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Comparing CNC Lathes Using Data Envelopment Analysis

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ABSTRACT

This paper reports on an application of Data Envelopment Analysis (DEA) to compare products which vary in excellence along a number of dimensions, and for each of which there might be a number of associated 'cost'. The DEA method is illustrated by comparing 21 CNC(Computer Numerical Control) lathes for small-size shell production. Potential uses of a DEA analysis of products might be: to assist military buyers who may need to reconcile a diversity of present and future uses in one standardized purchase; in competitors analysis; in determining unexplored market niches: and as a normative model of product excellence against which product purchasing behavior could be compared.
Keywords: Data Envelopment Analysis; Product comparison; Efficiency.

1. Introduction

This paper reports on an application of Data Envelopment of Analysis (DEA) by Charnes, Cooper, and Rhodes (1978) [1] to compare CNC lathes which vary in excellence along a number of dimensions, and for each of there might be a number of associated 'cost'.

For many years, the Combined Service Force (CSF), a military logistics agency in Taiwan, has taken three steps in purchase of manufacturing machines for its logistical factories. In Step 1, acquisition officers make a list of alternatives based on some selection criteria. In Step 2, they ask suppliers submit proposals. In Step 3, they run an open meeting for competitive biding on a minimum unit price. There are two things missing here. First, one ignores the problem of how to measure one product against another when each product can be measured along a number of dimensions, and given that there exist no a priori satisfactory weighting scheme to combine these dimensions into an overall rating for each product. Second, how wisely the CSF spends tax dollars for purchasing manufacturing equipment is not examined. In this regard, an attempt to undertake a study to investigate of these issues is initiated.

Previous research done by Doyle and Green (1991) [2] motivates us in the way of understanding the problem of performance measurement and conducting this study. He presents the application of DEA to assess the performance of 37 computer printers. He uses one input (cost) and seven outputs (throughput, print quality, reliability, disruption through noise, and delay through occupancy) in the DEA mode. 11 printers of the 37 were identified efficient.

In this article we aim to show that DEA can also be used to analyse industrial products [3], which, to the best of our knowledge, has not been demonstrated to the military. We consider each product as having *outputs* (product features) and *inputs* (costs). The *efficiency* (excellence) of a product is some weighted sum of *outputs* divided by some weighted sum of *inputs*. A wealth of additional and incisive information flows from this apparently simple analysis. Our study used one inputs (unit cost) and five outputs (spindle max speed, spindle speed range, number of tool position, range of rapid traverse X-axis, range of rapid traverse Z-axis) in the DEA model to assess CNC latches. 4 lathes out of the 21 are identified as efficient in this study. The efficiencies obtained with this input-output set will be referred to as "Cost efficienct” Only one CNC lathe was selected from these four efficient machines due to its minimum unit cost.

There is a problem in comparing products/equipment using DEA in the military context, which is the identification of feasible products meeting defined military operational requirements. The efficiency of a product does not guarantee that the product meets military requirements. Therefore, one should identify qualified products before using DEA to compare products for military purchases. The application of DEA to assessment of these lathes is presented in the following sections.

The paper is organised as follows. Section 2 begins with a data collection. The selection of decision making units (DMUs), inputs and outputs for the assessment of comparative performance of CNC lathes is described. Next,Section 3 discusses the results obtained from the DEA assessment of the comparative performance of CNC lathes. Section 4 discusses the review of inefficient units and their potential improvements. Section 5 describes DEA as a normative model. Finally, Section 6 offers concluding remarks on how DEA can be utilized for military purchases and limitation of this study.

2. Data Collection

2.1 Selection of DMUs

To illustrate the potential of DEA we surveyed 21 CNC lathes from Ecoca, Match, Takisawa, Tong Tai, Yang Iron, Yeong Chin, Victor Taichung, and Far East which are the most representative machinery corporations in Taiwan. The twenty-one CNC lathes were used as DMUs in the DEA model.

We asked senior machinery engineers in Factory 202, an ammunition production factory, to specify the kind of CNC lathe needed for a small-size shell production. The selection criteria were that the lathe should be ‘bed’ station; its diameter of cutting tool should not over 300 mm; and the price should not be over NT$3 millions which is the maximum amount of money the CSF can obtain. We then asked the eight manufacturers to send their product categories to us. Finally, 21 CNC lathes were selected according to the selection criteria.

