Development of a Network DEA Model to Measure Production Line's Performance: A Case Study for Automation and Labor Combination

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***Abstract*— Nowadays, growth of industry can be seen as a nature of the world. Each company race again each other to increase productivity to produce new, high quality and product that fulfil customer demand. One can achieve the Key Performance Indicator (KPI) or targeted goal but without considering the cost, manpower, time or others elements is inefficient toward productivity. In this paper, we studied the effectiveness of production line that equipped with automation to determine whether the return of investment for automation is worth compared to output obtained. We apply Data Envelopment Analysis (DEA) to measure efficiencies of production line where DEA is one of excellent tool that can evaluate efficiencies and have been use widely in many sectors. As a case study, this research focuses on the production line that producing a product with a high and continues demand in order to observe how the investment on automation can give a good return or not and continue to see investments return profits automation done or not. We observed the performance of the production line that combined the automation and the labour using Network DEA model. Our observation found that the company can save production time by thirty five to fourty percent in producing the product.**

Keywords—network DEA; performance measurement; productivity; cost saving

I. INTRODUCTION

The manufacturing industry is one of fastest growing industry in Malaysia. This phenomenon makes company always create new changes toward human way of work, machines demand, company mission and vision and can line up against others company. Any changes can help company reduce cost of time, number of worker, rejection of unit, machine down (time and maintenance) and loss of customer due to customer dissatisfaction. Furthermore, save this reduces cost directly can save quality of product produce and indirectly lead company become one of most well-know company among customer. Therefore, production department in company need to precisely improve and maintain productivity of product with quality demand and effectively control this process and bring profit to company.

The efficiency of company performance need to measured to see productivity of company reach the Key Performance Indicator (KPI). In industry efficiency or productivity always has high concern in achieving excellence profitability. P. Jonsson and M. Lesshammar [1] stated that, to observe and improve system performance in an organization, many researchers designed diversified productivity techniques and performance measures. One of these techniques is line balancing. R. Shankar [2] stated that, assembly line is sequence of progressive assembly station linked by some material handling devices. The process flow become sufficient due to well up production line set up. L. J. Krajewski and L. P. Ritzman [3] stated that, the aim of line balancing is to align the output rate with the production plan. This will lead management in ascertain on-time delivery and avoid build-up of shipping schedule.

R. Shankar [4] stated that, the objective of an enterprise is to provide goods or services, and to earn some profit. Industries are focussing on continuous improvement and customer delight. Production people will approach new system frequently to increase productivity in their company day by day. The process of collecting, analyzing and reporting information regarding the performance of an individual, group, organization, system or component called performance measurement. This measurement can help improve productivity to achieved targeted percentage of productivity daily, monthly and even yearly. All factors even it is minor effect need to analyze to increase productivity.

II. Network DEA

DEA is one of conventional tool that can evaluate performance of multi-sector in industry. This method purpose by Charnes et al. [5] perhaps delegate best technique of performance evaluation among others techniques appraise organization performance. According to Hsieh and Lin [6], decision making units (DMUs) with multiple input and output is homogenous set to measure the relative efficiency by using this linear programming technique. Lazano et al. [7], account the production process of a DMU as a black box in calculating efficiency by using conventional DEA approaches. However, appropriate analysis is done which deal different interconnected processes each one with its own exogenous inputs and final outputs and also with median product that procreate and consumed within the system. This type of DEA approaches are generally known as network DEA by Fare and Grosskopf [8].

Lazano et al. [7], in addition to consuming and producing median products, network DEA account the actuality of several processes each of which consumes its own set of inputs and produce its own set of outputs. These median products are considered as inputs for some stages are outputs for others. According to Hsieh and Ling [6], the relational network DEA measures the overall organizational efficiency and the efficiencies of processes within the organization.

