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室內健康環境評估模式之分析與建立

Analysis and Construction of Indoor Healthy Environments Assessment Model

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本論文係陳錫欽君（D97628003）在國立臺灣大學園藝暨景觀學系完成之博士學位論文，於民國 102 年 9 月 24 日承下列考試委員審查通過及口試及格，特此證明

口試委員：

（指導教授）（簽名）

中文摘要

隨著生活型態轉變，每人每天平均約有 80%或更多的時間處於室內環境之中。室內環境產生的空氣污染，可能會引起不同層面的危害問題，例如，降低生產力、損失工時及增加成本，更直接的影響就是工作品質、效率和身體的健康。許多研究指出，植栽可以濾淨空氣、紓解壓力和提高工作效率，精油能讓人心情愉悅與移除負面的想法，而音樂具有令人心靈寧靜、放鬆肌肉和紓壓的效果，顯然植栽、精油和音樂三者都與健康紓壓具有正相關的關係。因此，本研究為了改善室內空氣品質，創造清新、紓壓的環境，並建立評估模式，首先，在第一章中，回顧了室內環境品質良窳的重要性，並指出植栽、精油和音樂三者交互作用，可以改善室內健康環境品質，降低「病態建築症候群」。第二章中，回顧了 DEA、6σ之 DMAIC 流程、ANP 及 TM 等四種主要的研究方法，並說明將該方法分別應用於本研究。第三章，以學校教室為例，應用 DEA 與 TM 選取植栽和最佳配置，以提升室內健康環境之品質。第四章，以安養照護機構的閱覽室為例，導入 6σ之 DMAIC 流程，選取植栽、精油及音樂的最佳組合，以提升室內環境之健康紓壓品質。第五章，以幼稚園的會議室為例，採用 ANP 篩選植栽、精油及音樂，透過 TM，評估室內健康環境品質，並以統計檢定驗證試驗結果。最後，在第六章中，說明本研究證實，植栽、精油及音樂的最佳組合，確實可以有效淨化室內空氣、紓緩壓力和提升環境品質，且效果非常的顯著，並強調一套室內健康環境的評估模式，已應然而生。相信透過本研究所提供的評估模式，可以有效改善室內的空氣品質，創造舒適、清新與健康的環境，亦可以提供醫療照護、養老院及辦公場所等機構，作為改善環境的參考。

Abstract

Currently, most people spend 80% to 90% of their time working in an airtight indoor environment. Indoor air pollution may cause different levels of hazard problem, e.g., would cause uncomfortable symptoms or relevant diseases, and therefore result in productivity reducing, time losing and cost increasing, which can degrade work quality, work efficiency, and long-term health. Many researchers have demonstrated that plants can be used to purify the air and relive stress, essential oils can promote positive emotions and eliminate negative thoughts, and music can relieve stress by calming nerves and relaxing muscles. All of these are positively related to the release of stress and the promotion of health. To improve IAQ, create a refreshing, stress-relieving environment and build an assessment model, this study first reviewed the importance of IAQ, highlighting the function of plants, essential oils and music in improving IAQ and reducing SBS. The second chapter reviews four key research methods, being DEA, DMAIC of 6 σ , ANP and TM, and explains how each of these methods are respectively applied to this research. In the third chapter, using a school classroom as an example, we employed DEA and TM to select plants and determine their optimum configuration, in order to enhance the quality of the indoor environment. In the fourth chapter, using the reading room of an aged care facility as an example, we applied the DMAIC procedure of 6 σ to select the optimum combination of plants, essential oils and music, in order to maximize the health-promoting and stress-relieving features of the indoor environment. In the fifth chapter, using the conference room of a kindergarten as an example, we employed ANP to select plants, essential oils and music, and used TM to evaluate the health-related quality of the indoor environment. This study also used statistical testing to verify the experimental results. Lastly, the sixth chapter discusses how our findings demonstrate that the optimal combination of plants, essential oils and music can effectively purify indoor air, relieve stress and enhance environmental quality. We also emphasize the importance of developing a model to evaluate the quality of an indoor environment in promoting health and relieving stress. We believe that the proposed system provides an effective means to enhance air quality in the promotion of a comfortable, clean, and healthy environment. Our findings provide a valuable reference for the implementation of environment improvements in medical facilities, retirement homes, and office spaces.

關鍵字：健康環境、植栽、精油、音樂、資料包絡分析法、網路層級分析法、六標準差、田口方法

Keywords：healthy environments, plants, essential oils, music, DEA, ANP, 6σ, TM

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縮寫字與符號說明

AHP：層級分析法，是 Analytic Hierarchy Process 的縮寫。

ANP：網路層級分析法，是 Analytical Network Process 的縮寫。

BCC 模式：是 Banker、Charnes 與 Cooper 於 1984 年提出的評估模式之簡稱。

CCR 模式：是 Charnes、Cooper 與 Rhodes 於 1978 年提出的評估模式之簡稱。

CI：信賴區間，是 Confidence Interval 的縮寫。

C.I.：一致性指標，是 Consistency Index 的縮寫。

C.R.：一致性比例，是 Consistency Ratio 的縮寫。

DEA：資料包絡分析法，是 Data Envelopment Analysis 的縮寫。

DMAC：指流程管理，是 Define、Measure、Analyze、Control 的縮寫。

DMADV：指流程設計，是 Define、Measure、Analyze、Design、Verification 的縮寫。

DMAIC：指流程改善，是 Define、Measure、Analyze、Improve、Control 的縮寫。

I_{E_i}: 重視度績效指標。

I_{S_i}: 滿意度績效指標。

k: 品質損失係數。

$\mathrm{L_a(b^c)}$：制式直交表的表示符號。

$L(y)$: 表示產品的品質特性。

P：衡量指標。

R.I.：隨機指標，是 Random Index 的縮寫。

S/N 比：是信號與雜訊(signal to noise)比值之簡稱。

σ：指 sigma，代表母體的標準差。

TM：田口方法，是 Taguchi Method 的縮寫。

第一章　緒論

第一節　研究背景與動機

現代社會中，每人每天平均約有 80％－90％的時間生活在室內環境裡(Abbriti and Muzi, 1995)。室內空氣具有二氧化碳、揮發性有機物(Volatile Organic Compounds, VOCs)、粉塵及生物性污染物等濃度過高的問題(李, 2004)。尤其現在的建築材料大多是由各種黏膠及樹脂黏結合成，辦公室的電子設備也會釋放數百種的 VOCs 污染室內空氣，影響人們的情緒，導致身體越來越不健康，產生所謂的「病態建築症候群」(Sick Building Syndrome, SBS)。此症候群的典型症狀如：眼睛和呼吸道刺激、喉嚨灼熱、皮膚乾燥過敏、嗜睡、噁心與頭痛等(USEPA, 1991)。

病態建築症候群所造成的室內空氣污染(Molhave *et al*., 1986)，可能會引起不同層面的危害問題。其中，就經濟面而言，空氣品質不佳所引起的不適症狀或相關疾病，會降低生產力、損失工時及增加成本。最直接的影響就是工作品質、效率降低，和身體的健康受損。因此，如何改善室內空氣，創造清新環境以提升工作效率、促進身體健康等議題，引起各界廣泛討論。

根據葉(2010)的研究，室內擺設植物可以減低SBS。Bringslimark 等(2009)指出，室內植栽具有視覺美感，可引起注意力，進而產生心理恢復的效益。Dijkstra 等(2008)亦指出，植栽不僅可以有效紓緩人們的負面情緒與壓力，同時可以濾淨空氣並降低 VOCs，減少病假日數，提升工作效率(Bringslimark *et al*., 2007)。尤其當人們置身於舒適、幽雅、清新與健康的環境，情緒、緊張與焦慮狀況都可以獲得有效的紓解(Chang and Chen, 2005)，甚至能夠改善人們的食慾、精神狀態 (Talbott *et al*., 1976)以及身體不適 (Ulrich, 1984)。Honeyman (1992)的研究進一步指出，辦公地點若擺放植栽，不僅能提高人們的正向情緒，有效紓解壓力，還能提升工作效率或

增加生產力；若沒有擺放植栽，則會增加人們的負面情緒，降低工作效率。

另外，精油透過嗅覺、皮膚吸收，具有紓壓、保健和淨化空氣等多樣性的功能。精油中所含的酯類是由醇和酸變化而來，效用溫和，較沒有危險性(黃, 2008)。1990 年法國皮耶佛朗秀姆(Pierre Franchomme)與潘威爾(Daniel Penoel)研究指出，植物體內含酯成分，可以抗真菌，鎮定中樞神經、平衡交感及副交感神經，對人體產生放鬆、紓壓的良好效果(卓, 2009)。德國茹絲．馮布朗史萬格(R.Von Braunschweig)亦表示，植物體內的酯成分，對人的情緒面的感覺具有緩和作用(Von Braunschweig and 溫, 2003)。因此，適當的使用精油，可以消除疲勞、緊張，達到心情愉悅與移除負面的想法。

根據 Hirokawa (2004), Kenny and Faunce (2004)與 Ghou and Lin (2006)等的研究指出，音樂是聽覺藝術，透過聲音與人體細胞共振的結果，常會令人感覺到寧靜、放鬆心情、紓壓和減輕憂鬱等效果。而 Brunges and Avigne (2003)與 McKinney 等(1997)的研究也證實，音樂可以減少心跳、放鬆肌肉和增加腦內啡(endorphins)，降低疼痛，形成愉悅感。Watkins(1997)指出，音樂可以恢復個體心理和生理健康的作用，以使個體行為上帶來良好的改變，達到身心與情緒的統合。

綜合前述，植栽可以濾淨空氣、紓解壓力和提高工作效率，精油能讓人心情愉悅與移除負面的想法，而音樂具有令人心靈寧靜、放鬆肌肉和紓壓的效果。顯然植栽、精油和音樂三者都能淨化心靈、紓緩壓力、改善 SBS，與健康紓壓具有正相關的關係。惟目前在探討室內環境健康紓壓時，多僅以單一選項為探討重點，並未提出一套完整有效的配套評估模式。因此，本研究運用資料包絡分析法(Data Envelopment Analysis, DEA)，選取可以降低空氣污染、紓緩焦慮並提升工作效率的室內植栽；導入六標準差(6σ)的 DMAIC 方法，提升安養照護機構經營環境之健康紓壓。並且藉由網路層級分析法(Analytical Network Process, ANP)，找出影響健康

紓壓環境構面中各準則的權重值，篩選出重要的影響準則。接著，分別透過田口方法(Taguchi Method, TM)，找出提升室內健康環境品質之最佳參數組合。透過本研究所提供的評估模式，不僅可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，創造舒適、清新與健康的環境，提供醫療照護、養老院及辦公場所等機構，作為改善環境的參考。

第二節　研究目的

隨著生活型態轉變，每人每天平均約有 80%或更多的時間處於室內環境之中。室內空氣品質(Indoor Air Quality, IAQ)的良窳，不僅會影響生產力和工作品質，更直接攸關個人健康。如上節所述，DEA、6σ之 DMAIC、ANP 及 TM 為本研究所應用的四種主要研究方法，而植栽、精油及音樂三項則為主要研究標的，同時也是重要的試驗因子。本研究將透過三個實際案例，分別應用上述四種主要研究方法，並搭配三項重要的試驗因子詳加探討，並希望可以達到以下四個目的：

一、選取淨化室內空氣的優良植栽，作為後續試驗的重要水準。

二、利用所選取的植栽搭配精油及音樂，透過 TM 找出可以提升室內健康環境品質之最佳組合。

三、設計問卷調查量表，與 TM 相結合，以提高室內健康環境之試驗結果的準確性。

四、建立健康環境評估模式，可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，提供各機構作為改善環境的參考。

第三節　研究架構

本論文為完成「室內健康環境評估模式之分析與建立」，共分為六章：

第一章：緒論。說明研究背景與動機，確立研究目的，研究架構及名詞解釋。

第二章：研究方法。簡介本論文使用之研究方法：DEA、6σ之 DMAIC 流程、ANP 及 TM 等。

第三章：應用 DEA 與 TM 提升室內健康環境品質。以學校教室為例，應用 DEA 選取優良植栽，配合置換時間，並透過 TM 進行探討。

第四章：導入六標準差概念提升室內健康環境品質。以安養照護機構的閱覽室為例，導入 6σ之 DMAIC 流程，進行探討。

第五章：採用 ANP 和 TM 評估室內健康環境品質。以幼稚園的會議室為例，應用 ANP 選取植栽、精油和音樂，再經由 TM 和統計檢定進行探討。

第六章：結論與建議，說明已建立之室內健康環境評估模式，並對日後從事相關議題的研究者，提出幾點建議。

研究流程如圖 1 所示：

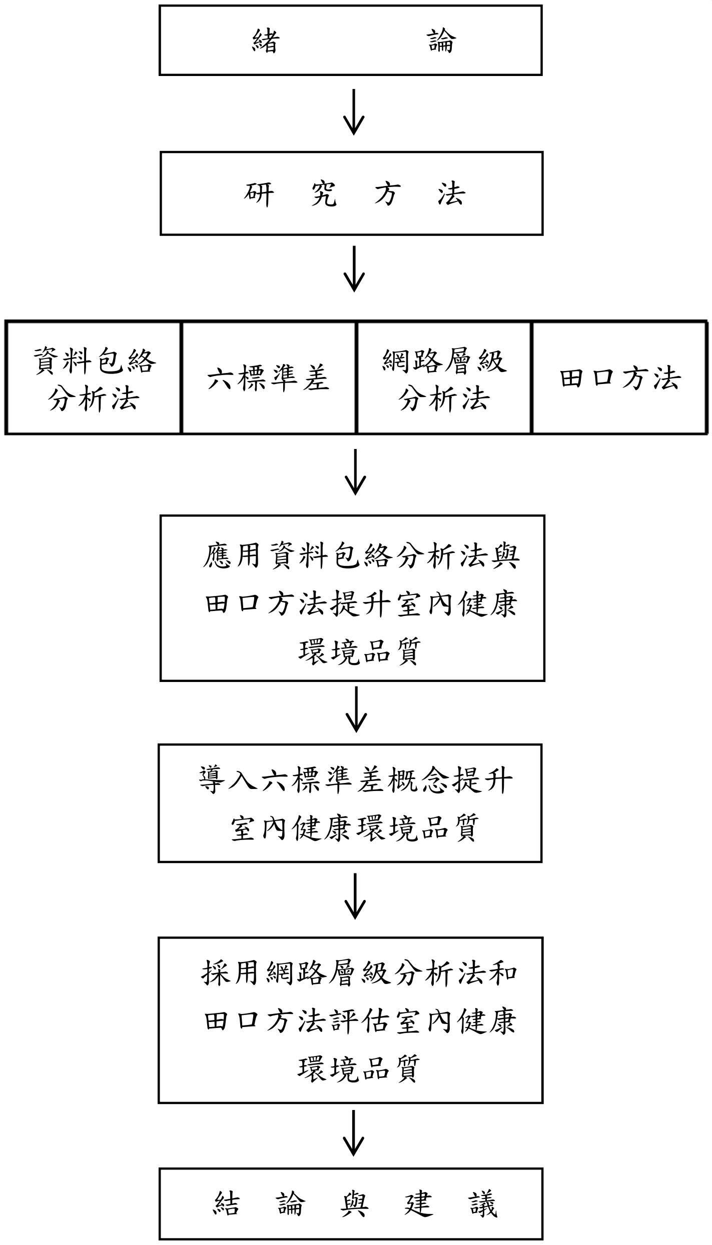

圖 1. 本論文研究流程圖

Fig. 1. The study flow diagram of this thesis.

第四節　名詞解釋

一、室內環境(Indoor Environment)：生活環境分為室內環境與室外環境，其中室內環境包括居室、辦公室、飯店、旅館、學校、醫院和文化娛樂體育活動等場所。本研究的室內環境係指醫療照護、養老院、教室、旅館及辦公場所等公共室內空間。

二、健康紓壓(Healthy Stress Relief)：根據聯合國世界衛生組織(World Health Organization, WHO)的定義，健康是指生理、心理及社會三方面均良好的狀態，而不僅是沒有疾病或不虛弱。並且，可以藉由各種方法加以改善或提升(WHO, 1948)。也就是說，廣義的健康涵蓋生理、心理及社會三方面。而本研究所指的則是狹義的健康，特別以心理方面為探討重點，並整合 Kaplan and Kaplan(1989)的功能演化論(functional-evolutionary theory)，以及 Ulrich(1983)的心理演化論(psycho-evolutionary theory)。爰定義健康紓壓為經試驗介入後，個人主觀感覺注意力恢復、心理疲勞消除及壓力減低等健康狀況呈正向相關反應，故又可稱為健康效益。

三、技術效率(Technical Efficiency, TE)：就投入與產出之間的關係而言，指於固定規模報酬(Constant Returns-to-Scale, CRS)之 CCR(Charnes、Cooper 與 Rhodes 的縮寫)模式下，用來衡量受評單位是否實現產出的最大化，或者在生產既定的產出時實現投入最小化。技術效率又稱為生產效率(productive efficiency)或技術與規模效率(technical and scale efficiency)。

四、純技術效率(Pure Technical Efficiency, PTE)：指於變動規模報酬(Variable Returns to Scale, VRS)之 BCC(Banker、Charnes 與 Cooper 的縮寫)模式下，用來衡量受評單位是否對於投入要素作最有效的運用。

五、規模效率(Scale Efficiency, SE)：指衡量組織之投入與產出的比例是否達到最適合之經營規模，也就是說，評估該組織是否處在固定規模報酬下之生產。

六、柏拉圖最適境界(Pareto Optimality)：又稱經濟效率(economic efficiency)或柏拉圖效率(pareto efficiency)，係指經濟體系已無法在不損及他人利益的情況下，而仍可以增進某些人的利益。也就是指無論如何重新配置資源，在不損害他人利益的情況下，已無法再提高任何個人的利益。相反地，非柏拉圖最適化即表示，在不損及他人利益的情況下，尚能提高個人的利益。

七、凸性(Convexity)性質：生產可能曲線凸向原點。

八、無效率(Inefficiency)性質：若產業為遞增規模報酬型態，則投入增加一單位，其產出增加超過一單位；若產業為遞減規模報酬型態，則投入增加一單位，產出增加少於一單位。此種現象在經濟學中稱為強勢自由處置(strong free disposability)。

九、射線無邊界(Ray Unboundedness)性質：產業若為固定規模報酬 (CRS)之型態，則投入增加一單位，產出亦增加一單位，其射線為通過原點之直線。

十、最小外插(Minimum Extrapolation)性質：生產可能集合滿足凸性、無效率和射線無邊界等三項性質假設，則交集為最適生產可能集合。

十一、夏普指數（Sharp Ratio）：乃係由諾貝爾獎得主夏普博士於 1960 年代所提出，用以衡量每個單位之風險，可換得的平均報酬率。夏普指數越高，

表示基金操作績效越好，而當夏普指數為負數時，則顯示其報酬率不如無風險利率（通常以三個月定存利率為準）。

十二、最佳化：田口方法的目的在找出產品設計的「最佳」表示方法。產品設計的重心在於產品概念的選擇和參數的最佳化，以降低重要品質之變異，並確保可以達到目標值。

十三、因子與水準：因子指影響產品績效的因素。水準則為各因子可設置不同的狀態條件，測量方式可分為計量值、計數值和感知表達。

第二章　研究方法

為了提升室內健康環境的品質，本研究應用 DEA、6σ之 DMAIC 流程、ANP 及 TM 四種研究方法，以建立評估模式。首先利用 DEA 投入導向模式選取優良植栽，其次應用 6σ之 DMAIC 流程，提升安養照護機構的健康環境品質，最後採用 ANP 篩選室內健康環境品質的影響因子。過程中分別以 TM 找出最佳參數設計因子。以下將詳述這四種研究方法：

第一節　資料包絡分析法(DEA)

DEA 是由 Charnes 等(1978)所提出的績效評估方法。其理論主要是以 Farrell (1957)的生產前緣作為衡量生產效率，並採用柏拉圖最適之境界(pareto optimality)的概念，作為效率的定義基礎。由於 DEA 是以數學模式求得生產前緣，因此無須事前預設生產函數的模式與函數的參數，就可以將各個決策單位(Decision Making Unit, DMU)之實際資料與生產前緣作比較。接著，據以衡量各個決策單位的相對效率與相對無效率程度，以達到相對效率之改善目標。其模式基本假設如下(Farrell, 1957)：

一、 生產前緣係由最有效率的 DMU 組成，相對地，較無效率的 DMU 則全部位於此前緣的下方。

二、固定規模報酬(CRS)，指投入與產出之單位成等比例之關係。亦即每增加一分投資，產出就會增加一分。

三、生產前緣凸向原點(convexity)，指每點斜率皆小於或等於 0。

DEA 係以一綜合性指標評估 DMU 之間的相對效率，其效率值介於 0 與 1 之

間。凡點落在邊界上的 DMU，代表相對有效率的，其效率值為 1；表示在其他產出不減少或投入不增加之情形下，DMU 無法減少投入，或增加產出。相反地，若點落在邊界外的 DMU，則屬相對無效率，其效率值小於 1；表示在投入不變之下，產出應可再行增加，或產出不變之下，投入應可再行減少。DMU 可據以提出改進方向與策略，並包含具體之改善數值及參考集合。

目前 DEA 在國內外的運用領域相當廣泛。例如，王(2012)利用 DEA 探討不同規模商學院的績效表現；陳(2012) 以 DEA 預測破產銀行之實用性及精確度。Joseph(2000)則運用 DEA 評估全美二十四座機場的經營績效，發現天候不良將導致營運效率降低。Gregoriou 等(2005)使用 DEA 分析美國避險基金(hedge fund)的資料，發現基金績效與夏普指數（sharpe ratio）的相關性很高。Nayar 等(2012)使用 DEA，從城市醫院的急診室效率和品質，衡量醫院的績效。以上這些研究皆獲得良好成效，足以證明 DEA 確實有推廣與使用的價值。

DEA 的模式以「規模報酬 (return to scale)」與「導向 (oriented)」為基礎，主要可區分為 CCR、BCC 二種模式。「規模報酬」是指投入項與產出項同時增加 (減少)時的倍數是否相當。若兩者倍數相當，表示為固定規模報酬，意指為已處在最適合規模的狀態下生產。當產出項的增加倍數大於投入項時，謂為遞增規模報酬(Increasing Returns to Scale, IRS)，可增加其投入項；相反則稱為遞減規模報酬(Decreasing Returns to Scale, DRS)，應減少投入項。遞增與遞減之情況，皆屬於變動規模報酬(VRS)。至於「導向」可區分為投入導向(input- oriented)、產出導向(output-oriented)二種。投入導向，指在給定產出之下，將投入項做一定比率的縮減，使無效率的 DMU 可往前緣線移動；產出導向，是指在給定投入之下，將產出項比率增加至最高的能力，使 DMU 能達到生產目標。有關 CCR、BCC 二種模式，茲簡述如下：

一、CCR 模式：是由 Charnes、Cooper 與 Rhodes(CCR)於 1978 年提出。主要以 Farrell(1957)的效率評估理論為基礎，運用確定性的無參數法(deterministic nonparametric approach)，進行單一投入、單一產出的技術效率(TE)評估。隨後這個理論發展為不需要預設函數的型態，且為多重投入與產出之效率評估的模式，並建立數學規劃模式，以衡量生產邊界，謂為 CCR 模式。此模式運用無參數法，並將效率評估的觀念推廣至多重產出的模式。CCR 模式又可區分為投入導向、產出導向二種模式。

二、BCC 模式：是由 Banker、Charnes 與 Cooper(BCC)於 1984 年提出。他們針對 CCR 模式加以擴展，提出四項公設：生產可能集合滿足凸性(convexity)、無效率(inefficiency)、射線無限制(ray unboundedness)及最小外插(minimum exdtrapolation)性質。並且，引入 Shephard 距離函數的觀念，以導出與 CCR 相同的模式，俾提供 CCR 模式的理論基礎。放寬固定規模報酬限制，改為變動規模報酬，同時將技術效率拆解成純技術效率(PTE)與規模效率(SE)之評估模式，謂為 BCC 模式。在變動規模報酬的假設下，不僅可用以衡量 DMU 的投入面是否具有效率的技術效率值，也可進一步評估營運規模是否達到最適合的規模效率值。Cooper 等(2000)則定義 SE＝CCR/BCC，亦即技術效率(TE) =PTE×SE。倘若 SE=1，代表具有最適合之固定規模報酬的生產特性；倘若 SE<1，則代表不具有規模效率。BCC 模式亦可分為投入、產出二種導向模式。

除了上述二種模式外，DEA 尚有差額衡量法 (Slack-Based Measure, SBM)模式、Super SBM(Slack-Based Measure of Super-Efficiency)模式、A&P 模式、交叉模式及多目標模式(multiple objective programming)等超過 160 種模式，以各種不同功能分析模式分別評量受評估對象的效率。其所使用的投入、產出值都相同，差別在以不同分析角度為理論基礎的情況下，權重的大小，以及不同相對效率基準的分析

效率之改善方向。

由於本研究係利用植物的淨化化學氣體指數、栽培容易度、病蟲害抵抗力以及水分蒸散作用率等四項評估值為投入項，並以整體淨化空氣指數為產出項，屬於固定規模報酬下之相對效率。因此，在此採用 CCR 投入導向模式，選取相對淨化室內空氣效率較高、紓壓效果較佳的植物，作為本研究採用的植栽對象。

第二節　六標準差概念(6σ)

自從Motorola公司於1987 年開始運用，六標準差概念對業界已經不是一個陌生的名詞，許多國際企業已經引進六標準差的方法，來改善企業體質與提升企業競爭力，並獲得顯著的成效。例如，奇異公司在1995年導入六標準差方法，精簡合約審核流程，每年因此省下百萬美元之交易成本。

在21世紀的今天，許多學者亦應用六標準差的方法，致力於研究服務業的各種特性，希望能更有效率地提升經營環境的績效品質，以滿足顧客的需求。例如Ham and Lee(2002)所提的MAIC之改善流程。Geogel(2001)提出的DMAIC之流程概念，有效改進各種交易流程的品質和速度。Linderman等(2003)更進一步提出DMADV改善步驟，有組織且有系統的應用在製程的改善以及新產品的設計上，皆具成效。而國內也有許多有關六標準差的研究，如Chen等(2006)透過六標準差的MAIC流程，提升TFT-LCD面板的製程品質；Hsia等(2009)導入六標準差步驟，增加網際網路行銷的服務品質；Chen等(2010a)導入六標準差DMAIC步驟，提升休閒服務品質。顯然地，六標準差是提升各種製造及服務流程的方便工具，吸引許多學者投入相關研究，各企業也因導入六標準差而獲得顯著成效。

六標準差的流程有許多種，比較普遍應用且有效率的方法有：流程改善(DMAIC)、流程設計 (DMADV)和流程管理 (DMAC)三種。DMAIC著重在對結果

產生影響的因素；DMADV強調取代而非修正一個流程，或在單純改善現有流程仍無法達成目標時採用；DMAC則專注於全體組織的管理流程。企業在推動六標準差時，可以依本身的條件或需求，決定採用那一種流程方法。茲就上述三種方法分述如下(陳, 2008)：

一、 流程改善(DMAIC)

(一) 定義(Define)：誰是顧客？顧客最在意的是什麼？界定核心流程和關鍵顧客，找出現在與未來顧客之關鍵品質，訂定專案項目。

(二) 衡量(Measure)：過程如何執行評估？建立量測基準，瞭解現況與顧客間的差距，找出關鍵流程所造成的失誤。

(三) 分析(Analyze)：缺點發生的重要原因？探究缺失發生的根本原因，擷取可能影響重要品質特性之眾多變數，設法降為少數致命變數，評估財務成效。

(四) 改善(Improve)：如何改善缺點起因？找出最佳解決方案，落實執行。確認少數致命變數，尋求最佳解決方案並確認，完成風險評估。

(五) 控制(Control)：如何維持改善成果？效果確認、標準化，持續改善。並利用統計學流程控制或簡單的檢驗表等工具，維持關鍵變數在最大的容忍範圍內。

二、流程設計(DMADV)

(一) 定義(Define)：誰是顧客？顧客最在意的是什麼？界定核心流程和關鍵顧客；建立企劃流程，訂定專案項目。

(二) 衡量(Measure)：過程如何執行評估？建立量測基準，瞭解現況與顧客間的差距。瞭解技術、市場趨勢，進行分析。

(三) 分析(Analyze)：過程設計分析。掌握顧客聲音(voice of customer, VOC)，轉成性能需求；選擇最佳設計概念，滿足性能要求；性能要求轉成產品或服務的設計參數；產品或服務的設計參數轉成製造條件。

(四) 設計(Design)：設計並執行新流程；系統設計、參數設計與最佳化；允差設計與最佳化。

(五) 驗證(Verification)：驗證結果並維持績效；驗證、測試與試產作最佳控制。

三、流程管理(DMAC)

(一) 定義(Define)：界定流程、關鍵顧客要求和流程擁有人。

(二) 衡量(Measure)：衡量主要流程指標及績效是否達到顧客要求。

(三) 分析(Analyze)：分析資料以強化衡量並修正流程管理機制。

(四) 控制(Control)：控制績效，透過監視投入/作業/產出，對問題和流程變異即時回應。

本研究係以安養照護機構整體室內環境的營造為探討重心，目的在尋求問題，並加以分析、改善，著重在對結果產生影響的因素。因此，將應用6σ之DMAIC流程，提升安養照護機構室內環境的健康紓壓之效果。

第三節　網路層級分析法(ANP)

層級分析法 (Analytic Hierarchy Process, AHP)是 Thomas L. Saaty 於 1971 年提出，主要應用在無法確定之情況，及具有多個評估準則的問題。AHP 是一種單目標多準則的決策分析方法，可在評估方案已知的情況下，協助決策者處理數個評估準則的決策問題。在同時衡量多個屬性後，從評估方案中選出最適者。AHP 在問題求解的過程中，須假設每個階層的要素均需相互獨立，並將複雜的問題系統化，以進行評估(Saaty, 1990)。然而，現實生活中的問題，時常存在相依或回饋關係，往往會牽涉到相同階層屬性之間的互動關係，或不同階層之間的相互依賴效果，致使 AHP 的評估結果容易產生偏差。

ANP 是 Saaty (1996)與 Saaty and Vargas (2000)為了解決 AHP 決策階層模式的缺點而延伸的概念，係在 AHP 的層級基礎上，添加相依互存(dependence)及回饋(feedback)關係。Saaty (1996)建議構成集群與元素間之相依性的交互影響關係，可用圖形之方法進行分析，但圖形中的每個元素必須相連，不可分成兩個或兩個以上不相連的圖形。如此即可克服傳統 AHP 層級結構中，準則或層級之間可能產生的相互依存關係，以及回饋的問題。所以目前 ANP 已在學術上備受重視並應用到各個領域，獲致不錯的成效。例如：Taslicali and Ercan (2006)、Gencer and Gurpinar (2007)、Voulgaridou 等(2009)、Jung and Seo (2010)及 Tseng (2011)等。根據 Chung 等(2005)的研究指出，ANP 的決策程序可分成五個步驟，分述如下：

步驟 1：建立評估的網路層級結構

首先由決策群體整理與歸納決策問題的相關資訊，或透過專家訪談方式，找出影響決策問題的系統要素，包括目標、層面、準則，以及可行計畫或方案等。一般而言，參與的專家人數至少應有 10 位以上 (Parente and Anderson-Parente,

