Full Length Research Paper

Applying DEA and Taguchi methods in plant selection and optimal layout to increase commerce management environment quality

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Studies have reported that workers of today's businesses spend 80 - 90% of the time everyday in confined working environment. In such environment the air pollution may be 10 times worse than that outdoors, with various organic compounds polluting the air, leading to increasingly compromised health in workers and work efficiency, which decrease the commerce management efficiency and marketplace competitiveness. Many studies testified that plants disposed in commerce management environment are effective in cleansing the air and help release pressure off business workers. Hence, the present research applies Data Envelopment Analysis, DEA, to the selection of indoor plants that can decrease air pollution, mitigate anxiety and increase work efficiency, also identifies the combination of plant dispositions with optimal parameter design by Taguchi method. Whereby, this paper proposes concrete recommendations as reference for enterprises to create a comfortable, elegant, refreshing and healthy commerce management environment, while building a measuring model to further enhance the management efficiency and marketplace competitiveness for enterprises.

Key words: Commerce management environment, data envelopment analysis, super-efficiency, Taguchi method, plant selection.

INTRODUCTION

The increasingly fierce competition in today's marketplace often puts people under tense pressure. Davison and Neale (1990) even thought that few people experience not any anxiety for a whole week. High degree of anxiety affects not only normal reaction and concentration but also ability of conception and learning (Williams and Powers, 1991) . Besides the interior of enterprises, most employees of business also go to places like restaurants, hotels and café often to undertake their commercial activities. All these environments for commercial activities are what this paper refers to as commerce management environment. They have to offer beautiful, comfortable and elegant setup as well as fresh and healthy air, because only creating quality

creating quality commerce management environment can reduce negative moods, such as fear, anxiety, melancholy and sadness, in employees of businesses (Atienza et al., 2001) and enable them to be happier, comfortable and assured to work, further to elevate the marketplace competitiveness for businesses.

According to Abbriti and Muzi (1995), modern business employees spend 80-90% of the time working in confined surroundings every day. There, the air pollution can be 10 times worse than that outdoors. Today's building materials, in particular, are mostly made from synthesizing bonds and resins, while electronic equipment in office releases hundreds of kinds of volatile organic compounds (VOCs). These cause people to become less and less healthy, and gave rise to the term "Sick Building Syndrome", SBS, which includes, e.g., typically sore eyes, sore throat and respiratory problem.

SBS is mostly associated with air pollution created by the buildings in the working environment (Molhave et al.,

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1986). Dijkstra et al. (2008) verified that plants not only effectively mitigate the negative moods in and pressure on people, they also filter the air and decrease VOCs, which has the benefits such as reducing days of sick leave and increasing working efficiency (Bringslimark et al., 2007). A comfortable, elegant, refreshing and healthy commercial management environment does more than emotional and mental relief to business employees; when they are in such environment, they even improve their appetite, mind (Talbott et al., 1976) and discomfort in body (Ulrich, 1984). Honeyman (1990) further revealed that plants in offices not only elevate the positive mood in people and effectively mitigate the pressure, they also increase working efficiency or productivity, whereas, without them, the negative mood is higher and work efficiency is lower.

As earlier stated, many studies have proven that plants disposed in commercial management environment can effectively cleanse the air and help release pressure on business workers. Hence, this paper applies Data Envelopment Analysis, DEA, to select indoor plants that can lessen air pollution, mitigate anxiety and increase working efficiency. Taguchi method is also employed to identify the combination of plant dispositions with optimal parameter design, whereby to present specific recommendations as reference for businesses in creating a comfortable, elegant, refreshing and healthy commercial management environment. The present research also builds a measurement model to further enhance the management efficiency and marketplace competitiveness for businesses.

APPLYING ANALYSIS WITH DEA-CCR INPUT-ORIENTED MODEL IN SELECTION OF GOOD PLANTS

DEA is a performance assessing method proposed by Charnes et al. (1978). The DEA theory is based on production frontier as measurement of production efficiency by Farrell (1957), and uses the concept of Pareto optimality as basis to define efficiency. The production frontier being determined by mathematical model, DEA needs not preset model for production functions or parameters for model to compare the actual data of decision making units, DMU, with the production frontier. By such measurement, it can determine the relative efficiency and relative inefficiency of the DMUs, to achieve the goal of proposing improvement of relative efficiency.

