluation" is an analysis of each manufacturing factories' features among the same ranked factories.

3.2. Constructing structure of KPI/KAI database (Phase 2)

KPI/KAI database consist of three data categories derived in Phase 1 as shown in Figure 4. Factory performance category is made based on KPI category and KAI category. KPI category and KAI category have the same structure of database. The structure of database

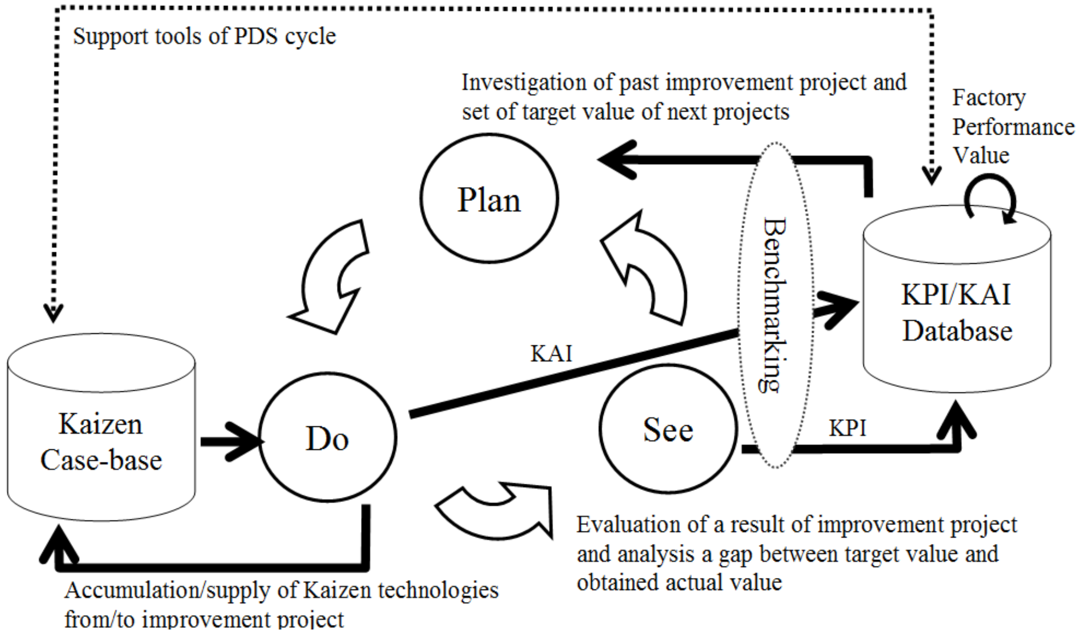

Figure 2: Relationship among PDS Cycle, KAI/KPI database and Kaizen Case-base

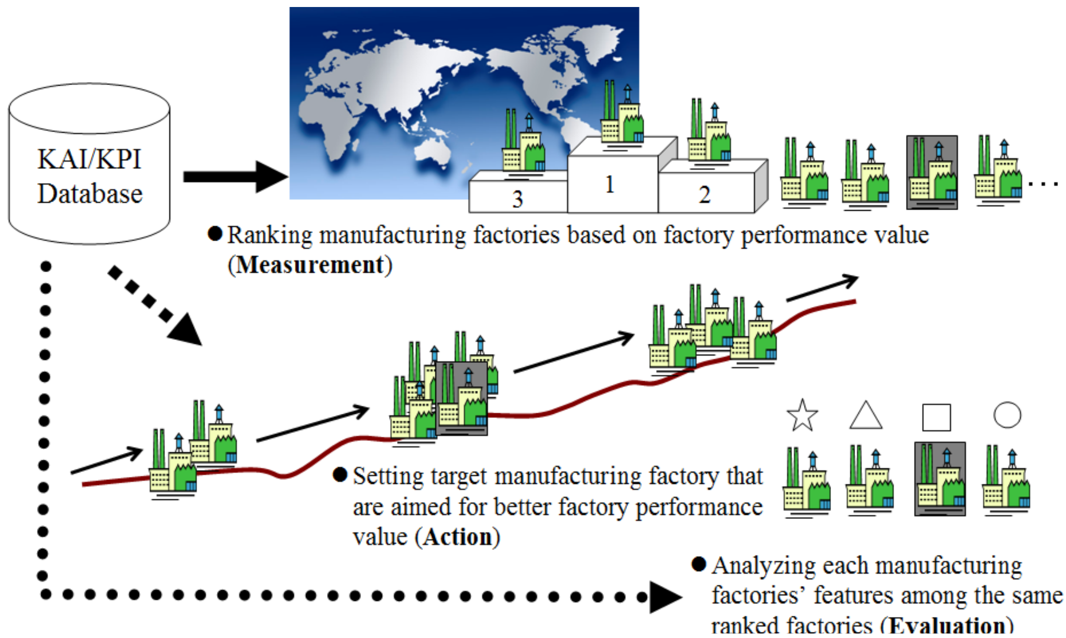

Figure 3: Framework for utilizing KAI/KPI database

consists of three elements, which are manufacturing factories' name, kinds of data and actual data each manufacturing factory.

