行政院國家科學委員會專題研究計畫 成果報告

以導引式螞蟻演算法求解運輸與運籌領域之排序問題
研究成果報告(精簡版)

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中 文 摘 要 ： 考量海運兼具運輸與運籌管理的重要性，以及排序問題的研究問地，本研究以船席指派問題(Berth Allocation Problem, BAP) 為研究的焦點。船席指派問題旨在指派船席給船舶接受相關的服務。依據已知的船舶抵達時間動態資訊，模式之目標式在最小化所有船舶之總服務時間，其包含了船舶的等待時間以及處理時間。尤其，在本研究假設船舶的處理時間與指派的船席具相關性，因此會受到船席指派決策的影響。由於船席指派問題為一排序問題，而螞蟻演算法(Ant Colony Optimization, ACO)在排序問題上的搜尋能力及求解過程相較於其他巨集啟發式演算法具有優勢。因此，本研究採用螞蟻演算法作為求解方法。首先，透過螞蟻演算法產生船舶的指派順序。再藉由啟發式指派法則，參考船舶的抵達時間以及與船席相關的處理時間，依序進一步得到船舶的船席指派與起始的服務時間規劃。由數值測試可知，本研究之啟發式演算法與文獻中採用拉式鬆弛法之研究相較，能有效提升求解品質。

中文關鍵詞： 船席指派問題、啟發式演算法、螞蟻演算法

英 文 摘 要 ： Given the importance for both transportation and logistics as well as the scope of sequencing problems, the focus of this study is the Berth Allocation Problem (BAP), which determines the assignment of the berths to the calling ships. Given the dynamic information of the ship arrival times, the objective of the dynamic BAP is to minimize the total service times, defined as the sum of the waiting times and handling times, for all calling ships. In particular, the handling time is assumed to be berth-dependent and thus affected by the berth assignment decision. Owing to the nature of the sequencing decision problem associated with the BAP, this study chooses the Ant Colony Optimization (ACO), which has some inherited advantages over other meta-heuristics due to its sequential framework for the searching process and the solution building procedure. This study designs an ant-based algorithm to generate the ship assignment sequence, by which a greedy heuristic assigns a berth to a ship and determines the berthing window by considering its arrival time and the berth-dependent handling time. In the numerical experiment, the developed algorithm is compared with a solution algorithm based on Lagrangian Relaxation in the literature. It is found that the developed ant-based algorithm is promising with respect to the solution quality for the dynamic BAP.

英文關鍵詞： Berth Allocation Problem, Heuristics, Ant Colony Optimization

行政院國家科學委員會補助專題研究計畫

□期中進度報告
■期末報告

以導引式螞蟻演算法求解運輸與運籌領域之排序問題

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共同主持人：
計畫參與人員：

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中　華　民　國　101　年　10　月　31　日

中文摘要

摘要

考量海運兼具運輸與運籌管理的重要性，以及排序問題的研究問地，本研究以船席指派問題(Berth Allocation Problem, BAP) 為研究的焦點。船席指派問題旨在指派船席給船舶接受相關的服務。依據已知的船舶抵達時間動態資訊，模式之目標式在最小化所有船舶之總服務時間，其包含了船舶的等待時間以及處理時間。尤其，在本研究假設船舶的處理時間與指派的船席具相關性，因此會受到船席指派決策的影響。由於船席指派問題為一排序問題，而螞蟻演算法(Ant Colony Optimization, ACO)在排序問題上的搜尋能力及求解過程相較於其他巨集啟發式演算法具有優勢。因此，本研究採用螞蟻演算法作為求解方法。首先，透過螞蟻演算法產生船舶的指派順序。再藉由啟發式指派法則，參考船舶的抵達時間以及與船席相關的處理時間，依序進一步得到船舶的船席指派與起始的服務時間規劃。由數值測試可知，本研究之啟發式演算法與文獻中採用拉式鬆弛法之研究相較，能有效提升求解品質。

關鍵詞：船席指派問題、啟發式演算法、螞蟻演算法

Abstract

Given the importance for both transportation and logistics as well as the scope of sequencing problems, the focus of this study is the Berth Allocation Problem (BAP), which determines the assignment of the berths to the calling ships. Given the dynamic information of the ship arrival times, the objective of the dynamic BAP is to minimize the total service times, defined as the sum of the waiting times and handling times, for all calling ships. In particular, the handling time is assumed to be berth-dependent and thus affected by the berth assignment decision. Owing to the nature of the sequencing decision problem associated with the BAP, this study chooses the Ant Colony Optimization (ACO), which has some inherited advantages over other meta-heuristics due to its sequential framework for the searching process and the solution building procedure. This study designs an ant-based algorithm to generate the ship assignment sequence, by which a greedy heuristic assigns a berth to a ship and determines the berthing window by considering its arrival time and the berth-dependent handling time. In the numerical experiment, the developed algorithm is compared with a solution algorithm based on Lagrangian Relaxation in the literature. It is found that the developed ant-based algorithm is promising with respect to the solution quality for the dynamic BAP.