This paper investigates the efficiencies at the angle of input, that is, to compare the use of inputted resources based on the current levels of outputs, which is called as input-oriented efficiency. Constant Return to Scale, CRS, is hypothesized, which means when the amount of input (x) increase at a constant ratio, the output (y) increases at a constant ratio too. The analysis of DEA-CCR (Charnes, Cooper and Rhodes, CCR) input-oriented model is thus applied to investigate, with the equation

with term of input and output as follows:

CCR input-oriented model (ratio): Efficiency = Weighted combination of inputs / Weighted combination of outputs

$$E_k = Max \frac{\sum_{r=1}^{s} u_r Y_{rk}}{\sum_{i=1}^{m} v_i X_{ik}} \qquad (1)$$

$$S.T. \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \leq 1, j = 1,........, n$$

$$u_r, v_i \geq \varepsilon > 0, r = 1,........, s, i = 1,......., m$$

Where, E_k = relative efficiency value of the kth plant (the kth DMU), Y_{rk} = the rth output value of the kth plant, X_{ik} = the ith input value of the kth plant, u_r = the rth weighted output value of the kth plant, v_i = the ith weighted input value of the kth plant

ε = a minimum positive number, which is a non-Archinidean quantity

It is clear from the above that DEA method determines the ratio of output and input, Y_{rk}, X_{ik}, Y_{rj}, X_{ij} being given quantity, and the model searches for the optimal weighted values (namely, v_i, u_r) in the set of solutions formed by all DMUs such that the efficiency value E_k for each unit is greatest. In which process, the input and output of each DMU are taken as target function and calculated N times, each calculation determining the optimal weighted value for DMU and resulted in N sets of (v_i, u_r).

Because such model of ratio is a fractional programming model (FP), which is nonlinear programming, and provides no ease in solving, it is transformed into a linear programming model. Also, a restrain of

$\sum_{n=1}^{m} v_i X_{ik} = 1$ is incorporated to avoid infinite solutions

with the FP model. The Input-Oriented CCR Model is as follows:

$$Max \ h_k = \sum_{r=1}^{s} u_r Y_{rk}$$

$$S.T. \sum_{i=1}^{m} v_i X_{ik} = 1$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0$$

$$j = 1,........,n \ u_r, v_i \geq \varepsilon > 0, r = 1,........, s, i = 1,......., m$$

Model (2) is the weighted sum produced by maximizing

Table 1. 2 Examples of 2 inputs and 1 output.

	DMU	A	B	C	D	E	F
Input	$x1$	7	4	8	4	2	10
	$x2$	3	3	1	2	4	1
Output	y	1	1	1	1	1	1

the combinations of weighted output values that are determined by setting the weighted combination of inputs equal to 1 after subjecting the restraint that the weighted sum of inputs is 1. As the number of restrains is greater than that of variables in model (2), it is possible to further utilize the dual theory of linear programming and transform equation (2) into Duality model, by which after the transformation of minimization model can be expressed as the only Envelopment Form. This Duality model is as follows:

$$Min\, \theta \qquad\qquad (3)$$
$$_{\theta,\lambda}$$

$$S.T. \quad \sum_{k=1}^{K} \lambda_k Y_{rk} \geq Y_{rk}$$

$$\theta\, X_{ik} \geq \sum_{k=1}^{K} \lambda_k X_{ik}$$

$$\lambda_r \geq 0$$

$$k = 1,2,……..,K$$
$$r = 1,2,……..,R$$
$$i = 1, 2, …, I$$

where, θ represents relative efficiency of DMU and λ_k, non-negative pure quantity.

Take an example from Cooper et al., 2 Inputs and 1 Output, Table 1 shows 6 DMUs with 2 inputs and 1 output where the output value is unitized to 1 for each DMU (as Table 1 shows). The linear program for DMU *A* is:

$$Max\, = u$$

$$S.T. \quad 7v_1 + 3v_2 = 1$$

$$u\, 7v_1 + 3v_2 \quad (A) \quad u\, 4v_1 + 3v_2 \quad (B)$$
$$u\, 8v_1 + 1v_2 \quad (C) \quad u\, 4v_1 + 2v_2 \quad (D)$$
$$u\, 2v_1 + 4v_2 \quad (E) \quad u\, 10v_1 + v_2 \quad (F)$$

where all variables are constrained to be nonnegative.