Database of factory performance category is regarded as a table for ordering manufacturing factories. This table has several groups each a category of business. Manufacturing factories, which have the similar factory performance values, are classified into the same group.

On a case of Factory j in business B (See Figure 4), registration of KPI data (Py_{1j}, Py_{2j}, $\ldots$, Py_{sj}) and KAI data (Ay_{1j}, Ay_{2j}, $\ldots$, Ay_{mj}) to each category database is performed. Factory performance value of Factory j is calculated by registered two categories data of Factory j. Factory j is assigned to Rank C in business B based on derived factory performance value. If Factory j is gray factory in Figure 3, ranking of Factory j is six places in the same category of business as shown in "Measurement" as a part of Figure 3. Next target of Factory j is considered as factory group on the right end as shown in "Action" as a part of Figure 3. And features of Factory j among the four factories are considered as like square mark as shown in "Evaluation" as a part of Figure 3.

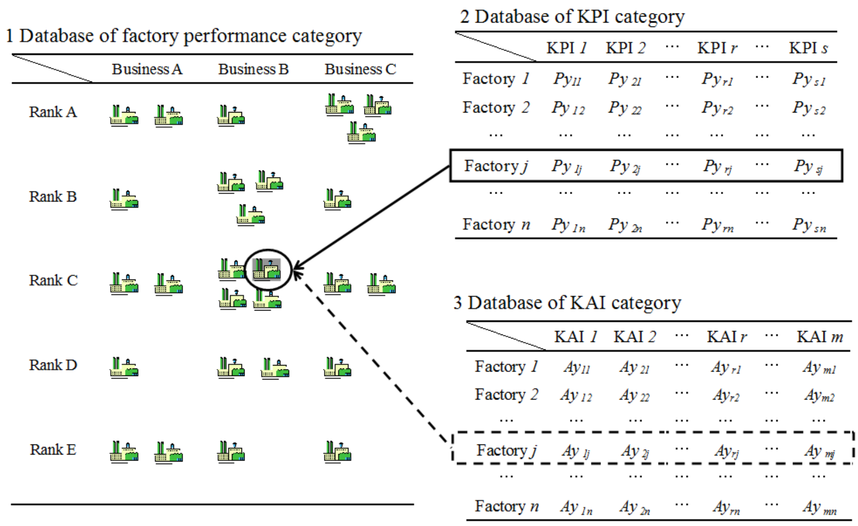

Figure 4: Relationship among three database of proposed system

3.3. Formulating evaluation of factory performance (Phase 3)

For calculating factory performance value in KPI/KAI database, proposed model is formulated with Data Envelopment Analysis (DEA). There are two kinds of model, which are for calculating an efficiency value of KPI and an efficiency value of KAI.

Mathematical representation of these models is degenerated Charnes Cooper Rhodes (CCR) model. Mathematical representation of a model for calculating an efficiency value of KPI of each factory is given as the following formula.

$$\max \sum_{r=1}^{s} pu_r Py_{rj_o} \tag{3.1}$$

subject to

$$\sum_{r=1}^{s} pu_r Py_{rj} \leq 1 \qquad (j = 1, \ldots, n) \tag{3.2}$$

$$pu_r \geq 0 \qquad (r = 1, \ldots, s) \tag{3.3}$$

Where j_o is a factory, which is to be evaluated, Py_{rj} is a value of the KPI r of factory j, pu_r is a weighting coefficient for KPI r, n is a number of factory, s is a number of KPI, j is a suffix of factory, and r is a suffix of KPI.

The technological essence of this model is to obtain the optimal weighting coefficient values of KPI linear functions of the target factory which enable to accomplish maximum ratio of these functions defined mentioned above. As the constraints introduced in Equation (3.2), this maximum value cannot exceed 1 and each variable as well as coefficient is non-negative. Therefore, measured performance of the target factory, i.e. maximum ratio, is between 1 and 0. The same calculation described in Equation (3.1) - Equation (3.3) is performed for all factories. Then, maximum ratios of all factories are obtained as their position among the considered factories.

And then, mathematical representation of a model for calculating an efficiency value of KAI of each factory is given as the following formula.

$$\max \sum_{r=1}^{m} au_r Ay_{rj_o} \tag{3.4}$$

subject to

$$\sum_{r=1}^{m} au_r Ay_{rj} \leq 1 \qquad (j = 1, \ldots, n) \tag{3.5}$$

$$au_r \geq 0 \qquad (r = 1, \ldots, m) \tag{3.6}$$

Where j_o is a factory, which is to be evaluated, Ay_{rj} is a value of the KAI r of factory j, au_r is a weighting coefficient for KAI r, n is a number of factory, m is a number of KAI, j is a suffix of factory, and r is a suffix of KAI.