1987)。在問題層級結構中，利用迴圈弧形(loop arcs)與單、雙兩向箭線連結，以表示層級、從屬關係，及存在的回饋關係，如圖 2 所示。

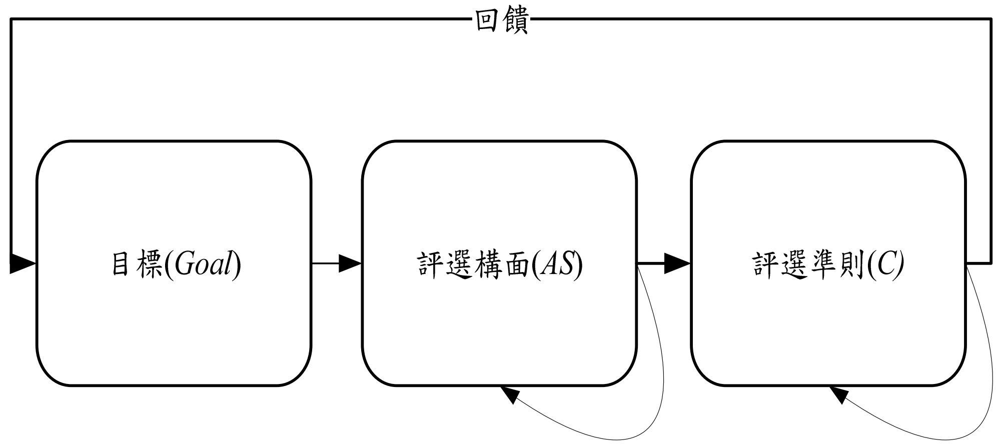

圖 2. 目標層級構面相依回饋圖

Fig. 2. Target level dimensions dependencies feedback

步驟 2：建立成對比較矩陣

根據決策群體(專家)填寫的問卷，可以得到許多成對比較矩陣。此時必須計算各成對比較矩陣的特徵值與特徵向量，並進行一致性檢定。根據 Saaty (1980)指出，在相同階數的矩陣下，需利用一致性指標(Consistency Index, C.I.)與隨機指標(Random Index, R.I.)的比例，稱為一致性比例(Consistency Ratio, C.R.)，如公式(1)及(2)所示。若 C.R.值小於 0.1，矩陣一致性的程度才夠。

$$C.I.= (\lambda_{\max} - n)/(n-1) \quad (1)$$

$$C.R.= C.I./R.I. \quad (2)$$

其中，

$\lambda_{\max}$表示最大特徵值，n表示該矩陣之階層數，R.I.為評估矩陣的隨機指標值。

步驟 3：計算各矩陣的相對權重

超級矩陣是由多個子矩陣組合而成。每一個子矩陣的值皆是由成對比較所計算出的特徵向量值，作為子矩陣之權重值，最後形成超級矩陣。本步驟主要在計算每一個矩陣的相對權重，形成一個矩陣行向量總合不等於 1 的未加權超級矩陣 M' (Unweight Supermatrix)。

步驟 4：超矩陣的運算

ANP 的超矩陣運算過程中包含三個矩陣，分別是未加權超矩陣 M' (unweighted supermatrix)、加權超矩陣 M (wighted supermatrix)、極限化超矩陣 M* (limit supermatrix)。M'為未加權(unweighted)的初步矩陣，矩陣中的行值總和不等於 1，不符合行隨機 (column- stochastic)之原則。所以，必需經過特定的程序加以轉換，即可獲得加權超矩陣(weighted supermatrix)，並以 M 表示。藉由上述轉換的程序，再經極限化(limiting)過程，運用公式(3)，將加權超矩陣 M 進行連乘後 k 次方(k 為主觀決定的值)，即可得到極限化超矩陣 M*。M*為一個收斂的極限值時，即可求得各要素間之相對權重值(Saaty, 1996)。

$M^* = \lim_{k\to\infty} M^k$ ；$K \in$ 整數 (3)

步驟 5：計算可行計畫的權重

承上步驟,極限化超矩陣所呈現的收斂值,即為各準則相對應之優先權重值。優先權重值愈高，表示被採納的優先順序愈高，可作為決策者進行決策時的參考依據。

前文已指出，植栽、精油及音樂具有改善室內環境的健康紓壓效果。本研究亦利用美國太空總署(NASA)原始植栽的數據，透過 DEA 選取優良植栽，但精油及音樂方面，因缺乏明確數據，難以比照進行。鑑於 DEA 方法受到因子水準應具備明確數據，及僅能進行個別因子選取的限制，無法將植栽、精油及音樂三者相互依存及回饋的關係納入考量，因此，本研究進一步應用 Chung 等(2005) ANP 的五個步驟，篩選植栽、精油及音樂，作為本研究採用的標的。

第四節　田口方法(TM)

TM 由田口玄一(Dr. Taguchi Genichi)博士於 1950 年代所開發倡導，係以試驗的方式來決定設計參數。主要是訂定試驗計畫後，依控制因子及其水準的數目，選用適當的直交表(Orthogonal Arrays, OA)。其原理是在完整排列組合的全因子試驗中先進行均勻分布的選擇，而後進行所選取之部分試驗。是以，TM 具有控制因子與水準之選擇、直交表之配置、交互作用之忽略、損失函數之品質特性及 *S/N* 比之決定等五項特點：

一、控制因子與水準之選擇：訂定試驗計畫後，選擇關鍵的控制因子，並設立水準。本研究為建立室內健康紓壓的評估模式，以改善室內空氣品質，應用 DEA、ANP 及石川馨(Kaoru Ishikawa)提出的特性要因圖(cause and effect diagrams)篩選控制因子與水準。

二、直交表之配置：直交表是以拉丁方格(Latin Squares)的基本原理設計的多因素試驗配置法。其優點在於能以較少的試驗次數，換得較為經濟、有效率且不損失重要資訊的試驗設計。目前已經出版各種不同需求的制式直交表，以 $L_a(b^c)$ 符號表示：

其中，

L：拉丁方格的字頭。

a：直交表的列數，也就是試驗的處置數或是試驗的條件數。

b：直交表的行可考慮的水準數，也就是配置因素的水準數。

c：直交表的行數，也就是試驗可考慮的因素個數。

直交即謂為平衡(balance)或分離(separable)。意謂著各水準的組合皆需存在，且出現的次數務必相同。所以，直交表可空行，也可對調任意兩列，但絕對不可以空列，因空列會導致不平衡。田口博士共列了 18 種直交表，一般稱作「標準直交表」。

三、交互作用之忽略：因子水準之間通常存在著交互作用，惟其作用不安定、無法捉摸，且往往無法明確知道其效應是否顯著。因此，田口博士主張應該盡量想辦法予以排除，於是提出 *S/N* 比之推算，以增加試驗結果的有效性及再現性。而本研究的三個標的因子為植栽、精油及音樂，三者之間的交互作用，亦無法明確評估是否顯著存在。因此，採用直交表及 *S/N* 比之推算，以減少

交互作用產生，並進行確認試驗，驗證結論是否具有可靠性。

四、損失函數之品質特性：品質的定義有多種說法，田口博士對品質的定義為：「產品產出後所帶給社會大眾的損失，但不包含機能本身所造成的損失。」也就是說，理想品質應該是對社會大眾的損失為零。田口博士對品質的評價是以損失為基礎，他將品質損失函數設為如公式(4)所示：

$$L(y) = k(y-m)^2 \tag{4}$$

$$k = \frac{A}{\Delta^2}$$

在以上的公式中，y 表示產品的品質特性，m 為目標值，而 k 是品質損失係數(quality loss coefficient) ，其中 A 為維修或更換成本，Δ表示公差範圍 (容許偏差量)。當產品符合目標值時，損失為零；當 y 愈偏離 m，則損失愈大。

五、*S/N* 比之決定：根據 Taguchi(1987)與 Taguci(1991)指出，*S/N* 比是信號與雜訊(signal to noise)比值的簡稱，是一種用來衡量品質的統計量度，與品質損失函數有密切的關係。*S/N* 比愈高，表示品質損失愈少；*S/N* 比愈低，表示品質損失愈大。*S/N* 比之推算，係將損失函數直接取對數值轉換而得，可完成加法模式(additive models)，作為產品績效衡量之準則。*S/N* 比主要能減少交互作用產生，有效釐清各控制因子的主效果，並增強產品之穩定性。*S/N* 比的特性可分為望大型 *S/N* 比、望小型 *S/N* 比及望目型 *S/N* 比三種。由於本研究所考量的乃是目標函數的最大化，屬於望大型 *S/N* 比，計算公式如公式(5)所示：

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right]\text{dB}\ (望大型品質特性) \quad (5)$$

承上，有關 TM 的基本步驟簡述如下：

步驟 1：訂定試驗計畫後，選取控制因子與水準，並整理於表 1。

表 1. 控制因子水準表

Table 1. Control factors and levels

因子	水準 1	水準 2	水準 3
因子 A	A_1	A_2	A_3
因子 B	B_1	B_2	B_3
因子 C	C_1	C_2	C_3
因子 D	D_1	D_2	D_3

步驟 2：根據因子與水準找出最適合的直交表(如表 2)，並進行試驗，接著將試驗結果透過 *S/N* 比進行轉換。

表 2.　$L_9(3^4)$直交表試驗結果

Table 2. Experiment results by $L_9(3^4)$ orthogonal matrix

試驗號碼	參數與水準				結果			
	A	B	C	D	Y_1	Y_2	Y_3	S/N (dB)
1	1	1	1	1	A_1	A_2	A_3	S/N_1
2	1	2	2	2	B_1	B_2	B_3	S/N_2
3	1	3	3	3	C_1	C_2	C_3	S/N_3
4	2	1	2	3	D_1	D_2	D_3	S/N_4
5	2	2	3	1	E_1	E_2	E_3	S/N_5
6	2	3	1	2	F_1	F_2	F_3	S/N_6
7	3	1	3	2	G_1	G_2	G_3	S/N_7
8	3	2	1	3	H_1	H_2	H_3	S/N_8
9	3	3	2	1	I_1	I_2	I_3	S/N_9

步驟 3：分析因子水準反應及交互影響，如表 3。因子水準的效果是定義為自總平均值的離差，當離差愈大，則效果值愈大，表示設計因子對 S/N 比反應愈高，品質愈好。接著，將各試驗因子水準的平均 S/N 比值數據繪製成因子效果圖，如圖 3 所示。最後，再從圖 3 中選擇 S/N 比值較大的因子水準，而獲得最佳因子水準組合。

表 3. 設計因子對 *S/N* 比反應表

Table 3. The reaction of designed factors to *S/N* Ratio

水準	A	B	C	D
水準 1	A_1	B_1	C_1	D_1
水準 2	A_2	B_2	C_2	D_2
水準 3	A_3	B_3	C_3	D_3
效果	效果 $_A$	效果 $_B$	效果 $_C$	效果 $_D$
排序	排序 $_A$	排序 $_B$	排序 $_C$	排序 $_D$

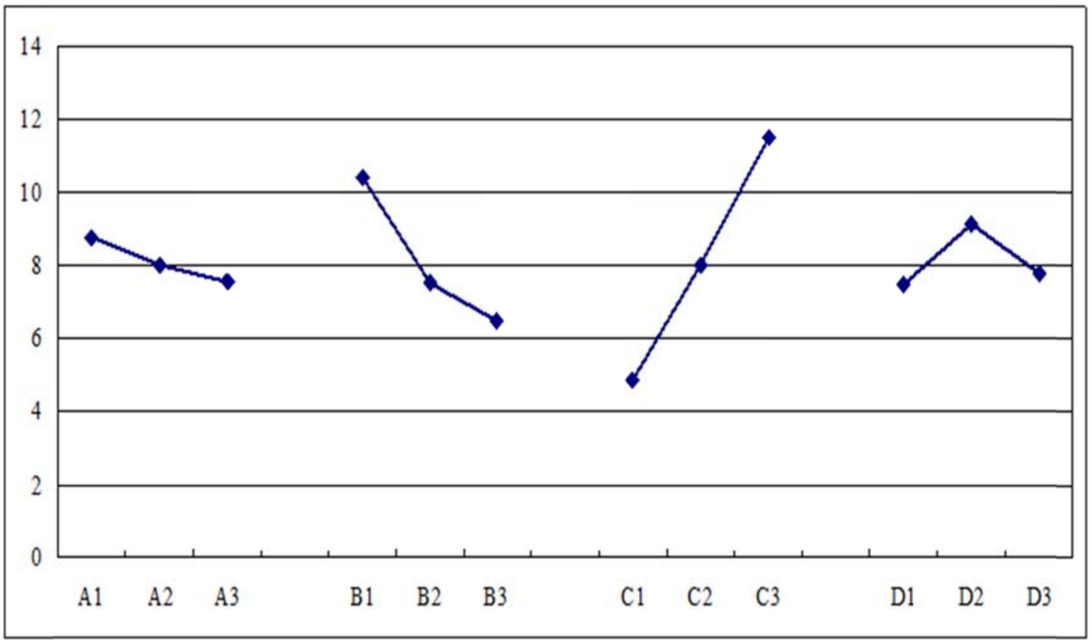

圖 3. 設計因子對 *S/N* 比因子效果圖

Fig. 3. Main effects plot for S/N ratio

步驟 4：進行確認試驗，首先將最佳的因子水準組合再進行試驗，由試驗結果計算 *S/N* 比，接著透過 *S/N* 比預測式，如公式(6)，預測最佳因子水準組合的 *S/N* 比。倘若 *S/N* 比預測值比其他的水準組合大，表示此水準組合能將變異降低。若預測值與試驗值的差異落在 95%信賴區間(cnfidence interval, CI)之內，如公式(7)，表示試驗成功，結果具有加法性，且結論是可靠的；否則表示試驗失敗，因子之間存在著交互作用，結論是可疑的。

$$S/N\text{比預測式} = \overline{\eta} + (A_i - \overline{\eta}) + (B_j - \overline{\eta}) + (C_k - \overline{\eta}) + \cdots\cdots - \left(N_n - \overline{\eta}\right)$$

$$= A_i + B_j + C_k + \cdots\cdots + N_n - (\mathrm{n}-1)\overline{\eta} \qquad (6)$$

其中，

A_i表示 A 因子的最佳水準 *S/N* 比，B_j表示 B 因子的最佳水準 *S/N* 比， C_k表示 C 因子的最佳水準 *S/N* 比，N_n表示N因子的最佳水準S/N比⋯，n 表示所考慮到的因子個數，$\overline{\eta}$表示所有 *S/N* 比的平均。

$$\mathrm{CI} = \pm\sqrt{\frac{\mathrm{S}^2}{\mathrm{N_p}} + \frac{\mathrm{S}^2}{\mathrm{N_e}}} \times \mathrm{T}(1-\alpha\%,\ \mathrm{dof}) \qquad (7)$$

其中，

$\mathrm{N_p}$表示預測值樣本數，$\mathrm{N_e}$表示試驗值樣本數，S 表示標準偏差，dof 表示自由度，α%表示信賴水準(confidence level)。

綜上而言，田口博士認為良好的品質必須符合二個條件：一是品質特性之變異愈小愈好，二是品質特性的平均值與目標值一致。因此，TM 參數設計利用 *S/N* 比將試驗中可預測的部分作為信號(signal)，不可預測的部分作為雜訊(noise)，試驗的目的在求得最大化的信號，最小化的雜訊，以此降低變異，提升產品品質。

本研究旨在提供一套完整的評估模式，不僅可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，創造舒適、清新與健康的環境。因此，應用 DEA、ANP 及特性要因圖篩選控制因子與水準後，就分別透過 TM 的流程，找出提升健康紓壓環境品質之最佳參數組合。

第五節　小結

承上之四種研究方法，本研究為建立室內健康環境之評估模式，將分三個層次來探討。首先，以學生為對象，應用 DEA 選取優良植栽，配合環境置換時間，再透過 TM 找出室內健康環境之最佳組合。其次，安養照護機構是政府列為六大新興產業之一，前景看漲，商機無限。本研究將以安養照護機構整體室內環境的營造為觀點，以老年人為對象，導入 6σ之 DMAIC 流程，建立評估模式，俾提升健康紓壓環境品質，強化其競爭力。最後，植栽、精油和音樂三者都能淨化心靈、紓緩壓力、改善 SBS，與健康紓壓具有正相關關係，則選擇幼稚園的老師和幹部為對象，應用 ANP 篩選室內健康環境的影響因子，再透過 TM 找出最佳組合，並藉統計檢定作為改善後績效評估的工具。有關評估模式詳細內容，如圖 4 所示，本研究將分三個實例來探討。

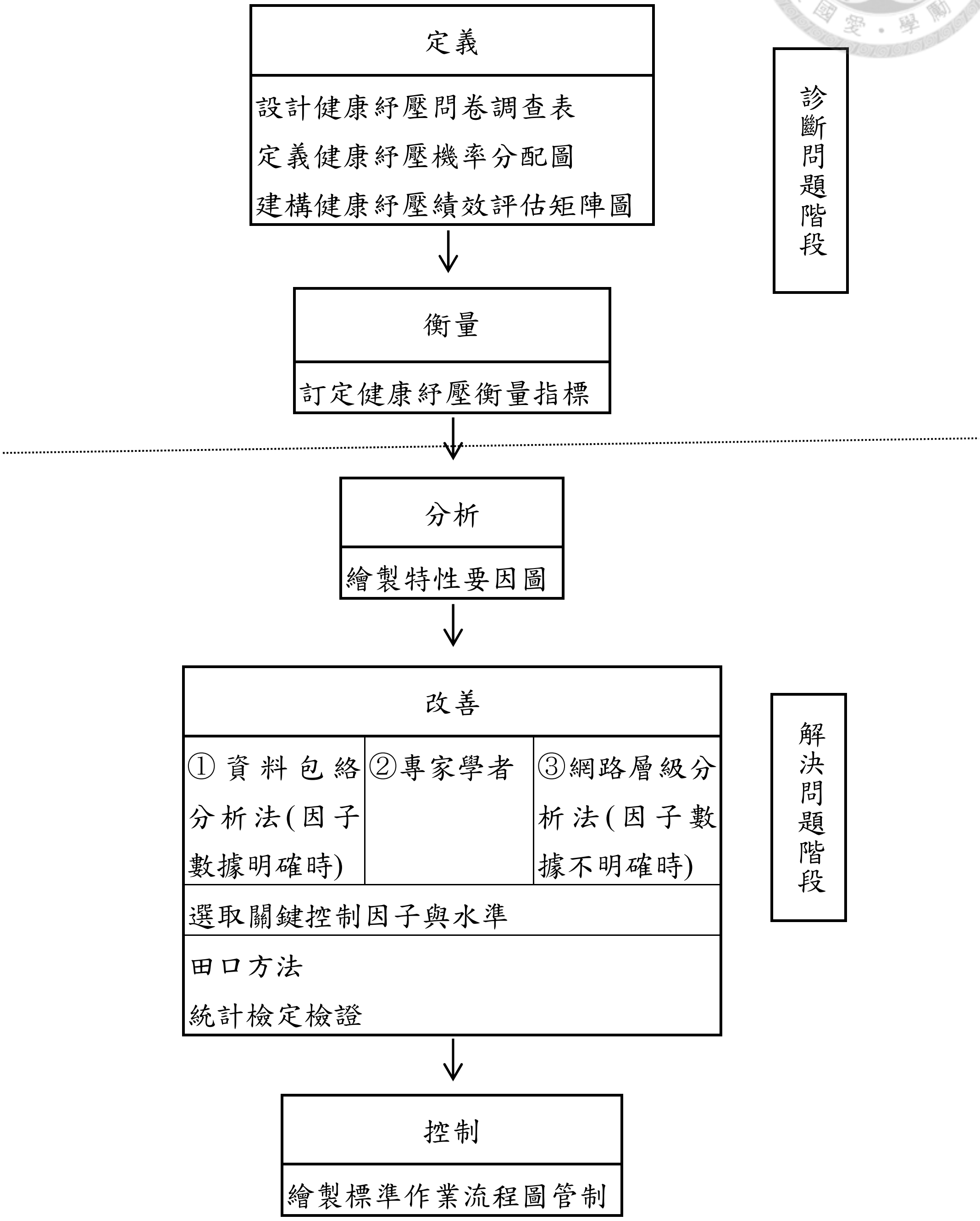

圖 4. 室內健康環境之評估模式圖

Fig. 4. The assessment mode of indoor healthy environments

第三章　應用資料包絡分析法與田口方法提升室內健康環境品質

本章以學校教室為例，應用 DEA 與 TM 選取植栽和最佳配置，以提升商務經營環境之健康紓壓品質。茲說明如下：(Chen *et al.*, 2010b)

第一節　前言

現今社會競爭越來越激烈，常使人們處在精神壓力緊繃的狀態。Davison and Neale (1990)甚至認為，很少有人在一星期之內沒有嚐到焦慮的滋味。而高度的焦慮不僅會影響身體正常的反應，導致注意力不集中，進而影響認知學習的能力(Williams and Powers, 1991)。尤其商場如戰場，一般企業的員工，除了在企業內部辦公之外，也常常要到餐廳、飯店、咖啡廳及其他場所進行商務活動。本研究所指的商務經營環境，就是上述商務活動的環境。這些環境除了美觀、舒適與幽雅之外，更需要清新健康的空氣。因為營造優質的商務經營環境，才能降低企業員工的負面情緒(negative mood)，如恐懼、焦慮、憂鬱、冷漠及悲傷等(Atienza *et al*., 2001)，並能使企業員工變得更快樂、舒服且更能安心地工作，進而提升企業之競爭力。

根據Abbriti and Muzi(1995)的研究，現代的企業員工，每天約有80％－90％的時間是在密閉式環境中工作。密閉式環境中空氣污染的程度可能是室外的十倍以上，各種有機化學物質污染室內空氣，致使企業員工的身體越來越不健康、工作效率變差，進而降低商務經營之效率與競爭力。

Dijkstra等(2008)與Honeyman (1992)研究證實，商務經營環境配置植栽可以達到淨化空氣的功效，幫助企業員工釋放壓力。尤其當企業員工置身於舒適、幽雅、清新與健康的商務經營環境，情緒、緊張與焦慮狀況，都可以獲得有效的紓解(Chang and Chen, 2005)，甚至還能夠改善人們的食慾、精神狀態 (Talbott *et al*., 1976)

以及身體不適 (Ulrich, 1984)。

綜上，本研究運用 DEA 選取可以降低空氣污染、紓緩焦慮，並提升工作效率的室內植栽，透過 TM 找出最佳參數設計之植栽配置組合，俾提出具體建議，作為企業的參考。最後，利用這一套評估模式，創造一個舒適、幽雅、清新與健康的商務經營環境，進而提升企業之經營效率與競爭力。

第二節　應用資料包絡分析法投入導向模式分析選取優良植栽

本研究是以投入角度探討效率，在目前之產出水準下，比較投入資源之使用情形，謂為投入導向效率。假設為固定規模報酬，當投入量(x)以等比例增加時，產出(y)亦應等比增加。因此以 CCR 投入導向模式分析進行探討，其公式與投入項及產出項如公式(8)所示：

CCR 投入導向模式 (比率式)：效率=產出的加權組合/投入的加權組合

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

$$S.T. \frac{\sum_{r=1}^{s} u_r Y_{rj}}{\sum_{i=1}^{m} v_i X_{ij}} \le 1, j = 1,........,n \tag{8}$$

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

其中，

E_k：第 k 個植栽的相對效率值(受評單位 DMU 之相對效率值)

Y_{rk}：第 k 個植栽的第 r 項產出值

X_{ik}：第 k 個植栽的第 i 項投入值

u_r：第 k 個植栽的第 r 個產出值的加權值

v_i：第 k 個植栽的第 i 個投入值的加權值

ε：一極小的正數 (極微正數；非阿基米德數，non-Archinidean quantity，此小數是為了防制分數計畫法的分母成為 0，實務上常設為10^{-4}或10^{-6}，代表任一因子均不可忽略不計。)

承上得知，DEA 在求產出與投入的比值，Y_{rk}、 X_{ik}、 Y_{rj}、 X_{ij} 為已知數。而模式即在各被評估單位(DMU)所形成的解集合中，找尋最有利的加權值(即 v_i, u_r)，而使各單位的效率值 E_k 為最大。即在求算的過程，每次將一個受評單位 DMU 的投入與產出作為目標函數，執行 N 次，每次找出 DMU 最有利的權值，設為 N 組(v_i, u_r)。

鑑於原比率模式為一分數規劃模式(Fractional Programming, FP)，為非線性規劃，求解並不容易。因此將之轉變為線性規劃模式(Linear Programming, LP)求解，並加入$\sum_{n=1}^{m}\sum v_i X_{ik}=1$的限制，以避免分數規劃模式，有無限多個組解的情況發生，則 Input-Oriented CCR Model，如公式(9)所示：

$$
\begin{aligned}
& Max \quad h_k=\sum_{r=1}^{s}u_rY_{rk} \\
& S.T. \quad \sum_{i=1}^{m}v_iX_{ik}=1 \\
& \sum_{r=1}^{s}u_rY_{rj}-\sum_{i=1}^{m}v_iX_{ij}\le 0 \qquad j=1,........,n \\
& u_r,v_i\ge\varepsilon>0, r=1,........,s, i=1,.......,m
\end{aligned} \tag{9}
$$

模式(9)是加上投入加權和為 1 的限制後，令投入項加權組合值為 1，求產出加權組合值之最大，極大化產出加權總和。由於模式(9)的限制式個數大於變數個數，因此，可再利用線性規劃的對偶理論，將上式(9)轉換成對偶模式(duality)，轉換極小化模型後，可表示為唯一的包絡形式(envelopment form)。此對偶模型如公式(10)所示：

$Min_{\theta,\lambda}\,\theta$ (10)

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

$\theta_{x_{ik}} \geq \sum_{k=1}^{k}\lambda_k X_{ik}$

$\lambda_r \geq 0$

k= 1,2,……..,K

r= 1,2,……..,R

i = 1, 2,…….,I

其中，

θ：代表 DMU 的相對效率值；λ_k：代表非負純量。

如表 4 所示，有 A～F 的 6 個 DMUs，分別具有 2 個投入，1 個產出。為了簡化例子，產出值均假定為 1。求 DMU A 的效率性的 CCR 投入導向模式，是將v_1，v_2，u，當作投入與產出的權重，計算方式及說明如下：

表 4. 2 個投入和 1 個產出範例

Table 4. Example of 2 Inputs and 1 Output

	DMU	A	B	C	D	E	F
投入	x1	7	4	8	4	2	10
	x2	3	3	1	2	4	1
產出	y	1	1	1	1	1	1

$Max\ \theta = \mu$

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

$\mu \leqq 7v_1+3v_2$ (A) $\mu \leqq 4v_1+3v_2$ (B)

$\mu \leqq 8v_1+1v_2$ (C) $\mu \leqq 4v_1+2v_2$ (D)

$\mu \leqq 2v_1+4v_2$ (E) $\mu \leqq 10v_1+v_2$ (F)

$v_1 \geq 0$，$v_2 \geq 0$，$u \geq 0$

凡所有權重變量都限制為非負純量。

其次，將θ，λ當作對偶變數，取對偶形時，即成為

$Min_{\theta,\lambda}\,\theta$

S.T. $-3\lambda_A-3\lambda_B-1\lambda_C-2\lambda_D-4\lambda_E-1\lambda_F+3\theta \geq 0$

$-7\lambda_A-4\lambda_B-8\lambda_C-4\lambda_D-2\lambda_E-10\lambda_F+7\theta \geq 0$

$\lambda_A+\lambda_B+\lambda_C+\lambda_D+\lambda_E+\lambda_F \geq 1$

$\lambda_i \geq 0(\mathrm{i}=\mathrm{A,B,C,D,E,F})$ ；θ：無限制(因 $\sum_{i=1}^{m} v_i X_{ik}$ =1 是形成等式之緣故)。

此式最適解是v_1*=0.0526，v_2*=0.2105，u*=0.6316，θ*=0.6316。目標函數值亦即 A 的 CCR-efficiency 是 0.6316。表示 DMU A 的投入項，如縮小 0.6316 倍即具有完全技術效率，其餘類推。

受評單位 DMU 相對效率之判斷，若$\theta \leq 1$, j 則無 CCR 效率，表示有技術無效率的情況存在；當θ=1 時，表示具有完全技術效率。

使用 DEA-CCR 投入導向模式進行分析時，最後的結果，可能會出現多個 DMU 同時相對有效之情形，但對這些有效之 DMU，卻無法進一步的評價與比較。為彌補此一缺陷，Andersen and Petersen(1993) 提出 CRS 超效率模式(super-efficiency model)，用於解決效率前緣上各 DMU 相對有效的優先順序問題；同時也應用 DEA super-efficiency 模式區別 extreme efficient DMUs (Thrall, 1996)。有關 Input-Oriented CRS super-efficiency DEA 模式如公式(11)所示：

$Min\ \theta^{super}$ (11)

S.T. $\sum_{i=1, j\neq 0}^{n} \lambda_j x_{ij} \leq \theta^{super} x_{i0}$ i=1,2,…,n;

$\sum_{i=1, j\neq 0}^{n} \lambda_j y_{rj} \geq y_{r0}$ r=1,2,…,s;

$\lambda_j \geq 0$ j≠0.