Keywords: Berth Allocation Problem, Heuristics, Ant Colony Optimization

一、　前言

綜觀全球的國際貿易活動，先前的國際貿易往往皆以海洋運輸為大宗。即便在幾十年前航空運輸的問市，其一舉縮短了相當幅度的運輸時間，但受限於空運載量少、運費高的要件，往往只有保值期受限或高單價的貨物，才會選擇使用空運當作國際貿易的運輸方式。因此，遑論過去、現在或是將來，海運在國際貿易的地位仍是不可撼動的。進而分析海洋運輸的領域，船舶視為運輸工具，港埠則是起訖點，同樣也是裝卸貨物的場域，對於國際貿易活動為主的國家來說，海洋運輸必然扮演著不可或缺的角色，要能有出色的經濟發展，其港口的競爭力自然成為不得不關注的焦點。

儘管全球的總體經濟有所起伏，長遠來說，海運的運量，尤其是在貨櫃數量上的走勢仍是持續向上攀升，全世界的港口往往都需解決船隻停泊的擁擠問題。此外，面臨油價高漲的趨勢，對於海運成本更是錙銖必較，如何控管整體海運成本自然是為相當重要的議題

有別於過去貨櫃港埠經營的人工作業，目前較為先進的貨櫃港埠經營模式多採電腦輔助作業，以解決如此大型且繁複的船席指派問題。因此，在面對眾多需要靠港的船舶且船席有限的情況下，如何進行「船舶最適化的調派服務」之決策，使得整體的港埠營運更有效率乃為本研究所欲探討的核心課題。

二、　研究目的

船席在貨櫃碼頭中乃為相當重要的資源，而船席規劃對於港口經營者以及航運業者而言，更是扮演著舉足輕重的角色，可謂港口營運成本的結構中最為關鍵的一環。以港口經營者的角度，如何提升工作效率以及服務水準乃為船席規劃中的核心議題；另一方面，航運業者也同樣關心船舶的裝卸貨作業是否產生延遲。然而，船席的建造費用往往所費不貲，不可能一昧地靠提高供給來提供航運業者所要求的服務，有效地加以運用船席資源更為重要。

三、　文獻探討

有關船席指派問題，Theofanis *et al*. (2009)提供了相當完整的文獻整理。本研究之文獻回顧將著重於 DDBAP 相關的文獻上，其中並未考量碼頭起重機(quay crane)以及貨櫃場營運(yard operation)的交互影響。以下兩節分別就動態且離散型的船席指派問題(DDBAP)相關研究的發展，以及螞蟻演算法在船席指派問題的應用，分別加以闡述。

3.1 動態離散型船席指派問題之相關研究發展

Imai *et al*. (2001)為了改進過去先來先服務(first-come-first-service)的決策方式，將 DDBAP 以混合整數規劃(Mixed Integer Programming, MIP)來定義。目標式為最小化所有船舶的的等待時間和處理裝卸貨時間，並採用以拉式鬆弛為基礎的啟發式解法來求解。之後，Nishmura *et al*. (2001)參考 Imai *et al*. (2001)，在目標式相同的情況下，並符合港埠限制之情形，納入可在單一船席服務一艘以上船舶的可能性，並以基因演算法求解。另外，Imai *et al*. (2003)考慮有關權重的服務優先權限制，進一步修正 DDBAP 的數學規劃模式，修正目標式為最小化所有船舶的加權服務時間，其採用基因演算法進行求解。在數值測試中，並探討了包含不同權重的優先權所產生的影響。

近年來，多篇研究更積極將更多實務情況納入考量，目標式值也不僅僅是傳統的形式(諸如像等候時間及處理時間)，也考慮了一些實務性因素。舉例來說，此外， Imai *et al*. (2007a)引進具有凹型船席(indented berth)的 DDBAP 模式。基於大型貨櫃船的等待成本較高，應擁有較高的優先順序；因此，在其 DDBAP 的架構中，大型貨櫃船將盡可能地先接受服務。而其求解方式，亦採用基因演算法求解。Imai *et al*. (2007b)在船席調派的問題上，額外考慮兩個構面。除了最小化所有船舶服務時間外，也要檢視其服務水準，透過船舶駛離時間以及船席的使用績效兩者來進行評估。Hansen *et al*. (2008)在 DDBAP 的架構上，除了考慮等待時間和裝卸貨時間極小化，也納入了提早和延遲完工等要素做為目標式的一部分。透過雙目標式的模式建構，採用變動鄰域搜尋法(Variable eighborhood Search, VNS)進行求解。最後，Golias *et al*. (2009)根據船舶的優先權，採用多目標式的 DDBAP 以解決船舶服務差異化的問題，並透過基因演算法進行求解。

3.2 螞蟻演算法在船席指派問題的應用

過去文獻中，Nishmura *et al*. (2001)、Imai *et al*. (2007)及 Golias *et al*. (2009)等多篇研究採用基因演算法求解，可知基因演算法已廣泛被使用於許多型態之船席指派問題。然而，極少研究使用螞蟻演算法進行求解，本研究相信其可提升對船席指派問題的求解效能，並開發螞蟻演算法更廣的應用。

螞蟻演算法在各種組合性最適化問題上成效卓著，其中也包含了許多排序問題，但過去應用螞蟻演算法於船席指派問題的研究相當稀少，主要僅有兩篇研究：Tong *et al*. (1999)、Cheong and Tan (2008)。Tong *et al*. (1999) 將螞蟻演算法應用至連續型的 BAP，問題型態與本研究不同；其目標式在儘量減少所需服務船舶的碼頭長度，亦與一般研究相異。而 Cheong and Tan (2008)則提出了一種多目標的群聚螞蟻演算法，其中每一隻螞蟻僅負責單一船席如何指派的規劃順序。在其求解架構中，先以螞蟻演算法導引出一組船舶的指派順序，之後再針對每艘船舶以另一螞蟻演算法產生出相應的船席。為避免兩螞蟻在演算法上產生干擾，而本研究則認為一旦產生船舶的指派順序，即可透過一套具系統性的啟發式法則來產生船舶指派決策。

有關 DDBAP 之相關研究，近來有許多研究致力於更多實務層面的目標式或限制式。然而，典型的 DDBAP 仍是各種延伸型船席指派問題的基礎，亦仍舊有多個研究致力於基本問題的求解效能。因此，本研究遵循這個方向能針對基本型的 DDBAP，以 Imai *et al*. (2001)為例，發展一套以螞蟻演算法為基礎的新演算法，以在可行時間內求得大型問題的理想近似解。

