Examining Inter-firm Relationships Using Network-Based DEA: A Case Study of Mazda Yokokai

T. Ito, M. Sakamoto, R. Mehta, and S. Ikeda

***Abstract*—**Increasing efficiency is an important issue in corporate management. Although many tools to measure efficiency have been developed, this paper proposed a new approach known as network-based Data Envelopment Analysis (DEA) as an even more effective tool for examining inter-firm relationships. More specifically, network-based DEA makes it possible to detect system-wide effects when marginal changes in related phenomena occur. This new approach was illustrated using data drawn from Mazda's Yokokai keiretsu to reveal the impact that transactions among member firms in the network have on sales. Managerial implications in the formulation of corporate strategy are discussed. Study limitations are identified and directions for future research are proffered.

***Keywords*—**Corporate performance, the DEA, degree, efficiency criterion, network, Yokokai.

I. Introduction

KEIRETSUS have been recognized as one of the sources of competitive advantage of Japanese firms. Various characteristics of Japanese keiretsu include: 1) access to stable financing, 2) insulation from market pressures, 3) risk reduction, 4) monitoring benefits and reduction of information asymmetries, and 5) mutual assistance [1]. In order to understand how inter-firm relationships influence corporate performance, it is necessary to measure efficiency. Many effective tools to measure the efficiency have been developed. Data Envelopment Analysis (DEA) is one of the typical tools [2-3]. In this paper, the authors reviewed the literature associated with the DEA and proposed the new approach called network-based DEA. Furthermore, the authors calculated the efficiency of each firms in Yokokai, and revealed the relationship between inter-firms relationship and corporate performance.

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II. Problem Formulation

Several studies have been published that examine rational inter-firm relationships among members of Keiretsus. For example, stability and influence of inter-firm relationships in Mazda's Yokokai was assessed by Ito et al [4], a structural analysis of the Yokokai was conducted by Tagawa et al. [5], and another study examined centrality issues of Yokokai [6]. Concurrently, many statistical packages that can be used to measure efficiency have been developed. Of these, the DEA provides a practical way to assess performance and relative efficiency issues using a linear programming-based method [7]. For instance, DEA was applied to investigate the efficiency of banks in transition by Igor and Boris [8], and a simultaneous analysis of the interrelationships among economic growth, environmental pollution and energy consumption was reported by Christina and George [9].

Although input and output data can be considered independently and separately, the DEA also allows the data to be interchanged freely. This feature makes DEA especially appealing and appropriate to studying interrelationships among members of a Keiretsu. That is because it is widely recognized that interrelationships among real world phenomena are interconnected wherein even a marginal change in one variable can dramatically alter the whole system. In short, with DEA it is feasible to detect systemic effects due to interrelated factorial changes. This is illustrated by means of an example below. For instance, a small network can be diagrammed as follows.

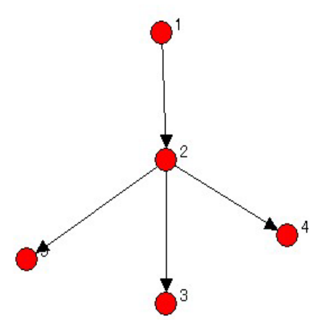

Fig. 1 A five-node network

Fig. 1 shows a network, albeit asymmetric, that is composed of five nodes. A node may be represented by a human, computer or firm. For this network, it is possible to calculate the in-degree and out-degree using the degree equation. The input and output data shown in Table 1 is based on the supposition that the node represents a company, and output reflects sales.

Table 1 Input and output data of Fig. 1

	Input data		Output data
	Out-degree	In-degree	Sales
1	20	0	1,000
2	135	20	2,000
3	0	30	4,000
4	0	45	200
5	0	60	9,000

Based on the analysis of the DEA model, the results obtained are reported in Table 2.