雖然利用超效率方法可以解決在效率前緣上各 DMU 的排序問題，但並不適用於全部的模型，對於特定的資料評估也會產生不正確的判斷。因此，當 DMU 的投入項與產出項的值為零，或是有效率 DMU 的集合中包含極端型 DMU，該投入型的 SE-CCR 模式就不適用於超效率方法(Seiford and Zhu, 1999)。而本研究中投入項與產出項值不為零，DMU 集合中也未包含極端型的 DMU，因此，本研究將再以 Andersen and Peterson(1993)提出的「超效率模式」為輔助研究工具，以提高 DEA 模式的區別能力。

第三節　實證分析

科學已經證實數十年來園藝學家深信不疑的信念：植物可以幫助人類釋放壓力，紓緩心理疲勞，同時也能有效淨化空氣，提升工作效率。美國太空總署(NASA) Wolverton(1997)也指出，優良淨化室內空氣的植物，應具備有較高的淨化化學氣體指數、栽培容易度、病蟲害抵抗力以及良好的水分蒸散作用率等四項指標值。指標值愈高，表示淨化空氣的能力及紓壓效果愈好。有關這四項指標的功能，簡略說明如下：

一、淨化化學氣體指數：乾燥的空氣是室內環境的特色，會刺激鼻腔和喉嚨的敏感黏膜，使人更容易遭受空氣中化學物質、病毒、黴菌孢子、灰塵和過敏原的感染。而植物會透過光合作用吸收大氣中的二氧化碳，並釋放一些可抑制空氣中黴菌孢子和細菌的植物化學物質，所以說植物是天然的空氣淨化器。根據 Wolverton(1997)研究指出，佈置滿植物的室內空氣含菌量，比未佈置的室內空氣含菌量少 50%~60%。

二、栽培容易度：室內環境與室外環境的差異相當大。選擇室內植物最重要的是衡量室內的溫度、光度和濕度，適當的生長環境和合理的栽培管理，才能使植物

保持良好的生長(葉, 2010)，否則無法達成淨化室內空氣的效果。因此，栽培容易度指標也應納入考量。

三、病蟲害抵抗力：每株植物都會分泌糖、胺基酸、荷爾蒙、有機酸及其他物質的複雜混合物，來刺激其生存所需之特定微生物的成長，並抑制對其有害的微生物。同時植物也會吸收室內空氣中的揮發性有機物質，並將這些化學物質傳輸到根部區域，由該處的微生物分解。微生物在許多方面協助維護其宿主植物的健康，作用就好像守衛一樣，會驅除有害植物的微生物，而且也會消化落葉及植物根部附近的其他碎屑，替植物產生養分。系統性的殺蟲劑就是利用植物的這項輸送能力來吸收運送化學物質。

四、蒸散作用率：水分從植物的葉子蒸發的過程稱為蒸散作用。植物本身就是天然的增濕器，空氣愈乾燥，植物就會透過蒸散作用散發愈多的水分。蒸散作用會形成空氣的流動，只要葉表面與空氣間的溫差顯著，就會產生對流。即使在空氣不流通的情況下，也會使空氣流動。產生空氣流動的能力對植物移除室內環境的毒素來說相當重要。因此，室內乾燥的空氣，可藉由植物蒸散作用率將含有毒素的空氣往根部移動，由根部的微生物將氣體分解為養分與能量的來源。

承上，Wolverton在生態屋的試驗中，計算植物的四項評估值及綜合平均值，選出優良室內植栽共五十種，作為有效改善空氣污染的參考。由於試驗中僅測出植栽的四項評估值，無法對植栽淨化空氣能力作出績效優先順序的排列，又其中有九種植栽在台灣市面上比較不常見，因此，本研究以台灣常見的四十一種為例，引用植物的淨化化學氣體指數(X1)、栽培容易度(X2)、病蟲害抵抗力(X3)以及水分蒸散作用率(X4)的評估值，並以Y代表總評分(如表5)。運用DEA-CCR投入導向模式評估多項投入與產出相對績效排名的優勢，找出相對改善室內空氣效率值較高的植物，作為本研究採用的植栽對象。

表 5. 美國太空總署(NASA)評估植栽之原始數據資料
Table 5. Source data of NASA assessed plants

DMU(受評單位)		Input				Output
中文名稱	植物學名	X1	X2	X3	X4	Y
中斑香龍血樹	*Dracaena fragrans 'Massangeana'*	8	7	8	7	7.5
紅邊竹蕉	*Dracaena marginata*	6	7	8	7	7.0
虎尾蘭	*Sansevieria trifasciata*	3	10	10	2	6.3
黃椰子	*Chrysalidocarpus lutescens*	8	8	8	10	8.5
觀音棕竹	*Rhapis excelsa*	7	9	10	8	8.5
雪佛里椰子	*Chamaedorea seifrizii*	9	8	8	9	8.4
羅比親王海棗	*Phoenix roebelenii*	9	7	8	7	7.8
袖珍椰子	*Chamaedorea elegans*	4	8	8	7	6.6
白鶴芋	*Spathiphyllum spp.*	8	7	7	8	7.5
黃金葛	*Epipremnum aureum*	5	10	8	7	7.5
合果芋	*Syngonium podophyllum*	4	9	8	7	7.0
噴雪黛粉葉	*Dieffenbachia'Exotica Compacta'*	7	8	6	7	6.8
白玉黛粉葉	*Dieffenbachia'Camilla*	5	7	6	7	6.2
羽裂蔓綠絨	*Philodendron selloum*	3	8	8	6	6.3
心葉蔓綠絨	*Philodendron oxycardium*	4	9	9	4	6.3
銀后粗肋草	*Aglaonema 'Silver Queen'*	4	6	5	6	5.3
火鶴花	*Anthurium andraeanum*	3	5	6	7	5.3
印度橡膠樹	*Ficus robusta*	9	9	8	7	8.0
垂榕	*Ficus benjamina*	8	6	6	6	6.5
常春藤	*Hedera helix*	9	8	8	7	7.8
澳洲鴨腳木	*Schefflera actinophylla*	8	8	4	7	6.5
波士頓腎蕨	*Nephrolepis exaltata ‘Bostoniensis’*	9	4	8	9	7.5
皺葉腎蕨	*Nephrolepis obliterata*	9	4	8	9	7.4
菊花	*Chrysanthemum morifolium*	9	4	8	8	7.4
非洲菊	*Gerbera jamesonii*	9	4	8	8	7.3
豹紋竹芋	*Maranta leuconeura `Kerchoviana'*	3	6	8	7	6.0
孔雀竹芋	*Calathea makoyana*	5	4	6	6	5.0
麥門冬	*Liriope spicata*	7	4	6	5	5.5
中斑吊蘭	*Chlorophytum comosum 'Vittatum'*	6	6	5	5	5.4
石斛蘭	*Dendrobium sp.*	7	4	6	5	5.5
蝴蝶蘭	*Phalaenopsis sp.*	3	5	7	3	4.5
變葉木	*Codiaeum variegatum pictum*	3	6	8	5	5.3
聖誕紅	*Euphorbia pulcherrima*	3	5	7	5	5.1
蘆薈	*Aloe barbandensis*	2	8	8	2	5.0
鬱金香	*Tulipa gesneriana*	7	4	5	3	4.7
麗格海棠	*Begonia hiemalis*	4	6	8	7	6.3
小葉南洋杉	*Araucaria heterophylla*	2	7	9	6	6.2
螃蟹蘭	*Schlumbergera bridgesii*	3	9	8	3	5.8
西洋杜鵑	*Rhododendron simsii "Compacta"*	6	4	5	5	5.1
仙客來	*Cyclamen persicum*	3	5	6	5	4.8
長壽花	*Kalanchoe blossfeldiana*	2	7	7	2	4.5

接著運用 Input-Oriented CCR Model 計算出在四十一個植栽樣本中，有十七種室內植栽的效率值均為 1，表示這些植栽具有淨化室內空氣的完全技術效率。這十七種植栽為：虎尾蘭(*Sansevieria trifasciata*)、黃椰子(*Chrysalidocarpus lutescens*)、黃金葛(*Epipremnum aureum*)、合果芋(*Syngonium podophyllum*)、羽裂蔓綠絨(*Philodendron selloum*)、銀后粗肋草(*Aglaonema 'Silver Queen'*)、火鶴花(*Anthurium andraeanum*)、垂榕(*Ficus benjamina*)、澳洲鴨腳木(*Schefflera actinophylla*)、波士頓腎蕨(*Nephrolepis exaltata 'Bostoniensis'*)、菊花(*Chrysanthemum morifolium*)、蝴蝶蘭(*Phalaenopsis sp.*)、蘆薈(*Aloe barbandensis*)、鬱金香(*Tulipa gesneriana*)、小葉南洋杉(*Araucaria heterophylla*)、螃蟹蘭(*Schlumbergera bridgesii*)及西洋杜鵑(*Rhododendron simsii "Compacta"*)。其餘二十四種植栽的效率值均小於 1，表示淨化室內空氣有技術無效率的情況存在。

接著再由 Super-SBM 模型進一步篩選出相對效率排名前四種的植栽，分別為澳洲鴨腳木(*Schefflera actinophylla*)、小葉南洋杉(*Araucaria heterophylla*)、虎尾蘭(*Sansevieria trifasciata*)以及鬱金香(*Tulipa gesneriana*)。這四種植栽由於具有高淨化室內空氣的完全技術效率，將作為本研究的植栽對象。

第四節　田口方法

根據上述分析的結果，並透過特性要因圖歸納整理後，找出澳洲鴨腳木、小葉南洋杉、虎尾蘭、鬱金香四種具高淨化室內空氣的完全技術效率的植栽，如再配合環境置換時間，將使得商務經營環境的室內空氣淨化及紓壓之效果，達到更具完全技術效率。根據 Ross (1988)與 Taguchi (1990)的研究指出，TM 是以試驗的方式來決定設計參數，主要是依控制因子與其水準的數目，選用適當的直交表，並以 S/N 比替代品質損失函數，以減少交互作用。這個方法能在最低成本、最短時間與最少試驗次數的情況下，對產品品質與設計提供穩健的建議。因此，為得

到較佳的設計參數，本研究將使用 TM 進行分析。

承上所述，本研究將針對淨化商務經營環境之室內空氣的影響原因，選擇控制因子與其水準(如表 6)，並以 TM 找出植栽品種與置換時間的最佳參數設計。

表 6. 田口方法控制因子水準表

Table 6. T Table of control factors and levels of Taguchi method

	因子	水準 1	水準 2	水準 3	水準 4
A	植栽品種	澳洲鴨腳木	小葉南洋杉	虎尾蘭	鬱金香
B	環境置換時間	1 週	2 週	3 週	4 週

本試驗共有二個 4 水準因子，因此採用 $L_{16}(4^5)$直交表，而 L_{16} 直交表也是田口博士高度推薦的直交表之一(如表 7)。本試驗分別於 99 年 5 月 7 日、14 日、21 日、28 日下午，針對台中某科技大學 45 位選修通識課程學生進行問卷調查。性別方面，受測者中男生為 20 人(44.44%)，女生為 25 人(55.56%)，年齡平均為 21.18。由於韓(2006)「環境復癒量表精簡改良版」，融合 Kaplan andKaplan (1989)功能演化論與 Ulrich(1983)心理演化論，具有高信度與高效度，本研究引用以量化自然元素對人

類所產生的心理疲勞以及注意力恢復的影響。問卷衡量尺度採用 Likert 的 5 等量表，結果平均滿意度亦列於表中。

表 7. $L_{16}(4^5)$直交表試驗結果

Table 7. Experiment results by $L_{16}(4^5)$ orthogonal matrix

試驗號碼	參數與水準		結果	
	A	B	平均滿意度	*S/N*(dB)
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
17	對照組		2.316	7.2948

接著本研究將以表 7 的試驗結果，透過式(5)計算出每次試驗結果的 *S/N* 比。*S/N* 比越大，表示對淨化商務經營環境之室內空氣的影響愈大，代表紓壓品質水準愈高。再利用表 7 所列的 S/N 比，可求得二個因子各水準的平均 S/N 值，如表 8 所示。

表 8. 設計因子對 *S/N* 比反應表

Table 8. The reaction of designed factors to S/N Ratio

水準	A	B
水準 1	11.464	11.420
水準 2	11.361	11.433
水準 3	11.637	10.870
水準 4	9.979	10.719
效果	1.658	0.714
排序	1	2

當表 8 中各因子的效果值愈大時，表示設計因子對 *S/N* 比反應愈高。最後，將這些數據繪於圖 5 中，即可獲得因子設計組合 A3、B2 為商務經營環境之最佳參數設計。換言之，當植栽品種為虎尾蘭與環境置換時間為兩週時，將可使得商務經營環境的品質水準提升至最佳。接著，進行確認試驗，求得 *S/N* 比預測值為 11.96，試驗值為 11.535，兩個數值的差異為 0.425，落在 95%的信賴區間之內。這表示試驗成功，結果具有加法性，結論是可靠的。

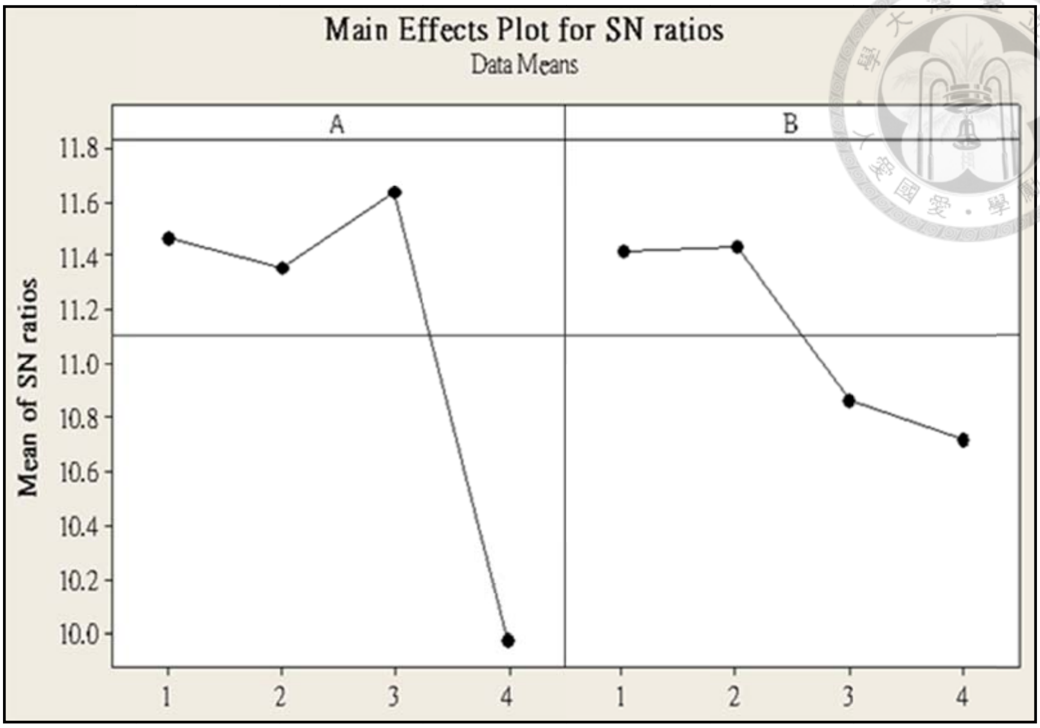

圖 5. *S/N* 比因子效果圖

Fig. 5. Main effects plot for S/N ratio

第五節　小結

本研究首先運用 DEA 選取淨化商務經營環境能力較高的前四名室內植栽，分別為澳洲鴨腳木、小葉南洋杉、虎尾蘭以及鬱金香。接著再配合環境置換時間，透過 TM 找出，當室內擺放虎尾蘭與環境置換時間為兩週時，將可使環境品質的水準提升至最佳。經由本研究的探討，已建立一套可以淨化室內空氣，紓緩壓力，並提升工作效率的植栽評估模式。這套模式不僅可以強化商務經營之效率、提升企業競爭力，相信面對未來激烈競爭的商場環境，亦有助於再創經營佳績。

第四章　導入六標準差概念提升室內健康環境品質

本章以安養照護機構的閱覽室為例，導入6σ之DMAIC流程，建立評估模式，以提升室內環境的健康紓壓品質，並強化競爭力。茲說明如下：(Chen *et al.*, 2013a)

第一節　前言

隨著生活水準提升、醫療進步與預防保健的推展，台灣社會人口結構逐漸呈現高齡化現象。根據內政統計年報顯示(內政部, 2013a)，1993年台灣已正式邁入「高齡化社會(aging society)」，65歲以上人口占總人口數7.09%，達到WHO的高齡化社會指標。截至2012年底，65歲以上人口更突破260萬人，已達到總人口數的11.14%。這個趨勢顯示，台灣高齡化的速度明顯高於歐美國家，並持續增高，推估至2026年，65歲以上人口的比例將超過20%，達到所謂的「超高齡化社會」。

面對高齡化社會來臨，各種社會福利制度、醫療技術與社會安全的問題也逐漸浮現。加上現今少子化與雙薪家庭的現象普遍，人們往往在工作忙碌之餘，無法妥善顧及老人的需求，於是安養機構已成為老人福利措施中最具規模之服務提供者。再者，人口結構高齡化與疾病型態慢性化，亦是全球性的議題，加上各國人口平均壽命延長，皆促使醫療資源的需求急速增加，因此全球居家照護產業，呈現逐年成長的趨勢。財團法人資訊工業策進會 (2011) 更預估，2015年全球健康照護產值將可能高達5,970億美元，其中我國市場產值則會成長至180億美元。可見與高齡化社會議題相關之產業，具有可觀的需求及發展潛力。

根據內政統計年報顯示(內政部, 2013b)，我國老人的居住型態雖以「與子女居住」的比例最高，但比例已出現逐年下降趨勢，從1986年占70.24%，降到2005年的57.28%。截至2012年底，老人長期照顧及安養機構計有1,067所，提供進住人

數57,968人，實際進住人數43,035人，使用率為74.23％。其中，實際進住人數與使用率分別較2009年底增加3.23％及1.69%。另外，政府於2009年亦將「長期照護產業」列為六大新興產業之一。由上述可知，在國家政策的推動與高齡化社會的趨勢下，照護產業市場前景持續看漲，帶來的龐大需求與商機，可望成為台灣下一波的兆元產業。因此，許多安養照護機構紛紛設置，並卯足全勁搶攻市場。在這種情況下，業者如何提供健康與舒適的安養環境，使老年人的晚年生活更自在與受到尊重，實為刻不容緩的使命與課題。

「安養照護機構」主要是提供二十四小時全天候的安養服務。服務內容包含各種適合老年人的生活服務、居住設施的照應與協助，以及醫療保健等。針對入住老年人的身心機能情況，又可分為長期照護機構、養護機構、安養機構及護理之家等型態。隨著安養照護產業興起，老人服務機構紛紛加入，使各家業者的競爭更白熱化，提供老年人健康舒適的安養環境，可說是業者全力追求的目標。因此，藉由提升安養照護機構經營環境之健康紓壓，勢必能贏得民眾對安養機構的認同與降低空房率，進而提升業者的市場競爭優勢。這不僅能達到顧客和業者間雙贏的局面，也可面對未來安養照護產業龐大的市場需求。因此，本研究將導入6σ之DMAIC方法，以提升安養照護機構健康紓壓暨營運績效。

本研究應用Kaplan and Kaplan(1989)的功能演化論(functional-evolutionary theory)，以及Ulrich(1983)的心理演化論(psycho-evolutionary theory)。首先設計「健康紓壓問卷調查量表」，透過Hung等(2003)的概念發展「績效評估矩陣圖」，定義關鍵問題，並提出健康紓壓衡量指標。接著，透過「特性要因圖」分析老年人對安養照護機構健康紓壓品質不滿意的主要因素，並利用TM找出提升健康紓壓與營運績效之最佳組合。最後，建構標準作業程序(Standard Operating Procedure, SOP)，持續監控健康紓壓品質，俾強化安養照護機構之競爭力。

第二節　定義

Kaplan and Kaplan(1989)與Ulrich(1983)，均主張以心理學的觀點，探討人類與自然環境的互動，藉由接收和分析環境中的資訊，以分辨環境是否適宜居住。他們並且強調自然景色會吸引人類注意力，接觸自然元素的好處，不僅限於視覺的美感，更包含多樣化的正向反應。另外，有研究指出，注意力疲乏與壓力是可重疊的，而壓力是有效用且有意義的概念，須經由一段時間的療癒才可以減輕(韓. 2002)。善用自然環境元素，將有助於人類消除心理疲勞和減輕壓力。

承上，為瞭解安養照護機構之健康紓壓服務品質，本文整合Kaplan and Kaplan (1989)與Ulrich(1983)的理論，及參照Hartig等(1996)、Laumann等(2001)、Purcell等(2001)和曾(2002)的復癒內容特徵進行研究。並且，根據Parasuraman等(1985；1988；1991)的研究指出，顧客服務品質水準可藉由顧客事前對服務的期望(重視度)與事後對服務的實際感受或認知(滿意度)來衡量。問卷中的問句採正向敘述，設計「健康紓壓問卷調查量表」。本問卷主要援用Purcell等(2001)量表，此表已獲得證明，具有高信度與高效度，可節省測試新量表的過程。本量表在正式施測前，經由問卷前測之信度與效度分析，重視度與滿意度之Cronbach's α值分別為0.959與0.956；重視度與滿意度之KMO值則分別為0.629與0.72，顯示問卷結果具有高信度與高效度。因此，建構出七個構面與二十六個評量項目之「健康紓壓問卷調查量表」，如表9所示。藉以評估安養照護機構經營環境之健康紓壓，強化經營環境品質與提升市場競爭力。

此外，為增加安養照護機構使用的方便性，以及符合老年人對數字運用的習慣性，問卷調查的尺度量表採用百分比，描述老年人對安養照護機構經營環境之健康紓壓的滿意度與重視度。當百分比是100%時，表示老年人完全滿意或完全重

視安養照護機構所提供健康紓壓的服務；當百分比是0%時，表示老年人完全不滿意，或完全不重視安養照護機構所提供健康紓壓的服務。百分比愈高，表示老年人對安養照護機構所提供的健康紓壓服務滿意度或重視度愈高；相反地，百分比愈低，則表示老年人對安養照護機構所提供的健康紓壓服務滿意度或重視度愈低。

表 9. 健康紓壓問卷調查量表

Table 9. The scale of healthy stress relief questionnaires

變 項	健康紓壓問項	重視度	滿意度
遠離	1. 此環境可逃離我不想要的不專心。	71.0	68.2
Being away	2. 我可花時間在此並遠離每天律生活。	65.3	72.4
	3. 此環境可遠離每天需要我注意的事情。	69.6	75.0
	4. 此環境可幫助我停止思考必需作的事情。	75.5	72.6
	5. 在此環境我不用注意我不感興趣的事情。	75.4	71.2
一致性	6. 此環境的實質排序有清楚的順序。	73.5	67.1
Coherence	7. 此環境的事情與活動都如此的相稱。	70.2	64.3
	8. 在此很容易看到事物很有次序的。	67.9	67.1
	9. 這裡的每一事物都有適當的位置。	65.3	68.7
範 圍	10.此環境很少有界線去阻止我的移動。	70.6	64.3
Scope	11.此環境夠大到可讓我探索我的方向。	70.1	69.6
	12.這個環境似乎是永恆的。	65.7	67.4
	13.此環境本身有能力自我形成一個世界。	72.7	64.7
魅 力	14.此環境是有魅力。	70.1	65.1
fascination	15.此環境發生的事情引起我的興趣。	66.7	68.7
	16.這環境喚起我的好奇心。	66.4	65.0
	17.這裡有許多可以探索與發現的地方。	69.3	63.7
	18.我的注意力被這裡許多有趣事情吸引。	66.9	64.8
相容性	19.此環境很少阻止我想作的事情。	65.5	62.8
compatibility	20.在此可以符合我目前的個人意圖。	66.9	63.3
	21.在這裡很容易做我想作的事。	65.2	60.2
	22.在此我可很容易找到我的路。	64.5	66.4
	23.這裡有我喜歡作的活動。	64.3	59.9
偏 好	24.我喜歡這個環境讓我心情舒暢。	76.3	58.6
Preference	25.我偏好這個環境勝過其他地方。	67.9	65.1
熟悉感	26.這環境是我熟悉的地方。	63.8	68.1
Familiarity			

由於每位顧客的需求與期望間之差異程度不一致，所以不同的顧客對機構所提供健康紓壓之服務滿意度與重視度的認知也會有所差別。假設 X 代表顧客對機構所提供健康紓壓的滿意度，顯然 X 為介於 0 到 1 的隨機變數。根據 Johnson(1999)所提出之觀念，隨機變數介於 0 與 1 之間，通常會服從具有母數(α,β)的 Beta 機率分配。因此，本研究令隨機變數 S 為顧客對機構所提供健康紓壓感受的滿意度，隨機變數 E 為顧客對機構所提供健康紓壓期望的重視度，針對表 9 各評量問項，分別定義滿意度指標與重視度指標，如公式(12)和(13)所示：

$$I_{S_i} = \frac{\alpha_{S_i} - \beta_{S_i}}{\alpha_{S_i} + \beta_{S_i}} \qquad \text{(滿意度績效指標)} \tag{12}$$

$$I_{E_i} = \frac{\alpha_{E_i} - \beta_{E_i}}{\alpha_{E_i} + \beta_{E_i}} \qquad \text{(重視度績效指標)} \tag{13}$$

其中$i = 1, \cdots, n$，α_{S_i}及β_{S_i}為 i 問項滿意度分配的母體參數，α_{E_i}及β_{E_i}為 i 問項重視度分配的母體參數。對某問項而言，當滿意度績效衡量指標$I_{S_i} > 0$時，即$\alpha_{S_i} > \beta_{S_i}$，其機率分配屬於左偏分佈(圖 6 中 A 分佈情況)，表示平均滿意度高於不滿意度，即顧客對機構所提供健康紓壓感到滿意。當滿意度績效衡量指標$I_{S_i} < 0$時，即$\alpha_{S_i} < \beta_{S_i}$，其機率分配屬於右偏分佈(圖 6 中 B 分佈情況)，表示平均不滿意度會高於滿意度，即顧客對機構所提供健康紓壓感到不滿意。當滿意度績效衡量指標$I_{S_i} = 0$時，即$\alpha_{S_i} = \beta_{S_i}$，其機率分配屬於對稱分佈(圖 6 中 C 分佈情況)，表示平均滿意度與平均不滿意度各為一半，即顧客對機構所提供健康紓壓感到普通。

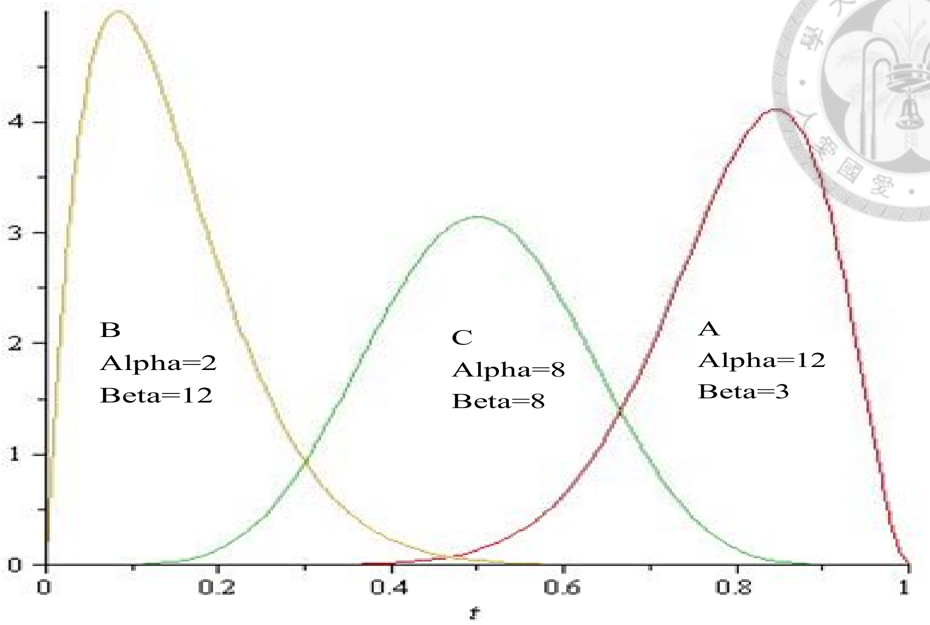

圖 6. 滿意度機率分配圖

Fig. 6. Probability distribution of satisfaction

顯然，從以上的分析可以得知，健康紓壓的滿意度和重視度水準與α值的大小有關。當α＞β時，表示健康紓壓滿意度或重視度越好；相反地，若α＜β時，則表示顧客感受到的健康紓壓滿意度或重視度越差。而針對各問項的重視度推導，也與滿意度相同，故以此類推。因此，以滿意度績效指標為橫軸座標，重視度績效指標為縱軸座標，建構出機構的健康紓壓績效評估矩陣圖，如圖 7 所示。

此外，Hung 等(2003)修正 Lambert and Sharma(1990)矩陣圖中的績效重視區，重新定義一套績效評估矩陣圖。針對 I、II 盲點的問題，把不用改善的合理區域，由原先三大塊改成兩斜線所圍成的區域替代，以解決 I、II 盲點的問題。至於兩斜線之間的距離大小，可依使用機構本身考量內、外在環境、資源成本及組織運作模式等因素而定。

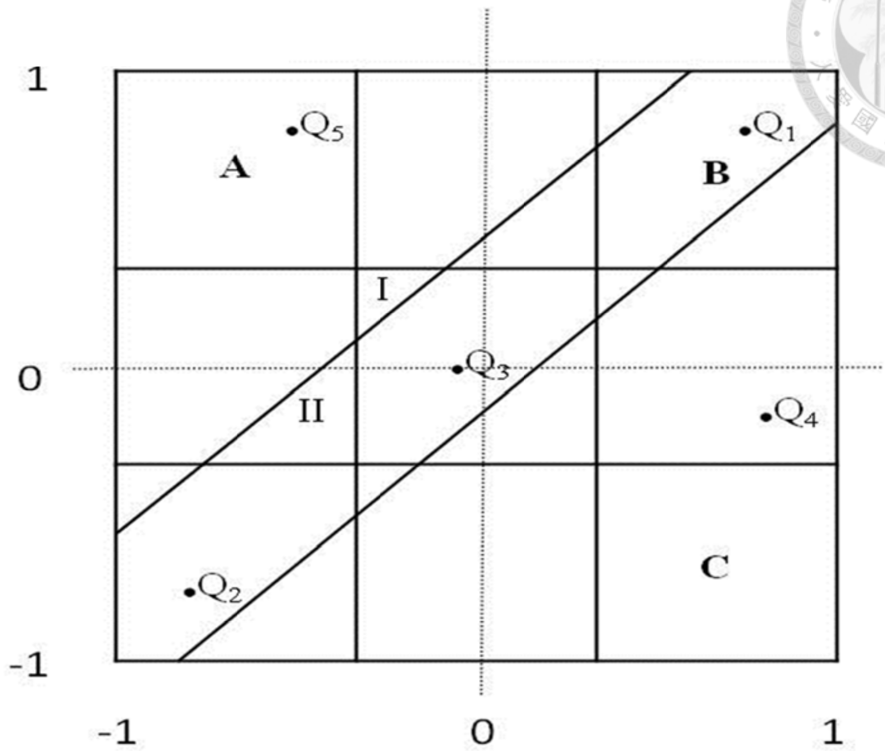

圖 7. 健康紓壓績效評估矩陣圖

Fig. 7. Healthy stress relief performance evaluation matrix

根據上述績效評估矩陣圖，A 類為顧客重視度高於滿意度，代表機構的健康紓壓不如顧客預期，應檢討現行的經營策略，確切執行改善，以提升機構整體健康紓壓。B 類為重視度與滿意度相當的接受區，代表機構的健康紓壓與顧客預期相當，應維持現行的經營策略。C 類為重視度小於滿意度，代表機構的健康紓壓已超出顧客預期。值得注意的是，C 類的滿意度雖高，但機構業者投入的人力資源與經費成本相對較高。在現今競爭激烈且資源有限的情況下，應審慎評估，以免影響機構之整體營運。因此，當機構使用本研究所建立的績效評估矩陣圖評估後，若其評估項目落於 A、C 兩區時，則此評估項目將成為機構改善的問題點，均可成為六標準差的一個專案，進行分析改善。

第三節　衡量

六標準差的第二個步驟為「衡量」，本研究透過績效評估矩陣上的落點，找出顧客高重視且低滿意的問項，定義出需改善的重點。由於顧客對此問項的重視度高但滿意度低，因此，重視度與滿意度的機率分配圖交集重疊部分非常少，代表此問項的重視度與滿意度的差距非常顯著，必需進行改善。例如某問項之滿意度機率分配函數服從βeta(2,10)，其重視度機率分配函數服從βeta(12,3)，即可得知滿意度績效指標$I_{S_i} < 0$與重視度績效指標$I_{E_i} > 0$，意謂顧客對於該問項的健康紓壓重視度高於滿意度，如圖 8 所示。

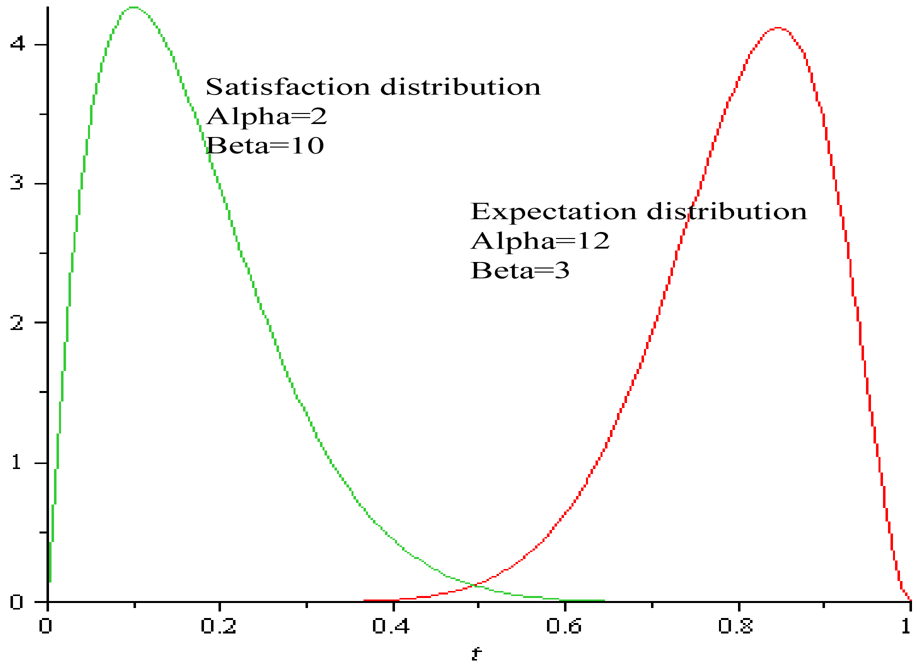

圖 8. 重視度與滿意度的機率分配圖

Fig. 8. Diagram of probability distributions of expectation and satisfaction

而根據績效評估矩陣圖的原意,當重視度與滿意度相當的區域始為合理區域，即圖 7 中 B 類。這表示顧客對於機構的健康紓壓重視度與滿意度相當，重視度與滿意度的機率分配圖交集重疊面積非常大，可分為三種情形探討：