2.2 Selection of Input

Unit price of the CNC lathe was selected as input measure by the engineers.

2.3 Selection of Outputs

Five outputs (spindle max speed, spindle speed range, number of tool position, range of rapid traverse X-axis, range of rapid traverse Z-axis) were chosen by the engineers as output measures.

Table 1 represents input and output data of the twenty-one CNC lathes. Table 2 shows correlation of input and output measures

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Two points are worthy of note here:

- The input measure has positive and low correlation with number of tool position. The input measure has negative correlation with other three outputs. This implies that a high-cost lathe might not have better performance figures.
- Some of output measures are highly correlated with certain output measures. The highest correlation coefficient is 0.98, found between spindle max speed and spindle speed range. The spindle max speed has a low and positive correlation with number of tool position. The second highest correlation coefficient is 0.92, found between range of rapid traverse X-axis and range of rapid traverse Z-axis. There was low and negative correlation among four outputs (spindle max speed, spindle speed range, number of tool position, and range of rapid traverse X-axis).

Table 1 Input /output data of the twenty-one CNC lathes

CNC Lathe (DMU)	Input	Output				
	Money(NT) (X_1)	Spindle Max. speed(rpm) (Y_1)	Spindle speed Range(rpm) (Y_2)	No. of tool Position(no.) (Y_3)	Rapid Traverse X-axis(m/min) (Y_4)	Rapid Traverse Z-axis(m/min) (Y_5)
YANG ML-15A (DMU1)	1,200,000	6,000	5,950	8	24	24
YANG ML-25A (DMU2)	1,550,000	3,500	3,465	8	20	20
YCM-TC-15 (DMU3)	1,400,000	6,000	5,950	12	15	20
Vturn 16 (DMU4)	1,100,000	6,000	5,940	12	12	15
FEMCO HL-15 (DMU5)	1,200,000	6,000	5,940	12	12	16
FEMCO WNCL-20 (DMU6)	1,500,000	3,500	3,465	12	6	12
FEMCO WNCL-30 (DMU7)	2,600,000	4,000	3,960	12	12	16
EX-106 (DMU8)	1,320,000	5,000	4,950	12	24	30
ECOCA SJ20 (DMU9)	1,180,000	4,500	4,480	8	24	24
ECOCA SJ25 (DMU10)	1,550,000	4,000	3,950	12	15	20
ECOCA SJ30 (DMU11)	1,600,000	3,500	3,450	12	15	20
TOPPER TNL-85A (DMU12)	1,200,000	3,500	3,465	8	20	24
TOPPER TNL-100A (DMU13)	1,350,000	3,000	2,970	8	20	24
TOPPER NL-100AL (DMU14)	1,400,000	3,000	2,970	12	24	30
TOPPER TNL-85T (DMU15)	1,350,000	3,500	3,465	12	30	30
TOPPER TNL-100T (DMU16)	1,450,000	3,000	2,970	12	20	24
TOPPER TNL-120T (DMU17)	1,520,000	2,500	2,475	12	20	24
ATECH MT-52S (DMU18)	1,376,000	4,800	4,752	12	20	24
ATECH MT-52L (DMU19)	1,440,000	4,800	4,752	12	20	24
ATECH MT-75S (DMU20)	1,824,000	3,800	3,790	10	12	20
ATECH MT-75L (DMU21)	1,920,000	3,800	3,790	10	12	20

Table 2 Correlation coefficients among input and outputs

	Money(NT) (X_1)	Spindle Max. speed(rpm) (Y_1)	Spindle speed Range(rpm) (Y_2)	No. of tool Position(no.) (Y_3)	Rapid Traverse X-axis(m/min) (Y_4)	Rapid Traverse Z-axis(m/min) (Y_5)
Money(NT) (X_1)	1.00	-0.32	-0.35	0.18	-0.41	-0.31
Spindle Max. speed(rpm) (Y_1)	-0.32	1.00	0.98	0.08	-0.13	-0.24
Spindle speed Range(rpm) (Y_2)	-0.35	0.98	1.00	0.00	-0.12	0.23
No. of tool Position(no.) (Y_3)	0.18	0.08	0.00	1.00	-0.24	-0.10
Rapid Traverse X-axis(m/min) (Y_4)	-0.41	-0.13	-0.12	-0.24	1.00	0.92
Rapid Traverse Z-axis(m/min) (Y_5)	-0.31	-0.24	0.23	-0.10	0.92	1.00