四、 數學模式

根據 Imai *et al*. (2001)，DDBAP 可被視為混合整數規劃問題。數學模式與服務次序有相互關係；而其中，船舶的處理時間則與船席位置具相關性。

$$Minimize \sum_{i\in B}\sum_{j\in V}\sum_{k\in U}(kC_{ij}+S_i-A_j)x_{ijk}+\sum_{i\in B}\sum_{j\in V}\sum_{k\in U}ky_{ijk} \quad (1)$$

subject to

$$\sum_{i\in B}\sum_{k\in U}x_{ijk}=1 \quad \forall j\in V \quad (2)$$

$$\sum_{j\in V}x_{ijk}\le 1 \quad \forall i\in B, k\in U \quad (3)$$

$$\sum_{l\in V}\sum_{m=k+1}^{T}(C_{il}x_{ilm}+y_{ilm})+y_{ijk}-(A_j-S_i)x_{ijk}\ge 0 \quad \forall i\in B, j\in V, k=1\ to\ (T-1) \quad (4)$$

$$x_{ijk}\in\{0,1\} \quad \forall i\in B, j\in V, k\in U \quad (5)$$

$$y_{jik}\ge 0 \quad \forall i\in B, j\in V, k\in U \quad (6)$$

符號說明：

i ： 代表船席，$i = 1, \ldots, I$，而 B 為船席的集合。

j ： 代表船舶，$j = 1, \ldots, T$，而 V 為船舶的集合。

k ： 代表船席的服務位置，$k = 1, \ldots, T$，而 U 為服務位置的集合。

A_j ： 船舶 j 的抵達時間。

C_{ij} ： 為船舶 j 在船席 i 所需的裝卸貨處理時間。

S_i ： 為船席 i 開始可用的時間點。

P_k ： 為 U 的子集合，定義為 $P_k = \{p|\ p > k\in U\}$。

決策變數:

x_{ijk} ： 為二元變數。若為 1，則代表代表船舶 j 在 i 船席的位置 k 接受服務。

y_{ijk} ： 代表在船席 i，從位置 k+1 的船舶駛離，直至位置 k 的船舶 j 抵達的閒置時間。

根據式(1)，目標式為最小化所有船舶的等待時間以及裝卸貨時間。此數學模式中，會受服務次序 k 之影響。然而，相較於開始服務時間而言，此服務次序 k 恰好與其相反。也就是說，當 $k = 1$，代表最後一艘至船席接受服務之船舶，而當 $k = T$，也就為第一艘至船席接受服務之船舶。因此式(1)中，考量同一船席對後續而來之船舶所產生的影響時，處理時間(C_{ij})與兩接續服務次序的船席閒置時間(y_{ijk})，在目標式中皆乘上 k，另外再加上船舶抵達時間與船席開始可服務的時間差，即可得到船舶的總服務時間。限制式(2)在確保每一艘船可以在某船席某位置下被服務。限制式(3)著重在每船席同時最多提供一艘船舶進行服務。透過代表閒置時間變數(y_{ijk})的引入，限制式(4)確定船舶為抵達後才接受服務。限制式(5)表示指派決策為二元變數。限制式(6)則表示船席的閒置時間，必然不小於 0。

五、　研究方法

由於船席指派問題為 NP-hard 之問題，面臨船舶數量較多時，問題可行解的空間將變得相當龐大。為了達到縮小搜索空間又兼顧求解品質的前提，本研究先將求解演算法區分為兩個環節。分別為螞蟻演算法產生船舶服務的指派順序，以及透過啟發式指派原則產生船席指派決策。

在 5.1 小節，介紹如何透過螞蟻演算法產生船舶服務的指派順序；主要乃透過累積之費洛蒙值以及依照 DDBAP 所發展的啟發式值，以隨機的方式產生指派順序。一旦得到指派順序，在 4.2 小節仍須將該組船舶的指派順序轉為船席指派之決策。本研究開發一項啟發式演算方法，稱為貪婪指派規則(Greedy Assignment Rule, GAR)，將該組指派順序，轉為船席指派決策。在得到該組指派順序的目標式值後，進一步回饋給螞蟻演算法，藉由更新費洛蒙值，以供下一迭代所使用，進而產生出更佳的指派順序與船席指派決策。

5.1 以螞蟻演算法產生指派順序

螞蟻系統演算法(Ant System Algorithm, ASA)為一具有迭代性的演算法。在迭代中，模仿螞蟻的搜索行為，產生了不同的解答。這些人工螞蟻選擇路徑的機率性，乃是參照前一迭代的費洛蒙濃度大小，而有所差異。關於本研究螞蟻演算法所構築的搜索空間，以及各節點順序的選擇情況，如圖 1 所示。螞蟻的搜索空間係包含「船舶」與「選擇階段」之二維空間。其中，船舶與選擇階段皆等於船舶的總數。在不同的選擇階段上，n 個節點就如同擁有 n 艘船舶可供選擇，唯有兩接續的選擇階段才會進行路徑的連結。

在建構螞蟻路徑的過程中，關於節點隨機選取的相關數學式，說明如下。假設某螞蟻在迭代 t、第 m 階段位於某一節點 i，選擇要走向下一節點 j 的選擇機率如式(7)；其中，除了費洛蒙之外，也納入考量問題特性的啟發式值。式(8)則表示每一迭代的費洛蒙值更新，前半段乃指迭代費洛蒙值的蒸發情況，後半段則