The technological essence of this model is to obtain the optimal weighting coefficient values of KAI linear functions of the target factory which enable to accomplish maximum ratio of these functions defined mentioned above. As the constraints introduced in Equation (3.5), this maximum value cannot exceed 1 and each variable as well as coefficient is non-negative. Therefore, measured performance of the target factory, i.e. maximum ratio, is between 1 and 0. The same calculation described in Equation (3.4) - Equation (3.6) is performed for all factories. Then, maximum ratios of all factories are obtained as their position among the considered factories.

After concept of Kaizen was introduced by *Kaizen: The Key to Japan's Competitive Success* [6], successful factors for Kaizen or Continuous improvement (CI) which has been regarded as Kaizen in Western writing [12] have been investigated.

One of successful factors for Kaizen or CI is considered as process orientation. For this orientation, Spear and Bowen [18] discussed Toyota Production System (TPS), it is one of systematic Kaizen scheme, is a great present as works have continuously made efforts to improve the system for fifty years. Berger [2] thought the principle of this orientation from two points of view as follows.

- Management's main responsibility is to stimulate and support the effort of organizational members to improve process.
- Process-orientation calls for evaluating criteria which can monitor and bring attention to the improvement process itself, while simultaneously acknowledging its outcome.

Actually KAI such as an accumulative number of proposed Kaizen cases and a total time for Kaizen activities is considered as a basis for evaluation of TPM awards [17]. Therefore if efficiency value of KAI which a factory gets is nearly 1, continuity of improvement projects which this factory has will be estimated at high.

3.4. Classifying multiple factories based on factory performance values (Phase 4)

Estimation of efficiency of result of improvement project can be possible by established efficiency values of KPI in Equation (3.1) - Equation (3.3). And estimation of efficiency of process for improvement project can be possible by established efficiency values of KAI in Equation (3.4) - Equation (3.6). Furthermore factory performance value is calculated based on two kinds of efficiency values because it necessary to be clear a relationship between two kinds of efficiency values for ranking factories in the same category of business as shown in "Measurement" as part of Figure 3 and Figure 4. Based on established efficiency values of KPI in Equation (3.1) - Equation (3.3) and KAI in Equation (3.4) - Equation (3.6), factory performance value is calculated. Mathematical representation for calculating a factory performance value is given as the following formula.

$$\frac{\sum_{r=1}^{s} pu_r^* Py_{rj_o}}{\sum_{i=1}^{m} au_r^* Ay_{rj_o}} = \tan\theta \tag{3.7}$$

Where pu_r^* is established weighting coefficient for KPI r in Equation (3.1) - Equation (3.3), au_r^* is established weighting coefficient for KAI r in Equation (3.4) - Equation (3.6).

The formula described in Equation (3.7) represent $\tan\theta$, which is a slop value of a line joining the origin and a point as shown in Figure 5. An efficiency value of KAI is value of a x-axis. An efficiency value of KPI is value of a y-axis. If $\tan\theta$ is 1, an efficiency value of KPI is the same as an efficiency value of KAI. If $\tan\theta$ is less than 1, an efficiency value of KPI is lower than an efficiency value of KAI. If $\tan\theta$ is more than 1, an efficiency value of KPI is higher than an efficiency value of KAI. $\tan\theta$ expresses transformation level of KAIs into KPIs. It means contribution of activities for improvement project to results of improvement project. The higher $\tan\theta$ which a factory gets is, the higher transformation level of KAIs into KPIs which this factory has will be estimated at.

Classification of analyzed factories is utilized by each factory performance value described in Equation (3.7). It means that a similarity of transformation level of KAI into KPI among factories is evaluated. Through this classification, it will be easy of each ranked factory to find out target factory group that are aimed for better factory performance value (as shown in "Action" as a part of Figure 3). And if detailed data such as KPI and KAI among the same ranked factories are analyzed, several strong/weak points of each factory will be clear (as shown in "Evaluation" as a part of Figure 3). In this paper, all factory performance values are divided into several groups at equal parts between the highest factory performance value and the lowest factory performance value. If a number of equal parts are not enough, many factories are included to the same group and the features of group are not clear. If a number of equal parts are a lot, a group, to which only one factory is included, is occurred. Simulation of several cases followed by a number of equal parts is performed and suitable number of equal parts is determined.

4. Preliminary Experimentation

In this section, simple experimentation of evaluation of factory performance, which is particularly Phase 3 and Phase 4 of proposed procedure, is performed. Actual data of TPM