3. DEA Assessment

3.1 Selection of DEA Model

We select the CCR model for efficiency assessment. In running the assessment, we assume constant returns to scale hold in converting cost to performance features. This assumption is likely to be safe if a doubling of input leads a doubling outputs [4][5][6][7]. To our research interest, we would like to examine the issue of input minimisation:

Given the level of outputs used by the units produce, how much could their use of inputs have been reduced by while maintaining their current level of outputs? Therefore, we run the CCR model with input minimisation by using Frontier Analyst, a DEA software package developed by Banxia Software Ltd..

3.2 Results of DEA

By applying the CCR model to the data of Table 1, the efficiency of each CNC lathe can be calculated. As can be seen in Table 3 the DEA assessment yields 4 CNC lathes with an efficiency rating of 100%. The 'outstanding buys' are YANG ML-15A(Yang Iron), VTURN 16 (Victor Taichung), TOPPER TNL-85T (Tong Tai), and EX-106 (Takisawa). The rest of CNC lathes have efficiency scores of less than 1.0.

The efficiency ratings obtained appear in Table 3, under the second column. These ratings measure the context to which cost level at each product can improve if it were to perform efficiency relative to other lathes. For example the efficiency ratings of 42.87% of FEMCO WNCL-30 (Far East) (see Table 3) reflects the fact that its performance features are at the best only 42.87 of the level that could be achieved if the lathe had been relatively efficient.

An inspection was next made of how frequently each efficient product was used as a comparator of 'efficient peer' for inefficient products. The purpose of this inspection was to identify an exemplar of good performance according to the number of frequency efficient lathes appeared in the reference set. The results show in Table 3.

The total number of frequencies efficient lathes appeared in the reference set of other inefficient products were 14 for EX-106, 13 for VTURN 16, 8 for TOPPER TNL-85T, and 5 for YANG ML-15A. This means that these four efficient products have the most usual mixes of cost and performance and that is why they are used so often as comparators for inefficient products. These four CNC lathes were 'outstanding buys' in terms of all their input-output levels. It is plain to see that those chosen are not only efficient but also compete in a crowed part of the market.

Four points are worthy of note here:

- YANG ML-15A is the niche player. Niche players will seldom appear in the reference sets of other lathes because, almost by definition, there can be few competitors in any one niche. Lathes with broad scope will appear in many others' reference sets. If we examine how YANG ML-15A achieves 100% efficiency, we see that it does so high spindle maximum speed, spindle max range, and so low in unit cost. From Table 3, YANG ML-15A appeared only five times in other's reference sets. It is extraordinary to think that it has so few competitors in this part of the market.
- Consequently, EX-106 and VTURN 16 would have many competitors in any one niche.
- There is a significant trend for more expensive CNC lathes to be less efficient. This finding is consistent with the finding by Dole and Green (1991). The correlation between cost and efficiency is –0.89. Since, presumably, more cheap lathes are sold than expensive ones, manufacturers of cheap lathes can practice economies of scale and keep their prices low. Because of large turnover, they can survive on smaller margins, which turns up as efficiency in our analysis.
- The DEA analysis results agreed quite well with the senior engineers' judgments. They all agreed that these four CNC lathes can be considered as alternatives for further selection. This agreement validates the method.

4. Review of Inefficient Units

Some 17 out of the 21 CNC lathes were found to have an efficiency rating under 100%. From the manufacturer's point of view, review of inefficient lathes will provide information on how to improve their products in order to compete with other competitors in the market.

4.1 Contrasting Inefficient Lathes with Their Efficient Peers

A good view of the performance of each inefficient lathe can be gained when its input-output contribution are contrast with those of it efficient peer references unit, identified in Table 4. Input/output contribution can be measured on how much input/output of a DMU have been used in determining efficiency. The values are 'normalized' to show a percentage of the overall input and output contribution. Table 4 shows the input/output contributions of all CNC lathes. Thus, one may make comparisons of an inefficient unit and it reference set using tables such as Table 5.