是螞蟻經過路徑所新增的費洛蒙值。後者，可由式(9)，根據路徑所對應解的目標式值以及費洛蒙值的比例參數 Q 來決定。

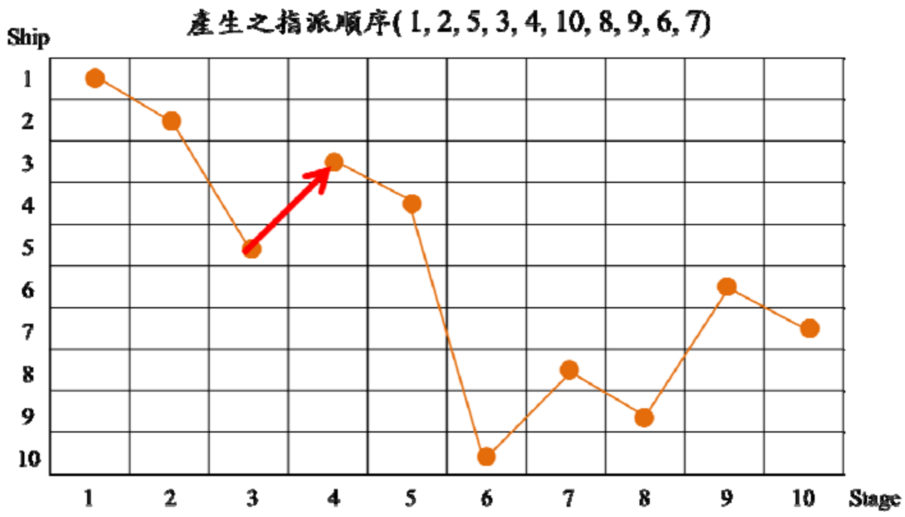

圖 1 搜尋空間與節點順序選取之示意圖

$$p_{mij}(t)=\begin{cases}0 & if\ (i,j)\in B_{mi}\\ \dfrac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}]^{\beta}}{\sum_{l\notin B_{mi}}[\tau_{il}(t)]^{\alpha}[\eta_{il}(t)]^{\beta}} & otherwise\end{cases} \tag{7}$$

$$\tau_{ij}(t+1)=(1-\rho)\tau_{ij}(t)+\sum_{w=1}^{p}\Delta\tau_{ij}^{w}(t) \tag{8}$$

$$\Delta\tau_{ij}^{w}(t)=\begin{cases}\dfrac{Q}{f^{w}(t)} & if\ (i,j)\ is\ used\ by\ ant\ w\\ 0 & otherwise\end{cases} \tag{9}$$

符號說明如下:

t	：	迭代編號。
p	：	每一迭代的螞蟻數量。
$\tau_{ij}(t)$	：	迭代 t，節點 i 到節點 j 的費洛蒙值。
α	：	費洛蒙值之權重。
η_{ij}	：	節點 i 到節點 j 的啟發式值。
β	：	啟發式值之權重。
B_{mi}	：	第 m 階段從節點 i 出發，所不能前往的禁忌名單。
$p_{mij}(t)$	：	迭代 t、第 m 階段，節點 i 到節點 j 的選擇機率。
ρ	：	每一迭代中，費洛蒙值的蒸發比率。
$f^{w}(t)$	：	迭代 t，螞蟻 w 所求解出的目標式值。
Q	：	每隻螞蟻所帶有的費洛蒙值。

根據式(7)，費洛蒙值與啟發式值越大，越會增加路徑選擇的可能性。此外，尚需考量費洛蒙值與啟發式值的權重關係，分別為α、β。另外，仍須透過Q、ρ兩參數架構好整體求解機制。使得螞蟻會依據先前的求解經驗，選擇可能較短之路徑。另一方面，仍有選擇其他路徑之可能性，避免陷入區域最佳解。

另外，在建構螞蟻路徑產生指派順序部份；首先，本研究先假設存在一個虛無起點，作為第一階段前之路徑選擇起始點。爾後於每個階段都會選擇到不同的船舶作為路徑下一階段的節點，直至所有階段的選擇皆完成。之後，再將這個路徑做為一組指派順序，交由下一部分的貪心指派法則進行求解作業。以圖 1 例子為例，十艘船舶的指派順序為 1-2-5-3-4-10-8-9-6-7。

最後，關於螞蟻演算法的設計，如何設定啟發式值亦是相當關鍵的要素。若以過去 TSP 之研究而言，啟發式值通常是為路徑 i to j 之倒數，可藉此吸引螞蟻選擇鄰近節點繼續前進。基於 DDBAP 的特性，本研究納入船舶的抵達時間作為參考因素；如式(10)，啟發式值可大略視為兩船舶抵達時間差之倒數。然而，還需透過 b_1 與 b_2 進行調整，以處理兩船舶抵達時間差為零或負數之情況。一般來說，一旦下一階段船舶 j 與本階段的船舶 i 的抵達時間越接近，啟發式值就會越高，船舶 j 便更有機會被選取。透過求解所累積經驗的費洛蒙值以及船舶抵達時間差的啟發式值，希望將可以得出一組理想的指派順序。

$$\eta_{ij} = \frac{1}{b_1 + b_2 \times Max(A_j - A_i, 0)} \tag{10}$$

5.2 以貪婪指派規則進行求解

延續上一節的指派順序。若是就螞蟻演算法求解 TSP 而言，一旦產生螞蟻的路徑即是解答；然而，本研究中，一旦有了指派順序後，還需要設計出在該順序下，如何產生相應的船席指派與接受服務的時間。值得注意的是，本研究中的船舶處理時間與船席位置相關；另外，也須要確保各船席現有船舶已處理結束後，才能進行新船的停泊服務。以下，在最小化船舶的等待時間及處理時間的目標下，本研究提出了兩個版本的貪婪指派規則(Greedy Assignment Rule, GAR)：GAR1 與 GAR2。