III. Application Network DEA in Industries

There are several industries with different background use network DEA to evaluate their performance such as tourism, banking, medical and transportation. They are using different model of Network DEA to evaluate their company performance. Fornell et al. [9] discussed, customer contentment has become an essential performance indicator for both private and public firms. According to Renner [10], the hotel's performance is the aggregated efforts of multi departments, involving both the front of the house and the back of the house. Gronroos and Ojasalo [11]; Hit and Mathis [12], the effort made by these departments can be evaluated in terms of the level of service provided, enabling an evaluation of whether the internal resources have been used efficiently. Once the tangible and intangible services have been supplied, they will either be wasted or consumed. To evaluate the performance of the hotel industry, they used the relational network DEA by Kao [13]. Besides that, Mickael and Magnus [14] has design a model that allows the inclusion of information on customer satisfaction in efficiency and productivity measures and to show how such a model can be applied and be of use for an organization that need to monitor both productivity and customer satisfaction have been present by using DEA. They modify and apply the DEA network model introduced by Färe and Grosskopf [15] to model both production and consumption activities in the pharmacies. According to Forsund and Kittelsen [16], the research of energy- saving has become an important topic and network DEA also being use in airport construction energy, with the architecture market farther development. DEA have being use to develop Airport Construction Energy-saving measures, but none of these DEA studies have assimilate energy-saving material. Lazano et al. [7], have improved incomplete weight deficiency of information processing by using Data Envelopment Analysis- Analytic Hierarchy Process (DEA-AHP) methodology to analyze the Airport Construction Energy-saving measure.

IV. Theory Of Network DEA

Network DEA considers that there are n DMUs which are structurally homogeneous, i.e. they consist of the same interrelationships among them. In this section, they provide a heuristic road map to the different network models discussed in the current paper. Denote inputs by $x = (x_1, \dots, x_N)$ and outputs by $y = (y_1, \dots, y_M)$. The simple static non-network model, often referred to as the "black box," is illustrated first (see Figure. 1). Here, inputs x are employed in the production process P to produce output y. P may be modelled, in the simplest case, by a production function or as a DEA model in more complex cases. Independent of how P is modelled, there is no information about what is taking place within the production process P. Only the transformation of inputs into outputs $x \to y$ is modelled.

This static model can also be used to measure performance over time, as in Figure 1. The comparative static model takes technology and inputs as fixed and exogenous in each period, however (disembodied) technical change can occur over time. This idea has been used to model productivity change in a DEA framework, as in Färe et al.[17]. They show how to use DEA.

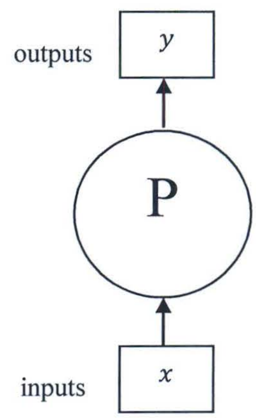

Fig. 1. The static technology.

to compute and decompose Malmquist productivity indexes into changes in efficiency("catching up") and technical change (shifts in the frontier) Färe et al.[18].

Färe and Grosskopf [8], illustrated full network model in Figure 2, which consist three producing subprocesses, a source, and an outlet. From the model, they grant a total of five nodes (0, ... ,4) and they denote total obtainable inputs by x and let ${}^{i}_{0}x, i = 1,2,3$. Node i is to allocate the volume of the vector of input. In particular, the source node model for exogenous inputs is:

$$x \geq \sum_{i=1}^{3} {}_{0}^{i}x \qquad (1)$$

or

$$x_n \geq {}_{0}^{1}x_n + {}_{0}^{2}x_n + {}_{0}^{3}x_n, n = 1, \dots, N.$$

Denote the vector of outputs produced by subprocess or subtechnology i and delivered to node j by ${}_{i}^{j}y$. The total production of node 1 from Figure 4 is ${}_{1}^{3}y + {}_{1}^{4}y$, where ${}_{1}^{3}y$ is its output of intermediate products and ${}_{1}^{4}y$ is its final output. Node 1 does not use any intermediate products as input same with node 2. However, node 3 uses inputs from both node 1 and node 2 as well as inputs ${}_{0}^{3}x$. The output that release from this node only ${}_{3}^{4}y$. The final output from node 1,2 and 3 was collected at node 4, given that each subtechnology produces distinct output vectors, ${}_{j}^{4}y \in R_{+}^{Mj}, j = 1,2,3$, where $M = M^1 + M^2 + M^3$, can be written as