This problem can be solved by a linear programming code. It can also be solved by simply deleting v_2 from the inequalities by inserting $v_2 = (1-7v_1)/3$ and observing the relationship between v_1 and *u*. The optimal solution is

$(v_1^* = 0.0526,\ v_2^* = 0.2105,\ u^* = 0.6316,\ \theta^* = 0.6316)$, and the CCR-efficiency of *A* is 0.6316.

Interpreting DMU's relative efficiency, if $\dfrac{\theta}{\theta} < 1$, it is CCR inefficient, meaning technically inefficient; when $= 1$, it means perfectly technical efficiency. When analysis by DEA-CCR input-oriented model is used in investigation, there may be such final result as a multiple of relatively effective DMUs, which, however, cannot be further evaluated and compared. To mend this deficiency, Andersen and Petersen (1993) proposed using the CRS Super-efficiency Model in ranking the efficient DMUs. Also, the super-efficiency DEA models can be used in identifying the extreme efficient DMUs (Thrall, 1996). The Input-oriented CRS super-efficiency DEA model as follows:

$$Min\, \theta^{super} \qquad\qquad (4)$$

$$S.T. \sum_{\substack{i=1 \\ j\neq0}}^{n} \lambda_j x_{ij} \leq \theta^{super} x_{i0} \qquad i=1,2,…,n;$$

$$\sum_{\substack{i=1 \\ j\neq0}}^{n} \lambda_j y_{rj} \geq y_{ro} \qquad r=1,2,…,s;$$

$$\lambda_j \geq 0 \quad j\, 0.$$

The super-efficiency method is capable to solving the problem of ranking the DMUs on efficiency frontier; however, it does not apply to all models, while it could come up with incorrect judgment on certain data evaluations. It does not apply to the input-oriented SE-CCR model when the values of input and output of DMU are zero or a set of efficient DMUs contains extreme DMU (Seiford and Zhu, 1999). Because neither values of input or output is zero in this paper, and that the DMU set does not contain any extreme DMU, this paper will employ the Super efficiency method, proposed by Andersen and Peterson (1993), as an auxiliary tool of research to enhance the discriminating ability of DEA model.

EMPIRICAL ANALYSES

Wolverton (1997) at NASA chose 50 species of indoor plants that can effectively improve on air pollution. Of which species, nine are rare commercially in Taiwan; thus, citing Wolverton (1997), this

Table 2. Source data of NASA assessed plants.

DMU	Input				Output
Scientific name	X_1	X_2	X_3	X_4	Y
Dracaena fragrans 'Massangeana'	8	7	8	7	7.5
Dracaena marginata	6	7	8	7	7.0
Sansevieria trifasciata	3	10	10	2	6.3
Chrysalidocarpus lutescens	8	8	8	10	8.5
Rhapis excelsa	7	9	10	8	8.5
Chamaedorea seifrizii	9	8	8	9	8.4
Phoenix roebelenii	9	7	8	7	7.8
Chamaedorea elegans	4	8	8	7	6.6
Spathiphyllum spp.	8	7	7	8	7.5
Epipremnum aureum	5	10	8	7	7.5
Syngonium podophyllum	4	9	8	7	7.0
Dieffenbachia'Exotica Compacta'	7	8	6	7	6.8
Dieffenbachia'Camilla	5	7	6	7	6.2
Philodendron selloum	3	8	8	6	6.3
Philodendron oxycardium	4	9	9	4	6.3
Aglaonema 'Silver Queen'	4	6	5	6	5.3
Anthurium andraeanum	3	5	6	7	5.3
Ficus robusta	9	9	8	7	8.0
Ficus benjamina	8	6	6	6	6.5
Hedera helix	9	8	8	7	7.8
Schefflera actinophylla	8	8	4	7	6.5
Nephrolepis exaltata 'Bostoniensis'	9	4	8	9	7.5
Nephrolepis obliterata	9	4	8	9	7.4
Chrysanthemum morifolium	9	4	8	8	7.4
Gerbera jamesonii	9	4	8	8	7.3
Maranta leuconeura ÁKerchoviana'	3	6	8	7	6.0
Calathea makoyana	5	4	6	6	5.0
Liriope spicata	7	4	6	5	5.5
Chlorophytum comosum 'Vittatum'	6	6	5	5	5.4
Dendrobium sp.	7	4	6	5	5.5
Phalaenopsis sp.	3	5	7	3	4.5
Codiaeum variegatum pictum	3	6	8	5	5.3
Euphorbia pulcherrima	3	5	7	5	5.1
Aloe barbandensis	2	8	8	2	5.0
Tulipa gesneriana	7	4	5	3	4.7
Begonia hiemalis	4	6	8	7	6.3
Araucaria heterophylla	2	7	9	6	6.2
Schlumbergera bridgesii	3	9	8	3	5.8
Rhododendron simsii "Compacta"	6	4	5	5	5.1
Cyclamen persicum	3	5	6	5	4.8
Kalanchoe blossfeldiana	2	7	7	2	4.5