根據 GAR1，並以圖 1 的指派順序 1-2-5-3-4-10-8-9-6-7 為例，船舶 1 首先被指派至船席，而船舶 2 以及船舶 5 亦已陸續被指派，如圖 2。在考慮第四艘船(船舶 3)的指派時，其服務船席的選擇機制乃是依照各船席處理時間及等待時間之總和最小者，進行指派。以圖 2 為例，假如船席 1 至船席 3 的等待時間以及處理時間的總和分別是(2+12)=14、(8+15)=23 以及 (0+18)=18，船舶 3 將會被指派至船席 1 接受服務。

然而，GAR2 的方式，則不同於 GAR1 一次挑選單一船舶的指定船席，改採一次選定接續兩次序的船舶進行考量。仍舊以圖 2 做說明，若現在針對第 4、第 5 順序(船舶 3、船舶 4)進行指派作業，因有 3 個船席，所以有 3^2 種組合，仍擇其最優者作為選取的船席組合。但需注意的是，最後只先確認第一次序的船席

指派作業，進行更新。(例如選擇組合船席 1+船席 3，則只先指派船席 1 給船舶 3。) 有了 GAR1 或 GAR2 兩種指派原則，即可將螞蟻演算法所給定之指派順序進行船席指派，並得到該組順序下的目標式值。

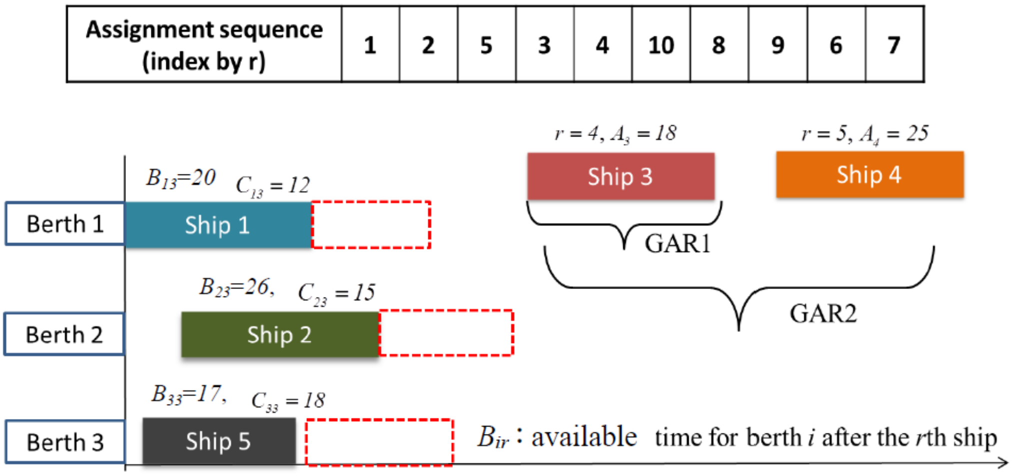

圖 2 貪婪指派規則之示意圖

每一迭代之指派順序已全數完成指派後，就各個指派順序下的目標式值，本研究再將求解結果回饋給螞蟻演算法。藉由式(8)與式(9)更新費洛蒙值，提高較優指派順序的選擇機會，以供下一迭代所使用，進而再產生出更佳的指派順序與船席指派決策。

5.3 求解步驟與設計流程

參考前述兩個環節的演算法設計，整體的求解演算流程可參見圖 3。首先，先決定整體螞蟻演算法所欲設定的相關參數值，如每一迭代的螞蟻數量、螞蟻每隻所帶有的費洛蒙值、啟發值的選用設計、初始費洛蒙、迭代消散比率為、費洛蒙值與啟發值兩者的權重比等。再以此為基準，透過 4.1 小節產生一組指派順序。進而在 4.2 小節透過 GAR 將船舶依序指派到不同船席進行服務，並得到該指派順序下所屬的目標式值。若每一迭代服務完畢，將該代的求解經驗進行回饋，以更新螞蟻演算法的費洛蒙值，優化系統求解機制，以便從迭代中找到更好的服務次序作為船席指派之用。

六、　結果與討論

在題目設計的部分，本研究依照船舶數量的規模大小區分為 25 艘船、75 艘船以及 150 艘船等三個類群。每一個類群安排 10 個測試問題，共有船席 A 到船席 E 共 5 個船席可供船舶到港停靠；船舶的處理時間為盡可能符合現狀。就一船舶 j，隨機設定某特定船席所需處理的時間最為短暫，其處理時間為服從 1~200 的均等分配，關於船舶 j 在其餘船席的處理時間，則因距離的遠近而成線性關係。舉例來說，針對船舶 j 而言，隨機決定的船席 g_j 有最短的處理時間 h_j