$$y = ({}_{1}^{4}y, {}_{2}^{4}y, {}_{3}^{4}y). \qquad (2)$$

If we don't insist that each node produce distinct outputs, total production can be written as the sum $\sum_{j=1}^{3} {}_{j}^{4}y$ of the individual node's outputs. The appropriate number of zero must be added.The piecewise linear or DEA technology associated with $k = 1, \dots, K$ observations may be written in terms of the output set as:

$$B(x) = \{y = ({}_{1}^{4}y, {}_{2}^{4}y, {}_{3}^{4}y)$$

$${}_{3}^{4}y_m \leq \sum_{k=1}^{K} z_k^3 \, {}_{3}^{4}y_{km}, m = 1, \dots, M^3,$$

$$\sum_{k=1}^{K} z_k^3 \, {}_{0}^{3}x_{kn} \leq {}_{0}^{3}x_n, n = 1, \dots, N,$$

Node 3

$$\sum_{k=1}^{K} z_k^3 \, {}_{1}^{3}y_{km} \leq {}_{1}^{3}y_m, m = 1, \dots, M^1,$$

$$\sum_{k=1}^{K} z_k^3 \, {}_{2}^{3}y_{km} \leq {}_{2}^{3}y_m, m = 1, \dots, M^2,$$

$$z_k^3 \geq 0, k = 1, \dots, K,$$

$$({}_{1}^{3}y_m + {}_{1}^{4}y_m) \leq \sum_{k=1}^{K} z_k^1 ({}_{1}^{3}y_{km} + {}_{1}^{4}y_{km}), m = 1, \dots, M^1,$$

Node 1

$$\sum_{k=1}^{K} z_k^1 \, {}_{0}^{1}x_{kn} \leq {}_{0}^{1}x_n, n = 1, \dots, N,$$

$$z_k^1 \geq 0, k = 1, \dots, K,$$

$$({}_{2}^{3}y_m + {}_{2}^{4}y_m) \leq \sum_{k=1}^{K} z_k^1 ({}_{2}^{3}y_{km} + {}_{2}^{4}y_{km}), m = 1, \dots, M^2,$$

Node 2

$$\sum_{k=1}^{K} z_k^2 \, {}_{0}^{2}x_{kn} \leq {}_{0}^{2}x_n, n = 1, \dots, N,$$

$$z_k^2 \geq 0, k = 1, \dots, K,$$

Distribution of exogenous inputs

$${}_{0}^{1}x_n + {}_{0}^{2}x_n + {}_{0}^{3}x_n \leq x_n, n = 1, \dots, N\} \qquad (3)$$

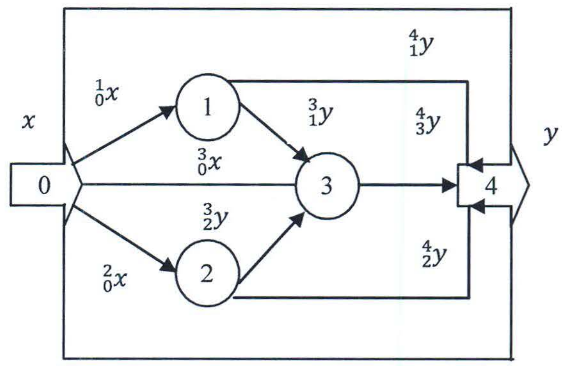

Figure 2. The Network Technology

V. Network DEA Model to Measure Production Line's Performance

As stated in previous section, the inputs and outputs data for the evaluation must be identified and relevant. Figure 3 shows the network DEA model to measuring performance of production line. At stage 1, we evaluated the productivity of each line and the appropriate inputs are No. of labor (L), automation (N_a), total working hour (T_w) and no. of unit standard time (U_{tstd}) and outputs are no. of unit produce (U_p) and no. of unit quality (U_q). Both outputs from stage 1 become input in stage 2 and outputs in stage 2 are time save (T_s), cost save (C_s) and productivity (P). At stage 2, we evaluate the production time with the involvement of automation and labor combination.