paper used the remaining 41 species that are common in Taiwan for examples, as shown in Table 2. Their indices of cleansing gaseous chemicals (X_1), assessed ease of planting (X_2), resistance to pests (X_3) and evaporation rate of water (X_4) were cited, with the total score represented by Y (as shown in Table 2). DEA, being advantageous of assess-ment of relative performance ranking for multiple inputs and outputs, was used to identify the plant species with relatively high efficiency in improving indoor air as the target of this paper.

And Input-oriented CCR Model was employed in calculation, which resulted in 17 of 41 species, whose efficiency value was 1, meaning they are perfectly technical efficient in cleansing indoor air. They are *Sansevieria trifasciata*, *Chrysalidocarpus lutescens*, *Epipremnum aureum*, *Syngonium podophyllum*, *Philodendron selloum*, *Aglaonema 'Silver Queen'*, *Anthurium andraeanum*, *Ficus benjamina*, *Schefflera actinophylla*, *Nephrolepis exaltata*

Table 3. Table of control factors and levels in Taguchi design of experiments.

	Factor	Level 1	Level 2	Level 3	Level 4
A	Species of plant	*Schefflera actinophylla*	*Araucaria heterophylla*	*Sansevieria trifasciata*	*Tulipa gesneriana*
B	Disposition time in environment	1 week	2 weeks	3 weeks	4 weeks

Table 4. Experimental results of L_{16} (4^5) orthogonal array.

Experiment number	Parameters and levels		Result	
	A	B	Mean satisfaction	S/N
1	1	1	3.719	11.4085
2	1	2	3.734	11.4435
3	1	3	3.753	11.4876
4	1	4	3.766	11.5176
5	2	1	3.663	11.2767
6	2	2	3.687	11.3335
7	2	3	3.717	11.4039
8	2	4	3.728	11.4295
9	3	1	3.814	11.6276
10	3	2	3.825	11.6526
11	3	3	3.808	11.6139
12	3	4	3.826	11.6549
13	4	1	3.701	11.3664
14	4	2	3.674	11.3028
15	4	3	2.810	8.9741
16	4	4	2.592	8.2727

'Bostoniensis', *Chrysanthemum morifolium, Phalaenopsis sp., Aloe barbandensis, Tulipa gesneriana, Araucaria heterophylla, Schlumbergera bridgesii* and *Rhododendron simsii "Compacta"*. As with the remaining 24 species, their less-than- 1efficiency values meant they are technically inefficient in cleansing indoor air.

The Super-SBM model was now employed to further sort out the top four plants in terms of relative efficiency. They were *S. actinophylla, A. heterophylla, S. trifasciata* and *T. gesneriana*. Perfectly technical efficient in clean-sing indoor air, these four species of plant were to be taken as the subject of this paper.

TAGUCHI'S DESIGN OF EXPERIMENTS

With the analytic results further organized by using the cause-effect diagram, this paper found that the four plants would be more perfectly efficient in the effect of cleansing indoor air and mitigating pressure in commercial management environment, if they were subjected to timing of disposition in the environment. According to Ross (1988) and Taguchi (1990), Taguchi's design of experiments is to determine the parameters of design by experiments, which chooses an appropriate orthogonal array for experiment by the numbers of control factors and their levels; S/N ratios are also used to substitute for function of quality loss to decrease the

interaction. This method is capable of providing robustness for product designing and quality in least time, at minimal cost and with least experiments. This paper thus will employ Taguchi design of experiments in analysis in order to obtain optimal design parameters.