小時，與則其他船席的處理時間 C_{ij} 可用$(1+\alpha|i - g_j|)h_j$來表示，其中α在各測試例題中皆為 10%。

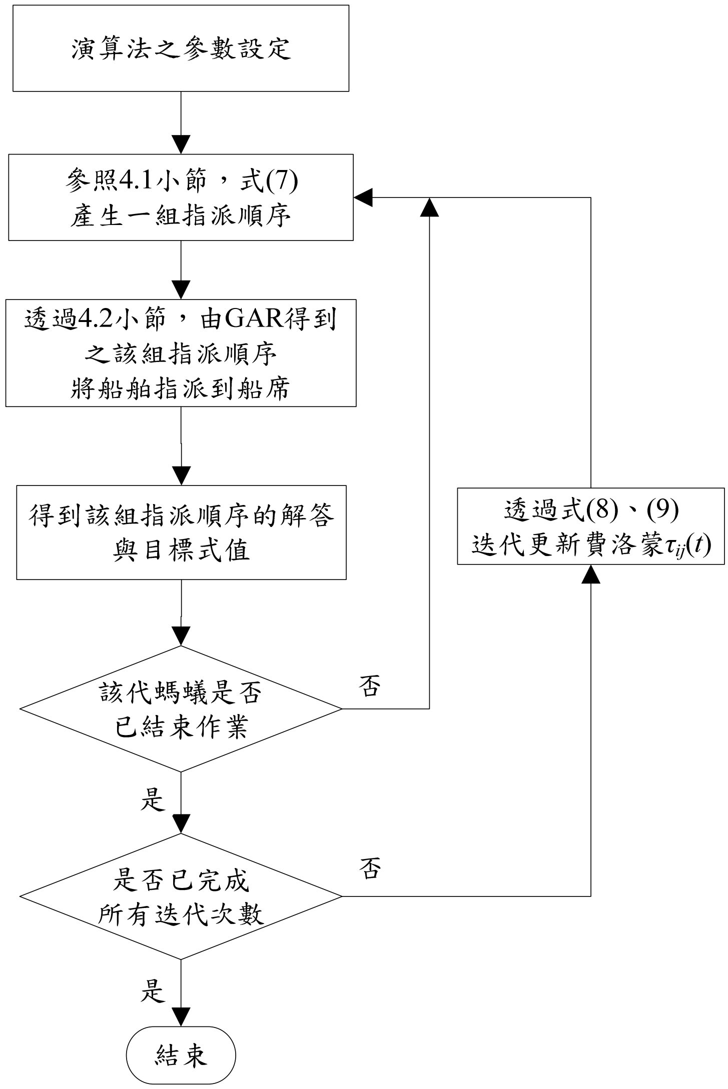

圖 3 求解演算法之流程示意圖

船舶的抵達時間亦為隨機產生，其服從平均值為 300 的指數分配。因此，船舶的抵達情況將會集中於前期，使得船席指派上容易有阻塞之情況；當然，船舶集中前期抵達的前況，仍會明顯有別於靜態 BAP 的情境。本研究相信如此題的情境假設，將相較於抵達時間平均分散於各時段之研究更具挑戰性，船席之選用決策也將更具影響力。

參數設定方面，本研究設定初始費洛蒙為 1、迭代消散比率為 0.1、費洛蒙值與啟發值兩者的權重比為 1.5。其中，有關每一迭代的螞蟻數量以及螞蟻每隻所帶有的費洛蒙值，由於問題規模將大大影響求解的搜索空間，本研究因而設定每一迭代的螞蟻數量為船舶數/2，提高大規模例題的搜尋。而螞蟻每隻所帶有的費洛蒙值則為 100*船舶數，以因應大規模例題的路徑長度。

此外，本研究所發展演算法與 Imai *et al*. (2001)當中的拉式鬆弛法進行比較。於問題規模大小為 25 艘船、75 艘船以及 150 艘船時，GAR2 能顯著優於

GAR1，改善幅度分別為 1.24%、4.79%以及 7.66%。如此一來，可印證 GAR2 的運算流程的確有其必要性。

就 GAR2 與 Imai *et al*. (2001) Lagrangian 鬆弛法(SUBG)的比較，在 25 艘船的小規模例題中，GAR2 相較於 SUBG 的平均改善幅度為 5.59%，在 75 艘船的中型規模，平均改善幅度則拉升為 8.59%。在更大型 150 艘船的規模中，平均改善幅度更可達 9.14%。顯然 GAR2 相較原先 SUBG 的求解效能更為卓越，在大例題中，更可顯現其效果。因此，本研究認為相較於 Imai *et al*. (2001) Lagrangian 鬆弛法，本研究的螞蟻演算法可視為一項相當不錯的求解方法。

七、　結論與建議

本研究之焦點為動態且離散型之船席指派問題，根據船舶動態抵達的資訊，針對入港船舶給定相應的船席指派決策。目標式是想要最小化所有船舶的服務時間。本研究採用對排序問題之效能相當不錯的螞蟻演算法作為建構求解的基本架構，根據數值測試可得到下述幾點結論。

1. 針對 DDBAP，本研究成功導入螞蟻演算法到此問題上，港口經營者即可得知任一艘船須在何時、何處進行指派作業。
2. 比較 GAR1 以及 GAR2 的求解效能，一旦問題的複雜程度越高，更能彰顯 GAR2 的求解效能，可印證 GAR2 的運算流程的確有其必要性。
3. 本研究透過螞蟻演算法搭配 GAR2 的求解機制與 Imai *et al.* (2001)進行比較，可發現無論問題的規模大小，本研究的求解能力都較為卓越。此舉顯示本研究在處理船席指派的問題上，的確有其代表性，也可供其他欲投入螞蟻演算法到船席指派之學者作為參考。

有關後續研究，在提升求解演算法效能的部分，還可嘗試其他先進類型的螞蟻演算法。另外，連續型的船席指派問題，也是日後可以延伸的參考方向。最後，在指派法則上，後續應該可以設計出更臻完備的規則，以使得在單一指派順序下，可以尋求出更為精良的船席指派決策。

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國科會補助專題研究計畫項下出席國際學術會議心得報告

日期：101 年 10 月 31 日

計畫編號	NSC 100 － 2221 － E －009 － 124 －		
計畫名稱	以導引式螞蟻演算法求解運輸與運籌領域之排序問題		
出國人員姓名	黃寬丞	服務機構及職稱	交通大學運輸科技與管理學系
會議時間	101 年 5 月 27 日至 101 年 5 月 30 日	會議地點	日本福岡
會議名稱	(中文) 第五屆國際海運、港口與物流論壇 (英文) The Fifth International Forum on Shipping, Ports and Airports (IFSPA 2012)		
發表論文題目	(中文) 以修正式之螞蟻演算法求解航機降落問題 (英文) An Analysis of the Pricing Decision under the Influence of Revenue Management and Market Condition - The Example of the Domestic Air Market in Taiwan		