一、當問項之平均重視度與平均滿意度相對較高，即$\alpha_{S_i} > \beta_{S_i}$與$\alpha_{E_i} > \beta_{E_i}$，則機率分配均屬於左偏分佈，其績效分佈落點如圖 7 點 Q1 之情形，意謂顧客對於機構的健康紓壓重視度高與滿意度也高。

二、當問項之平均重視度與滿意度相對較低，即$\alpha_{S_i} < \beta_{S_i}$與$\alpha_{E_i} < \beta_{E_i}$，則機率分配均屬於右偏分佈，其績效分佈落點如圖 7 點 Q2 之情形，意謂顧客對於機構的健康紓壓重視度與滿意度均低。

三、當問項之重視度與滿意度均為普通，即$\alpha_{S_i} = \beta_{S_i}$與$\alpha_{E_i} = \beta_{E_i}$，則機率分配均屬於對稱分佈，其績效分佈落點如圖 7 點 Q3 之情形，意謂顧客對於機構的健康紓壓重視度與滿意度皆為普通。

根據上述觀念，本研究以各服務問項之滿意度與重視度的機率分配圖交集重疊面積大小作為衡量依據。為衡量每一個服務問項之重視度與滿意度的交集重疊面積，訂定一個健康紓壓衡量指標 P。P 的定義如公式(14)所示：

$$P = P_{S_i} + P_{E_i}, 0 \leq P \leq 1 \quad (14)$$

然而，問項重視度與滿意度的機率分配圖交集重疊面積少的情形，又可分為兩種：

一、某問項之滿意度高於重視度時，其績效分佈如圖 7 中 C 類點 Q4 之情形，重視度與滿意度的機率分配圖如圖 9 所示。

其中$P_{S_i} = \int_0^a \frac{t^{\alpha_{S_i}-1}(1-t)^{\beta_{S_i}-1}}{B(\alpha_{S_i},\beta_{S_i})}dt$，為顧客對第 i 個問項滿意度表示百分比 a 以下之比例。

$P_{E_i} = \int_a^1 \frac{t^{\alpha_{E_i}-1}(1-t)^{\beta_{E_i}-1}}{B(\alpha_{E_i},\beta_{E_i})}dt$，為顧客對第 i 個問項重視度表示百分比 a 以上之比例。

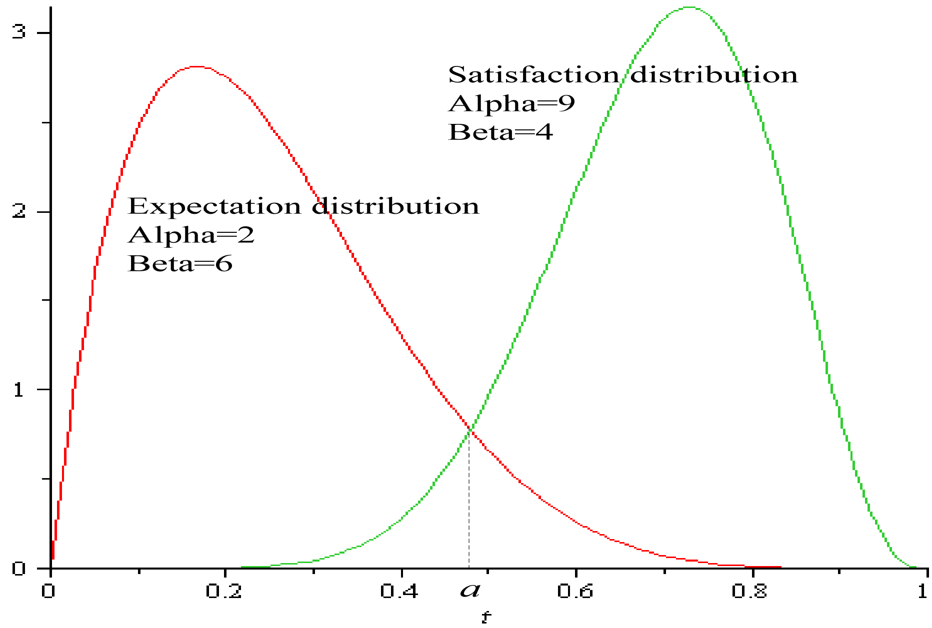

圖 9. 重視度低與滿意度高的機率分配圖圖

Fig. 9. Diagram of low expectation distribution vs. high satisfaction distribution

二、某問項之滿意度低於重視度時，其績效分佈如圖 7 中 A 類點 Q5 之情形，重視度與滿意度的機率分配圖如圖 10 所示。

其中$P_{S_i}=\int_a^1 \frac{t^{\alpha_{S_i}-1}(1-t)^{\beta_{S_i}-1}}{B(\alpha_{S_i},\beta_{S_i})}dt$，為顧客對第 i 個問項滿意度表示百分比 a 以上之比例。

$P_{E_i}=\int_0^a \frac{t^{\alpha_{E_i}-1}(1-t)^{\beta_{E_i}-1}}{B(\alpha_{E_i},\beta_{E_i})}dt$，為顧客對第 i 個問項重視度表示百分比 a 以下之比例。

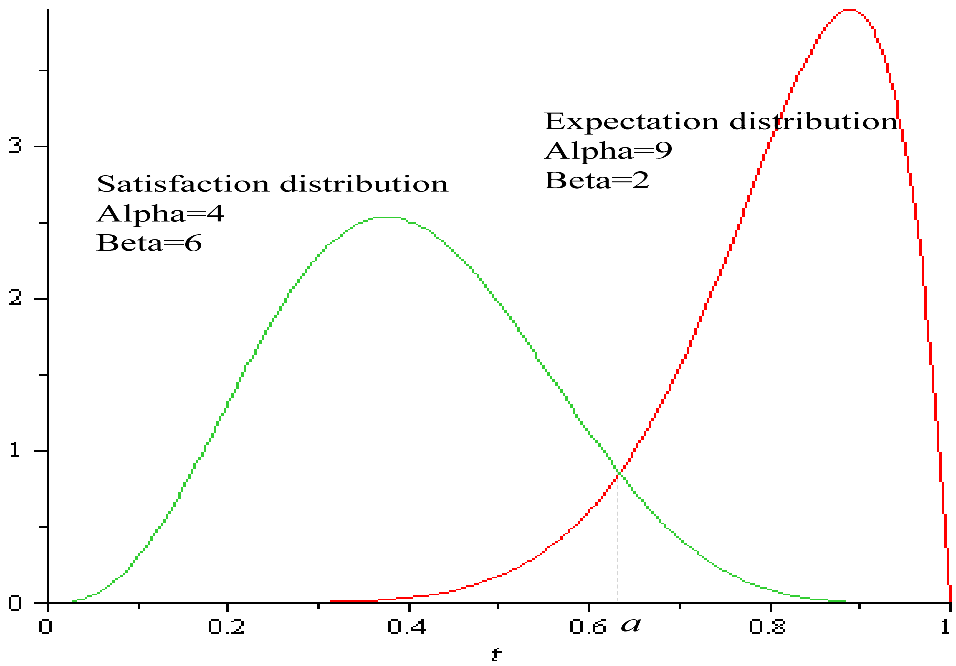

圖 10. 重視度高與滿意度低的機率分配圖

Fig. 10. Diagram of high expectation distribution vs. low satisfaction distribution

因此，當P值越大時，表示顧客對於機構所提供的健康紓壓滿意度與重視度越相近；若P值等於1時，則表示顧客對於機構所提供的健康紓壓滿意度與重視度完全一致；若P值等於0時，則表示顧客對於機構所提供的健康紓壓滿意度與重視度完全不一致。

承上，若點落於A類與C類太多，則可根據上述觀念，計算出重視度與滿意度的交集重疊面積最小的評估問項，列為優先改善的問題點，進行分析、改善，其餘則按面積大小，以此類推。

第四節　分析

六標準差的第三個步驟為「分析」。本研究以臺中某安養照護機構為研究個案，本次問卷調查有效問卷計55份，調查日期為100年4月2日至3日。性別方面，受測者中男生為23人(41.82%)，女生為32人(58.18%)，年齡平均為66.16。在問卷回收登錄完畢後，運用 minitab 16 軟體分析，有關重視度平均數及滿意度平均數所在績效矩陣位置之分析結果，如表9所示。接著，透過前述所提出的績效評估矩陣圖，發現問項第23、24項，分別落於C、A兩區。表示此兩問項將成為安養照顧機構改善的問題點，均可成為六標準差的一個專案進行分析、改善，如圖11所示。最後，再透過健康紓壓衡量指標P，計算此兩問項的重視度與滿意度的交集重疊面積，找出問項第24項的交集重疊面積最小，即為關鍵問項，列為優先改善項目。如圖12所示。

接著針對安養照護機構經營環境健康紓壓不佳的原因進行分析。事實上分析的工具和方法有很多，如甘特圖、散佈圖、製程能力分析等。而目前業界主要以「特性要因圖」作為重要且方便使用的分析工具，係利用人員、方法、材料、測量、機器等五個主要因素再尋找次要影響因素，逐一找出不良的原因，再進行改善。例如Huang等(2010)利用特性要因圖，以人員、機具、設計及材料等四大構面

分析監控攝影機設備焊錫作業不良之問題。Chen等(2010a)也曾使用特性要因圖以專業訓練、知識體系、管理制度及投資與創新等四個構面，分析休閒服務品質不佳之原因。

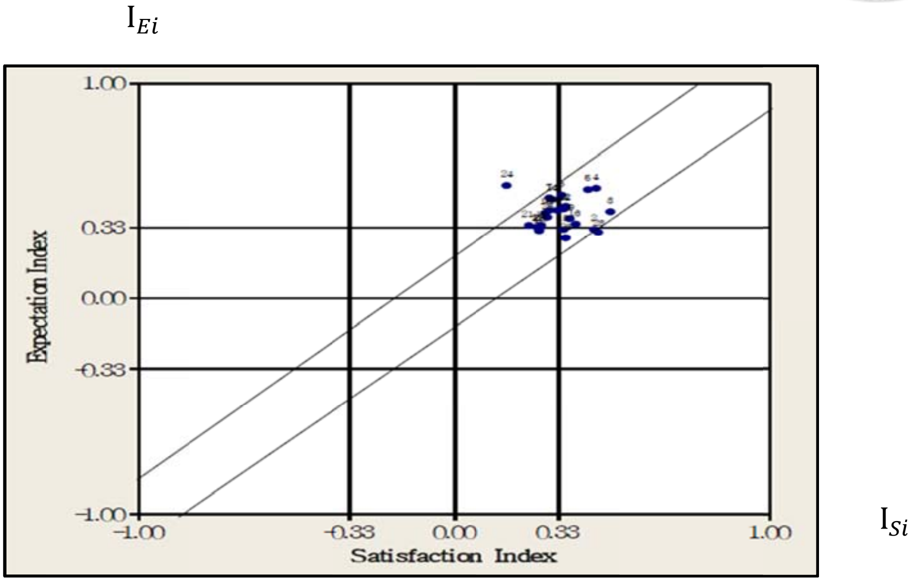

圖 11. 安養照護機構之健康紓壓績效評估矩陣圖

Fig. 11. The healthy stress relief performance evaluation matrix of nursing and caring institutions.

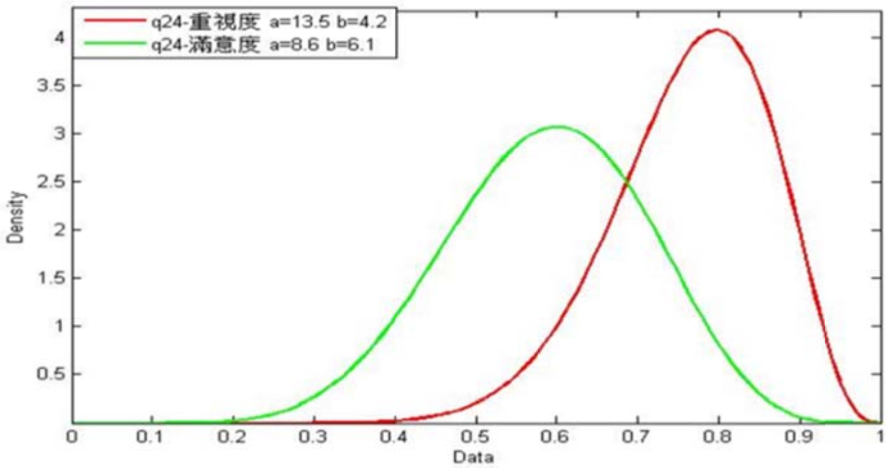

圖 12. 問項第24項的重視度與滿意度的機率分配圖

Fig. 12. Diagram of expectation distribution vs. satisfaction distribution for item 24

如前所述，特性要因圖是一項很好的分析工具，透過特性要因圖，使得越來越多企業的產品品質或服務品質更加完善。故本研究以特性要因圖作為分析安養照護機構的健康紓壓品質不佳之重要工具，將影響安養機構健康紓壓不佳歸類為四大構面，即人員、設施、環境及制度。另外，政府於2007年開始針對安養照護機構進行實地評鑑機制，亦訂定相關法規加以規範。其中對於工作人員、機構設施、管理制度及環境衛生防護等項，均加以輔導、監督，以保障老年人權益，促進安養照護機構業務發展，進而提升機構經營環境之健康紓壓與整體服務品質。因此，本研究將以安養機構的整體室內環境營造為重點，再透過特性要因圖探討導致健康紓壓不佳之因素，分為植栽品種、精油種類、音樂類別等三部分，如圖13所示。

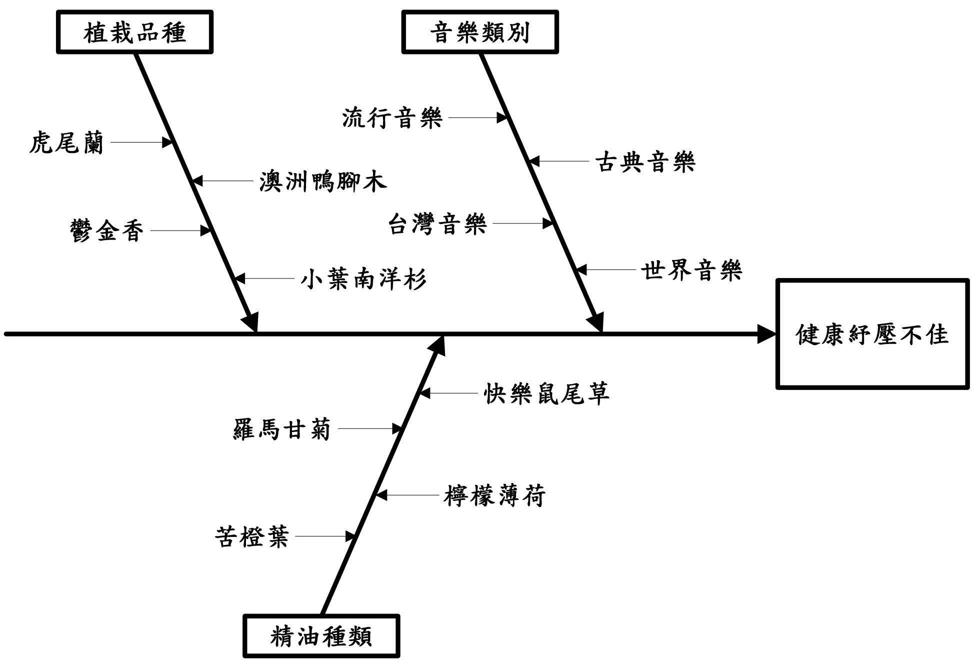

圖 13. 健康紓壓不佳之特性要因圖

Fig. 13. The cause and effect diagrams for poor healthy stress reliefs

一、植栽品種：人們處於室內環境的時間長，尤其老年人停留在室內的時間經常超過 90%以上。室外之氣懸微粒藉由氣流傳輸進入室內，直接影響室內空氣品質，間接影響人體呼吸系統的健康。Bringslimark 等(2009)指出，室內植栽具有視覺美感，會引起注意力，進而產生心理恢復效益。Honeyman(1992)亦表示，室內環境若擺放植栽，不僅能提高人們正向情緒，有效紓解壓力，還能提升工作效率及增加生產力；若沒有擺放植栽，則會提高人們的負面情緒，降低工作效率。而有多項研究證實，商務經營環境配置植栽，可以達到淨化空氣的功效，幫助企業員工釋放壓力(Dijkstra *et al*., 2008；Chang and Chen, 2005)。因此，擺放適當的植栽品種，將能有效提升安養照護機構的室內空氣品質，消除疲勞、紓緩壓力，進而提升整體環境之健康紓壓。

二、精油種類：精油的化學組成分為 12 類，各具親油性、親水性、陰性及陽性之不同性質。精油透過嗅覺、皮膚接觸進入人體，能平衡身心靈、增強免疫功能、促進新陳代謝和血液循環，以達到強化身體各系統的功能。根據 1990 年法國皮耶佛朗秀姆(Pierre Franchomme)與潘威爾(Daniel Penoel)的研究指出，植物體內的含酯成分對人體放鬆、情緒舒壓，具有良好的效果。德國茹絲‧馮布朗史萬格(R.Von Braunschweig)亦表示，植物體內的酯成分，對人的情緒面的感覺具有緩和作用(Von Braunschweig and 溫, 2003)。因此，使用符合老年人的精油，必定能使人心情愉悅、移除負面想法，也將能營造舒適與健康的安養環境，提升經營環境的健康紓壓。

三、音樂類別：音樂是聽覺藝術，由音量、音調、節奏與速度組合而成，常會令人感覺到寧靜，具有沉澱心靈、放鬆心情和紓壓的效果。而音樂亦可作為治療的一種媒介，根據美國國立音樂治療協會(The National Association for Music Therapy)在 1977 年對「音樂治療」的定義為：音樂治療是把音樂的成就當成治療的目標，令音樂達到恢復(restoration)、保持(maintenance)以及改進

(improvement)個體心理和生理健康的作用，以使個體行為上帶來良好的(desirable)改變。另外 Gauthier and Dallaire (1993)指出，音樂治療即為控制性的使用音樂與其要素，幫助病患與老年人於治療期間能達到身心與情緒統合的一種治療。透過上述可知，音樂治療是運用音樂對人的生理與心理所可能產生的影響，協助個體達到維持及增進身心健康的目標。因此，在安養照護機構內，播放適合老年人的音樂曲目，將可改善老年人的情緒狀態，與負向心理感受，以營造出具有健康紓壓的安養環境。

第五節　改善與控制

本研究係以安養照護機構之整體室內環境營造為重點，運用特性要因圖找出導致機構環境健康紓壓不佳的因素，分為植栽品種、精油種類、音樂類別等三大主因。由於老年人居住在室內的時間比一般人還長，甚至超過 90%以上，所以提醒機構業者應重視老年人的安養環境，以營造一個具有健康紓壓暨舒適的居住環境為目標，俾守護每位老年人的健康，進而提升市場競爭力與營運績效。

在植栽品種方面，本研究根據 Chen 等(2010b)藉由 DEA 挑選淨化室內空氣能力較高的前四名植栽，分別為澳洲鴨腳木(Schefflera actinophylla)、小葉南洋杉(Araucaria heterophylla)、虎尾蘭(Sansevieria trifasciata)以及鬱金香(Tulipa gesneriana)，作為提升安養照護機構健康紓壓之標的植栽。精油種類方面，參考卓(2009)對植物體內之酯分子含量的分析，挑選較高的前四名精油，分別為羅馬甘菊(Anthemis nobilis)80%、快樂鼠尾草(Salvia sclarea)70%、苦橙葉(Citruus aurantium)50～70%及檸檬薄荷(Mentha citrata)66%，作為本研究的標的精油。而音樂類別方面，衡量本研究以安養照護機構的老人為研究對象，因此，參考曾(1997)、曾(2005)的音樂分類基礎及鄭(2007)探討老年人的音樂偏好及生理反應，故選用放鬆型的「古典音樂」、「世界音樂」、「流行音樂」與「台灣音樂」等四種音樂類型，並經由受

測者親自選取的曲目分別為「Mozart-Serenade No.13 for Strings in G major」、「You Can Call Me Al」、「そばにいるね」和「落花流水」。接著，將挑選出的植栽、精油與音樂三者相互搭配，找出提升安養照護機構健康紓壓之最佳組合。

為得到較佳的設計參數，本研究將利用 TM 進行探討，並針對影響安養照護機構健康紓壓之不佳原因，選擇控制因子與其水準(如表 10)，找出植栽品種、精油種類與音樂類別的最佳參數組合，將作為提升其室內健康環境品質之參考。

表 10. 田口方法控制因子水準表

Table 10. Table of control factors and levels of Taguchi method

	因子	水準 1	水準 2	水準 3	水準 4
A	植栽品種	澳洲鴨腳木	小葉南洋杉	虎尾蘭	鬱金香
B	精油種類	羅馬甘菊	快樂鼠尾草	苦橙葉	檸檬薄荷
C	音樂類別	古典音樂	世界音樂	流行音樂	台灣音樂

本試驗共有三個 4 水準因子，因此，採用 $L_{16}(4^5)$直交表。本試驗於 100 年 7 月 4 日至 19 日下午，針對台中某安養照護機構 52 位老年人進行問卷調查。性別方面，受測者中男生為 24 人(46.15%)，女生為 28 人(53.85%)，年齡平均為 65.76。調查量表引用韓(2006)「環境復癒量表精簡改良版」，問卷衡量尺度採用 Likert 的 5 等量表，結果平均滿意度亦列於表 11 中。

表 11. $L_{16}(4^5)$直交表試驗結果

Table 11. Experiment results by $L_{16}(4^5)$ orthogonal matrix

試驗號碼	參數與水準			結果	
	A	B	C	平均滿意度	*S/N*(dB)
1	1	1	1	3.6901	11.3408
2	1	2	2	3.4596	10.7805
3	1	3	3	3.3755	10.5668
4	1	4	4	3.2621	10.2699
5	2	1	2	3.5070	10.8987
6	2	2	1	3.4354	10.7195
7	2	3	4	3.8741	11.7634
8	2	4	3	3.3656	10.5412
9	3	1	3	3.9353	11.8996
10	3	2	4	3.8957	11.8117
11	3	3	1	3.8533	11.7167
12	3	4	2	3.8280	11.6594
13	4	1	4	3.7589	11.5012
14	4	2	3	3.2750	10.3042
15	4	3	2	3.5807	11.0794
16	4	4	1	3.6946	11.3513
17	對照組			2.8731	9.1671

接著，本研究將以表 11 的試驗結果，透過式(5)計算出每次試驗結果的 *S/N* 比，*S/N* 比越大，表示影響安養照護機構環境的健康紓壓愈大，代表健康紓壓品質水準愈高。再利用表 11 所列的 S/N 比，可求得三個因子各水準的平均 S/N 值，如表 12 所示。

表 12. 設計因子對 *S/N* 比反應表

Table 12. The reaction of designed factors to S/N Ratio

水準	A	B	C
水準 1	10.740	11.410	11.283
水準 2	10.982	10.900	11.106
水準 3	11.772	11.284	10.830
水準 4	11.066	10.967	11.344
效果	1.032	0.510	0.514
排序	1	3	2

當表 12 中各因子的效果值愈大時，即設計因子對 *S/N* 比的反應愈高。其中，植栽品種的效果值最大，表示影響安養機構整體環境之健康紓壓所占比例最重，音樂類別次之，而以精油種類所占影響程度最輕。最後，將這些數據繪於圖 14 中，可獲得因子設計組合 A3、B1 與 C4，為提升安養照護機構健康紓壓之最佳參數設計。換言之，當安養機構於室內擺放虎尾蘭植栽與播放台灣音樂，並使用羅馬甘菊精油，將可提供健康與舒適的安養環境，使老年人對機構整體環境的健康紓壓品質提升至最佳。接著，進行確認試驗，求得 *S/N* 比預測值為 12.25，試驗值為 11.509，兩個數值的差異為 0.741，落在 95%的信賴區間之內，表示試驗成功，結果具有加法性，結論是可靠的。

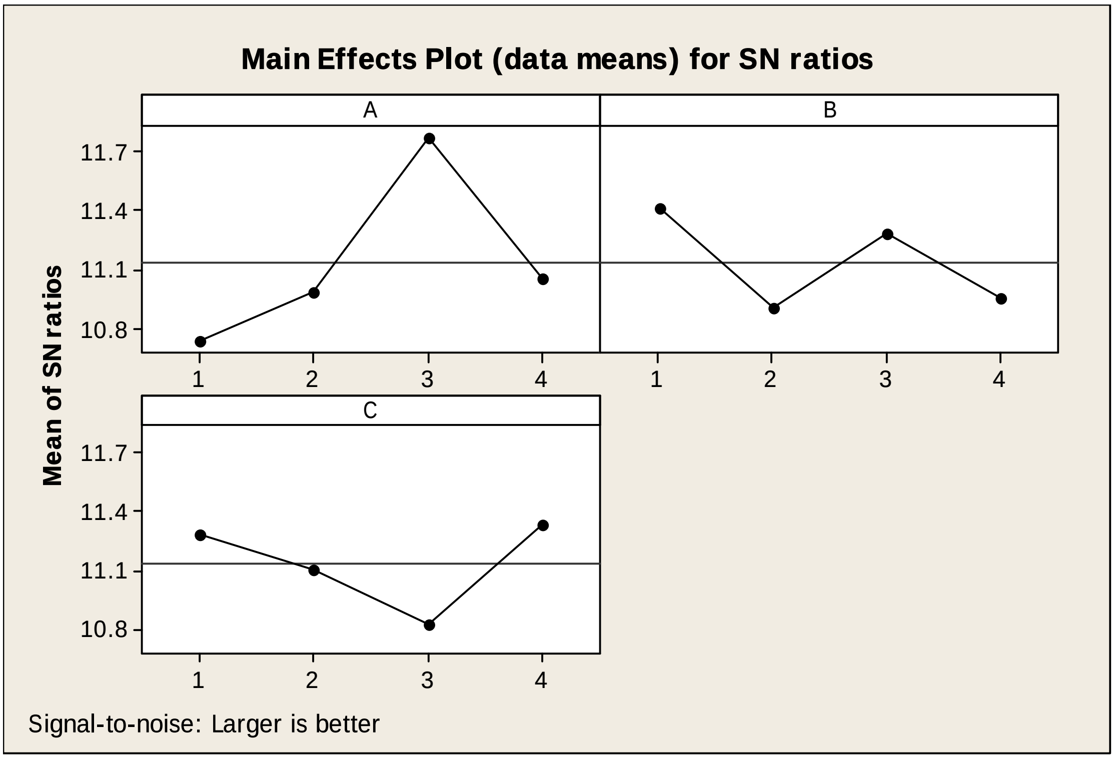

圖 14. *S/N* 比因子效果圖

Fig. 14. Main effects plot for S/N ratios

六標準的最後步驟為「控制」。本研究將建立 SOP，如圖 15 所示，隨時檢視老年人對機構環境健康紓壓績效之變化，立即檢討分析問題，提出具體改善策略。藉由 SOP 有效監控健康紓壓之品質，可作為業者提升機構健康紓壓之參考，以營造具有健康舒適的居住環境，進而提升市場競爭力與營運績效。

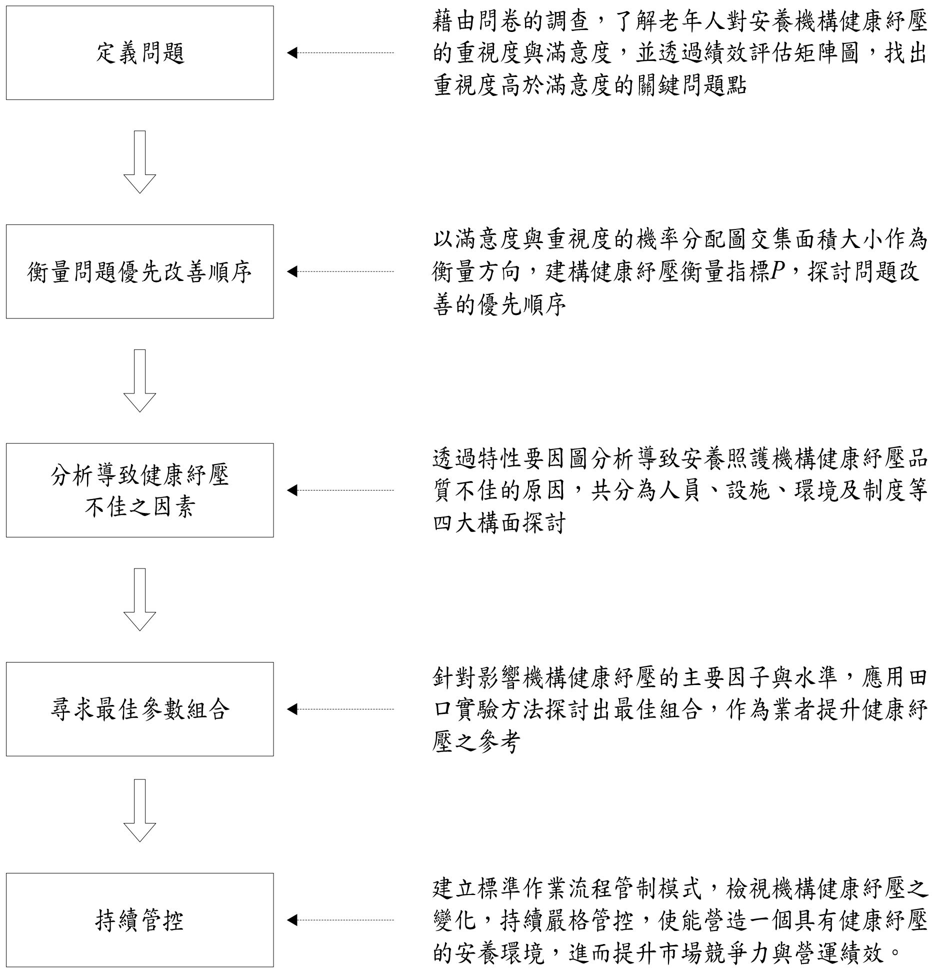

圖 15. 標準作業流程圖

Fig. 15. SOP chart

第六節　小結

本研究利用「健康紓壓問卷調查量表」，調查老人對安養照護機構經營環境之健康紓壓的重視度與滿意度。透過績效評估矩陣圖定義關鍵問題，以滿意度與重視度的機率分配圖交集重疊面積大小作為衡量方向。建構健康紓壓衡量指標 P，探討問題改善的優先順序，並運用特性要因圖找出健康紓壓不佳的原因。再以 TM 將老年人的意見作為重要性指標，找出提升經營環境之健康紓壓之最佳組合。

綜合而言，本研究藉由導入六標準差之 DMAIC 流程，已建立一套適用於安養照護機構的健康環境評估標準作業流程，用以維持、控制機構整體環境的健康紓壓品質。相信面對未來激烈的競爭環境，這套評估模式可提升安養照護機構的競爭力，並創造經營佳績。

第五章　採用網路層級分析法和田口方法評估室內健康環境品質

本章以幼稚園的會議室為例，採用 ANP 篩選室內健康環境影響因子，透過 TM 找出最佳參數組合，以提升室內環境之健康紓壓的品質。茲說明如下：(Chen *et al.*, 2013b)

第一節　前言

現代社會中，每人每天約有 80％－90％的時間是在密閉式環境中工作(Abbriti and Muzi, 1995)。由於室內可能含有各種有機化學物質，污染室內空氣，導致人員的身體越來越不健康、工作效率變差。許多研究指出，室內植栽具有視覺美感，可引起注意力，進而產生心理恢復效益(Bringslimark *et al*., 2009)。例如可以濾淨空氣、紓解壓力等(Chang and Chen, 2005；Bringslimark *et al*., 2007；Dijkstra *et al*., 2008)。精油透過嗅覺、皮膚吸收，能讓人心情愉悅，移除負面的想法(Von Braunschweig and 溫, 2003)。而音樂是聽覺藝術，具有令人心靈寧靜、放鬆肌肉和紓壓的效果(Brunges and Avigne, 2003；McKinney *et al*., 1997)。綜合以上的研究，植栽、精油和音樂三者都能淨化心靈、紓緩壓力和改善 SBS，與健康紓壓具有正相關的關係。