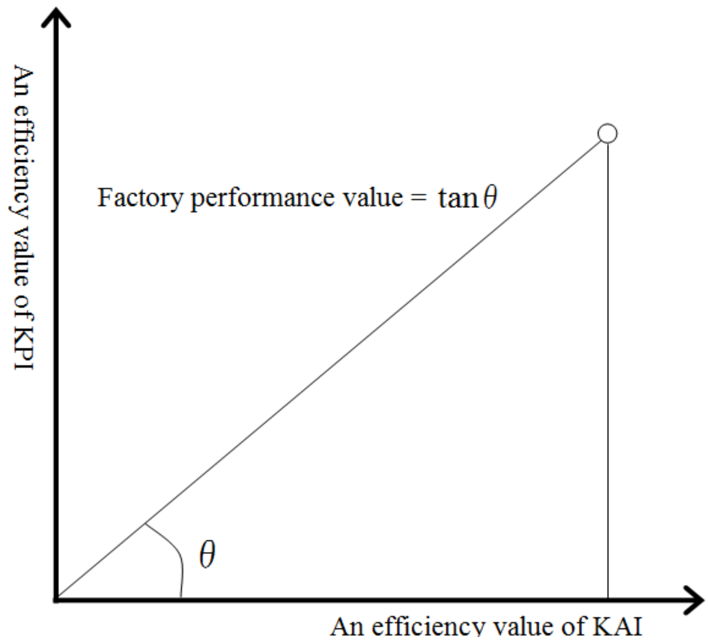

Figure 5: Relationship among a factory performance value, an efficiency value of KAI and an efficiency value of KPI

activity is applied to this experimentation. Detail description of the data and analysis results of its data are described in following three chapters of this section.

4.1. Data description

A total of 50 factories of automobile related industries with the TPM Awards from 2004 to 2006 were investigated in order to collect the data followed by outline reports of TPM Awards [8–10]. For each factory, several KPI and KAI are inserted in outline reports of TPM Awards. A total number of inserted KPI and KAI in outline reports of TPM Awards is 128 indicators.

But a kind of inserted indicators is different every factory, and definition of its indicators, e.g. indicator's meaning or period for acquiring actual data of indicator, is unclear. It is difficult to utilize all actual data of 50 factories. The condition of this experimentation is to acquire actual data, which has the same definition in all analyzed factories. From this point of view, 14 factories were selected in investigated 50 factories. The 14 factories are divided into three types of automobile related industries. First type factory assembles engine. Second type factory assembles car battery. Third type factory manufactures other automobile parts, e.g. a wheel, a body of an automobile and a vibration-proof rubber. Acquired data were either obtained on three KAIs related to employees or Kaizen process and two KPIs related to financial performance and performance efficiency rate. The DEA methodology was applied to evaluate the relative efficiency of the 14 factories based on these three KAIs and two KPIs. The original data for the study are summarized in Table 1.

The three KAIs related to employees or Kaizen process are: (1) Ay1: the number of employees in the factory; (2) Ay2: the months from the start of the TPM program to winning the TPM Awards; and (3) Ay3: the number of attach Efus, which show contents of malfunctions as management tool, to malfunction points on equipment.

The two KPIs related to financial performance and performance efficiency rate are: (1) Py1: Over Equipment Efficiency (OEE) in the year obtained the TPM Awards; (2) Py2:

annual sales in the year obtained the TPM Awards. OEE is original performance efficiency of TPM by given as the following formula [17].

- Overall equipment efficiency (OEE) = Availability × Performance rate × Quality products rate

Where,

- Availability = (Loading hours - Downtime) ÷ Loading hours
- Performance rate = Net utilization rate × Speed utilization rate

Where, Net utilization rate means continuance, and minor stoppage losses are to be calculated = Output × Actual cycle time ÷ (Loading hours - Downtime). Speed utilization rate indicates speed difference = Standard cycle time ÷ Actual cycle time.

- Quality product rate = Number of quality products ÷ Input volume

Where, Number of quality products = Input volume - (Start-up defect volume + Number of process defects + Number of rework case).

Simulation tool for solving proposed KPI model and KAI model utilized DEA is LINGO version 6.0. LINGO is a comprehensive tool designed to make building and solving linear, nonlinear and integer optimization models faster, easier and more efficient [13].

Table 1: 14 factories' original data of KPIs and KAIs

Factory #	*Main product*	$Py1$	$Py2$	$Ay1$	$Ay2$	$Ay3$
A	Engine	79.3	80.0	162	72	19,100
B	Engine	82.0	312.0	310	44	10,891
C	Car battery	84.4	126.0	215	35	6,678
D	Car battery	81.4	101.0	297	35	2,144
E	Car battery	82.0	436.6	360	35	7,576
F	Other parts	86.0	50.4	152	32	2,100
G	Other parts	83.1	111.0	164	113	11,101
H	Other parts	87.7	211.0	835	51	18,000
I	Engine	85.0	83.2	279	51	31,000
J	Car battery	86.0	36.6	166	86	3,000
K	Other parts	85.0	50.0	321	70	1,010
L	Engine	82.2	70.2	219	18	591
M	Engine	87.0	158.0	448	209	10,375
N	Engine	85.0	51.0	225	113	5,552

4.2. Result of calculating factory performance value

A summary of analysis results is illustrated from Table 2, Table 3 and Table 4. Average of 14 factories' efficiency values of KPI is 0.965. Range of 14 factories' efficiency values of KPI is 0.096. Factories that score 1.000 as an efficiency value of KPI are Factory E and H. Annual sales in the year obtained the TPM Awards (Py2) of Factory E is the highest of 14 factories. OEE in the year obtained the TPM Awards (Py1) of Factory H is the highest of 14 factories.