Accordingly, this paper chose the control factors and their levels (Table 3) for the effects on the cleansing of indoor air in commercial management environment, and identified the best design of parameters by the method of Taguchi design of experiments. There were two factors in 4 levels in this experiment. Thus, we adopted the $L_{16}(4^5)$ Orthogonal array, which was among the orthogonal arrays Dr. Taguchi highly recommended (Table 4). The table also includes the mean satisfactions as the results of a survey by questionnaire conducted on students at National Chin-Yi University of Technology for this paper. According to Taguchi (1987) and Taguchi (1991), S/N ratio stands for the ratio of signal to noise. A high S/N ratio means the signal is more intense than the noise; in this case, it is easier to discern which is received: signal or noise. S/N ratios are derived by converting directly from the logarithm of function of loss, as a criterion for measurement of product performance. They have the purpose of reducing interaction, so as to enhance product robustness, and are expressed by the following equation:

Table 5. Reaction of design factors to S/N ratio.

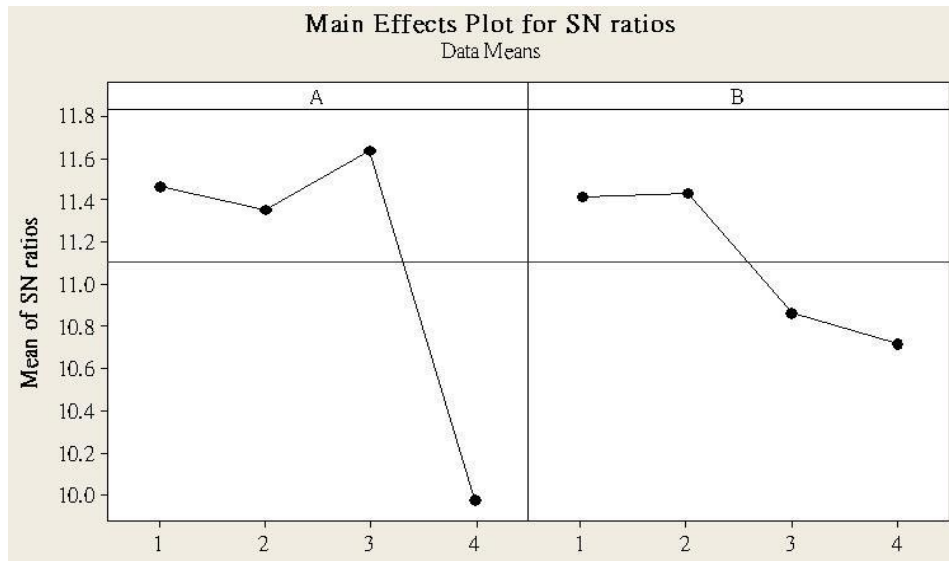|	A	B
Level 1	11.464	11.420
Level 2	11.361	11.433
Level 3	11.637	10.870
Level 4	9.979	10.719
Effect	1.658	0.714
Rank	1	2

Figure 1. Main effect plot for S/N ratio.

$$SN = -10\log\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$$

(5)

This paper proceeded to deriving the ratio for the results of each experiment as contained in Table 4, by equation (5). A higher S/N ratio means greater effect on the cleansing of indoor air in commercial management environment, also, better quality of pressure mitigation. The S/N ratios listed in Table 4 were also used to obtain the mean S/N of each of the two factors at various levels, as Table 5 shows.

With the factors in Table 5, a greater value of effect means more intense reaction of the design factor to S/N ratio. Lastly, with these figures plotted on Figure 1, it is possible to arrive at the combination of design factors A3 and B2 as the optimal parameter design in commercial management environment. In other words, the plant species of *S. trifasciata* and disposition in the environment for 2 weeks would elevate the quality of the commercial management environment to the best level.

Conclusion

This paper began by using the Data envelopment analysis to select the indoor plants that cleanse the commercial management environment best; they were *S. actinophylla*, *A. heterophylla*, *S. trifasciata* and *T. gesneriana*. With disposition time in environment, Taguchi method was used to identify *S. trifasciata* and disposition for 2 weeks as the factors being able to best improve the quality of the environment. The present research has built a model for measuring plants that would be able to cleanse indoor air, mitigate pressure and increase working efficiency. As a result, not only can work efficiency of commercial management and marketplace competitiveness be enhanced, it is also believed to better business performance will be made again and again amid the fierce competing commercial environment.

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