在前面的章節中，案例 1 應用 NASA 植栽原始數據資料，透過 DEA 選取優良植栽；案例 2 以特性要因圖找出植栽、精油和音樂三要素是導致健康紓壓不佳的原因，並探討室內健康紓壓環境效果。惟植栽由於投入項及產出項的數據明確，可以透過 DEA 選取，但精油及音樂的部分，因缺乏明確數據，難以比照施行。而 DEA 也受到僅能個別選取因子條件之限制，無法將植栽、精油及音樂三者相互依存及回饋的關係納入考量，因此本研究參考 Chen 等(2013a)的概念，透過特性要因圖分析、專家訪談及文獻回顧，針對植栽、精油與音樂等影響室內環境健康等因素，建構影響健康紓壓環境的構面與準則，並導入 ANP 找出影響健康紓壓環境構

面中各準則的權重值，篩選出重要的影響準則。接著利用 TM 找出提升環境紓壓品質之最佳參數組合，最後發展統計檢定模式來驗證改善前後的效益。透過本研究所提供的評估模式，不僅可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，創造舒適、清新與健康的環境，提供醫療照護、養老院及辦公場所等機構，作為改善環境的參考。

第二節　網路層級分析法篩選室內健康環境影響因子

本研究將同時考量以音樂、精油及植栽等三項影響因子為基礎，建構健康紓壓的環境。有關各因子間的關係說明如下：

一、植栽構面：首先在植栽的選擇部分，Chen 等(2010b)曾針對美國太空總署(NASA) Wolverton(1997)選出有效改善空氣污染的室內植栽共五十種，應用 DEA-CCR 投入導向模式分析選取優良植栽。本研究參酌專家意見，篩選出相對效率排名前七名的植栽，分別為澳洲鴨腳木(*Scheffleraactinophylla*)、小葉南洋杉(*Araucaria heterophylla*)、虎尾蘭(*Sansevieriatrifasciata*)、鬱金香(*Tulipagesneriana*)、蘆薈(*Aloe barbandensis*)、火鶴花(*Anthuriumandraeanum*)及蝴蝶蘭(*Phalaenopsis sp.*)，作為探討室內健康紓壓環境之植栽。

二、精油構面：根據 1990 年法國皮耶佛朗秀姆(Pierre Franchomme)與潘威爾(Daniel Penoel)研究指出，植物體內的含酯成分對人體放鬆、情緒紓壓具有良好的效果；德國茹絲‧馮布朗史萬格(R.Von Braunschweig)亦表示植物體內的酯成分，對人的情緒面的感覺具有緩和作用。所以，適當的使用精油種類，能消除疲勞、緊張，達到心情愉悅與移除負面的想法。因此，本研究在精油因子的選擇部分，以卓(2009)曾挑選植物體內酯成分含量較高的精油，分為羅馬洋甘菊(*Anthemisnobilis*)80%、快樂鼠尾草(*Salvia sclarea*)70%、苦橙葉

(*Citruusaurantium*)50～70％、檸檬薄荷(*Menthacitrata*)66%、摩洛哥茉莉(*Jasminumofficinalis*)54%、薰衣草(*Lavandulaangustifolia*)45%及佛手柑(*Citrus bergamia*)40%等七種，作為研究的標的精油。

三、音樂構面：根據 Hirokawa (2004), Kenny and Faunce (2004)與 Ghou and Lin (2006)指出，音樂是聽覺藝術，透過聲音與人體細胞共振的結果，常會令人感覺到寧靜，具有放鬆心情、紓壓和減輕憂鬱等效果。而 Chen 等(2013a)探討台灣安養照護機構的音樂偏好及心理反應時指出，選用輕鬆類型的台灣音樂比較能提升室內環境的紓壓品質。惟台灣音樂種類繁多，分類方式因時空與觀點會有所差別(簡, 2001)。因此，本研究將採用呂(1996)與簡(2001)對台灣音樂依「演出型態」的分類以及參酌專家意見，選用民歌、歌樂、器樂、戲曲、古典音樂及西洋樂曲等 6 種音樂，作為研究標的音樂。

四、音樂與植栽的關係：根據趙等(2001)與段等(2005)的研究指出，植物生長在自然環境中，是以細胞為單位，感受並透過磷酸化作用傳遞各種聲波的信號，進而轉化成一定的生理生化效應，以維持細胞增殖和分化的平衡。李等(2001), Wang 等(2003)與魏等(2008)的研究亦指出，不同頻率和強度的聲波對煙草細胞周期的影響，說明一定範圍聲波刺激可影響細胞分裂的同化，促使細胞合成的 DNA 合成，有助於細胞的有絲分裂，促進植物的生長發育。以上說明聲波包括音樂等，對植物的刺激會影響其基因表現，進而影響植栽的生長(姜等 2010；祝等 2011)。

五、精油與植栽的關係：植物精油是植物體內的次級代謝物質，具有芳香的氣味，在常溫下能揮發，可隨水蒸氣蒸餾出油狀液體。根據 Van de Braak and Leijten (1999)指出，植物精油成分複雜，有數百種化學成分，估計目前已知的精油有三千種以上，其中的三百種具有重要的商業用途，主要用於香料和調味市場。

另江等(2002)指出，精油可用於植物的保護，而卓(2009)更進一步的具體說明，精油可用於預防食草性動物的侵犯、預防水分過度蒸發、驅除蚊蟲、防治害蟲、療癒受傷的部位、預防細菌、真菌及微生物的危害、維護本身的生存空間和吸引傳粉者，進行授粉繁衍的目的等，這說明精油與植物間具有密切的回饋關係。

因此，本研究將針對前三項衡量構面及二十項指標因素，以及構面間的關係建構 ANP 層級架構，如圖 16 所示。接著將以 ANP 找出影響人體健康紓壓的室內環境關鍵影響因素。

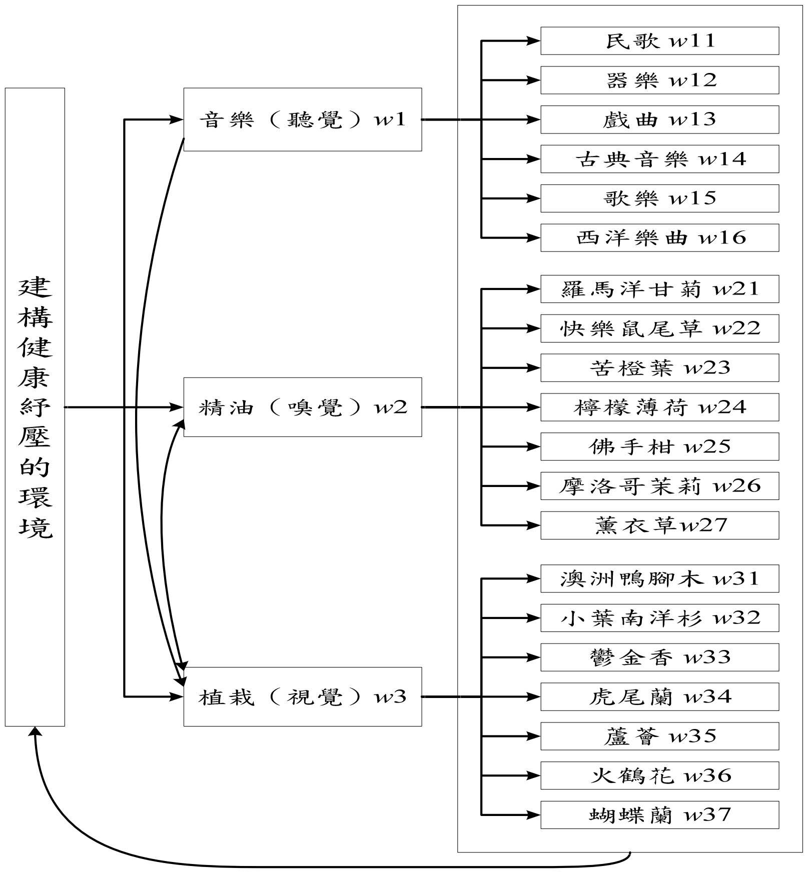

圖 16. 本研究之目標層級構面相依回饋圖

Fig. 16. Target level dimensions dependencies feedback of this study

ANP 為 Saaty (1996)與 Saaty and Vargas (2000)所提出，主要克服傳統 AHP 層級結構中，準則或層級之間可能產生的相互依存關係，以及回饋的問題。本研究將根據 Chung 等(2005)的概念，將 ANP 決策程序分成五個步驟，詳細流程如下：

步驟 1：建立評估的網路層級結構

本研究根據 Chen 等(2013a)的概念，並運用 ANP 建構評估模式，探討準則與方案間，以及準則與準則間的相互依存與回饋的關係，區分為目標層級、第一層級(健康紓壓評估構面)及第二層級(健康紓壓衡量指標)，共計二十項影響因素，設計「建構健康紓壓的環境」問卷調查表。針對兩兩準則進行比較，建立成對比較矩陣，再透過矩陣求得之特徵向量值建立超級矩陣。評估尺度分為五等級，即同等重要、稍重要、重要、極重要及絕對重要，並賦予名目尺度 1、3、5、7、9 衡量值。本研究考量問卷實施的可行性，決定專家人數為三十人，主要的對象為專家學者及研究生各十五人，且瞭解植栽、精油及音樂相關知識及問題。各層級之結構及相依關係詳如圖 16 所示。

步驟 2：建立成對比較矩陣

本研究將依前述影響人體健康紓壓環境的影響因素，建構各矩陣在超矩陣之相對位置(如表 13 所示)，並針對健康紓壓的環境構面與評選準則，計算每個要素的權重值(w)。

表 13. 各子矩陣在超矩陣中的相對位置表

Table 13. Relative position of each sub-matrix in the supermatrix

	目標	評選構面	評選準則
目標			D
評選構面	A	B	
評選準則		C	

接著本研究根據公式(1)及(2)計算獲得音樂構面的λ_{max}值為 6.4188，C.R.值為 0.0675，如表 14 所示。精油構面的λ_{max}值為 7.0456，C.R.值為 0.0058，如表 15 所示。植栽構面的λ_{max}值為 7.5953，C.R.值為 0.0752，如表 16 所示。其餘各構面 C.R.值亦均小於 0.1，顯示本研究各矩陣具有足夠的一致性程度。

表 14. 音樂構面之成對比較矩陣

Table 14. Paired comparison matrix of the dimension of music

	*w*11	*w*12	*w*13	*w*14	*w*15	*w*16	權重 *W*
*w*11	0.96	0.69	1.09	0.66	0.59	0.72	0.117
*w*12	1.33	0.95	1.57	0.94	1.26	0.63	0.166
*w*13	0.68	0.42	0.80	0.26	0.27	0.10	0.063
*w*14	1.71	1.27	2.43	1.26	1.84	1.66	0.253
*w*15	1.28	0.43	1.72	0.30	0.67	0.51	0.122
*w*16	1.69	1.83	3.72	1.09	1.54	1.35	0.279
	λ_{max} = 6.4188		CR= 0.0675		CI = 0.0838		

表 15. 精油構面之成對比較矩陣

Table 15. Paired comparison matrix of the dimension of essential oils

	*w*21	*w*22	*w*23	*w*24	*w*25	*w*26	*w*27	權重 *W*
*w*21	0.44	0.51	0.75	0.77	1.43	1.33	0.91	0.105
*w*22	0.67	1.00	0.12	0.40	0.84	0.50	0.73	0.073
*w*23	0.32	0.71	1.00	0.73	1.32	0.57	0.38	0.086
*w*24	0.83	0.68	0.65	1.08	1.83	1.65	1.17	0.135
*w*25	1.97	1.98	1.88	2.19	2.62	2.31	2.27	0.260
*w*26	1.35	1.30	1.37	1.53	2.36	1.89	1.59	0.195
*w*27	0.93	0.75	0.97	1.15	1.78	1.67	1.25	0.145
	λ_{max} = 7.0456		CR = 0.0058		CI = 0.0076			

表 16. 植栽構面之成對比較矩陣

Table 16. Paired comparison matrix of the dimension of plants

	*w*31	*w*32	*w*33	*w*34	*w*35	*w*36	*w*37	權重 *W*
*w*31	0.59	0.41	0.63	0.83	0.56	0.61	0.91	0.077
*w*32	0.50	0.35	0.32	0.75	1.50	1.32	0.84	0.095
*w*33	0.35	0.30	0.37	0.53	0.57	0.89	1.31	0.074
*w*34	1.53	2.48	1.86	1.86	3.36	2.70	2.00	0.270
*w*35	0.11	0.12	0.26	0.57	0.76	0.99	1.05	0.066
*w*36	0.46	0.42	0.76	1.45	3.56	1.80	1.10	0.163
*w*37	0.96	1.45	1.85	2.13	3.20	2.86	2.46	0.255
	λ_{max} = 7.5953		CR = 0.0752		CI = 0.0992			

步驟 3：計算各矩陣的相對權重

首先，將每個矩陣成對比較後所計算出的特徵向量(Eigenvector)作為矩陣之權重值，逐一透過 Super Decision 軟體計算出各矩陣之值。接著依元素間的相互依存關係填入依存關係表中，形成未加權的超矩陣 M' (Unweight Supermatrix)，如表 17 所示。

表 17. 各要素相依關係的未加權超矩陣 M'

Table 17. Unweighted supermatrix M' of each elements' interdependencies

	音樂	精油	植栽	*w*11	*w*12	*w*13	*w*14	*w*15	*w*16	*w*21	*w*22	*w*23	*w*24	*w*25	*w*26	*w*27	*w*31	*w*32	*w*33	*w*34	*w*35	*w*36	*w*37
音樂	0.260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
精油	0.208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
植栽	0.231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*11	0	0.020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*12	0	0.028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*13	0	0.011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*14	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*15	0	0.020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*16	0	0.047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*21	0.018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*22	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*23	0.014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*24	0.023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*25	0.043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*26	0.032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*27	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*31	0	0	0.013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*32	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*33	0	0	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*34	0	0	0.045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*35	0	0	0.011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*36	0	0	0.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*37	0	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

步驟 4：超矩陣的運算

超矩陣是由數個子矩陣所組成，子矩陣即是由準則與準則之間，相互比對後之特徵向量所形成。表 17 為未加權(unweighted)的初步矩陣，因為矩陣中的行值總和不等於 1，不符合行隨機 (column- stochastic)之原則，所以，必需經過特定的程序加以轉換，即可獲得加權超矩陣(weighted supermatrix)，並以 M 表示，如表 18 所示。

表 18. 各要素相依關係的加權超矩陣 M

Table 18. Weighted supermatrix M of each elements' interdependencies

	音樂	精油	植栽	*w*11	*w*12	*w*13	*w*14	*w*15	*w*16	*w*21	*w*22	*w*23	*w*24	*w*25	*w*26	*w*27	*w*31	*w*32	*w*33	*w*34	*w*35	*w*36	*w*37
音樂	0.373	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
精油	0.296	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
植栽	0.331	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*11	0	0.117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*12	0	0.166	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*13	0	0.063	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*14	0	0.253	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*15	0	0.122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*16	0	0.279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*21	0.105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*22	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*23	0.086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*24	0.135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*25	0.260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*26	0.195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*27	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*31	0	0	0.077	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*32	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*33	0	0	0.074	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*34	0	0	0.270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*35	0	0	0.066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*36	0	0	0.163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
*w*37	0	0	0.255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

接著本研究經由公式(3)將加權超矩陣 M 連乘後 k 次方(k 為主觀決定的值)，即可得到一個收斂的極限化超矩陣 M*，並求得各要素間之相對權重值，如表 19 所示。

表 19. 各要素相依關係的極限化超矩陣 M*

Table 19. Limited supermatrix M* of each elements' interdependencies

	音樂	精油	植栽	*w*11	*w*12	*w*13	*w*14	*w*15	*w*16	*w*21	*w*22	*w*23	*w*24	*w*25	*w*26	*w*27	*w*31	*w*32	*w*33	*w*34	*w*35	*w*36	*w*37
音樂	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282
精油	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237
植栽	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
*w*11	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
*w*12	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
*w*13	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
*w*14	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
*w*15	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
*w*16	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
*w*21	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
*w*22	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
*w*23	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
*w*24	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
*w*25	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
*w*26	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
*w*27	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
*w*31	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
*w*32	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
*w*33	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
*w*34	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
*w*35	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
*w*36	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
*w*37	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016

步驟 5：計算可行計劃的權重

最後，決策者可根據超矩陣多次相乘後所得之極值，做為選擇最佳方案之評選依據，如表 20 所示。

表 20. 建構健康紓壓的環境影響因子之權重

Table 20. Weighted value of factors for the construction of an environment to promote stress relief

	音樂	精油	植栽	*w*11	*w*12	*w*13	*w*14	*w*15	*w*16	*w*21	*w*22	*w*23	*w*24	*w*25	*w*26	*w*27	*w*31	*w*32	*w*33	*w*34	*w*35	*w*36	*w*37
權重	0.282	0.237	0.257	0.009	0.011	0.007	0.015	0.009	0.016	0.010	0.008	0.009	0.010	0.017	0.014	0.012	0.008	0.009	0.008	0.016	0.008	0.012	0.016

根據表 20 的分析結果顯示，音樂前三名的權重為:西洋樂曲(*w*16)、古典音樂(*w*14)、器樂(*w*12)；精油前三名的權重為:佛手柑(*w*25)、摩洛哥茉莉(*w*26)、薰衣草(*w*27)；植栽前三名的權重為: 虎尾蘭(*w*34) 、蝴蝶蘭(*w*37)、火鶴花(*w*36)。接著本研究將以 TM 找出健康紓壓環境的最佳參數設計。

第三節 田口方法

根據前述 ANP 之歸納，在音樂中選擇西洋樂曲(w16)、古典音樂(w14)、器樂(w12)三種類型，並由受測者親自選取比較輕鬆、柔和的曲目，分別為「YOU」、「落花流水」和「思念」(小提琴協奏)。精油則選擇佛手柑(w21)、摩洛哥茉莉(w26)、薰衣草(w27)，與三種植栽虎尾蘭(w34)、蝴蝶蘭(w37)、火鶴花(w36)，為影響健康紓壓環境的主要原因。本研究為了得到較佳的設計參數，使用 TM 進行分析，其因子與水準如表 21 所示。

表 21. 田口方法控制因子水準表
Table 21. Table of control factors and levels of Taguchi method

	因子	水準 1	水準 2	水準 3
A	植栽	蝴蝶蘭	火鶴花	虎尾蘭
B	精油	佛手柑	摩洛哥茉莉	薰衣草
C	音樂	西洋樂曲	古典音樂	器樂

表 22. 田口方法紓壓問卷調查表

Table 22. Stress relief questionnaire of Taguchi method

紓壓問項	Y(分數)
1.這裡可遠離日常煩惱，讓我放鬆並思考感興趣的事情(遠離性)。	Y1
2.這裡很迷人，很多事物值得我的發現和喚起好奇心(魅力性)。	Y2
3.這裡的活動及事物都有條理和組織(一致性)。	Y3
4.這裡很寬敞，不會限制行動，能讓我自成一個世界(範圍)。	Y4
5.這裡很容易找到方向並四處走動，讓我能做自己喜歡做的事情(相容性)。	Y5
6.整體而言，我對這個環境感到滿意。	Y6

本試驗共有三個 3 因子水準，自由度為 8，因此採用 $L_9(3^4)$直交表(如表 23 所示)。當完成直交表的配置後，即可進行問卷調查。而 Berto(2005)在探討人與自然元素的互動關係時，建立「簡易環境恢復性知覺量表」(Perceived environmental Restorativeness Scale, PRS)，量測注意力恢復、消除疲勞及紓解壓力等。這份量表操作簡便、有效率，效果良好，頗獲佳評。本研究擬廣泛適用於各個室內環境，包括醫療院所、辦公場所等，不適宜使用過長之問卷。所以，本試驗以 Berto 的量表為基礎，再增加第 6 項，設計「紓壓問卷調查量表」(如表 22 所示)，以瞭解受測者對室內環境的健康紓壓滿意度及取得試驗觀察值，並以 Y 代表試驗結果。另外，本問卷主要援用 Berto(2005)的量表，此表已獲得證明，具有高信度與高效度，可節省測試新量表的過程。本量表在正式施測前，經由前測分析，其 KMO 值為 0.815，Cronbach's α 值為 0.931，顯示問卷結果具有良好的內部一致性。

本試驗於 101 年 10 月 15 日至 26 日共 10 天(星期六、日除外)施行，在當日下午受測者身體比較疲憊的狀態下進行，總共蒐集五十二個重複試驗數據以作為試驗分析之用。性別方面，受測者中男生為 18 人(34.62%)，女生為 34 人(65.38%)，年齡平均為 34.63，試驗結果詳列於表 23。

表 23. $L_9(3^4)$直交表試驗結果

Table 23. Experiment results by $L_9(3^4)$ orthogonal matrix

試驗號碼	參數與水準			結果	
	A	B	C	Y	*S/N*(dB)
1	1	1	1	83.86	38.4710
2	1	2	2	79.75	38.0346
3	1	3	3	79.61	38.0194
4	2	1	2	81.85	38.2604
5	2	2	3	81.19	38.1901
6	2	3	1	84.37	38.5237
7	3	1	3	76.49	37.6721
8	3	2	1	81.45	38.2182
9	3	3	2	79.93	38.0542
10	對照組			58.70	35.3727

經由 TM 配置試驗後，希望受測者對健康紓壓環境感受程度越大，顯示環境健康紓壓效果越好。換言之，如果 *S/N* 比愈大，則表示環境健康紓壓效果越好。

因此，將每個試驗組合的量測值，利用望大特性的公式(5)可以計算出每個試驗組合的 *S/N* 比。

本研究接著使用 Minitab16 軟體計算各試驗因子水準的平均 *S/N* 比，列於表 23，並獲得設計因子的 *S/N* 比反應表(如表 24 所示)與因子效果圖(如圖 17 所示)。

表 24. 設計因子對 *S/N* 比反應表
Table 24. The reaction of designed factors to *S/N* Ratio

水準	A	B	C
水準 1	38.175	38.134	38.404
水準 2	38.325	38.148	38.116
水準 3	37.982	38.199	37.961
效果	0.343	0.065	0.443
排序	2	3	1

圖 17 中顯示，當因子設計組合為 A2(火鶴花)、B3(薰衣草)、C1(西洋樂曲)時，為健康紓壓環境之最佳參數設計，即表示室內健康紓壓環境的效果最好。接著進

行確認試驗，求得 *S/N* 比預測值為 38.61，試驗值為 38.309，兩個數值的差異為 0.301，落在 95%的信賴區間之內，表示試驗成功，結果具有加法性，結論是可靠的。

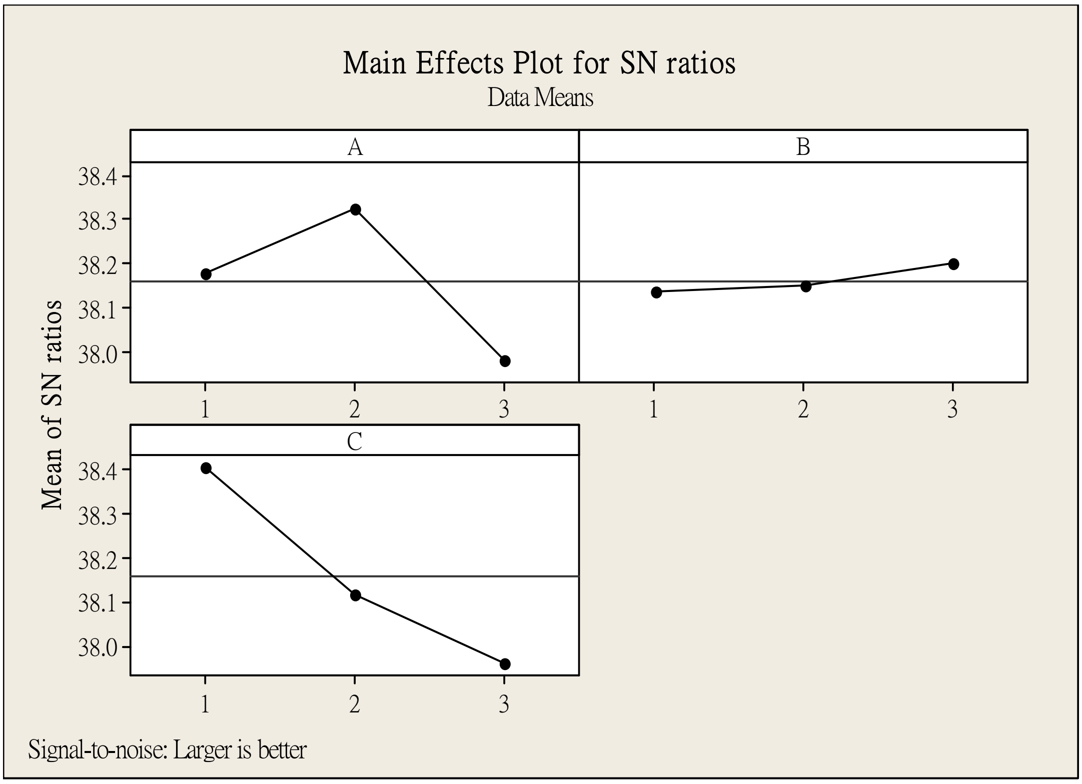

圖 17. *S/N* 比因子效果圖

Fig. 17. Main effects plot for *S/N* ratios (conference room)

第四節　試驗驗證

本研究的植栽選擇火鶴花，價格便宜，栽植又不受季節影響；精油選擇薰衣草精油，價格平價，符合一般民眾所能接受的範圍；而器樂種類選擇西洋樂曲，民眾可透過網路及商店管道購得。因此，上述三項健康紓壓環境的最佳參數設計因子，皆符合一般建構健康紓壓環境時的認知及便利性。接著，本研究將以上述條件建構健康紓壓環境，蒐集五十二個重複試驗數據，作為試驗分析之用，並在原來無特別布置的環境取得五十二個重複試驗數據為對照組，以統計檢定驗證建構健康紓壓環境前後的成效。

根據 Chen 等(2002)指出，統計檢定是評估績效的客觀方法之一，所以本研究根據統計檢定的方法，評估建構健康紓壓環境改善前後的成效。首先，將改善前的五十二數據依小至大的順序$(X_{(1)}, X_{(2)},\ldots, X_{(52)})$ 排列，其中$X_{(i)}$代表第 i 個依照順序排列後的資料數值；同理將改善後的五十二數據依小至大的順序$(X'_{(1)}, X'_{(2)},\ldots, X'_{(52)})$ 排列，並令$Y_i = X'_{(i)} - X_{(i)}$ 表示第 i 筆建構健康紓壓環境改善前後差之和。就常理而言，改善若有顯著的效果，則每一個$X'_{(i)} - X_{(i)}$應為正值，即$Y_i > 0$，且其平均值愈大，代表改善的效果愈顯著。因此當檢定健康紓壓環境改善前後差之總平均數μ_y 大於 0，即可判定最佳健康紓壓環境參數設計具有顯著的改善成效，其檢定假設如公式(15)所示：

$$H_0：\mu_y \leq 0 \tag{15}$$

$$H_\alpha：\mu_y > 0$$

接著以$\bar{Y}$做為檢定統計量，評估最佳健康紓壓環境參數設計是否具有顯著成效。若由樣本資料的觀察值計算而得到檢定統計量的值為$\bar{Y} = \mathrm{v}$，則可以計算健康紓壓環境改善前後的 p，如公式(16)所示：

$$p = p(\bar{Y} > v/\mu_y = 0) \quad (16)$$

$$= p\left(Z > \frac{v}{s/\sqrt{n}}\right) = 1 - \Phi\left(\frac{v}{s/\sqrt{n}}\right)$$

本研究以 p 作為健康紓壓環境改善績效評估的工具，並將生產者風險訂為 α=0.05，當 $p< 0.05$時，表示最佳健康紓壓環境參數設計具有顯著成效。因此，將五十二健康紓壓環境改善前後的樣本資料，依小至大順序排列，並計算所有改善前後樣本資料差之平均值 $\bar{Y} = 25.667$ 和標準差 S=3.622。接著將值代入公式(15)，可以計算 p = 0.0000，表示最佳健康紓壓環境參數設計具有非常顯著的成效。

另外，繼續進行成對樣本 T 檢定(paired sampled t-test)，針對同一受測者檢定健康紓壓環境改善前後的成效，試驗結果顯示，前後平均數差為 25.667，實測 t=7.601> $t_{0.05/2,\ 51} = 2.000$，p = 0.0000(p<0.05)，再次驗證具有相同的顯著差異。

第五節　小結

本研究首先運用 ANP 針對植栽、精油及音樂三項健康紓壓環境的衡量構面及二十項指標因素，分別計算其相對權重值，選取植栽、精油及音樂等各項構面中最重要的三項環境影響因子。接著透過 TM 找出火鶴花、薰衣草精油及西洋樂曲等三個關鍵影響因子，可使得健康紓壓環境品質的水準提升至最佳。最後利用統計檢定的方法作為健康紓壓環境改善績效評估的工具，檢定健康紓壓環境改善前後的樣本資料，結果發現，最佳健康紓壓環境參數設計具有非常顯著的成效。本研究已建立一套可以淨化室內健康環境的衡量模式。採用這套評估模式，不僅可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，創造舒適、清新與健康的環境，提供醫療照護、養老院及辦公場所等機構，作為改善環境的參考。

第六章　結論與建議

許多研究證實，室內空氣污染程度是室外的十倍以上，容易出現SBS的危害，導致身體不健康，降低工作效率。本研究導入6σ之DMAIC流程，透過「健康紓壓問卷調查量表」、「機率分配圖」、「績效評估矩陣圖」、「健康紓壓衡量指標P」及「特性要因圖」分析得知，安養機構應重視老年人的室內環境營造。因此，淨化室內環境、提升環境品質，以達健康紓壓的效果，是為各界所共同關心且需解決的問題。本研究為深入探討並解決目前所面臨的問題，揚棄以往以單一選項為探討重點，強調配套組合的觀念。應用DEA、6σ之DMAIC流程、ANP及TM四種主要研究方法，並以植栽、精油及音樂三項因素為主要研究標的，建立一套完整且有效的室內健康環境的最佳評估模式，藉以提升室內環境品質。

本研究從室內健康環境的角度出發，以三個案例為探討對象。案例1利用NASA歷經二十五年的研究成果為依據，結果指出植物的淨化化學氣體指數、栽培容易度、病蟲害抵抗力以及水分蒸散作用率等四項總合的平均值，即為該植栽整體的淨化空氣指數。本研究進一步應用DEA篩選出淨化空氣植栽的優先排序，找出相對改善室內空氣效率值較高的植栽，並經試驗證實，當教室內擺放虎尾蘭與環境置換時間為兩週時，將可使得環境品質的水準提升至最佳。本研究利用DEA公式，計算各種植栽淨化空氣指數的模式，可提供各界作為選取淨化空氣植栽時的參考，而配合TM分析找出最佳參數水準組合，也為改善室內環境品質另闢不同的思考角度。

案例2從老人安養照護機構整體室內環境營造的觀點着手，導入6σ之DMAIC流程，藉由問卷調查，瞭解老年人對該機構健康紓壓的重視度與滿意度，並透過績效評估矩陣圖找出關鍵問題點。接著，以滿意度與重視度的機率分配圖交集重疊面積大小作為衡量方向，建構健康紓壓衡量指標P，探討問題改善的優先順序，

再透過特性要因圖分析導出該機構健康紓壓不佳的原因。最後指出，該機構應重視老年人的安養環境，以營造具有健康紓壓暨舒適的居住環境為目標。本研究從問題定義、衡量、分析的結果，再次強調淨化室內空氣品質的重要性，同時提出新的評估模式供參考。接著，透過特性要因圖分析指出，植栽、精油及音樂三項試驗因子係為室內健康環境品質提升的關鍵要素。再利用 TM 方法找出，當室內擺放虎尾蘭與播放台灣音樂，並使用羅馬甘菊精油，將使老人安養機構的健康環境品質提升至最佳。最後，建立標準作業流程管制監控品質。本研究係一套嚴謹的評估模式，除已證實虎尾蘭、羅馬甘菊精油和台灣音樂的最佳組合，可以有效改善室內環境品質外，未來這套模式，也可隨時因應顧客的需求，用以維持與提升安養照護機構的環境品質。