Table 3 Efficiency scores of the twenty-one CNC lathes

CNC lathe	(DMU)	Efficiency scores(%)	Reference set	Frequency
EX-106	(8)	100		13
Vturn 16	(4)	100		13
TOPPER TNL-85T	(15)	100		8
YANG ML-15A	(1)	100		5
ECOCA SJ20	(9)	96.99	1.15	0
TOPPER NL-100AL	(14)	94.29	8	0
FEMCO HL-15	(5)	93.38	1.4.8.	0
ATECH MT-52S	(18)	89.83	4.8.15	0
TOPPER TNL-85A	(12)	88.33	8.15	0
YCM-TC-15	(3)	85.99	1.4.8	0
ATECH MT-52L	(19)	85.83	4.8.15	0
TOPPER TNL-100T	(16)	85.24	4.8.15	0
TOPPER TNL-120T	(17)	81.32	4.8.15	0
TOPPER TNL-100A	(13)	79.10	1.8.15	0
ECOCA SJ25	(10)	75.70	4.8	0
ECOCA SJ30	(11)	73.33	4.8	0
FEMCO WNCL-20	(6)	73.33	4.8	0
YANG ML-25A	(2)	62.42	1.4.15	0
ATECH MT-75S	(20)	56.29	4.8	0
ATECH MT-75L	(21)	53.47	4	0
FEMCO WNCL-30	(7)	42.87	4.8	0

Table 4 Input/output contributions of the twenty-one CNC lathes

CNC Lathe	(DMU)	Input	Output				
		Money(NT) (X_1)	Spindle Max. speed(rpm) (Y_1)	Spindle speed Range(rpm) (Y_2)	No. of tool Position(no.) (Y_3)	Rapid Traverse X-axis(m/min) (Y_4)	Rapid Traverse Z-axis(m/min) (Y_5)
YANG ML-15A	(DMU1)	100	0.00	83.61	0.00	16.39	0.00
YANG ML-25A	(DMU2)	100	20.94	9.33	33.73	45.33	0.00
YCM-TC-15	(DMU3)	100	0.00	44.33	21.47	5.81	34.20
Vturn 16	(DMU4)	100	0.00	48.43	23.50	4E-5	28.07
FEMCO HL-15	(DMU5)	100	47.70	0.00	22.88	4.28	29.42
FEMCO WNCL-20	(DMU6)	100	7.95	7.94	99.99	2.73	5.45
FEMCO WNCL-30	(DMU7)	100	0.00	0.00	78.95	9.33	21.05
EX-106	(DMU8)	100	8.33	8.32	66.67	8E-5	33.33
ECOCA SJ20	(DMU9)	100	7.33	14.78	6.87	30.08	55.14
ECOCA SJ25	(DMU10)	100	8.81	8.77	74.99	6.61	25.00
ECOCA SJ30	(DMU11)	100	7.95	7.91	74.99	6.82	25.00
TOPPER TNL-85A	(DMU12)	100	6.60	6.59	7.55	9.43	90.57
TOPPER TNL-100A	(DMU13)	100	6.32	14.04	8.43	26.87	59.09
TOPPER NL-100AL	(DMU14)	100	5.30	5.29	0.00	8.48	99.99
TOPPER TNL-85T	(DMU15)	100	5.80	5.82	69.14	30.86	0.00
TOPPER TNL-100T	(DMU16)	100	5.87	5.86	71.20	8.09	20.71
TOPPER TNL-120T	(DMU17)	100	5.12	5.11	71.20	80.9	20.71
ATECH MT-52S	(DMU18)	100	8.91	8.89	71.20	8.09	20.71
ATECH MT-52L	(DMU19)	100	9.32	9.32	71.20	8.09	20.71
ATECH MT-75S	(DMU20)	100	0.00	0.00	71.43	7.11	28.57
ATECH MT-75L	(DMU21)	100	0.00	0.00	71.43	7.48	28.57

Table 5 relates to inefficient FEMCO WNCL-30. The column headed 'FEMCO WNCL-30' show its 'observed' input/output contributions. The input/output contributions under VTURN 16 are its input/output contributions. Table 5 shows that the peer input contributions are equal to the corresponding contributions of FEMCO WNCL-30. This makes it easy to compare FEMCO WNCL-30 with its peers as we can now focus on output contributions only.