一、參加會議經過

個人於 2012 年 5 月 26 日由台灣台中清泉崗機場，搭乘香港快運航空(UO 163)班機至香港，5 月 27-28 日參加會議，並發表論文。並於 2012 年 5 月 29 日搭乘香港快運航空(UO 192)班機由香港返抵台灣台中清泉崗機場。

二、與會心得

1. The International Forum on Shipping, Ports and Airports 係由香港理工大學(The Hong Kong Polytechnic University)的物流與航運管理學系(Department of Logistics and Maritime Studies)，在董浩雲國際海事研究中心(C.Y. Tung International Centre for Maritime Studies)的贊助支持下，於 2007 年首次主辦，此次會議已經是第五次辦理。會議包含以海運(Shipping)、港口(Ports)、物流(Logistics)為主的各項研究課題。雖然大多數所發表的論文屬於海運的領域，但也有多個關於航空、供應鏈等之 Sections。參加此會議之研究學者、與業界人士都對海運有深厚的知識與經驗，是深入了解海運研究，並進行學術交流的理想場合。

2. 參與此次會議藉由論文之發表、和與會者討論，獲得相當多的回饋意見及改進方向的參考，可以使得本篇論文能更加完善，以利後續研究工作之延伸。個人論文發表的 Section Chair 是加拿大 University of British Columbia 的 Prof. Anming Zhang，他是關於運輸經濟、航空定價的國際知名學者。個人透過論文的發表，也得到 Prof. Zhang 相當多的正面回饋，他也提供個人

相當多的研究建議和未來可能的研究方向，受益良多。此外，也與同場發表的 Prof. Hangjun Yang，也有所交流，他是 Prof. Anming Zhang 在 University of British Columbia 所指導的博士畢業生，目前在中國任教，未來也合作交流的機會。

3. 個人參加此次之 IFSPA 會議，發現此類的專業型會議雖然發表的論文數目不是太多，但是論文之間常有極高的相關性，會議的討論氣氛也很熱烈。透過此次會議所獲得的建議，個人目前也正開始進行下一個關於低價航空公司(Low-Cost Carrier, LCC)的訂價研究，相關的資料蒐集已經完成，下一階段則是票價模式的探討與分析，也是此次會議的收穫。

三、發表論文全文或摘要

個人所發表論文是屬於以台灣的研究標的的實證研究，所獲得的結果與類似文獻大致上是一致的，但也發現部分有趣的分析結果，其摘要如下，全文如附件。

Revenue Management (RM) has become a common practice in the airline industry worldwide since American Airlines successfully implemented it in the mid 1980s to beat the entrants in the post-deregulation era. As a core technique of RM, price differentiation is put into practice though the multi-fare scheme, which results in significant price dispersion in the market. At the same time, the implementation of price differentiation is believed to be closely related to market condition. The objective of this study is thus to examine the relationship between revenue management and market condition through the example of the domestic air market in Taiwan. This empirical study establishes several multiple linear regression models, in which ticket discount is chosen as the dependent variable given the partially-deregulated environment for fare control. With an aim to conduct a comparative analysis, it is found that the result is in general consistent with those in the prior empirical studies focusing on the U.S. and Europe domestic air markets and provide more evidence from the practical viewpoint regarding how airlines react to market condition while making the pricing decision. In particular, this study further employs two interaction models to investigate the impact of one independent variable on another. The results show that the interaction models provide insightful explanations about how the implementation of RM is affected by other factors.

四、建議

1. 個人認為國內之研究與許多國際間之研究，在水準上應無極大的差距，但與會者的簡報技巧及溝通能力較為不足，尤其是在進行 Q & A 的交流時，英文能力普遍較無法應付國際會議的場合。解決之道，可考慮先在國內透過課程或者 Workshop 來培養相關的能力；或者採用本校管理學院之方式，將博士班之 Seminar 改為以英文報告，提升相關的經驗與能力。此外，授課教師也可以考慮採用(部分)英語教學，以提升英文使用的熟練度。
2. 此次會議發現，不少研究係由跨國的研究人員共同完成。香港理工大學不僅有為數眾多的外籍學生，此外也透過短期訪問學人、訪問教授的方式，將世界上其他地方的學者延聘來校，進行短期的教學和研究。基於背景、經驗上的不同，可以激盪出許多新構想，也可以將資源與經驗截長補短。國內也應該強化國際合作與交流，效法鄰近國家的作法，投入更多資源，來提升研究的層次。

五、攜回資料名稱及內容

1. 研討會規劃手冊(Conference Program)

2. 會議承辦與贊助單位提供之文宣與簡介。

六、其他

(無)

Dear Dr Huang,
Thank you for your interest in the IFSPA 2012 conference and your full paper submission with us. We are pleased to confirm that your paper with the title

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An Analysis of the Pricing Decision under the Influence of Revenue Management and Market Condition - The Example of the Domestic Air Market in Taiwan

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Abstract

Revenue Management (RM) has become a common practice in the airline industry worldwide since American Airlines successfully implemented it in the mid 1980s to beat the entrants in the post-deregulation era. As a core technique of RM, price differentiation is put into practice though the multi-fare scheme, which results in significant price dispersion in the market. At the same time, the implementation of price differentiation is believed to be closely related to market condition. The objective of this study is thus to examine the relationship between revenue management and market condition through the example of the domestic air market in Taiwan. This empirical study establishes several multiple linear regression models, in which ticket discount is chosen as the dependent variable given the partially-deregulated environment for fare control. With an aim to conduct a comparative analysis, it is found that the result is in general consistent with those in the prior empirical studies focusing on the U.S. and Europe domestic air markets and provide more evidence from the practical viewpoint regarding how airlines react to market condition while making the pricing decision. In particular, this study further employs two interaction models to investigate the impact of one independent variable on another. The results show that the interaction models provide insightful explanations about how the implementation of RM is affected by other factors.