Table 2 Results of Fig. 1

	D Efficiency	Reference set	v_1	v_2
1	1.000	1(1.000)	0.050	0.150
2	0.205	1(0.385);5(0.068)	0.005	0.015
3	0.889	5(0.444)	0.011	0.033
4	0.030	5(0.022)	0.007	0.022
5	1.000	5(1.000)	0.006	0.017

In Table 2, v_1 and v_2 represents out-degree and in-degree respectively. The efficiency of node 2 is 0.205. The efficiency of node 2 will be improved if the out-degree and in-degree are to change 0.005 and 0.015 times respectively.

After using the solution shown in the Table 2, the newer results are revealed in Table 3, which shows that the efficiency of node 2 has been improved.

Table 3 New results of Fig. 1

	D Efficiency	Reference set	v_1	v_2
1	1.000	1(1.000)	0.050	6.552
2	1.000	2(1.000)	1.417	0.075
3	0.889	5(0.444)	0.630	0.033
4	0.030	5(0.022)	0.420	0.022
5	1.000	5(1.000)	0.315	0.017

But an important aspect which should not be overlooked is that out-degree and in-degree of node 2 are changed from 135 and 20 in Table 1 to 0.675 and 0.3, respectively, while the other data still remain same. This result is seemingly inconsistent with the fact that whole system will be changed even if a small change transpired. Thus, the input data should be recalculated after which the results are reported in Table 4.

Table 4 New input and output data of Fig. 1

	Input data		Output data
	Out-degree	In-degree	Sales
1	0.300	0	1,000
2	0.675	0.300	2,000
3	0	0.150	4,000
4	0	0..225	200
5	0	0.300	9,000

The efficiency of node 2 is 0.178, which is smaller than 0.205. This indicates that the DEA is not sufficiently suitable for detecting real systemic changes. Consequently, the DEA should be modified when it is used to measure efficiency.

III. Problem Solution

In this paper, a new approach for using the DEA is suggested that is based upon network model.

A. *Procedure of Network-Based DEA*

The procedure of the network-based DEA is as follows.

1) *Problem formulation*

Many types of DEA have been developed; the most basic one is known as the Charnes-Cooper-Rhodes (CCR) model. The generalized model of the CCR is formulated as follows.

$$e = Maximum\left(\sum_{r=1}^{s} u_r y_r\right) \tag{1}$$

Subject to

$$\sum_{l=1}^{m} v_l x_l = 1 \tag{2}$$

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{l=1}^{m} v_l x_{lj}} \le 1; \qquad j=1, 2, \ldots\ldots, n \tag{3}$$

$$v_1, v_{2,} \cdots\cdots, v_m \ge 0 \tag{4}$$

$$u_1, u_{2,} \cdots\cdots, u_m \ge 0 \tag{5}$$

2) *Efficiency calculation:*

The efficiency will be calculated using input and output data and then the solution for lower efficiency will be found.

3) *Data recalculation:*

The input and/or output data should be recalculated based on the solution using network model.

4) *Finding new results:*

The efficiency should be recalculated using the new data in 3). New result will be found.

5) *Efficiency comparisons:*

The new solution will be found after comparing the efficiencies between 2) and 4).

6) Criterion calculation

To ascertain the relative importance of each node, the efficiency criterion and its square value will be calculated if no difference between 2) and 4) exists. An efficiency criterion is defined as the summation of all nodes' efficiency when the solution is fixed at one specific company. And its square value is defined as the summation of the square of all nodes' efficiency. The former indicates the impact of each node', and the later suggests the importance of each node'.

B. Measurement and results

In order to study inter-firm relationships among keiretsu members, transaction data were obtained from Mazda's Yokokai, which represents a typical auto-maker and parts-suppliers keiretsu to calculate the efficiency of each company. Degree, including out-degree and in-degree, are calculated. Out-degree means that one company sells parts to other company, and in-degree means that one company purchases the parts from other company. Degree is considered as the input, and sales are considered as the output. The efficiency of all companies is shown in Table 5.