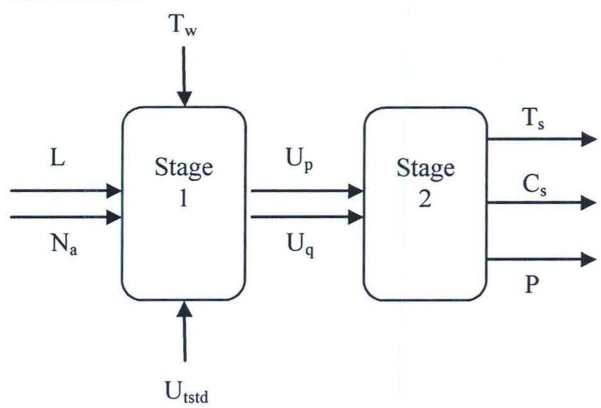

Fig. 3. Network DEA Model for Production Line Performance

The data was taken from the manufacturing company in Pahang. The model to evaluate the performance line is shown in Figure 3. The model use to evaluate performance of production line for automation and labor combination, 5 production line being selected to study the performance of production time and productivity which is assume as A, B, C, D and E. Using DEA-solver software, we do evaluation for data in two-stage.

A. *Stage 1: Evaluation of production line's productivity.*

Table 1 shows the inputs and outputs data to evaluate the productivity produce by 5 different production lines in 3 month. From table 1 we can see that the data tendency of value is mixed and different from each other. For no. of automation (N_a), the ideal situation is not using automation. Therefore we gave 100 marks for lines not using automation. Since the high number of automation usage is 4, we divided 100 by 5, which give 1 automation usage equal to 20 marks. The marks then being deduct from full mark (100 marks) depend on automation usage.

TABLE I. INPUTS AND OUTPUTS OF 5 PRODUCTION LINE IN MONTH 1, MONTH 2, MONTH 3

Month	DMU	A	B	C	D	E
1	(I)L	617	629	261	600	197
	(I)T_w	6752	6575	2396	5962	2077
	(I)T_{tstd}	197426	87784	94704	249456	54658
	(I)N_a	60	80	100	100	100
	(O)U_p	307501	103699	86326	244817	47024
	(O)Q_p	290574	103478	82676	242704	45916
2	(I)L	670	518	228	577	394
	(I)T_w	7417	5293	2028	5409	3476
	(I)T_{tstd}	216872	70668	80158	226318	91474
	(I)N_a	60	80	100	100	100
	(O)U_p	304201	78365	73500	212752	74445
	(O)Q_p	297206	78182	70810	211565	73455
3	(I)L	591	834	406	744	344
	(I)T_w	6598	8611	2702	7404	3033
	(I)T_{tstd}	192924	114967	106798	309790	79812
	(I)N_a	60	80	100	100	100
	(O)U_p	310701	128897	101500	308246	67389
	(O)Q_p	305476	128615	99067	306850	64389

Using DEA-Solver software, we calculated the data in Table 1 using window analysis where the length of window is 1 and results are shown in Table 2.

TABLE II. RESULTS EVALUATION OF PRODUCTIVITY

	1	2	3	C-Average
A	1			
		1		
			1	1
B	0.800904			
		0.807291		
			0.706525	0.771573
C	0.801804			
		0.883664		
			0.79772	0.827729
D	0.945934			
		0.976107		
			0.895148	0.939063
E	0.570766			
		0.585962		
			0.523605	0.560111

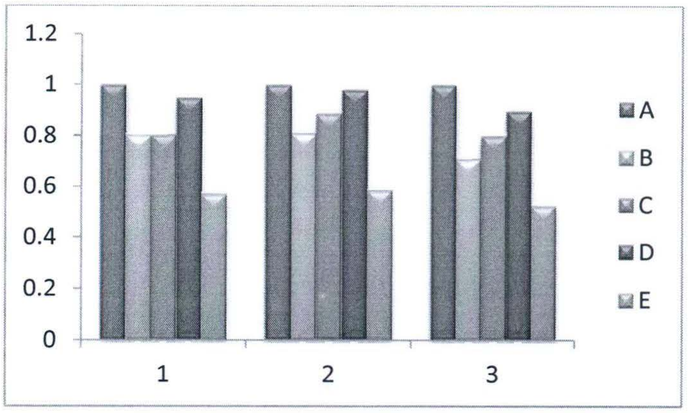

Fig. 4. Variation through window

Fig. 4 showed that performance of line A is the best-performing with no. of automation usage is higher. However, the second place is line D in producing high volume of product, where line D is non-automation usage. This happen due to rejection unit is low at this line. Line B and C are in average from all lines and line E is worst in performing. Management could utilize this information to investigate why line have automation usage has high productivity but low in quality.