Average of 14 factories' efficiency values of KAI is 0.584. Range of 14 factories' efficiency values of KAI is 0.760. Factories that score 1.000 as an efficiency value of KAI are Factory H, I and M. The number of employees in the factory (Ay1) of Factory H is the highest of 14 factories. The number of attach Efus to malfunction points on equipment (Ay3) of

Factory I is the highest of 14 factories. The months from the start of the TPM program to winning the TPM Awards (Ay2) of Factory M is the highest of 14 factories. A continuity of improvement projects which three factories have is considered as high because each factory has the best feature of all estimated factories.

Factory performance value of Factory H is the same as 1.000. Factory performance values of Factory A, B, C, D, E, F, G, J, K, L and N are more than 1.000. Factory performance values of Factory I and M are less than 1.000. Factory performance value of Factory F, which is 4.088, is the highest of 14 factories. That is to say, in Factory F, the efficiency of KPI is about four times as many as the efficiency of KAI. Factory performance value of Factory I, which is 0.969, is the lowest of 14 factories. That is to say, in Factory I, the efficiency of KPI is almost as same efficient as the efficiency of KAI. Factory performance value of all 14 factories is nearly 1.000 or more than 1.000. All 14 factories are regarded as efficient factories, which achieve excellent results of improvement project through reasonable investments for practicing improvement project.

Classified by main product of each factory, efficiency value of KPI, efficiency value of KAI and factory performance value are 0.956, 0.683 and 1.698 in engine factory group, 0.968, 0.408 and 2.387 in car battery factory group and 0.975, 0.610 and 2.090 in other parts factory group. Ranges of efficiency value of KPI, efficiency value of KAI and factory performance value are 0.088, 0.726 and 2.451 in engine factory group, 0.072, 0.105 and 0.525 in car battery factory group and 0.052, 0.760 and 3.088 in other parts factory group. Range of factory performance value in car battery factory group is lower than in engine factory group or other parts factory group. In car battery factory group, factories have similar efficiency each other.

Table 2: Efficiency values of KPI, efficiency values of KAI and factory performance values of 14 factories

Factory #	$\sum_{r=1}^{s} pu_r^* Py_{rj_o}$	$\sum_{r=1}^{m} au_r^* Ay_{rj_o}$	$\frac{\sum_{r=1}^{s} pu_r^* Py_{rj_o}}{\sum_{r=1}^{m} au_r^* Ay_{rj_o}}$
A	0.904	0.754	1.199
B	0.966	0.531	1.819
C	0.962	0.359	2.680
D	0.928	0.399	2.326
E	1.000	0.464	2.155
F	0.981	0.240	4.088
G	0.948	0.686	1.382
H	1.000	1.000	1.000
I	0.969	1.000	0.969
J	0.981	0.411	2.387
K	0.969	0.513	1.889
L	0.937	0.274	3.420
M	0.992	1.000	0.992
N	0.969	0.541	1.791
Ave.	0.965	0.584	2.007
Range	0.096	0.760	3.119

Table 3: Weighting coefficients for KPI and KAI of target factory (j_o) every 14 factories

Factory #	pu_1^*	pu_2^*	au_1^*	au_2^*	au_3^*
A	1.140×10^{-2}	0.000	0.000	3.466×10^{-3}	2.656×10^{-5}
B	1.075×10^{-2}	2.716×10^{-4}	5.450×10^{-4}	2.460×10^{-3}	2.331×10^{-5}
C	1.140×10^{-2}	0.000	5.450×10^{-4}	2.460×10^{-3}	2.331×10^{-5}
D	1.140×10^{-2}	0.000	1.042×10^{-3}	2.552×10^{-3}	0.000
E	0.000	2.290×10^{-3}	1.042×10^{-3}	2.552×10^{-3}	0.000
F	1.140×10^{-2}	0.000	1.042×10^{-3}	2.552×10^{-3}	0.000
G	1.140×10^{-2}	0.000	0.000	3.466×10^{-3}	2.656×10^{-5}
H	1.075×10^{-2}	2.716×10^{-4}	6.231×10^{-4}	0.000	2.665×10^{-5}
I	1.140×10^{-2}	0.000	0.000	0.000	3.226×10^{-5}
J	1.140×10^{-2}	0.000	0.000	4.785×10^{-3}	0.000
K	1.140×10^{-2}	0.000	1.042×10^{-3}	2.552×10^{-3}	0.000
L	1.140×10^{-2}	0.000	1.042×10^{-3}	2.552×10^{-3}	0.000
M	1.140×10^{-2}	0.000	0.000	3.466×10^{-3}	2.656×10^{-5}
N	1.140×10^{-2}	0.000	0.000	4.785×10^{-3}	0.000

Table 4: Efficiency values of KPI, efficiency values of KAI and factory performance values classified by main product of each factory