Table 5 Efficiency of the firm in Mazda Yokokai (selected part)

	D Efficiency	v_1 (out-degree)	v_2 (in-degree)	u_1 (sales)
Mazda	0	0	1	0
Ishizaki Honten	0.386	67	85,109	18
Keylex	0.298	42	53,647	11
Kurashiki Kako	0.404	90	113,851	24
Sumino	0.303	207	262,696	56
Nishikawa Rubber	0.552	50	64,085	14
Japan Climate systems	0.038	6	8,005	2
Hiluta Kogyo	0.321	66	84,043	18
Hiroshima Aluminium	0.353	37	47,075	1
Molten	0.675	92	117,163	25
Ring Techs Hiroshima	0.332	144	183,101	39
Akebono Brake	0.405	12	15,066	3
Asumo	0.322	8	9,771	2
Usui Kokusai Sangyo	0.429	33	41,902	9
NOK	0.386	6	7,385	2
Kayaba Industries	0.009	0	246	0
Calsonic Kansei	0.013	0	115	0
Kyosan Denki	0.305	36	45,838	10
Unipres	0.033	1	1,375	0

The primary business of one Yokokai member, Unipres, which was established in 1945, is manufacturing auto and allied electronic parts, which it sells not only to Mazda, but also non-keiretsu members, such as Nissan, Isuzu, Toyota and Jatco.

The efficiency of Unipres is 0.033. From Table 5, we can ascertain that the objective of Unipres would be to improve its efficiency, which can be accomplished by changing its out-degree and in-degree 1 and 1,375 times respectively. The detailed transaction information of Unipres in Yokokai can be shown as Table 6.

Table 6 Transaction of Unipres in Yokokai

	To Unipres	From Unipres
Mazda	0	1,224,575,000
Calsonic Kansei	0	3,896,375,000
Jatco	0	12,023,100,000
Nissan	0	65,570,425,000
Isuzu	0	779,275,000
Yorozu	661,854,000	0

Based upon Table 6, the out-degree is changed. And we get the new results as below using new input data.

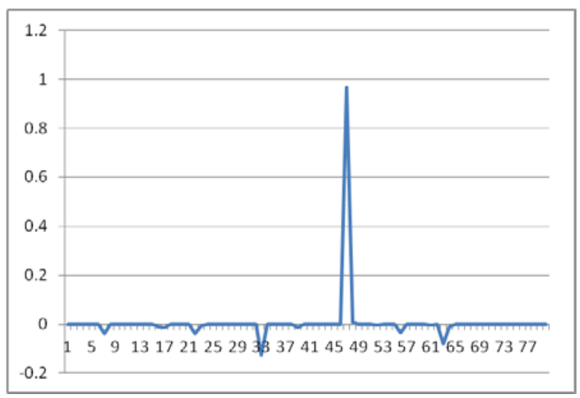

Fig. 2 New efficiencies using new input and output data

Based on the results reported in Fig. 2, it is evident that the efficiency of Unipres is improved. However, a crucial issue is to identify the importance of each company it deals with for the purposes of strategy formation. For ease of illustration Calsonic Kansei was selected to calculate efficiency of all firms—as depicted in Fig. 2.

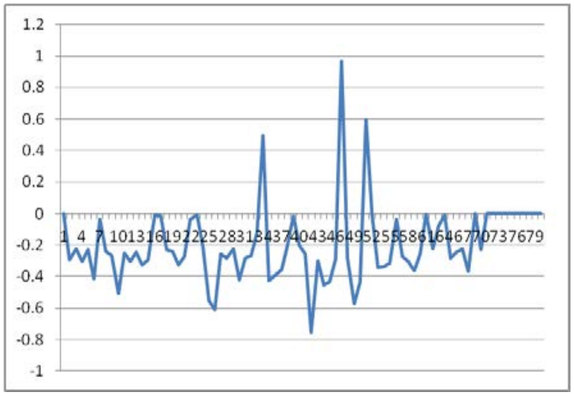

Fig. 3 The efficiency of all firms based on Calsonic Kansei

We calculated all efficiencies the five firms (Table 6), and found that the efficiency of Unipres remains the same. To identify the importance of each firm, we calculated the efficiency criterion and the square value of efficiency criterion. An efficiency criterion is defined as the summation of all efficiency when the transaction is fixed at one specific company. Square value of efficiency criterion is computed by squaring the efficiency criterion. The result is shown in Table 7.