If FEMCO WNCL-30 to be deemed to have equivalent performance to that of its efficient peers, its output contributions must be at least as good as those of efficient peers. In fact, it has to low contributions to spindle max speed, spindle speed range, and range of rapid traverse X-axis, range of rapid traverse Z-axis. This implies that it may have an opportunity of making improvements. Tables such as Table 6 were used to review the performance of other inefficient lathes.

Table 5 Efficient peers for FEMCO WNCL-30 (efficiency 42.87%)

Variable		Inefficient unit	Peer reference set	
		FEMCO WNCL-30	VTURN 16	EX-106
Money	(X_1)	100.00	100.00	100.00
Spindle Max. speed	(Y_1)	0.00	0.00	8.33
Spindle speed Range	(Y_2)	0.00	48.43	8.32
No. of tool Position	(Y_3)	78.95	23.50	6.67
Rapid Traverse X-axis	(Y_4)	9.33	4E-5	8E-5
Rapid Traverse Z-axis	(Y_5)	21.05	28.07	33.33

4.2 Slack Analysis

In order to find important information indicating by how much and in what areas an inefficient unit needs to improve in order to be efficient, a non-zero slack analysis was used. Non-zero slack analysis can identify marginal contributions in efficiency ratings with an additional increase in specific output amounts or with an addition decrease in specific input amounts. Table 6 represents results of the slack analysis.

Among the input measures, the number of money recorded has the greatest number of non-zero slacks 17 while the highest number of non-zero slacks for output measures is 15. Holding the level of money constant, on average, seventeen DMUs could reduce the number of money by 395,118(NT); fifteen DMUs could increase the spindle max. speed (rpm) by 1,274; fourteen DMUs could increase the spindle speed range(rpm) by 1,321; four DMU could increase the no. of tool position(no.) by 2.25; 7 DMUs could increase the rapid traverse x-axis(m/min) by 2.571, and 1 DMUs could increase the rapid traverse z-axis(m/min) by 3. Those having zero slack of course require no such addition to achieve their value if efficient. These estimated reductions in inputs would not in themselves suffice. They would also need to be accompanied by the estimated increases in outputs if an inefficient precinct were to achieve 100% efficiency.

Table 6 Slacks for each input and output for the inefficient DMUs

CNC Lathe	DMU	*input*	*output*				
		X_1	Y_1	Y_2	Y_3	Y_4	Y_5
YANG ML-25A	(DMU2)	582,456	0	3	0	0	0
YCM-TC-15	(DMU3)	196,175	9	0	4	1	0
FEMCO HL-15	(DMU5)	79,394	0	0	0	0	0
FEMCO WNCL-20	(DMU6)	500,000	2500	2475	0	6	3
FEMCO WNCL-30	(DMU7)	1485,333	1933	1914	0	1	0
ECOCA SJ20	(DMU9)	35,507	20	0	1	0	0
ECOCA SJ25	(DMU10)	376,667	1667	1660	0	1	0
ECOCA SJ30	(DMU11)	426,667	2167	2160	0	1	0
TOPPER TNL-85A	(DMU12)	140,000	300	335	2	0	0
TOPPER TNL-100A	(DMU13)	282,146	1009	1000	2	0	0
TOPPER NL-100AL	(DMU14)	80,000	2000	1980	0	0	0
TOPPER TNL-100T	(DMU16)	214,000	2200	2178	0	0	0
TOPPER TNL-120T	(DMU17)	284,000	2700	2673	0	0	0
ATECH MT-52S	(DMU18)	140,000	400	396	0	0	0
ATECH MT-52L	(DMU19)	204,000	400	396	0	0	0
ATECH MT-75S	(DMU20)	797,333	700	665	0	4	0
ATECH MT-75L	(DMU21)	893,333	700	665	0	4	0
Number of DMUs with slacks		17	15	14	4	7	1
Mean		395,118	1247	1321.429	2.25	2.571	3

4.3 Targets for Inefficient Lathes

After conducting an efficiency study, we have found important information about how much and in what areas an inefficient unit needs to improve in order to be efficient. This information can be enable targets to be set which could help guide inefficient units to be improved performance. This information provides the manufacturers important implications on improvements of these inefficient units. The information on target level are given in Table 7. The reader is referred to Thanassoulis and Dyer (1992) for further discussion on alternative targets for efficiency.