至於案例 3 則針對案例 1、案例 2 的研究方法提出改進。當植栽、精油及音樂三項試驗因子缺乏明確數據，且考量三者相互依存及回饋的關係時，建議可採用 ANP 找出準則與方案間，以及準則與準則間的相互依存及回饋的關係。計算各個因子要素間的相對權重，權重愈高者，表示被選擇為最佳方案的機會愈大。本研究應用 ANP 解決了 DEA 無法克服的問題，再搭配 TM 進行分析。在 TM 分析中，酌修 Berto 的 PRS 量表，設計「健康紓壓問卷調查量表」，不僅簡化問卷選項，方便使用，同時提高 TM 的信度與效度，並以統計檢定改善前後的樣本資料，增加試驗結果的可信度。藉由 ANP 和 TM 的作業流程，使得評估模式更加完備。最後，本研究發現，火鶴花、薰衣草精油及西洋樂曲的組合，具有非常顯著的健康紓壓成效。

經由上述的分析，本研究證實，應用 DEA、6σ 之 DMAIC 流程、ANP 及 TM 四種主要研究方法，可以找出植栽、精油及音樂的最佳參數組合。這個組合能夠有效淨化室內空氣、紓緩壓力和提升環境品質，效果非常顯著。此外，利用 DEA(個別因子數據明確時)、特性要因圖(專家意見)或 ANP(因子數據不明確或探討相互依

存及回饋的關係時)等研究方法，不僅可以有效選取影響環境的關鍵因子，透過 TM 分析也容易找出最佳參數組合。之後再以統計檢定或標準作業流程管制，評估或監控健康紓壓環境的品質。如此，一套室內健康環境的評估模式便已建立。相信透過本研究所提供的評估模式，不僅可以有效恢復注意力、減輕心理疲勞，也能改善室內的空氣品質，創造舒適、清新與健康的環境，同時亦可提供醫療照護、養老院及辦公場所等機構，作為改善環境的參考。

承上，本研究之評估模式，會因試驗時間、地點及對象不同，而產生選取影響環境因子與水準的差別，這是可以預期的現象。因為每個人對室內健康環境品質的認定，本來就會有不同的見解，如此反而更能證明本評估模式的有效性與再現性。本研究雖力求嚴謹，但受限於經費與時間有限，難免力有未逮，因此提出以下幾點建議，期望對日後從事相關議題研究者能有所助益：

一、植栽的配置：植栽的視覺美感、色彩、味道以及葉面積指數 (Leaf Area Index, LAI)等配合空間的安排與協調，都是相當重要的美學考量。因此，選取試驗植栽的尺寸和數量，要考量療癒景觀設計原則，配合室內環境的空間格局，以免影響試驗結果。

二、精油的噴灑：精油對情緒的影響，效果直接且副作用少，惟如何調配濃度且長時間均勻分布於室內中，則需要經驗的累積。此外，噴灑精油時要注意室內溫度，以及精油在空氣中比較不容易立即揮發的性質。因此，同一室內如需繼續使用其他精油試驗時，應於隔天再施作會比較適宜。

三、音樂的選取：音樂的種類繁多，分類方式分歧不一。本研究主要在探討室內健康環境的問題，因此，參酌文獻及專家意見，應用 ANP 找出權重較高的音樂類型，並經受測者親自選取，以比較輕鬆、柔和的曲目為主。只是實務上，

音樂之分類包羅萬象，往往會因研究主題而有不同的音樂偏好，因此，有關音樂的選取部分，未來仍可因應研究主題再作不同的分類。

四、自變項：植栽部分屬於視覺感受，而音樂是對聽覺產生影響，從試驗過程發現，兩者對情緒影響的顯著性較高，因此可調高其影響權重。而精油屬於嗅覺感知，容易受室內溫度的影響，若長期使用對人體是否有害，值得進一步探討。而且，相對於植栽與音樂，精油的價格比較昂貴，著眼於實用性與經濟性考量，可以適度降低其權重。此外，本研究發現，植栽與音樂在室內環境之健康紓壓上，具有相對較高的權重。因此，可將其列為固定項，再以精油為自變項，找出最佳化權重的組合方式，應是日後可以探討的方向。

五、試驗對象選擇：本研究選擇試驗對象時，採用系統性的隨機抽樣方式，這樣的抽樣方式對一般性的結論，雖然具備良好的外部效度，但是若要在現實環境中進行情境建構，仍然有不足之處。例如不同形態的作業環境、產業別、城鄉差異，或許會有適合度不一致的現象。因此分別針對不同的年齡、性別、學歷等群集，建立多樣性的適用模型，也是日後可以持續努力的方向。

六、隨機試驗的次數：雖然在問卷的設計上，本研究採用 Berto 的 PRS，其效度與信度足夠。然而，本研究的目的是期望獲得植栽、精油與音樂試驗樣本的最佳化組合。因此目前的試驗僅能採用有限的植栽、精油與音樂樣本，難免有遺珠之憾。所以如果研究經費與期限允許，應該採用更多的試驗樣本，並進行多次的隨機試驗，以獲得更好的試驗結果。

七、生理回饋儀的運用：本研究以問卷方式，測試個人心理主觀感覺，結果顯示，試驗介入後具有顯著健康紓壓效果。惟本研究側重心理主觀感受，未來的研究或可將質化研究和生理回饋儀亦納入試驗，這也是將來可以努力的重點。

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附錄

附錄 1. 老人安養照護機構健康紓壓問卷調查量表

敬愛的先生、小姐：您好

這是一份學術研究的不具名問卷調查，本研究的目的是想瞭解您對老人安養照護機構所提供健康紓壓服務項目的「重視度」與「滿意度」，希望透過您的意見表達，進而作為提升健康紓壓品質的參考。問卷資料僅作為學術研究，絕不外流，請您安心作答，最後衷心感謝您的幫助與支持！

敬祝

旅途愉快

順心如意

國立台灣大學園藝暨景觀學系博士班

研 究 生：陳錫欽 敬上

TEL：(02)22——519

E-mail：D97628003@ntu.edu.tw

中華民國 100 年 4 月　日

請您針對下列各項目的「重視度」與「滿意度」，分別予以評分：分數由 0 到 100 分，當分數是 100 分時，表示您完全滿意或完全重視安養照護機構經營環境所提供健康紓壓的服務，當分數是 0 分時，表示您完全不滿意或完全不重視安養照護機構經營環境所提供健康紓壓的服務，分數愈高，表示您滿意度或重視度愈高。

健康紓壓問項	重視度	滿意度
1.此環境可逃離我不想要的不專心。	______	______
2.我可花時間在此並遠離每天律生活。	______	______
3.此環境可遠離每天需要我注意的事情。	______	______
4.此環境可幫助我停止思考必需作的事情。	______	______
5.在此環境我不用注意我不感興趣的事情。	______	______
6.此環境的實質排序有清楚的順序。	______	______
7.此環境的事情與活動都如此的相稱。	______	______
8.在此很容易看到事物很有次序的。	______	______
9.這裡的每一事物都有適當的位置。	______	______
10.此環境很少有界線去阻止我的移動。	______	______
11.此環境夠大到可讓我探索我的方向。	______	______
12.這個環境似乎是永恆的。	______	______
13.此環境本身有能力自我形成一個世界。	______	______
14.此環境是有魅力。	______	______
15.此環境發生的事情引起我的興趣。	______	______
16.這環境喚起我的好奇心。	______	______
17.這裡有許多可以探索與發現的地方。	______	______
18.我的注意力被這裡許多有趣事情吸引。	______	______
19.此環境很少阻止我想作的事情。	______	______
20.在此可以符合我目前的個人意圖。	______	______
21.在這裡很容易做我想作的事。	______	______
22.在此我可很容易找到我的路。	______	______
23.這裡有我喜歡作的活動。	______	______
24.我喜歡這個環境讓我心情舒暢。	______	______
25.我偏好這個環境勝過其他地方。	______	______
26.這地方是我熟悉的地方。	______	______

附錄 2. 田口方法紓壓問卷調查表

敬愛的先生、小姐：您好

這是一份學術研究的不具名問卷調查，本研究的目的是想瞭解您對環境紓壓的感覺，希望透過您的意見表達，進而作為提升環境品質的參考。問卷資料僅作為學術研究，絕不外流，請您安心作答，最後衷心感謝您的幫助與支持！

敬祝

身體健康

順心如意

國立台灣大學園藝暨景觀學系
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中華民國 101 年　月　日

請您針對下列各項目分別予以評分：分數由 0 到 100 分，當分數是 100 分時，表示您完全滿意環境紓壓服務，當分數是 0 分時，表示您完全不滿意環境紓壓服務，分數愈高，表示您的滿意度愈高。

問項	分　數
1.這裡可遠離日常煩惱，讓我放鬆並思考感興趣的事情(遠離性)。	
2.這裡很迷人，很多事物值得我的發現和喚起好奇心(魅力性)。	
3.這裡的活動及事物都有條理和組織(一致性)。	
4.這裡很寬敞，不會限制行動，能讓我自成一個世界(範圍)。	
5.這裡很容易找到方向並四處走動，讓我能做自己喜歡做的事情(相容性)。	
6.整體而言，我對這個環境感到滿意。	

基本資料

1.性別：

□男　□女

2.年齡：

□19 歲以下 □20~29 歲 □30~39 歲 □40~49 歲 □50~59 歲 □60 歲以上

3.學歷：

□小學以下 □國中 □高中(職) □專科/大學 □研究所以上

4.居住地：

□北基宜地區　□桃竹苗地區　□中彰投地區　□雲嘉南地區

□高高屏地區　□花東地區　□澎湖金馬地區　□國外地區

5.婚姻狀況：

□未婚　□已婚　□其他

6.職業：

□學生　□家庭主婦　□農林漁牧業　□工商業　□服務業　□軍公教人員　□自由業　□其他

附錄 3. 環境復癒量表精簡改良版

敬愛的先生、小姐：您好

這是一份學術研究的不具名問卷調查，本研究的目的是想瞭解您對環境復癒的感覺，希望透過您的意見表達，進而作為提升環境品質的參考。問卷資料僅作為學術研究，絕不外流，請您安心作答，最後衷心感謝您的幫助與支持！

敬祝

身體健康

順心如意

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中華民國　年　月　日

請您針對下列各問項分別予以評分：衡量尺度由 1 到 5，當尺度是 5 時，表示您完全滿意環境復癒服務，當尺度是 1 時，表示您完全不滿意環境復癒服務，尺度愈高，表示您的滿意度愈高。

問項	1	2	3	4	5	問項
請描述在這個環境中的情緒反應。						
1.忿怒	□	□	□	□	□	和善
2.焦慮	□	□	□	□	□	放鬆
請描述在這個環境中的身體反應。						
3.我的呼吸變得急促(完全不會)	□	□	□	□	□	非常
4.我的手心冒汗(完全不會)	□	□	□	□	□	非常
請描述對這個環境的認知反應。						
5.我對這個環境感興趣(完全不會)	□	□	□	□	□	非常
6.這個環境能夠吸引我的注意(完全不會)	□	□	□	□	□	非常
請描述在這個環境中的行為反應。						
7.我想更常造訪這個地方(完全不會)	□	□	□	□	□	非常
8.我想在這地方停留久一點(完全不會)	□	□	□	□	□	非常

基本資料

1.性　別：□男　□女

2.年　齡：□19 歲以下 □20~29 歲 □30~39 歲 □40~49 歲 □50~59 歲
□60 歲以上

3.學　歷：□小學以下 □國中 □高中(職) □專科/大學 □研究所以上

4.居 住 地：□北基宜地區 □桃竹苗地區 □中彰投地區 □雲嘉南地區
□高高屏地區 □花東地區 □澎湖金馬地區 □國外地區

5.婚姻狀況：□未婚 □已婚 □其他

6.職　業：□學生 □家庭主婦 □農林漁牧業 □工商業 □服務業
□軍公教人員 □自由業 □其他

附錄 4. 建構室內健康紓壓環境問卷調查表

敬愛的專家(同學)您好：

這是一份有關「建構室內健康紓壓環境」學術問卷。根據專家與文獻探討的綜合意見，彙整出「音樂(聽覺)」、「精油(嗅覺)」與「植栽(視覺)」等 3 個構面及「民歌」等 20 項指標，本研究採用模糊問項結合網路層級分析法(Analytical Network Process, ANP)針對此 3 項衡量構面及 20 項指標因素來討論建構健康紓壓的環境，評定各因素之相對權重，求得建構健康紓壓環境的關鍵影響因素，以提供醫療照護、養老院及辦公場所作為後續環境改善的參考。本問卷採匿名方式進行，請您以本身的實際經驗與看法填答，您的意見非常寶貴，懇請您撥冗協助填答以下的問項，僅此致上最誠摯的謝意！

敬 祝

平安、喜樂

國立台灣大學園藝暨景觀學系
指導教授: 張祖亮老師
博士班研究生: 陳錫欽
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中華民國 101 年　月　日

問卷填答與範例說明：

本研究針對建構健康紓壓環境的影響因素進行網路層級架構之建立，計分為目標層級、第一層級(健康紓壓評估構面)與第二層級(健康紓壓衡量指標)，共計 20 項影響因素，各層級之結構關係如圖 1 所示：

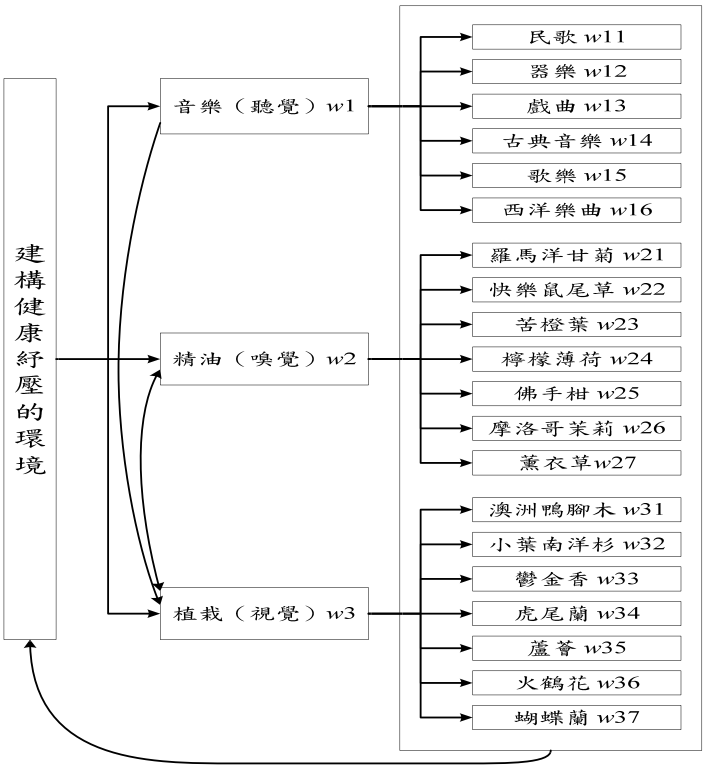


圖 1: 建構健康紓壓環境的影響因素網路分析架構圖

填答範例

範例及其規則說明如下：

準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
品質	☐	☐	☐	☐	☑	☐	☐	☐	☐	交期
	☐	☑	☐	☐	☐	☐	☐	☐	☐	成本
	☐	☐	☐	☐	☐	☐	☐	☐	☑	風險

如您覺得「關於封裝廠選擇」,「品質」與「交期」的重要程度為「同等重要」，則請您勾選 1:1；如您覺得「品質」比「成本」重要，重要程度為「極重要」，則請您勾選接近「品質」這方的 7:1；如您覺得「風險」比「品質」重要，重要程度為「絕對重要」，則請您勾選接近「風險」這方的 1:9。尺度名稱及其語意變數表參照如下：

尺度名稱	語意變數	三角模糊數或直觀模糊數
1:1	同等重要	
1:3	稍重要	
1:5	重要	
1:7	極重要	
1:9	絕對重要	

問卷填寫

(1) 健康紓壓評估構面

第一部分：「目標」準則與準則之間的兩兩比較

準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
音樂	☐	☐	☐	☐	☐	☐	☐	☐	☐	精油
	☐	☐	☐	☐	☐	☐	☐	☐	☐	植栽
精油	☐	☐	☐	☐	☐	☐	☐	☐	☐	植栽

(2-1) 健康紓壓衡量指標─音樂(聽覺)因素

(2-1): 在準則底下次準則與次準則之間的兩兩比較

音樂方面										
次準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	次準則
民歌	☐	☐	☐	☐	☐	☐	☐	☐	☐	器樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	戲曲
	☐	☐	☐	☐	☐	☐	☐	☐	☐	古典
	☐	☐	☐	☐	☐	☐	☐	☐	☐	歌樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	西洋樂曲
器樂	☐	☐	☐	☐	☐	☐	☐	☐	☐	戲曲
	☐	☐	☐	☐	☐	☐	☐	☐	☐	古典
	☐	☐	☐	☐	☐	☐	☐	☐	☐	歌樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	西洋樂曲
戲曲	☐	☐	☐	☐	☐	☐	☐	☐	☐	古典
	☐	☐	☐	☐	☐	☐	☐	☐	☐	歌樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	西洋樂曲
古典	☐	☐	☐	☐	☐	☐	☐	☐	☐	歌樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	西洋樂曲
歌樂	☐	☐	☐	☐	☐	☐	☐	☐	☐	西洋樂曲

(2-2) 健康紓壓衡量指標─提鍊精油-含酯量(嗅覺)因素

(2-2)：在準則底下次準則與次準則之間的兩兩比較

精油方面										
次準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	次準則
羅馬甘菊	☐	☐	☐	☐	☐	☐	☐	☐	☐	快樂鼠尾草
	☐	☐	☐	☐	☐	☐	☐	☐	☐	苦橙葉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	檸檬薄荷
	☐	☐	☐	☐	☐	☐	☐	☐	☐	佛手柑
	☐	☐	☐	☐	☐	☐	☐	☐	☐	摩洛哥茉莉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草
快樂鼠尾草	☐	☐	☐	☐	☐	☐	☐	☐	☐	苦橙葉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	檸檬薄荷
	☐	☐	☐	☐	☐	☐	☐	☐	☐	佛手柑
	☐	☐	☐	☐	☐	☐	☐	☐	☐	摩洛哥茉莉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草

苦橙葉	☐	☐	☐	☐	☐	☐	☐	☐	☐	檸檬薄荷
	☐	☐	☐	☐	☐	☐	☐	☐	☐	佛手柑
	☐	☐	☐	☐	☐	☐	☐	☐	☐	摩洛哥茉莉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草
檸檬薄荷	☐	☐	☐	☐	☐	☐	☐	☐	☐	佛手柑
	☐	☐	☐	☐	☐	☐	☐	☐	☐	摩洛哥茉莉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草
佛手柑	☐	☐	☐	☐	☐	☐	☐	☐	☐	摩洛哥茉莉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草
摩洛哥茉莉	☐	☐	☐	☐	☐	☐	☐	☐	☐	薰衣草

(2-3) 健康紓壓衡量指標─植栽(視覺)因素

(2-3)：在準則底下次準則與次準則之間的兩兩比較

植栽方面										
次準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	次準則
澳洲鴨腳木	☐	☐	☐	☐	☐	☐	☐	☐	☐	小葉南洋杉
	☐	☐	☐	☐	☐	☐	☐	☐	☐	鬱金香
	☐	☐	☐	☐	☐	☐	☐	☐	☐	虎尾蘭
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蘆　薈
	☐	☐	☐	☐	☐	☐	☐	☐	☐	火鶴花
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭
小葉南洋杉	☐	☐	☐	☐	☐	☐	☐	☐	☐	鬱金香
	☐	☐	☐	☐	☐	☐	☐	☐	☐	虎尾蘭
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蘆　薈
	☐	☐	☐	☐	☐	☐	☐	☐	☐	火鶴花
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭
鬱金香	☐	☐	☐	☐	☐	☐	☐	☐	☐	虎尾蘭
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蘆　薈
	☐	☐	☐	☐	☐	☐	☐	☐	☐	火鶴花
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭
虎尾蘭	☐	☐	☐	☐	☐	☐	☐	☐	☐	蘆　薈
	☐	☐	☐	☐	☐	☐	☐	☐	☐	火鶴花
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭
蘆　薈	☐	☐	☐	☐	☐	☐	☐	☐	☐	火鶴花
	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭
火鶴花	☐	☐	☐	☐	☐	☐	☐	☐	☐	蝴蝶蘭

(3) 健康紓壓評估構面間相依比較

本研究探討健康紓壓環境的評估構面時，因為「音樂」會影響「植栽」的生長，另外「植栽(視覺)」與「提鍊精油-含脂量)」之間彼此相關，因此接著探討健康紓壓評估構面之間的相依性比較

填答範例

交期方面										
準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
交期	☐	☐	☐	☐	☑	☐	☐	☐	☐	品質
	☐	☑	☐	☐	☐	☐	☐	☐	☐	成本

因為準則間會有交互作用，所以有第三部分問卷的產生，例如：交期的長短將會影響到品質與成本。如您從重視「交期方面」來探討，「交期」與「品質」的重要程度為「同等重要」，則請您勾選 1:1；如您覺得「交期」比「成本」重要，重要程度為「極重要」，則請您勾選接近「交期」這方的 7:1。尺度名稱及其語意變數表同第一部分問卷。

問卷填寫

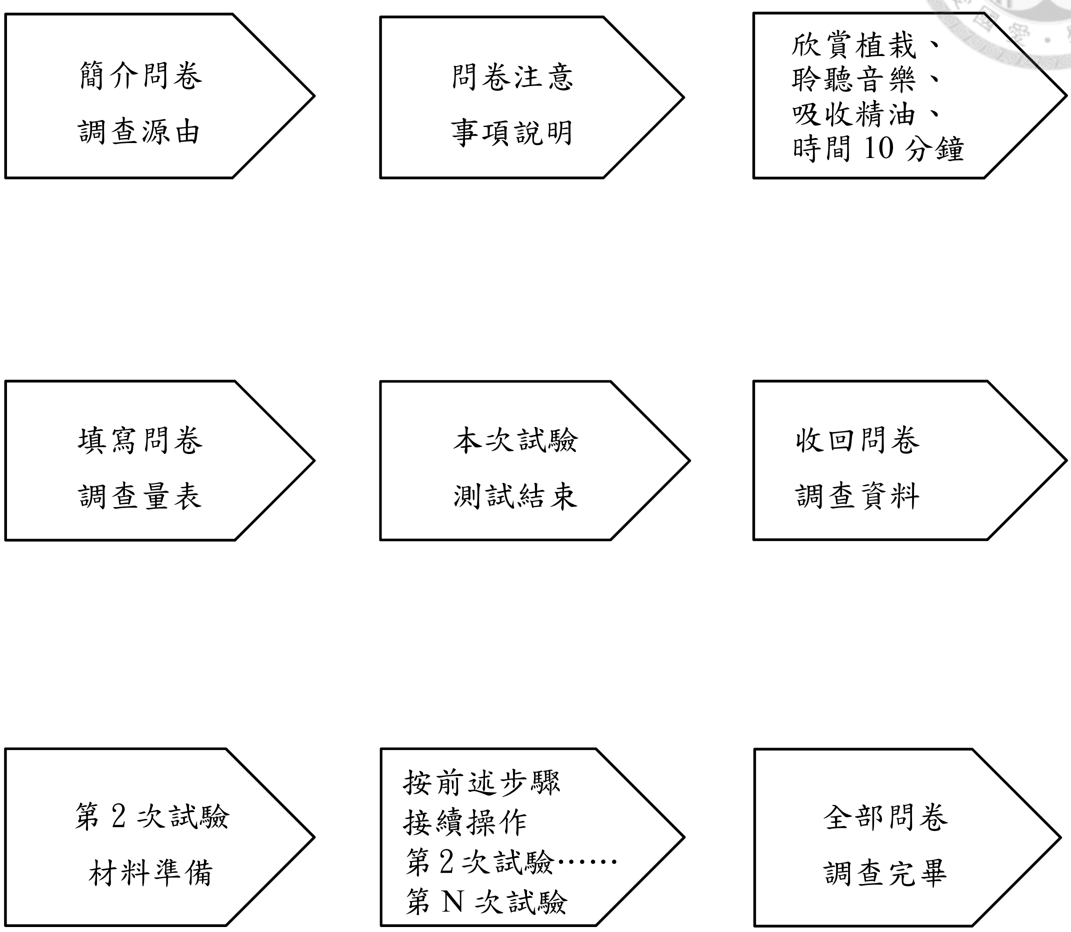
音樂方面										
準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
音樂	☐	☐	☐	☐	☐	☐	☐	☐	☐	植栽

精油方面										
準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
精油	☐	☐	☐	☐	☐	☐	☐	☐	☐	植栽

植栽方面										
準則	9:1	7:1	5:1	3:1	1:1	1:3	1:5	1:7	1:9	準則
植栽	☐	☐	☐	☐	☐	☐	☐	☐	☐	音樂
	☐	☐	☐	☐	☐	☐	☐	☐	☐	精油

非常感謝您冗撥時間於此問卷，本問卷到此為止，再次感謝您的協助，謝謝。

附錄5. 田口方法問卷調查流程.



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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

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

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

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

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 $\sum_{n=1}^{m} \Sigma v_i X_{ik} = 1$ 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	*x*1	7	4	8	4	2	10
	*x*2	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:

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

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

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

$$\lambda_r \geq 0$$

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 θ= u

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

$u \leq 7v_1 + 3v_2$ (A) $\quad u \leq 4v_1 + 3v_2$ (B)

$u \leq 8v_1 + 1v_2$ (C) $\quad u \leq 4v_1 + 2v_2$ (D)

$u \leq 2v_1 + 4v_2$ (E) $\quad u \leq 10v_1 + v_2$ (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, θ^* = 0.6316), and the CCR-efficiency of *A* is 0.6316.

Interpreting DMU's relative efficiency, if θ < 1, it is CCR inefficient, meaning technically inefficient; when θ = 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:

$$Min\ \theta^{\sup er} \qquad (4)$$

$$S.T.\ \sum_{\substack{i=1\\ j\neq 0}}^{n}\lambda_j x_{ij} \leq \theta^{\sup er} x_{io} \quad i=1,2,\ldots,n;$$

$$\sum_{\substack{i=1\\ j\neq 0}}^{n}\lambda_j y_{rj} \geq y_{ro} \quad r=1,2,\ldots,s;$$

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

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 `Kerchoviana'	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

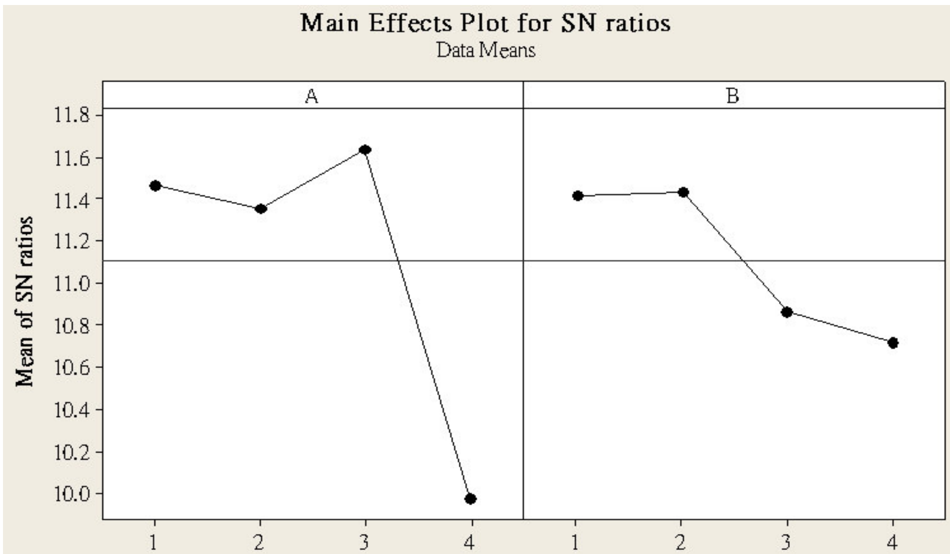

Figure 1. Main effect plot for S/N ratio.

$$SN = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \quad (5)$$

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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Application of DMAIC process to enhance health effects in caring institution

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Abstract Amid the rise of the caring and nursing industry, more and more service institutions for the aged start operation and to provide the healthy and comfortable environment for the aged is literally the object that the operators pursue. Hence this article introduces the six-sigma DMAIC methodology to enhance the health benefit of the nursing and caring institution. Here, performance evaluation matrix is used to define the key problems and give the index P for evaluating health benefits; cause and effect diagrams are used to analyze the causes of poor health benefits of caring institutions. Lastly, Taguchi method is employed to identify the optimal combination of health benefits of operation environment in caring institutions to serve as reference for the industry to upgrade the health benefits of operation environment in the institution.

Keywords Six sigma · Business performance · Performance evaluation matrix · Cause and effect diagram · Taguchi method · Healthy benefits

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1 Introduction

With the upgrade of living standards, medical advance and promotion of health prevention and maintenance, the demographic structure of the society in Taiwan is seen aging. According to Ministry of the Interior (2011a), Taiwan has officially reached "aged society" in 1993, with the aged accounting for 7.09% of the total population, which met the index for aged society set out by WHO. By the end of the year 2009, the population of people above 65 has gone as high as 2.45 million, accounting for 10.63% of the total population. Yet, such speed of aging not only is apparently higher than in Western countries but continues to accelerate; it is estimated that in 2026, the population of people above 65 would exceed 20%, reaching the so-called super-aged society.

In entering such aged society, problems like social welfare system, medical techniques and social security begin to emerge. Moreover, in today's trend of few children and double-income family, the needs of the aged are not well attended to after the busy work. As a result, caring institutions have become the service provider that is on largest scale for the welfare measures for seniors. However, as the aged demographic structure and chronicle diseases are a global issue, the growth of average life expectancy makes it a tendency that the demand or medical resources increases rapidly, in which the global industry of home care is seen to grow each year. The I.I.I. anticipated a 597 billion dollar-worth global industry of health and care in 2015, of which the market in Taiwan alone would grow to 18 billion dollars. It is clearly indicated that the aged society-related industry has considerable demands and great potential of growth.

According to Ministry of the Interior (2011b), the living type of the elderly is predominantly "together with children", but that proportion has gone down each year from 70.24% in 1986 to 57.28% in 2005. By the end of 2010, there were 1,067 long-term caring and caring institutions for the aged, which accommodated 56,256 people with 41,929 actually occupying, representing a use rate at 74.53%. That number of occupants and use rate increased by 3.23 and 1.69%, respectively, from a year earlier. In 2009, the Government also made "long-term caring industry" part of the development strategy of six new industries. The above all reveals that under state policy and in the tendency of aged society, the market of caring industry is a promising one and creates huge demands and business opportunity. Therefore, a great number of nursing and caring institutions begin to be set up and strive for a share of the market. How to provide a healthy and comfortable curing environment where the elderly live more comfortably and respected in their late years is a critical mission and issue for the industry.

A "nursing and caring institution" provides 24-7 caring services including services, living facilities and assistance that suit elderly life, health care as well as helping the aged in overcoming the stress of loneliness. These institutions are divided by the psychophysical functions of the occupying elderly in long-term caring, institution, nursing institution, caring institutions and nursing home to respond to the future development of nursing and living for the aged. Whichever category, institutions with services for the aged keep joining this new industry making the competition fiercer, hence, the provision of a healthy and comfortable environment of care for the aged is literally a primary object for the industry. As such, to elevate the health benefit of the operated environment in the nursing and caring institution should win people's recognition of the caring institutions and reduce the non-occupancy rate for the industry, further to upgrade the operators' competitive edge. To achieve the win–win situation between customers and the industry is to meet the massive market demand for nursing and caring industry in future. Therefore, this article will introduce the six-sigma DMAIC method to enhance the health benefit and business performance of the nursing and caring institution.