B. *Stage 2: Evaluation of production line's productivity.*

Table 2 show the next data being use to evaluate production time cost to see salary pay to labor is appropriate with the productivity produce or production line waste company profit. The outputs data from stage 1 have been use as inputs data in this stage.

TABLE III. INPUTS AND OUTPUTS OF 5 PRODUCTION LINE IN MONTH 1, MONTH 2, MONTH 3

Month	DMU	A	B	C	D	E
1	(I)U_p	307501	103699	86326	244817	47024
	(I)Q_p	290574	103478	82676	242704	45916
	(O)T_s	679.23	283.54	67.39	82.92	55.38
	(O)C_s	675.14	282.12	67.62	83.06	55.67
	(O)P	155.7	118	86.6	97.8	84.2
2	(I)U_p	304201	78365	73500	212752	74445
	(I)Q_p	297206	78182	70810	211565	73455
	(O)T_s	559.54	189.11	74	94.46	0.46
	(O)C_s	556.3	188.06	74.25	94.52	1.13
	(O)P	140	111.9	92.3	99.5	86.9
3	(I)U_p	310701	128897	101500	308246	67302
	(I)Q_p	305476	128615	99067	306850	64389
	(O)T_s	719.69	260.52	79.23	94.31	26.77
	(O)C_s	715.39	259.41	79.5	94.33	27.33
	(O)P	169.8	114.9	93.6	98.9	90.7

Using the same method (DEA-Solver software), we calculated the data in Table 3 using window analysis where the length of window is 1 and results are shown in Table 4.

TABLE IV. RESULT EVALUATION OF PRODUCTION TIME COST

	4	5	6	C-Average
A	0.853088			
		0.778334		
			1	0.8771406
B	1			
		1		
			1	1
C	0.595234			
		0.910718		
			0.782384	0.7627786
D	0.237044			
		0.328591		
			0.27876	0.2814653
E	1			
		0.826561		
			1	0.9421871

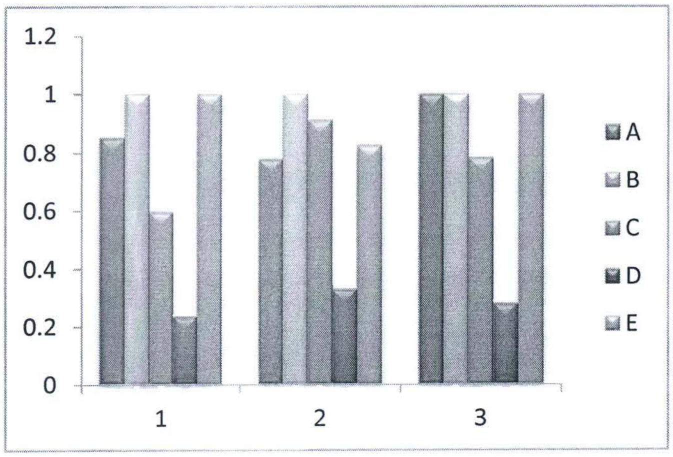

Fig. 5. Variation through window

Fig. 5 shows that the production line that line B highly brings and save company profit. Although line B at stage 1 only average in productivity and have only 1 automation, they manage to produce high volume of quality unit. Compare to line D that being rank as lowest performance in production line. Nevertheless, line A does not show high performance as in stage 1 due to low quality unit produce even the time cost of this line excellent.

VI. CONCLUSION

This paper use network DEA to evaluate the performance of production line. A model of network DEA being develop and use to evaluate data. From the calculation we can conclude that, the installation of automation give advantages in producing product. The productivity of line increase and can save production time from 35%-40%. But the result from investigation also shows the units produce low in quality. The problem producing low quality product put company at the risk for substantial losses for their investment installation the automation. From the result production department can appraise back the usage of automation and give output that standardize with customer order. This can help company decide which line need improvement and installation of automation in helping labor work in high performance.

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