Table 7 Targets and Potential improvements for inefficient CNC lathes

CNC Lathe	(DMU)	Target						Potentail improvement (%)					
		(X_1)	(Y_1)	(Y_2)	(Y_3)	(Y_4)	(Y_5)	(X_1)	(Y_1)	(Y_2)	(Y_3)	(Y_4)	(Y_5)
YANG ML-25A	(DMU2)	967,544	3,500	3,468	8	20	20	-37.58	0.00	0.08	0.00	0.00	0.92
YCM-TC-15	(DMU3)	1,203,825	6,009	5,950	12	16	20	-14.01	0.15	0.00	0.00	10.4	0.00
FEMCO HL-15	(DMU5)	1.120,606	6,000	5,940	12	12	16	-6.62	0.00	0.00	0.00	7.58	0.00
FEMCO WNCL-20	(DMU6)	1,000,000	6,000	5,940	12	12	15	-26.67	71.43	71.43	0.00	100.00	25.00
FEMCO WNCL-30	(DMU7)	1,114,667	5,933	5,874	12	13	16	-57.13	48.33	48.33	0.00	6.67	0.00
ECOCA SJ20	(DMU9)	1,144,493	4,520	4,480	9	24	24	-3.01	0.44	0.00	9.25	0.00	0.00
ECOCA SJ25	(DMU10)	1,173,333	5,667	5,610	12	16	20	-24.30	41.67	42.03	0.00	6.67	0.00
ECOCA SJ30	(DMU11)	1,173,333	5,667	5,610	12	16	20	-26.67	61.90	62.61	0.00	6.67	0.00
TOPPER TNL-85A	(DMU12)	1,060,000	3,800	3,762,	10	20	24	-11.67	8.57	8.57	20.00	0.00	0.00
TOPPER TNL-100A	(DMU13)	1,067,854	4,009	3,970	10	20	24	-20.9	33.65	0.00	18.69	0.00	0.00
TOPPER NL-100AL	(DMU14)	1,320,000	5,000	4,950	12	24	30	-5.71	66.67	66.67	0.00	0.00	0.00
TOPPER TNL-100T	(DMU16)	1,236,000	5,200	5,148	12	20	24	-14.76	73.33	73.33	0.00	0.00	0.00
TOPPER TNL-120T	(DMU17)	1,236,000	5,200	5,148	12	20	24	-18.68	108.00	108.00	0.00	0.00	0.00
ATECH MT-52S	(DMU18)	1,236,000	5,200	5,148	12	20	24	-10.17	8.33	8.33	0.00	0.00	0.00
ATECH MT-52L	(DMU19)	1,236,000	5,200	5,148	12	20	24	-14.17	8.33	8.33	0.00	0.00	0.00
ATECH MT-75S	(DMU20)	1,026,667	4,500	4,455	10	16	20	-43.71	18.42	17.55	0.00	33.33	0.00
ATECH MT-75L	(DMU21)	1,026,667	4,500	4,455	10	16	20	-46.53	18.42	17.55	0.00	33.33	0.00

The TARGET column shows the amount of inputs and outputs that an inefficient lathes should be using or producing in order to be efficient while POTENTIAL IMPROVEMENT column shows how much, in percentage terms, an inefficient product' use of inputs or production of output needs to change by in order for it to be efficient. For example, FEMCO WNCL-30 should increase its spindle max speed from 4,000 to 5,933 (rpm), increase spindle range from 3,960 to 5,874 (rpm), increase its number of tool position from 12 to 28; increase its rapid traverse X-axis from 12 to 30; and increase its rapid traverse Z-axis from 16 to 37. But, these improvements may pose some difficulties. First, it may be impossible for the manufacturers to improve features of these 'bad' products due to limited manufacturing capacity and technical complexity. Second, even it is possible, it may increase of the inefficient lathe.

4.4 Implications for Military Purchases

The review of inefficient units may provide military buyers and manufacturers some important implications as follows.