Main product	*Factory #*		$\sum_{r=1}^{s} pu_r^* Py_{rj_o}$	$\sum_{r=1}^{m} au_r^* Ay_{rj_o}$	$\frac{\sum_{r=1}^{s} pu_r^* Py_{rj_o}}{\sum_{r=1}^{m} au_r^* Ay_{rj_o}}$
Engine	A, B, I, L, M and N	Ave.	0.956	0.683	1.698
		Range	0.088	0.726	2.451
Car battery	C, D, E and J	Ave.	0.968	0.408	2.387
		Range	0.072	0.105	0.525
Other parts	F, G, H and K	Ave.	0.975	0.610	2.090
		Range	0.052	0.760	3.088

4.3. Results of classifying 14 factories based on factory performance values

Based on established factory performance values of 14 factories, 14 factories are classified into two, three or four equal parts between the highest factory performance value (4.088) and the lowest factory performance value (0.969) (See Figure 6, 7 and 8).

On a case of two equal parts, an equal interval value for classifying 14 factories is 1.558 (= (4.008-0.969) ÷ 2). 14 factories are classified into Factory C, F and L and Factory A, B, D, E, G, H, I, J, K, M and N. A number of factories each part is 3 and 11. On a case of three equal parts, an equal interval value for classifying 14 factories is 1.039 (= (4.008-0.969) ÷ 3). 14 factories are classified into Factory F and L, Factory C, D, E and J and Factory A, B, G, H, I, K, M and N. A number of factories each part is 2, 4 and 8. On a case of four equal parts, an equal interval value for classifying 14 factories is 0.779 (= (4.008-0.969) ÷ 4). 14 factories are classified into Factory F and L, Factory C, Factory B, D, E, J, K and N, and Factory A, G, H, I, and M. A number of factories each part is 2, 1, 6 and 5.

In particular, on a case of three classifications, a common feature every group is clear. Factory performance values are more than 3.00-score range in highest efficient part (Factory F and L). Factory performance values are 2.00-score range in middle efficient part (Factory C, D, E and J). Factory performance values are 1.00-score range or less than 1.00-score range in lowest efficient part (Factory A, B, G, H, I, K, M and N). Furthermore all four factories that manufacture car battery are included in middle efficient part.

On the other hand, on a case of two classifications, a number of factories is a lot (11 factories) in lower efficiency part. Discrepancies exist in the efficiency values of KAI obtained from 11 factories of lower efficient part. On a case of four classifications, a number of factories is only one factory in the second efficient part. As stated above, three classifications is the best of three kinds of classification in this preliminary experimentation.

Based on database of factory performance category as shown in Figure 4, result of three classifications is illustrated from Figure 9 and Table 5. Three ranks are constructed in this database. Two factories, four factories and eight factories are put on Rank A, Rank B and Rank C.

The above trial is very simple in an experimental laboratory but a lot of future works for realizing an evaluation of factory performance are found. Three future works are mainly considered as follows. Firstly formulation of evaluation of factory performance is based on CCR model in this paper, it is necessary to evaluate possibility of this formulation based on other advanced DEA model [1, 3, 5]. Secondly a difference between range of 14 factories' efficiency values of KPI (0.096) and range of 14 factories' efficiency values of KAI (0.760) is large. The result of classifying 14 factories is considered as one of the characteristics of automobile related industries' factory. Other industries' factories are analyzed with proposed methodology and a comparative study among some industries' factories is performed for extracting Kaizen pattern each industry. On the other hand the result of classifying 14 factories depends on efficiency values of one side indicator. It is necessary to develop a modification methodology of this difference and improve an accuracy of classification methodology. Finally the classification methodology of this preliminary experimentation depends on a distance between the highest factory performance value and the lowest factory performance value in all analyzed factories. The distances between one factory and the others factories is defined and analyzed factories are classified by the defined distance in the future. For example, a classification methodology based on data of two indicators itself in all analyzed factories is considered.

5. Conclusions

There were two proposals and an experimentation in this paper. For the first proposal, framework for evaluation system of factory performance was designed. This framework, setting KPI/KAI database as the central function that support Plan step and See step in PDS cycle, contributes to perform benchmarking for realizing effective Kaizen activity. For the second proposal, two methodologies were discussed to evaluate factory performance under proposed framework. First methodology for formulating evaluation of factory performance is based on two degenerated DEA model. First model supplies an efficiency value of KPI. Second model supplies an efficiency value of KAI. Then factory performance value is calculated with the two efficiency values. Second methodology for classifying analyzed factories is based on each factory performance values. The classification methodology uses equal parts between the highest factory performance value and the lowest factory performance value in all analyzed factories.

For the experimentation, 14 factories received TPM Awards in 2004-2006 were investigated. Finally, the performance of two proposed methodologies was validated by using 14 factories' KPI data and KAI data.