Table 7 Efficiency criterion and its Square value of Unipres

	Efficiency Criterion	Square value of efficiency Criterion
Mazda	0.609	0.961
Calsonic Kansei	-15.474	7.794
Jatco	0.609	0.961
Nissan	0.609	0.961
Isuzu	0.612	0.961

The detailed information of efficiency criterion and its square value of each firm can be illustrated as Fig. 4 and 5.

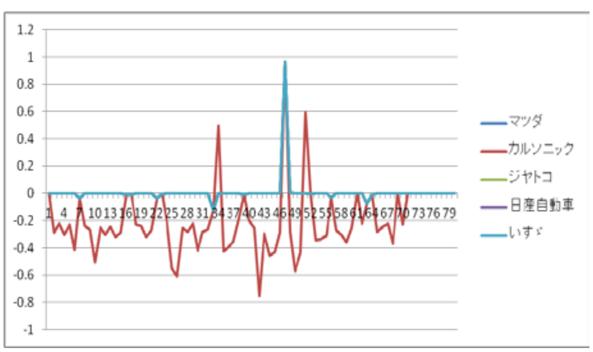

Fig. 4 Efficiency Criterion of each firm

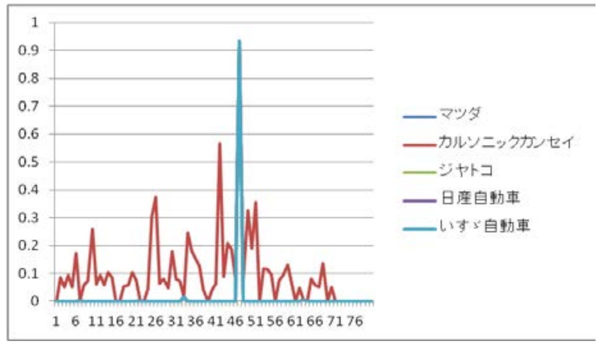

Fig. 5 Square value of efficiency criterion of each firm

Efficiency criterion can be considered as an index of the impact of the fixed company. It reveals that as the efficiency criterion gets bigger, its impact gets stronger. We can find the negative value in the row of efficiency criterion because it is a result of summation. Thus, we calculated the square value of efficiency criterion to express the extent of the importance. It indicates that as the square value of the efficiency criterion increases, the company becomes much more important. Calsonic Kansei has the highest efficiency criterion in Table 7.

C. Analysis and discussion

From Table 6, it is evident that five firms sell parts to Unipres, which include Mazda, Calsonic Kansei, Jatco, Nissan, and Isuzu. Table 7 shows that all of them except Calsonic Kansei have a positive impact. Thus, Calsonic Kansei is the most susceptible firm because it has the highest value of square value of efficiency criterion.

The sales of Unipres are 111,325 and 103,926 million Japanese Yen in 2004 and 2005 respectively. The transaction between Unipres and the five firms in 2004 and 2005 is shown in Table 8.

Table 8 Sales of the 5 firms in 2004 and 2005 (%)

	2004	2005
Mazda	1.1	1.1
Calsonic Kansei	3.5	4.3
Jatco	10.8	13
Nissan	58.9	58.8
Isuzu	0.7	0.8

The transactions between Calsonic Kansei and Jatco have increased tremendously. Compared with Calsonic Kansei, the efficiency criterion and its square value is small. Thus, it is reasonable to conclude that greater frequency of transactions with Calsonic Kansei could possibly be one of the reasons that resulted in decreasing sales of member firms, although the economic recession and the loosening of keiretsus may also be attributed as a possible determinant.

IV. Conclusion

In this paper, network-based DEA was proposed as a new approach for analyzing interrelationships among members of a keiretsu. Using transaction data drawn from Mazda's, Yokokai, the efficiency of all member firms' was calculated. The paper also suggested a new index—the efficiency criterion and its square value—to determine the importance of each firm in a given network.

The limitation of this paper is only one network index, degree is used. Additional network indices, such as betweenness, and density should be used. Furthermore, in future research not only transaction data, but also cross-shareholding data, should be applied to enhance our understanding of how keiretsus should be strategically managed.

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