- It provides the military buyers useful information on how to make a good bargain with the manufacturers who provide the 'bad performance' products. They may ask a reasonable price for each of these 'bad performance' products, i.e. NT$1,144,493 for ECOCA SJ120, NT$1,320,000 for TOPPER TNL-100AL, NT$ 1,120,606 for FEMCO HL-15, NT$ 1,236,000 for ATECH MT-52S, ATECH MT-52L, TOPPER TNL-100T, and TOPPER TNL-120T, NT$ 1,060, 000 for TOPPER TNL-85A, NT$ 1,203,825 for YCM-TC-15, NT$ 1,067,854 for TOPPER TNL-100A, NT$ 1,173,333 for ECOCA SJ25 and ECOCA SJ30, NT$ 1,100,000 for FEMCO WNCL-20, NT$ 967454 for YANG ML-25A, NT$ 1,026,667 for ATECH MT-75S and ATECH MT-75L, NT$ 1,114,667 for FEMCO WNCL-30. However, the reduction of the unit cost of a CNC lathe is up to the manufacturers.
- It provides the manufacturers important information on how much and in which areas an 'bad performance' product need to improve in order to compete with other competitors in the market. For example, ECOCA SJ120 needs to increase its spindle max speed from 4,500 to 4,520 (rpm) and number of tool position from 8 to 9. TOPPER TNL-100A needs to increase its spindle max speed from 3,000 to 5,000 (rpm) and spindle speed range from 2,970 to 4,950 (rpm). However, any improvement on product performances can lead to increase of unit cost of a product. This may cause a product less inefficient.

5. DEA As A Normative Model

We have applied DEA to product comparisons from something like the perspective of an idealized military buyer who may need to reconcile a diversity of present and future use of a product in a few standardised purchases. We have also touched on the possibility that DEA, in illuminating the structure of the CNC lathe market, could yield useful insights into military purchases and into the competition in the market. Fortunately, historical evidence is optimistic about adoption of even well known mathematical techniques such as decision analysis (Bude and Bresnick, 1992); so we should expect more than a minority of actual military buyers to become our idealised military buyer in using DEA, etc. From this very fact, those manufacturers who are willing to take the trouble to use DEA where appropriate may gain a significant edge over their competitors.

It would be desirable that, when confronted by a range of products differing in many dimensions, military buyers can behave as if they had in their heads an intuitive model of DEA to guide their choices. Furthermore, we can use DEA as a framework for looking at the different ways that decision makers differ from optimal performance, as seen by DEA.

Through this empirical study, DEA also can be seen as an *objective* and *scientific* method for the problem of comparing defence systems/equipment in the military acquisition process. With recourse to computerised DEA analysis containing a priori satisfactory weighting scheme, decision makers who must trust their judgment in the field can justify their decision.

6. Conclusions

We have presented a DEA technique for comparing units across a number of different measures (e.g. technical specifications). To illustrate the value of the technique we have compared 21 CNC lathes which were selected by the senior engineers. Four out of twenty-one lathes were identified as 'good buys' for Factory 202. The results of DEA agreed quite well with their judgments. We recommended the factory consider the four lathes in the final selection process. The selected CNC lathe was YANG ML-15A due to the lowest bid on unit cost.

The DEA analyses, reported in this paper, can be used by the CSF in the acquisition process to select the-best-value-for-money equipment in conjunction with other selection criteria (e.g. military requirements). DEA can give support and insight into the selection of "good buys" (e.g. assessing CNC lathes in terms of performance features). We hope that this DEA model will be enhanced by others and that merits of a more quantitative approach to comparing products will come to be appreciated by military or corporate buyers and used by them.

The limitation of this study is that other inputs or outputs were not included in this study due to data unavailable. For example, the level of maintaining difficulty. However, this not a limitation to DEA. For future study, one may impose restrictions on the output weights in efficiency ratings. DEA applications where weights restrictions have been used are those by Thompson et al. (1990) and Thanasoulis et al. (1995). A review of weights restrictions in DEA can be found in Allen et al. (1995).

Finally, the last but not least, the DEA analysis can provide the manufacturers some important information on potential improvement for their products. The manufactures may use it to increase their core competencies in the competitive market. The CSF may use it to make a good bargain with the manufacturers.

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