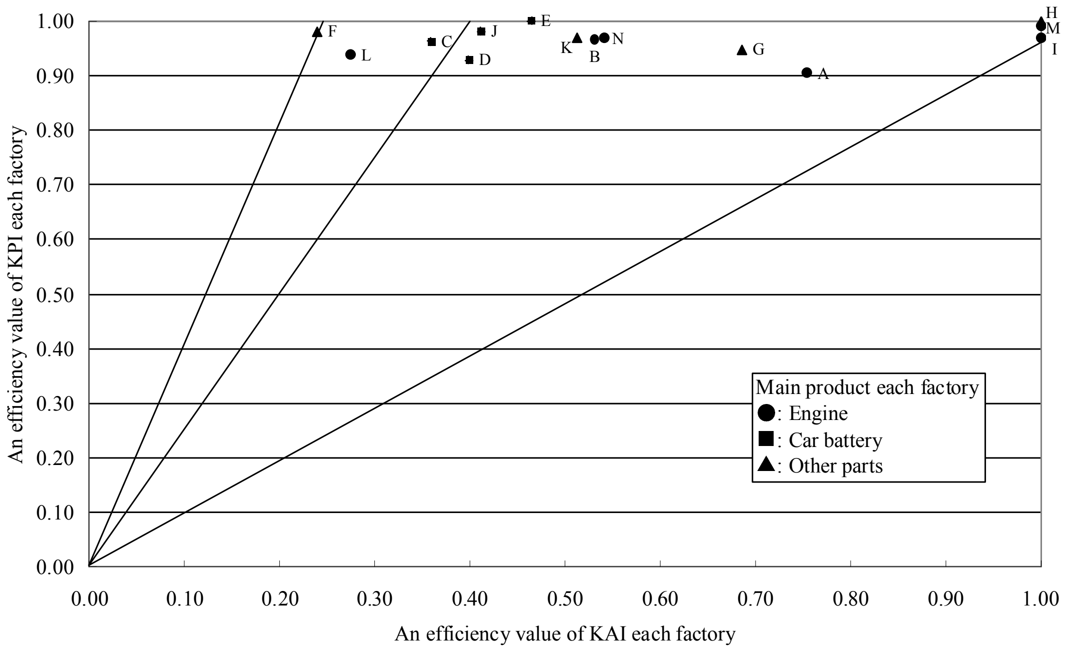

Figure 6: Two classifications of 14 factories based on factory performance values

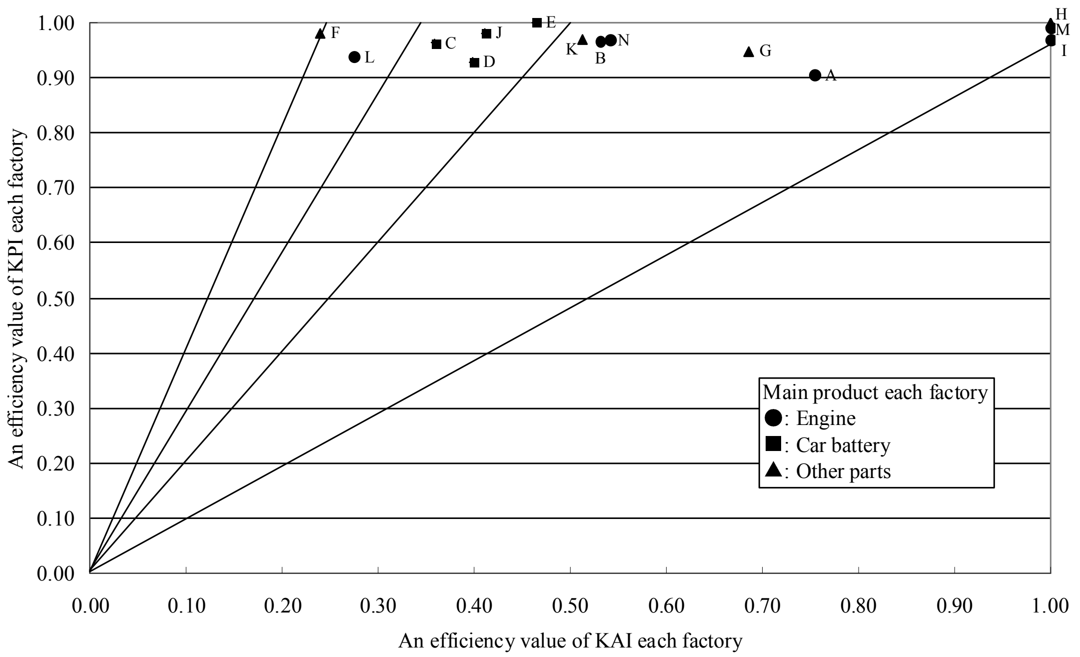

Figure 7: Three classifications of 14 factories based on factory performance values