Since the employment by Motorola Inc. in 1987, the concept of six-sigma was not a strange phrase to industries any more. Many cross-border enterprises have introduced the six-sigma methodology to improve the corporate quality and increase their competitive edges with significant achievement evidenced. For instance, GE introduced it in 1995 to simplify the process of reviewing contracts, saving the transaction cost by millions dollars each year (Chen et al. 2010a).

In this twenty-first century, a good number of researchers are also employing the six-sigma methodology to investigate the properties of the service industry hoping to better elevate the performance and quality of business environment and satisfy customer needs. For example, Ham and Lee (2002) proposed MAIC improvement process; Geogel (2001) proposed the concept of DMAIC process which effectively improved the quality and speed of various transaction processes; Linderman et al. (2003) further proposed DMADV improvement procedure to systematically employed to improve processes and designing new products in an organized way, displaying successful achievements. Six-sigma related research has been conducted extensively in Taiwan, for example, Chen et al. (2006) upgraded the quality of TFT-LCD panel process by six-sigma MAIC process; Hsia et al. (2009) introduced six-sigma procedure to increase the service quality of on-line marketing; Chen et al. (2010a) introduced six-sigma DMAIC procedure to enhance the quality of leisure service. Obviously the enterprises have obtained significant benefits by introducing the six-sigma and many researchers were drawn to the related studies. Thus, this article will utilize the six-sigma DMAIC method to enhance the health benefit of business environment in the nursing and caring institution and elevate the quality of the business environment further to strengthen the business performance.

This article begins by designing a "Scale of health benefit questionnaire" by employing Kaplan and Kaplan (1989) function evolution theory and Ulrich (1983) psychological evolution theory and developing a performance evaluation matrix through Hung et al. (2003) concept, to define key problems and to propose the indices for health benefits evaluation. The cause and effect diagrams proposed by Kaoru Ishikawa are then used to analyze the main factors of dissatisfaction of the elderly with the quality of health benefit in the nursing and caring institution. Taguchi design of experiments is also utilized to identify the best combination of improved health benefit and business performance. Finally, standard operating procedure is established to continue monitoring the quality of health benefits so as to reinforce the competitive edge of the nursing and caring institutions.

2 Define

In this article, Kaplan and Kaplan (1989) function evolution theory and Ulrich (1983) psychological evolution theory were synthesized, reference was made to the characteristics of the contents of recovery by Kaplan (1988), Hartig et al. (1997), Laumann et al. (2001) and Purcell et al. (2001), and the research by Parasuraman et al. (1985, 1988, 1991) which pointed out that the quality of customer service can be measured by customers' advance expectation (valuing) for the service and their actual perception of the service afterwards (satisfaction) was based. The questions are positively constructed in a scale of health benefit questionnaire. After analyzing the reliability and validity of the pre-questionnaire check and deleting two negative correlation items, Cronbach's α values for expectation and satisfaction are 0.959 and 0.956 respectively and KMO values for expectation and satisfaction are 0.629 and 0.72 respectively. The questionnaire result show the high degree of reliability and validity.

Table 1 Scale of health benefits questionnaire

Variable	Health benefit item	Expectation	Satisfaction
Escape	1. Here I can escape from the distraction I do not want	_______	_______
	2. I can spend time here and stay away from the daily routine life	_______	_______
	3. Here I can stay away from the things that need my attention	_______	_______
	4. Here I become able to stop thinking about what I should do	_______	_______
	5. Here I need not to pay attention to what I am not interested	_______	_______
Consistence	6. The physical sequence here is in clear order	_______	_______
	7. Things and activities here are so getting along	_______	_______
	8. Here it is easy to see things in good order	_______	_______
	9. Everything here is properly positioned	_______	_______
Range	10. My movement is seldom obstructed by boundaries in here	_______	_______
	11. The space in here is big enough for me to explore my direction	_______	_______
	12. It seems eternal here	_______	_______
	13. The environment here is capable of forming a world of its own	_______	_______
Appeal	14. The quality of health benefit is good here	_______	_______
	15. Things happening here interest me	_______	_______
	16. The environment here appeals to my curiosity	_______	_______
	17. There are many places to be explored and discovered in here	_______	_______
	18. My attention is drawn to many interesting things in here	_______	_______
Compatibility	19. I am seldom stopped from doing what I want to do here	_______	_______
	20. My current personal intention is met here	_______	_______
	21. It is easy to do what I wish to do here	_______	_______
	22. I can find my way without difficulties here	_______	_______
	23. There are activities that I like to engage in here	_______	_______
Preference	24. I like this environment to let me feel comfortable and carefree	_______	_______
	25. I prefer it here than to other places	_______	_______
Familiarity	26. This environment is where I am familiar with	_______	_______

Thus, a scale of health benefit questionnaire with 26 positive narrative items in seven constructs was composed, as Table 1 shows. This is used to assess the health benefits of the operational environment of the nursing and caring institutions and to reinforce the quality of operational environment and elevate the competitive edge in market. Also, with a view of easier use for the nursing and caring institutions, the scale describes the elderly's satisfaction with and expectation for the health benefits of the operational environment in the nursing and caring institutions in percentages. A 100% grade means the elderly are totally satisfied with or completely expect for the services of health benefits the nursing and caring institutions provide. A 0% grade means the elderly are totally dissatisfied with or completely disregard the services of health benefits the nursing and caring institutions provide. A higher percentage represents higher satisfaction or expectation by the elderly.

Every senior citizen has his/her distinct degree of demand and expectation, thus, their perceived satisfaction with and expectation for the service of health benefits provided by the nursing and caring institution are different. Assume X is the satisfaction of the elderly with the health benefit of the nursing and caring institution, apparently X is a random variable in

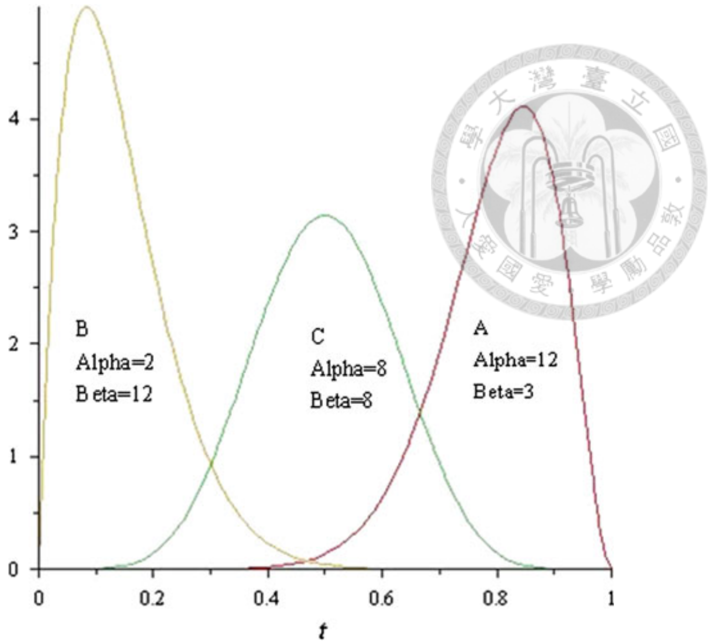


Fig. 1 Probability distribution of satisfaction

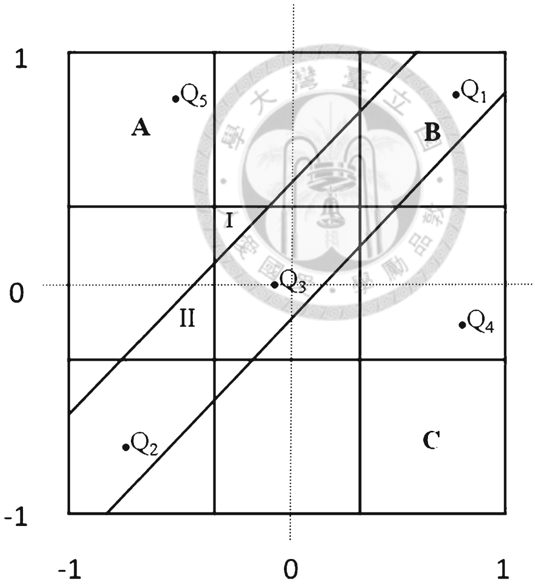
the range from 0 to 1. According to Johnson (1999) concept, a random variable anywhere between 0 and 1 usually obeys the β probability distribution with parameters (α, β). As such, let a random variable, S, herein be the perceived satisfaction of the elderly with the health benefit of the nursing and caring institution and a random variable, E, be the expectation for the health benefit of the nursing and caring institution; define the indices of satisfaction and expectation, respectively, for the items in Table 1 as follows:

$$I_{S_i} = \frac{\alpha_{S_i} - \beta_{S_i}}{\alpha_{S_i} + \beta_{S_i}} \text{ (satisfaction performance index)} \quad (1)$$

$$I_{E_i} = \frac{\alpha_{E_i} - \beta_{E_i}}{\alpha_{E_i} + \beta_{E_i}} \text{ (expectation performance index)} \quad (2)$$

where $i = 1, \ldots, 26$, α_{S_i} and β_{S_i} are the parameters of satisfaction distribution for the ith item, and α_{E_i} and β_{E_i} are the parameters of expectation distribution for the ith item. For an item, when the index for measuring the satisfaction performance, $I_{S_i} > 0$, i.e., $\alpha_{S_i} > \beta_{S_i}$, the probability distribution is left skewed (the case A in Fig. 1), meaning the average satisfaction is higher than dissatisfaction, which is that the elderly are satisfied with the health benefit of the nursing and caring institution. when the index for measuring the satisfaction performance, $I_{S_i} < 0$, i.e., $\alpha_{S_i} < \beta_{S_i}$, the probability distribution is right skewed (the case B in Fig. 1), meaning the average dissatisfaction is higher than satisfaction and the elderly are dissatisfied with the health benefit of the nursing and caring institution. When this index $I_{S_i} = 0$, i.e., $\alpha_{S_i} = \beta_{S_i}$, the probability distribution is symmetric (the case C in Fig. 1), meaning it is equally mixed satisfaction and dissatisfaction and the elderly feel the health benefit of the nursing and caring institution fair.

Fig. 2 Health benefit performance evaluation matrix



It is obvious from above analysis that the level of satisfaction with and that of expectation for health benefit are related to the value of α. When $\alpha > \beta$, the implication is better satisfaction with or expectation for health benefit; reversely, if $\alpha < \beta$, the implication is poorer satisfaction with or expectation for health benefit perceived by the elderly. The same applies to the deduction of the expectation for each item. Thus, with the satisfaction performance index as x axis of the coordinate and expectation performance index as y axis, a health benefit performance evaluation matrix for the nursing and caring institution is constructed, as Fig. 2 shows.

In addition, Hung et al. (2003) modified the the performance importance area in Lambert and Sharma (1990) matrix diagram and redefined a performance evaluation matrix. To solve the problem of the blind spots I and II, the reasonable zones of original three large areas that do without improvement are replaced by the area sandwiched by the two sloped lines. As with the space between the two slope lines, it can be decided by the factors like the interior and exterior environment for the institution, its resource costs and its organizational operation.

In the above performance evaluation matrix, type A is the elderly's expectation higher than their satisfaction, representing that the health benefits of the nursing and caring institution are under the elderly's expectation and the current operation stratagem needs review, improvement required too, to enhance the overall health benefits of the institution. Type B is the zone with equal perception of expectation and satisfaction, which means the health benefit of the nursing and caring institution is up to the elderly's expectation and the current operation strategy should be maintained. Type C is expectation less than satisfaction, representing the health benefit of the nursing and caring institution has exceeded the elderly's expectation; in such case, despite high satisfaction, the human resources and costs the institution operator invests are relatively high, and deserve discreet evaluation in view of today's tough competition and finite resources, so as not to affect the overall operation of the nursing and caring institution. Therefore, when the nursing and caring institution uses the performance evaluation matrix established herein to assess, if an assessed item falls in zones A and C, such item becomes a critical point for the caring institution to improve and a six-sigma project of analysis and improvement.

3 Measure

The second step of six sigma is measure. With the positions where the points lie, this article identified the items highly expected but hardly satisfied by the elderly, literally defining the critical points to be improved. In such item as with high expectation but low degree of satisfaction by the elderly, the probability distributions of expectation and satisfaction in the diagram scarcely overlap in very, meaning a significant gap between expectation and satisfaction for item, which thus requires improvement. For example, a certain item has the function for satisfaction probability distribution that obeys β (2, 10), and that for expectation probability distribution obeying β (12, 3); then it is clear that the satisfaction performance index $I_{S_i} < 0$ and the expectation performance index $I_{E_i} > 0$, which implies that the elderly have more expectation than satisfaction for the health benefit of such item, as Fig. 3 shows.

As performance evaluation matrix is originally intended, only a zone with equal expectation and satisfaction is a reasonable zone, that is type B in Fig. 2, which indicates that the elderly have equal expectation for and satisfaction with the health benefit of the nursing and caring institution. The intersection of probability distributions of such expectation and satisfaction is extensive and can be explored in three situations as follows:

(1) When the average expectation and average satisfaction on the item are relatively high, that is, $\alpha_{S_i} > \beta_{S_i}$ and $\alpha_{E_i} > \beta_{E_i}$, the probability distributions both are left skewed. And their performance distributions lie as the case of Q_1 in Fig. 2, which implies that the elderly have both high expectation for and high satisfaction with the health benefit of the nursing and caring institution.

(2) When the average expectation and satisfaction on the item are relatively low, i.e., $\alpha_{S_i} < \beta_{S_i}$ and $\alpha_{E_i} < \beta_{E_i}$, the probability distributions both are right skewed. Their

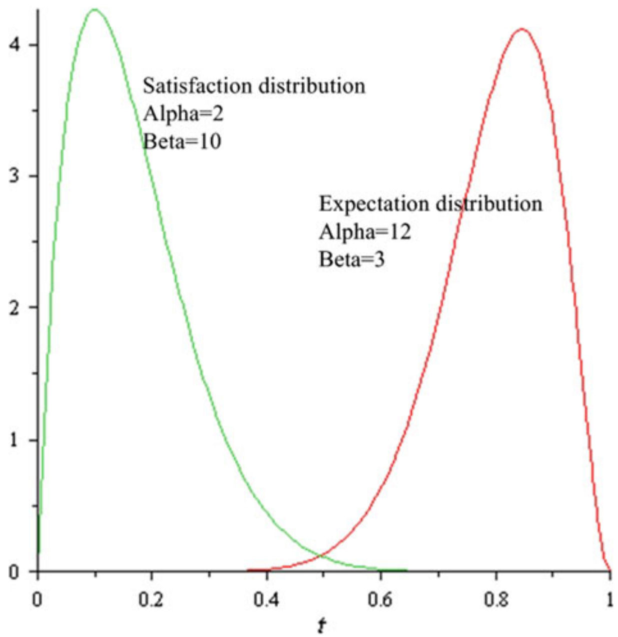


Fig. 3 Diagram of probability distributions of expectation and satisfaction

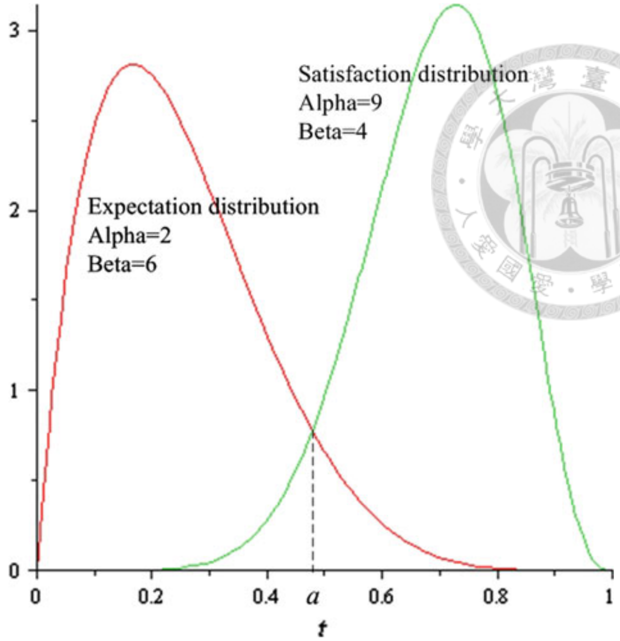


Fig. 4 Diagram of low expectation distribution versus high satisfaction distribution

performance distributions lie as the case of Q_2 in Fig. 2, which implies that the elderly have both low expectation for and low satisfaction with the health benefit of the nursing and caring institution.

(3) When both the expectation and satisfaction on the item are medium, i.e., $\alpha_{S_i} = \beta_{S_i}$ and $\alpha_{E_i} = \beta_{E_i}$, the probability distributions are symmetrical. Their performance distributions lie as the case of Q_3 in Fig. 2, which implies that the elderly have both medium expectation for and medium satisfaction with the health benefit of the nursing and caring institution.

From the above concept, and using the size of the intersection between as the direction of measurement, this article sets a health benefit measuring index, P, for measuring the area of intersection between satisfaction and expectation on each service item, where P is defined as below:

$$P = p_{S_i} + p_{E_i}, \quad 0 \leq P \leq 1 \tag{3}$$

Yet, the intersection area of probability distributions of expectation and satisfaction on an item can be small in two ways, as follows:

(1) When the satisfaction is higher than the expectation on an item, the performance distributions lie as the case of point Q_4 of type C in Fig. 2 and the probability distributions of expectation and satisfaction are as Fig. 4 shows.

In which, $p_{S_i} = \int_0^{\mathrm{a}} \frac{t^{\alpha_{S_i}-1}(1-t)^{\beta_{S_i}-1}}{\mathrm{B}(\alpha_{S_i},\beta_{S_i})} dt$, being the satisfaction of the elderly with the ith item expressed by percentage under a.

$p_{E_i} = \int_{\mathrm{a}}^1 \frac{t^{\alpha_{E_i}-1}(1-t)^{\beta_{E_i}-1}}{\mathrm{B}(\alpha_{E_i},\beta_{E_i})} dt$ being the expectation of the elderly with the ith item expressed by percentage above a.

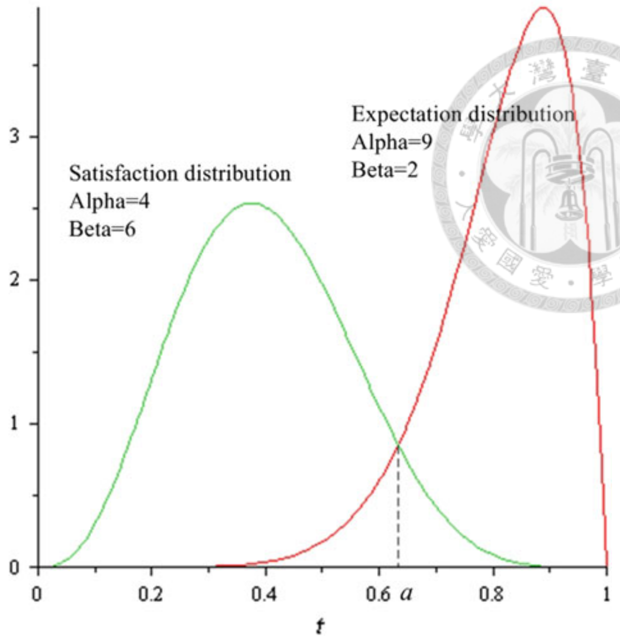


Fig. 5 Diagram of high expectation distribution versus low satisfaction distribution

(2) When the satisfaction is lower than expectation on an item, the performance distributions lie as the case of point Q_5 of type A in Fig. 2 and the probability distributions of expectation and satisfaction are as Fig. 5 shows.
In which, $p_{S_i} = \int_a^1 \frac{t^{\alpha_{S_i}-1}(1-t)^{\beta_{S_i}-1}}{\mathrm{B}(\alpha_{S_i},\beta_{S_i})}dt$, being the satisfaction of the elderly with the ith item expressed by percentage above a.
$p_{E_i} = \int_0^a \frac{t^{\alpha_{E_i}-1}(1-t)^{\beta_{E_i}-1}}{\mathrm{B}(\alpha_{E_i},\beta_{E_i})}dt$, being the expectation of the elderly with the ith item expressed by percentage under a.

Hence, a greater P value indicates the elderly have similar satisfaction with and expectation for the health benefit provided by the nursing and caring institution. If P is equal to 1, it implies that the elderly have equal degree of satisfaction with and expectation for the health benefit the nursing and caring institution provides. If P is equal to 0, then the elderly have totally different satisfaction with and expectation for the health benefit provided by the nursing and caring institution. If too many points lie in type A and type C, the assessment items with least intersection between expectation and satisfaction can be prioritized for improvement according to above-stated concept.

4 Analyze

Aimed at conducting the questionnaire in one caring center located in Taichung City, the article has employed the six sigma method to increase the health benefits of nursing and caring institutions and has identified item 24, which shows the least overlapped area between expectation and satisfaction, as the critical item through the aforementioned performance

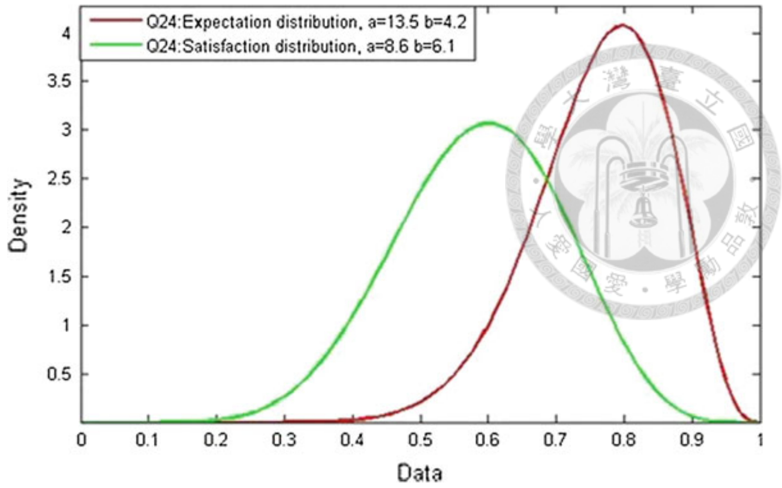


Fig. 6 Diagram of expectation distribution versus satisfaction distribution for item 24

evaluation matrix. Therefore, item 24 have high priority for improvement according to above concept as Fig. 6.

Now analysis will be made in the causes of poor health benefits of the business environment in the nursing and caring institution. There are actually many analytic tools and methods, such as Gantt chart, scatter diagram and process capability analysis. But, one important and handy tool most used currently by the industry is the cause and effect diagrams. It uses the factors of person, method, material, measurement and equipment to re-identify the sub-factors that affect and identify the causes of poor quality one by one to be analyzed for improvement. Huang et al. (2010) used cause and effect diagrams to analyze, in four constructs of person, equipment, design and material, the problems of poor quality in the operation of welding of surveillance cameras. Chen et al. (2010a) also used cause and effect diagrams to analyze, in the constructs of professional training, knowledge system, management system and investment and innovation, the causes of poor quality of leisure service.

As above-mentioned, the cause and effect diagrams are apparently a very good analytic tool, through which application more and more enterprises perfect their product quality or service quality. Hence, this article uses the cause and effect diagrams as an indispensable tool of analyzing the poor quality of health benefit of nursing and caring institutions. The factors possibly contributing to poor health benefits of the caring institutions are categorized in four constructs: person, facility, environment and system, as Fig. 7 shows. In 2007, however, the government began to conduct on-site evaluation in the nursing and caring institutions, with related regulations promulgated on the nursing and caring institution to counsel and supervise in respect of workers, institutional facilities, management system and environment tidiness. Its purpose is to protect the interest of the aged, promote the business development for the nursing and caring institutions, further to elevate the health benefits of the business environment of the institution and their total service quality. Hence, this article will focus on the overall creation of the caring institution's business environment in three aspects of vegetation, use of essential oil and background music to explore the factors contributing to poor health benefit.

(1) Vegetation: according to the research by Abbriti and Muzi (1995), the contemporary people spend 80–90% of their time indoors every day, in particular the aged, who often

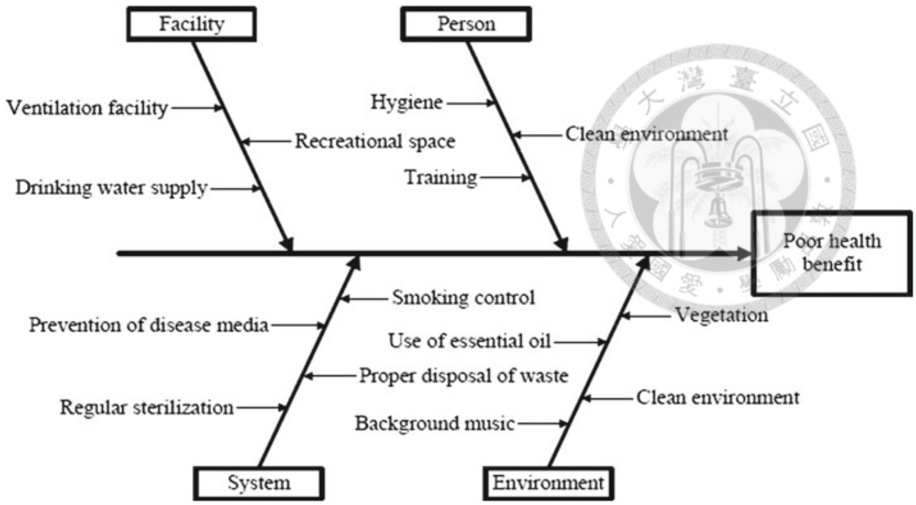


Fig. 7 Cause and effect diagrams for poor health benefit

stay indoors longer than 90% of their time. Thus, while people are in the indoor environment for long hours, the aerodynamic particles come into indoors through air flow and directly affect the indoor air quality and indirectly the health of human respiratory system. Honeyman (1992) suggested that plant placed indoors not only can increase positive emotion and effectively alleviate pressure in people but also uplift work efficiency and productivity. Without plant placed indoors, people have higher negative emotion and the work efficiency decreases. Many studies testified that the disposition of vegetation in business environment can work to clean the air and help the workers release their pressure. As such, the placement of appropriate species of plant will be able to effectively increase the indoor air quality of the nursing and caring institution and further enhance the health benefit of the overall environment.

(2) Use of essential oil: the chemical components of essential oils, which come in twelve types, each of different oil-solubility, water-solubility, masculine gender and feminine gender, enter human body through smelling and skin to balance the body, mind and soul, boost immunity function, promote metabolism and facilitate blood circulation to work to strengthen the systems of the body. The research by Pierre Franchomme and Daniel Penoel in 1990 indicated that the ester content in plants has good effects on relaxing and emotional alleviation in human body. Ruth von Braunschweig in Germany also suggested that the ester content in plants works to alleviate human feelings in emotions. Hence, the use of the right kinds of essential oils for the aged should be able to make them pleased and remove negative ideas in them and will create the comfortable and healthy caring environment, enhancing the health benefit of the business environment.

(3) Background music: music is an audible art, composed of tones, volume, rhythm and speed. It often makes man feel tranquilized, calm in mind, relaxed and pressure released. Music is a media of therapy as well. By the definition by The National Association for Music Therapy in 1977, music therapy, which takes the musical achievement as the object of therapy, makes music work in restoration, maintenance and improvement of individual psychological and physiological health so as to bring desirable changes to individual's behavior. Also, Gauthier and Dallaire (1993) pointed out that music

therapy is a treatment that uses music and its elements in a controlled way to help patients and the aged in achieving unification of psychophysiology and emotion during the treatment. It is known from above that music therapy employs the possible effects of music on human physiology and psychology to assist individuals in achieving the goal of maintain and enhancing psychophysiology health. As such, broadcasting music that suits the elderly in the nursing and caring institutions will improve their emotional states and the context of negative emotions, creating the caring environment that has health benefits.

5 Improve and control

As previously stated, this article applies cause and effect diagrams to identify the factors causing poor health benefit in the institutional environment from the viewpoint of creating overall environment in nursing and caring institutions. And the factors are vegetation, use of essential oil and background music, suggesting that the operators of the institutions should take the caring environment for the aged seriously and aim to create the living environment that has health benefits and is comfortable, to maintain every senior citizen in pleasant mood further to increase the competitive edge in market and the business performance.

Chen et al. (2010b) selected, by means of data envelopment analysis, the most cleansing indoor plants for business environment: *Schefflera actinophylla*, *Araucaria heterophylla*, *Sansevieria trifasciata* and *Tulipa gesneriana.* These are taken here as the subjects of enhancing health benefits of the nursing and caring institutions. Cho (2009) selected *Anthemis nobilis* (80%), *Salvia sclarea* (70%), *Citruus aurantium* (50–70%) and *Mentha citrata* (66%) for their high ester content in essential oils. These are taken herein as the subject essential oils. In background music, considering the research subjects being the aged in nursing and caring institutions, reference was made to Cheng (2007) who explored the preference of the aged for music and their physiological reaction. Thus, four types of music, namely, "classical music", "world music", "pop music" and "Taiwanese music", all of relaxing type are selected here in combination with the vegetation and essential oils to identify the best combination of health benefit of the business environment in caring institutions.

Ross (1988) and Taguchi and Clausing (1990) pointed out that Taguchi methodology, which decides design parameters by experiments, selects suitable experiment orthogonal matrix by the numbers of control factors and their levels. The method also uses S/N ratio to replace quality loss function to reduce interactions, whereby to be able to provide robustness to product design and quality in least time and at least cost with least times of experiments. Hence, to obtain optimal design parameters, this article will use the Taguchi methodology that was proposed by Taguchi in 1949 to explore and identify the best combination of vegetation, essential oil and music type to serve as reference in upgrading health benefits of the caring institutions.

This article selects the control factors and their levels (as Table 2) that affect the health benefit of the business environment in the nursing and caring institution and find out the best parameter design by Taguchi methodology.

The experiment herein has three four-level factors; hence we adopt the $L_{16}(4^5)$ orthogonal matrix, which happens to be one of the orthogonal tables Dr. Taguchi recommended. Herein, the average satisfactions obtained by questionnaire survey conducted at a nursing and caring institution in Taichung are also itemized in Table 3.

According to Taguchi (1987) and Taguchi (1991), S/N ratio refers to the ratio of signal to noise. A greater S/N ratio means the signal is stronger than the noise and it is easier to

Table 2 Table of control factors and levels of Taguchi experiment

	Factor	Level 1	Level 2	Level 3	Level 4
A	Plant species	*Schefflera actinophylla*	*Araucaria heterophylla*	*Sansevieria trifasciata*	*Tulipa gesneriana*
B	Type of essential oil	*Anthemis nobilis*	*Salvia sclarea*	*Citruus aurantium*	*Mentha citrata*
C	Type of music	Classical music	World music	Pop music	Taiwanese music

Table 3 Experiment results by $L_{16}(4^5)$ orthogonal matrix

Experiment number	Parameters and levels			Result	
	A	B	C	Average satisfaction	S/N
1	1	1	1	3.6901	11.3408
2	1	2	2	3.4596	10.7805
3	1	3	3	3.3755	10.5668
4	1	4	4	3.2621	10.2699
5	2	1	2	3.5070	10.8987
6	2	2	1	3.4354	10.7195
7	2	3	4	3.8741	11.7634
8	2	4	3	3.3656	10.5412
9	3	1	3	3.9353	11.8996
10	3	2	4	3.8957	11.8117
11	3	3	1	3.8533	11.7167
12	3	4	2	3.8280	11.6594
13	4	1	4	3.7589	11.5012
14	4	2	3	3.2750	10.3042
15	4	3	2	3.5807	11.0794
16	4	4	1	3.6946	11.3513

discern which is received, the signal or the noise. The deduction of S/N ratio takes logarithm of the loss function as the criteria for measuring product performance, which serves to reduce interactions and to strengthen product robustness. The equation is as follows:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \tag{4}$$

In which, y_i is observations and n is the number of observed.

Now this article will use the experiment results in Table 3 to calculate, by Eq. 4, the S/N ratio for each experiment result. A greater S/N ratio means greater effect on the health benefits of the business environment in the nursing and caring institution, which represents higher level of health benefit quality. Again, the mean S/N of the three factors at each level can be determined by the S/N ratio listed in Table 3, as Table 4 shows.

In Table 4, a greater effect value of the factor, literally a higher reaction of design factor to S/N Ratio, means the greatest contribution of plant species to the effect on the health benefit of the overall environment in the caring institution, with least effect by the type of

Table 4 Table of reaction of design factors to S/N ratio

	A	B	C
Level 1	10.740	11.410	11.283
Level 2	10.982	10.900	11.106
Level 3	11.772	11.284	10.830
Level 4	11.066	10.967	11.344
Effect	1.032	0.510	0.514
Rank	1	3	2

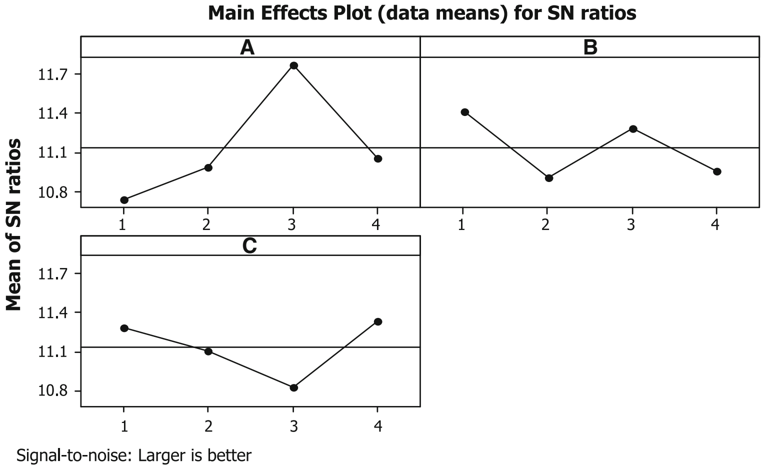


Fig. 8 Main effects plot for S/N ratios

essential oil. Finally, with these data plotted into Fig. 8, the design combination of factors A3, B1 and C4 can be selected as the best parameter design to elevate the health benefits of the nursing and caring institution. In other words, when the caring institution places *S. trifasciata* indoors, broadcast Taiwanese music and emanates essential oil of *A. nobilis*, it will be able to provide the healthy and comfortable caring environment, uplift the quality of health benefit of its overall environment for the aged.

The last step of six sigma method is control. This article will establish the control mode of standard operation procedure, as Fig. 9 shows, to examine the changes in health benefit performance of the institutional environment for the elderly at any time and analyze the problems immediately with concrete improving strategy proposed, whereby to effectively control the quality of health benefit. Such reference can be provided to the industry in elevating the health benefits of the institution to forge the comfortable living environment that has health benefits, further to upgrade their competitive edge in the market and business performance.

6 Conclusion

The elderly persons' expectation for and satisfaction with the health benefits of the business environment in nursing and caring institution was investigated by using the "scale of health benefit questionnaire". Critical problems were defined through the performance evaluation

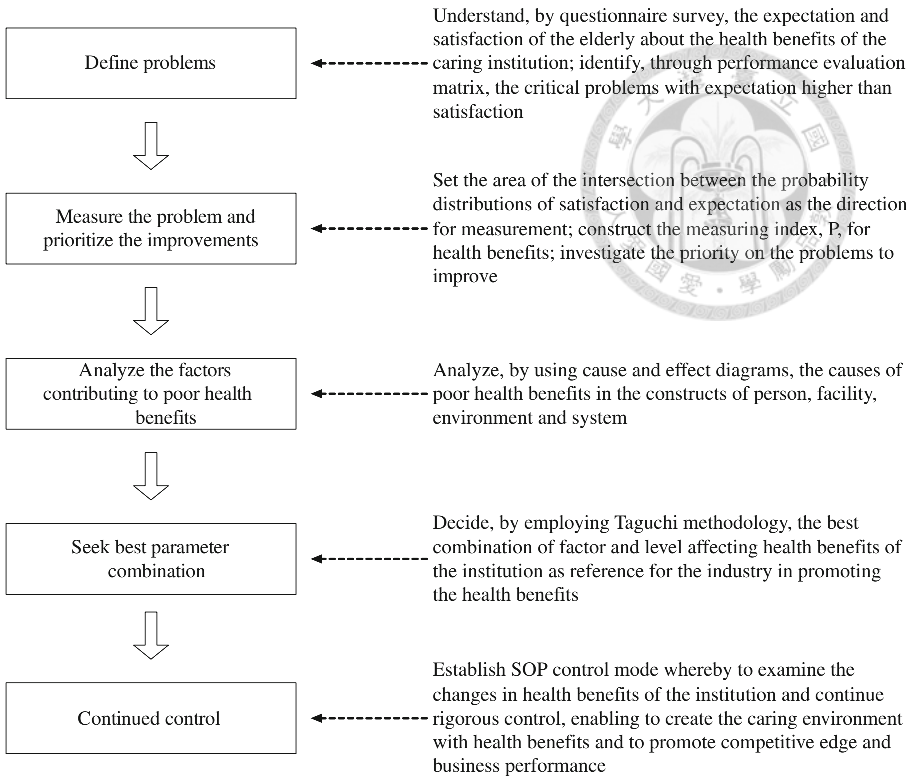


Fig. 9 SOP chart

matrix. With the size of the area of intersection between the distributions of satisfaction and expectation used as the direction for measurement, the measuring index, P, was established for health benefit to explore the priority on the problems to improve. Cause and effect diagrams were employed to identify the causes of poor health benefits before the Taguchi methodology was applied to set the voices of the elderly as important indices to find out the best combination for upgrading the health benefits of the business environment. By introducing the six sigma process to explore the health benefits and business performance of the nursing and caring institution, a standard operation procedure suitable for evaluating health benefits of the environment in nursing and caring institutions has been established in this article to maintain and control the health benefit quality of the institution's overall environment. It is trusted to be able to uplift the competitive edge of the nursing and caring institutions facing the fierce competition in future and generate good business performances.

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Analysis and construction of stress relief model for healthy indoor environments

Hsi-Chin Chen · Ching-Hsin Wang · Kuen-Suan Chen · Tsu-Liang Chang

Abstract Currently, the average person spends 80–90 % of their workday in an airtight indoor environment. Under such conditions, the presence of organic chemical pollutants in the air can compromise the health of workers and undermine work efficiency. Many researchers have demonstrated that plants can be used to purify the air and relive stress, essential oils can promote positive emotions and eliminate negative thoughts, and music can relieve stress by calming nerves and relaxing muscles. All of these are positively related to the release of stress and the promotion of health. This study employed three factors to construct environment-related dimensions with an influence on stress relief. We employed analytic network process to identify the environmental factors that are essential to stress relief, in conjunction with Taguchi method to determine the best combination of parameters. A model based on statistical analysis was used to verify the different benefits resulting from these changes. The proposed system provides an effective means to enhance air quality in the promotion of a comfortable, clean, and healthy environment. Our findings provide a valuable reference for the implementation of environment improvements in medical facilities, retirement homes, and office spaces.

Keywords Healthy stress relief environment · Analytic network process (ANP) · Indoor plants · Essential oil · Music

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1 Introduction

Currently, most people spend 80–90 % of their time working in an airtight indoor environment (Abbriti and Muzi 1995), which often has pollution levels ten times as high as the outdoor environment. This commonly leads to sick building syndrome (SBS), which can degrade work quality, work efficiency, and long-term health. Thus, determining the means to improve indoor air quality has been widely discussed.

According to Yeh (2010), indoor plants can decrease SBS. Bringslimark et al. (2007) and Dijkstra et al. (2008) have also shown that plants relieve stress and reduce negative emotions in addition to cleansing the air of volatile organic chemicals (VOCs), decreasing sick days, and promoting work efficiency. This is particularly evident when people are situated in a comfortable, clean, and healthy environment. Under such conditions, emotional stress can be effectively relieved, even to improve appetite (Talbott et al. 1976) and relieve discomfort (Ulrich 1984). Honeyman (1992) pointed out that maintaining plants within an office environment promotes positive emotions, relieves stress, and increases work efficiency and productivity. Environments without plants often promote negative emotions and decrease work efficiency.

Many essential oils have the ability to relieve stress, promote health, and freshen the air. Among this, ester is made up of alcohol and acid, has mild effects which is less dangerous (Huang 2008). French scientists, Pierre Franchomme and Daniel Penoel, pointed out in 1990 that plants emitting esters can prevent fungus, calm the central nervous system, balance sympathetic and parasympathetic nerves, and promote relaxation in the human body (Cho 2009). German Ruth von Braunschweig also showed that esters within plants can promote relaxation (Braunschweig and Wen 2003).

Hirokawa (2004), Kenny and Faunce (2004) and Ghou and Lin (2006) pointed out that the resonance of sound and human cells can promote feelings of calmness and relaxation as well as relieve stress and decrease depression. Brunges and Avigne (2003) and McKinney et al. (1997) showed that music can reduce one's heart rate, relax muscles, and increase the production of endorphins, which can diminish pain and increase happiness. Watkins (1997) pointed out that music can restore psychological and physical function, thereby attaining a unity of body and mind.

To summarize, plants can clean the air, relieve stress, and increase work efficiency; essential oils can induce happiness and eliminate negative thoughts; and music can calm the nerves, relax muscles and relieve stress. However, previous research on indoor environment stress relief has focused on single variables and failed to view the comprehensive effects of such factors together. This paper applied the methods proposed by Chen et al. (2013), by using cause and effect diagram analysis, consultation with experts, and a literature review to construct dimensions and guidelines related to environmental stress relief in targeting factors affecting human health indoors: indoor plants, essential oils, and music. We employed analytic network process (ANP) to identify the environmental factors that are essential to stress relief, in conjunction with Taguchi method to determine the best combination of parameters. A model based on statistical analysis was used to verify the different benefits resulting from these changes. The proposed system provides an effective means to enhance air quality in the promotion of a comfortable, clean, and healthy environment. Our findings provide a valuable reference for the implementation of environment improvements in medical facilities, retirement homes, and office spaces.

2 Using ANP to select factors affecting health environment

This paper simultaneously considered three factors (indoor plants, essential oils, and music) for the construction of a healthy stress-free environment. The relationships among these factors are outlined in the following:

(1) Plants: Chen et al. (2010) targeted the fifty species selected by NASA researcher Wolverton (1997), using DEA–CCR input-oriented model analysis for the selection of ideal species. In the same manner, this study referenced the opinions of experts to identify the following indoor plants as ideal: *Scheffleraactinophylla*, *Araucaria heterophylla*, *Sansevieriatrifasciata*, *Tulipagesneriana*, *Aloe barbandensis*, *Anthuriumandraeanum*, and *Phalaenopsis* sp.

(2) Essential oils: Esters emitted by plants can promote relaxation and relieve stress in the human body. Thus, we selected seven essential oils with a higher composition of esters, as described by Cho (2009): *Anthemisnobilis* 80 %, *Salvia sclarea* 70 %, *Citruusaurantium* 50–70 %, *Menthacitrata* 66 %, *Jasminumofficinais* 54 %, *Lavandulaangustifolia* 45 %, and *Citrus bergamia* 40 %.

(3) Music: Chen et al. (2013) discussed the role played by music in Taiwanese retirement homes with regard to musical preferences and physical reactions. However, Taiwanese music can be categorized many different ways according to the time period and one's personal perspective (Chien 2001). Thus, we adopted the "performance type" as described in Lu (1996) and Chien (2001) and referenced experts to select folk songs, song music, instrumental music, Taiwanese opera, classical Taiwanese music, and Western music for research.

(4) The relationship between music and plants: According to Zhao et al. (2001) and Duan et al. (2005), plants living in natural environment use single cells as units to sense and transmit signals via phosphorylation, which induces a series of physiology reactions to balance cell proliferation and differentiation. Lee et al. (2001), Wang et al. (2003), and Wei et al. (2008) have also shown that differences in the frequency and strength of sound waves can influence the cell cycle of tobacco plants, suggesting that sound waves within a certain range can stimulate cell division and assimilation, promote DNA synthesis, contribute to mitosis, and promote plant growth. Sound waves like those in music can stimulate gene expression and influence plant growth.

(5) The relationship between essential oils and plants: Essential oils are the secondary metabolite of plants, possessing aromatic odors and volatility at room temperature. These substances are an oily liquid that can be distilled by water vapor. According to Van de Braak and Leijten (1999), the complex composition of essential oil contains hundreds of chemical elements. It is estimated that over 3,000 types of essential oil exists, 300 of which have important commercial value. These substances can also be applied to plants to prevent their being eaten by herbivorous animals, maintain self-growth space, and attract pollinators for pollination. They can also be used to prevent excessive water evaporation, repel insects, heal injured areas, and prevent the growth of bacteria, fungus, and microbes.

This paper targeted the former three dimensions and 20 index factors, in addition to the relationships among dimensions to construct an ANP frame, as shown in Fig. 1. ANP was then used to identify the factors that most significantly influence stress relief in an indoor environment.

The ANP method was presented by Saaty (1996) and Saaty and Vargas (2000) as a means to overcome problems associated with the interdependencies among standards and levels as

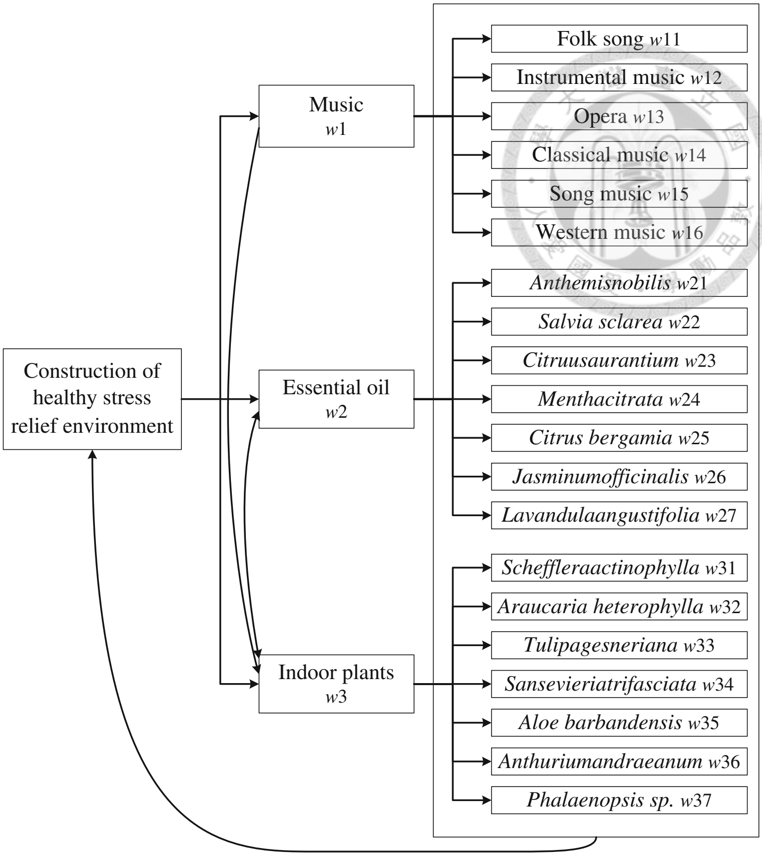

Fig. 1 Target level dimensions dependencies feedback

well as feedback in traditional analytical hierarchy process (AHP). ANP has been used to good effect by Taslicali and Ercan (2006); Gencer and Gurpinar (2007); Voulgaridou et al. (2009); Jung and Seo (2010), and Tseng (2011). This paper follows the approach established by Chung et al. (2005), using the five procedures in ANP as follows:

2.1 Procedure 1: Establish estimated network hierarchy structure

We adopted the approach of Chen et al. (2013), to construct and evaluate the interdependencies between criteria and subjects as well as the interdependencies of criteria. This was divided into a target level, primary level (stress relief evaluation dimensions), and secondary level (stress relief evaluation criteria), comprising 20 impact factors. We designed a questionnaire to address the issue of "constructing an environment for the relief of stress" to target the relationship between each two criteria in the establishment of paired matrices, the eigenvector of which were used to establish a supermatrix. Evaluation was performed using a 5-point scale (equally important, somewhat more important, very important, and essentially important), for the values of 1, 3, 5, 7, and 9, respectively. We also considered the applicability of the questionnaire, and recruited 30 experts (15 experts and 15 graduate students) who possess

Table 1 Relative position of each sub-matrix in the supermatrix

	Goal	Evaluated dimension	Evaluated criterion
Goal			D
Evaluated dimension	A	B	
Evaluated criterion		C	

Table 2 Paired comparison matrix of the dimension of essential oils

	w 21	*w* 22	*w* 23	*w* 24	*w* 25	*w* 26	*w* 27	Weighted *W*
w 21	1.00	0.51	0.75	1.33	2.83	2.17	1.47	0.105
w 22	1.95	1.00	1.40	1.68	2.75	2.41	2.01	0.073
w 23	1.33	0.71	1.00	1.74	3.85	2.09	1.39	0.086
w 24	0.75	0.60	0.57	1.00	1.75	1.57	1.09	0.135
w 25	0.35	0.36	0.26	0.57	1.00	0.68	0.65	0.260
w 26	0.46	0.41	0.48	0.64	1.47	1.00	0.70	0.195
w 27	0.68	0.50	0.72	0.92	1.53	1.42	1.00	0.145
		$\lambda_{max} = 7.0456$		$CR = 0.0058$		$CI = 0.0076$		

an understanding of indoor plants, essential oils, and music. The structure of each level and the related interdependencies are presented in Fig. 1.

2.2 Procedure 2: Establish a paired comparison matrix

This paper used the factors affecting stress relief to determine the relative position of each matrix within the supermatrix (as shown in Table 1). Environmental factors related to stress relief and evaluation criteria were used to calculate the weighted value (W) of each factor.

We used the results from the survey of experts to acquire numerous comparison matrices. At this point, calculating the value of characteristics and eigenvectors and verifying consistency is necessary. According to Saaty (1980), matrices using the same columns must be evaluated using the ratio of consistency index (CI) and random index (RI), called the consistency ratio (CR) as calculated in Eqs. (1) and (2). The value of CR must be less than 0.1 for the matrix to be considered sufficiently consistent.

$$CI = (\lambda_{max} - n)/(n - 1) \tag{1}$$

$$CR = CI/RI \tag{2}$$

In this formula, λ_{max} indicates the maximum eigenvector, n indicates the number of columns, and RI is the random index of the matrix. This paper used Eqs. (1) and (2) to calculate the λ_{max} of the essential oil dimension as 7.0456. The CR value was 0.0058, as shown in Table 2, indicating sufficient consistency. We then used the same method for all of the other dimensions and the CR value was always less than 0.1, indicating sufficient consistency.

2.3 Procedure 3: Calculate the weighted value of each matrix

First, the eigenvector calculated from each matrix is used as a weighed value. These are calculated one by one using Super Decision software. Then, according to the interdependencies of each factor, the unweighted supermatrix M' is developed, as shown in Table 3.

Table 3 Unweighted supermatrix M' of each elements' interdependencies

	Music	Essential oil	Plants	$w11$	$w12$	$w13$	$w14$	$w15$	$w16$	$w21$	$w22$	$w23$	$w24$	$w25$	$w26$	$w27$	$w31$	$w32$	$w33$	$w34$	$w35$	$w36$	$w37$
Music	0.000	0.371	0.625	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Essential oil	0.417	0.208	0.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plants	0.417	0.254	0.208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w11$	0	0.020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w12$	0	0.028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w13$	0	0.011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w14$	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w15$	0	0.020	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w16$	0	0.047	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w21$	0.018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w22$	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w23$	0.014	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w24$	0.023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w25$	0.043	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w26$	0.032	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w27$	0.024	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w31$	0	0	0.013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w32$	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w33$	0	0	0.012	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w34$	0	0	0.045	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w35$	0	0	0.011	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w36$	0	0	0.027	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w37$	0	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2.4 Procedure 4: Calculation of the supermatrix

The supermatrix comprises numerous sub-matrices, which comprise eigenvectors created by the comparison of dimensions. Table 3 presents the initial unweighted matrix. Because the column values do not meet the column-stochastic (the sum of column values does not equal one), certain applications must be made to acquire the weighted supermatrix (M) as shown in Table 4.

This paper employed the approach presented by Saaty (1996) to transform the weighted supermatrix (M) into a limit supermatrix M^* using Eq. (3).

$$M^* = \lim_{k \to \infty} M^k; k \in power \tag{3}$$

Equation (3) consecutively multiplies the weighted supermatrix M and takes the k exponential (k is a subjectively determined value) to acquire a convergence limit for supermatrix M^*. This, along with the relative weighted value calculated between the elements, is presented in Table 5.

2.5 Procedure 5: Calculate weighted values of feasible plans

Finally, decision makers can use the value acquired from the limit value of consecutive multiplications as a references for selections, as shown in Table 6.

According to Table 6, the top three forms of music include Western music ($w16$), classical music ($w14$), and instrumental music ($w12$). The top three essential oil include *Citrus bergamia* ($w25$), *Jasminumofficinalis* ($w26$), and *Lavandulaangustifolia* ($w27$). The top three plants are *Sansevieriatrifasciata* ($w34$), *Phalaenopsis* sp. ($w37$), and *Anthuriumandraeanum* ($w36$). We then employed Taguchi method to identify the best combination of parameters for a healthy indoor environment.

3 Taguchi method

As described in Ross (1988) and Taguchi (1991), Taguchi method uses tests to determine the parameters used in a design. It is determined primarily by the control factors and the number of levels involved in the selection of an appropriate orthogonal matrix. To decrease the effect of interactions, S/N ratio is used to replace the loss function to achieve product consistency, while minimizing computation time, costs, and the number of tests.

First, according to the ANP, the following are the most important factors affecting stress relief in an indoor environment: Western music ($w16$), classical music ($w14$), and instrumental music ($w12$); *Citrus bergamia* ($w21$), *Jasminumofficinalis* ($w26$), and *Lavandulaangustifolia* ($w27$); *Sansevieriatrifasciata* ($w34$), *Phalaenopsis* sp. ($w37$), and *Anthuriumandraeanum* ($w36$). Factors and levels are presented in Table 7.

This test comprises three three-level factors resulting in 8 degrees of freedom. Thus, we employed the $L_9(3^3)$ orthogonal matrix shown in Table 9. The experiment was ready for testing when the matrix was established. Because we were striving to obtain results applicable to every indoor environment, we attempted to keep the survey short. We employed the Perceived Environmental Restorativeness Scale described in Berto (2005), as the basis to design the stress relief questionnaire presented in Table 8. The goal was to determine the subjects' level of satisfaction with the overall environment and acquire sample observation values. Y scores were given for sample results. This test was administered over a 10 day

Table 4 Weighted supermatrix *M*

	Music	Essential oil	Plants	$w11$	$w12$	$w13$	$w14$	$w15$	$w16$	$w21$	$w22$	$w23$	$w24$	$w25$	$w26$	$w27$	$w31$	$w32$	$w33$	$w34$	$w35$	$w36$	$w37$
Music	0.000	0.445	0.750	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Essential oil	0.500	0.250	0.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plants	0.500	0.305	0.250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w11$	0	0.117	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w12$	0	0.166	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w13$	0	0.063	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w14$	0	0.253	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w15$	0	0.122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w16$	0	0.279	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w21$	0.105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w22$	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w23$	0.086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w24$	0.135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w25$	0.260	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w26$	0.195	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w27$	0.145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w31$	0	0	0.077	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w32$	0	0	0.095	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w33$	0	0	0.074	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w34$	0	0	0.270	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w35$	0	0	0.066	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w36$	0	0	0.163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
$w37$	0	0	0.255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 5 Limited supermatrix M^*

	Music	Essential oil	Plants	$w11$	$w12$	$w13$	$w14$	$w15$	$w16$	$w21$	$w22$	$w23$	$w24$	$w25$	$w26$	$w27$	$w31$	$w32$	$w33$	$w34$	$w35$	$w36$	$w37$
Music	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282	0.282
Essential oil	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237	0.237
Plants	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
$w11$	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
$w12$	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
$w13$	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
$w14$	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
$w15$	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
$w16$	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
$w21$	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
$w22$	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
$w23$	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
$w24$	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
$w25$	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
$w26$	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014	0.014
$w27$	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
$w31$	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
$w32$	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
$w33$	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
$w34$	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016
$w35$	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
$w36$	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
$w37$	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016	0.016

Table 6 Weighted value of factors for the construction of an environment to promote stress relief

	Music	Essential oil	Plants	$w11$	$w12$	$w13$	$w14$	$w15$	$w16$	$w21$	$w22$	$w23$	$w24$	$w25$	$w26$	$w27$	$w31$	$w32$	$w33$	$w34$	$w35$	$w36$	$w37$
Weighted value	0.282	0.237	0.257	0.009	0.011	0.007	0.015	0.009	0.016	0.010	0.008	0.009	0.010	0.017	0.014	0.012	0.008	0.009	0.008	0.016	0.008	0.012	0.016

Table 7 Control factors and levels

		Level 1	Level 2	Level 3
A	Plants	*Phalaenopsis* sp.	*Anthuriumandraeanum*	*Sansevieriatrifasciata*
B	Essential oils	*Citrus bergamia*	*Jasminumofficinalis*	*Lavandulaangustifolia*
C	Music	Western music	Classical music	Instrumental music

Table 8 Stress relief questionnaire

Stress relief item	Y (score)
1. That is a place which is away from everyday demands and where I would be able to relax and think about what interests me (being-away)	Y_1
2. That place is fascinating; it is large enough for me to discover and be curious about things (fascination)	Y_2
3. That is a place where the activities and the items are ordered and organized (coherence)	Y_3
4. That is a place which is very large, with no restrictions to movements; it is a world of its own (scope)	Y_4
5. In That place, it is easy to orient and move around so that I could do what I like (compatibility)	Y_5
6. Overall, I am satisfied with this place (satisfaction)	Y_6

Table 9 Experiment results by $L_9(3^3)$ orthogonal matrix

Sample number	Parameters and levels			Rsult	
	A	B	C	Y	S/N
1	1	1	1	83.86	38.4710
2	1	2	2	79.75	38.0346
3	1	3	3	79.61	38.0194
4	2	1	2	81.85	38.2604
5	2	2	3	81.19	38.1901
6	2	3	1	84.37	38.5237
7	3	1	3	76.49	37.6721
8	3	2	1	81.45	38.2182
9	3	3	2	79.93	38.0542

period between October 15th and October 26th of 2012. A total of 52 samples were collected for data analysis. The results are detailed in Table 9.

Following the Taguchi test, we wish that the greater impact our subjects felt about the healthy stress relief environment to indicate the better effect of healthy stress relief environment. In our results, the larger the S/N ratio, the better the effect of efforts to relieve stress. Therefore, we employed 'the larger the better' product characteristics in Eq. (4) to calculate the S/N ratio for each sample.

$$S/N = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right] \text{(the larger the better product characteristic)} \tag{4}$$

Table 10 The reaction of designed factors to S/N ratio

	A	*B*	*C*
Level 1	38.175	38.134	38.404
Level 2	38.325	38.148	38.116
Level 3	37.982	38.199	37.961
Effect	0.343	0.065	0.443
Sequence	2	3	1

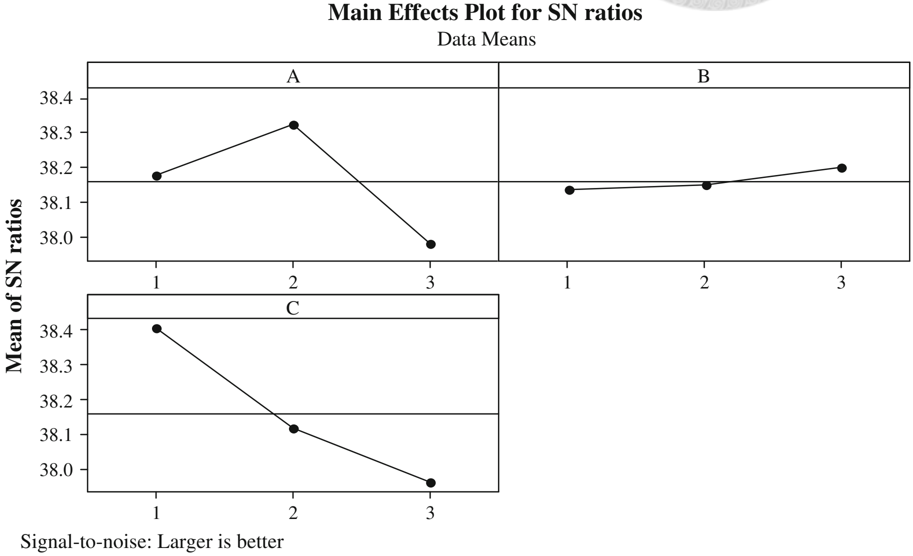

Fig. 2 Main effects plot of environmental factors affecting stress relief for S/N ratios

We used Minitab software to calculate the average S/N ratio of each factor level, as shown in Table 9. The reaction of designed factors to S/N ratio is presented in Table 10; factor effect diagrams are presented in Fig. 2.

We can infer from Fig. 2 that the best combination of factors related to stress relief is achieved using A2 (*Anthuriumandraeanum*), B3 (*Lavandulaangustifolia*), and C1 (Western music).

4 Experimental verification

Our results indicated that *Anthuriumandraeanum* as a cost-effective indoor plant, which is not effected by the season. *Lavandulaangustifolia* essential oil is reasonably priced and Western music is widely available. Hence, the three factors with the best designed parameters for healthy stress relief environment all correspond to the general consensus and are convenient for constructing healthy stress relief environment. According to the criteria described earlier, we collected 52 repeated sample data and used those with no specific arrangements as controls to analyze and evaluate the effects of changes in the stress relief environment.

In accordance with Chen et al. (2002), we employed statistical testing as an objective means to evaluate the effectiveness of an environment designed for stress relief. The 52 data before improvement were first sequenced from the smallest to largest $(X_{(1)}, X_{(2)}, \cdots, X_{(52)})$. $X_{(i)}$ indicates the i data after sequencing. Similarly, the 52 data after improvement were sequenced from the smallest to largest .$(X'_{(1)}, X'_{(2)}, \cdots, X'_{(52)})$ Let $Y_i = X'_{(i)} - X_{(i)}$ to indicate the difference in each i data. Generally, if there's a significant effect, the value of $X'_{(i)} - X_{(i)}$ should be positive with $Y_i > 0$ and the larger the mean the better the effect. Hence, when the mean μ_y is larger than 0 for an environment designed for stress relief, then the parameter for the best design has a significant effect. The hypotheses are as follow:

$$\begin{array}{c} H_0 : \mu_y \leq 0 \\ H_a : \mu_y > 0 \end{array} \tag{5}$$

$\bar{Y}$ is used to evaluate whether the parameter for the best environment has a significant effect. If the observed value acquired from the assessment statistics is $\bar{Y} = v$, then the $p - value$ for the improvement can be shown as follows:

$$\begin{aligned} p - value &= P\left(\bar{Y} > v \middle| \mu_y = 0\right) \\ &= P\left(Z > \frac{v}{s/\sqrt{n}}\right) = 1 - \Phi\left(\frac{v}{s/\sqrt{n}}\right) \end{aligned} \tag{6}$$

This paper used $p - value$ as an assessment tool for environment-related changes in stress relief with the producer risk set as $\alpha = 0.05$. A $p - value < 0.05$ indicates that the effect is significant. We sequenced the 52 sample data from smallest to largest and calculated the mean and standard deviation of the sample difference as $\bar{Y} = 25.667$ and $s = 3.622$. This value was then inputted into Eq. (6) to acquire a $p - value = 0.0000$, indicating that the parameters for the best stress relief design is significant.

5 Conclusion

This paper employed ANP to research plants, essential oils, and music to evaluate their influence on stress relief in an indoor environment and the twenty impact factors. Relative weighted values were calculated to select the most important three factors for each of the three dimensions. Taguchi method revealed that the plant *Anthuriumandraeanum*, the essential oil *Lavandulaangustifolia*, and Western music could provide the best combination in developing an environment conducive to stress relief. Statistical analysis was used to evaluate changes in stress relief, according to whether these changes resulted in a significant effect. We then established a model to enhance air quality in the promotion of a comfortable, clean, and healthy environment. Our findings provide a valuable reference for the implementation of environment improvements in medical facilities, retirement homes, and office spaces.

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