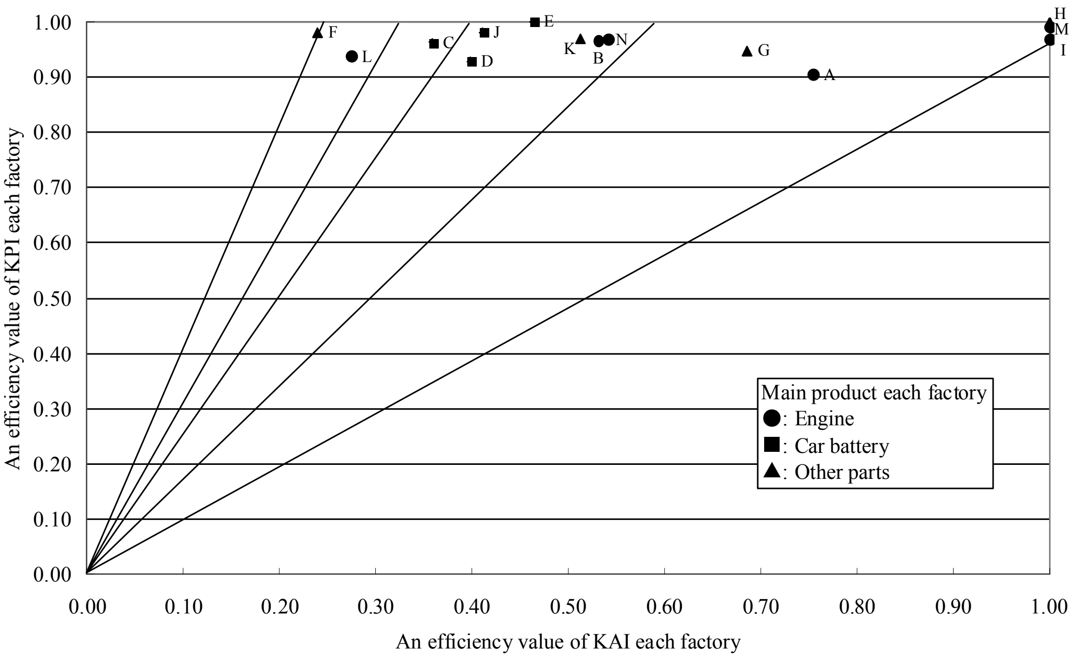

Figure 8: Four classifications of 14 factories based on factory performance values

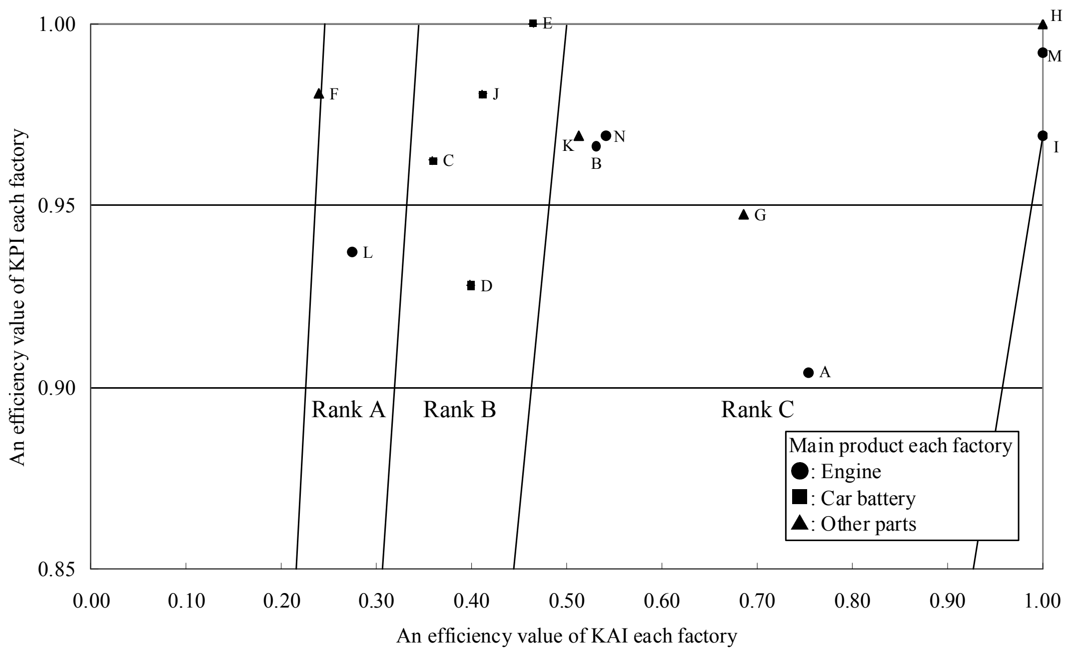

Figure 9: Enlarged drawing about Figure 7 with ranking

Table 5: Database based on three classifications of 14 factories of automobile related industries based on factory performance values

Rank # (Range of factory performance values)	*Factory #*
Rank A (more than 3.00-score range)	F and L
Rank B (2.00-score range)	C, D, E and J
Rank C (1.00-score range or less than 1.00-score range)	A, B, G, H, I, K, M and N

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