Keywords: Revenue Management, Price Differentiation, Market Condition, Regression Analysis

1. Introduction

The Airline Deregulation Act of 1978 significantly changed the environment of the domestic airline market in the U.S. Given the relaxed control on routes and fares, many new airlines aggressively entered the market. People Express was probably the most successful one. With minimal service and cheap labor, People Express considerably reduced airfares, not only lower than those of the existent major airlines, but also comparable to the fares offered by the intercity bus lines. The revenue of People Express increased dramatically throughout the early 1980s and reached one billion USD by 1985. After a failure in the initial price war, one of the major carriers, American Airlines, introduced the Ultimate Super Savers, a discount fare with restrictions, to compete against People Express for the price-elastic demands. This combined with the sophisticated computer reservation system for seat inventory control successfully defeated the low-price strategy of People Express and, at the same time, effectively secured the high-margin market for American Airlines. People Express, a new company without a high-end brand image, ceased operations in 1986 after losing its price advantage (Peterson and Glab, 1994).

Airline Deregulation has been cited as a success for free competition. Initially, the average airfare did decrease, and the number of airline passengers increased. However, after years of practice under the "Open Sky", many airlines have declared bankruptcy. The projection is for a handful of large airlines to dominate the airline industry in the future. There are several reasons why the Airline Deregulation did not live up to its advance billing or ended up with so many surprises as highlighted by Alfred E. Kahn (1988), an economist and the last Chairman of the Civil Aeronautics Board (CAB). However, price discrimination and other revenue management techniques, the key weapon used by American Airlines to defeat People Express, have certainly played a key role in the unexpected and undesired market concentration.

Although controversial, revenue management (RM, also known as yield management, YM) has become a global and common practice in the airline industry worldwide since American Airlines successfully implemented it in the mid 1980s to beat the entrants in the post-deregulation era. Not only is a strategic measure for price competition, RM is also an important operational technique for raising revenue. It has been estimated that RM practices have generated an additional revenue of 1.4 billion USD for American Airlines over a 3-year period around 1988 (Smith et al., 1992). Nowadays, it is difficult for a major airline to operate profitably without the use of RM, as according to most estimates that the extra revenue gained from the use of RM is about 4 - 5%, which is comparable to many airlines' total profitability in a good year (Talluri & van Ryzin, 2004).

Airline deregulation has become a global trend, and Sinha (2001) and Chang et al. (2004) serve as excellent references for its development across countries and regions. In particular, the latter focused on the issue of ownership and control, which is believed to be the most important barrier for airline industry linearization. There were many research works that have examined the impact of deregulation specifically on airfare, which is probably the most immediate and concerned influence of linearization. For example, Morrison and Winston (1990), Borenstein (1992), Dresner and Tretheway (1992), Maillebiau and Hansen (1995), Marin (1995), Jorge-Calderon (1997) focused on the markets in North American or Europe, the regions with early introduction of aviation deregulation. More recently, for the Asia Pacific region, Manuela (2007) adopted a similar empirical framework and developed an econometric model for the case of Philippines.

Above research works have shown that airfare, in terms of the average value, generally decreased due to the competition brought by deregulation, but they did not address another important aspect: the price dispersion due to the application of the price discrimination, which is legally permissible and strategically desirable in the post-deregulation era. Price discrimination, one of the core techniques of RM, is implemented by offering multiple airfares with various terms and conditions and/or by changing the fares dynamically. Its application is believed to be affected by the market condition. Thus, the focus of this empirical study is to analyze the relationship between price discrimination, revenue management, and market condition. This paper is organized as follows. The next section reviews the related literature. The framework of the empirical analysis is described in the third section, and the results are presented in the fourth section. Finally, the findings of this study are summarized and conclusions are drawn in the fifth section.

2. Literature Review

Price discrimination is usually categorized in three types (Varian, 1996). In the first-degree price discrimination, also known as perfect price discrimination, a supplier sets the price according to the willingness-to-pay by individual consumers. In the second-degree price discrimination, consumers make the purchase decision regarding the options offered by a supplier. That is why it is sometimes referred to as self-selection. As for the third-degree price discrimination, a supplier segments the market with multiple prices and conditions that are based on the diverse characteristics of the consumers. Revenue management as adopted by airlines is usually referred to as a practice of the second-degree price discrimination, although some tickets targeting a specific group of travellers (such as senior citizens) are closer to the third-degree price discrimination category.

In a monopolistic market, a firm is the price setter and can maximize its profit through price discrimination. At the other extreme, in perfect competition a supplier is simply a price taker, and the price is equal to the marginal cost. Therefore, it appears that there is no price dispersion in perfect competition. So, if we take a competitive market between the two extremes, then the obvious conclusion based on simple extrapolation should be that price dispersion will be reduced if competition increases. However, reality does not follow a rule this simple.

Some theoretical models instead concluded that price dispersion exists and may increase as a market moves from a monopoly to imperfect competition (*e.g.*, Valletti, 2000). In particular, for the airline industry, Gale and Holmes (1992a), Gale and Holmes (1992b), Gale (1993), and Dana (1998) used the advance-purchase requirement as a discriminatory device to investigate price dispersion under various market conditions. When competition is introduced into a monopoly market with price discrimination implemented, the pre-existing supplier is likely to lower the prices (especially for the lower-end products) so as to avoid giving room to the rivals. That is why it has been found price dispersion may increase as the market becomes more competitive. This phenomenon is even more apparent for the airline industry, in which the cost of holding inventory to meet demand is relatively high due to the associated demand uncertainty and supply non-storability.

Borenstein and Rose (1994) categorized price discrimination into “monopoly-type” discrimination and “competitive-type” discrimination. Consistent with the general concept of price discrimination, monopoly-type discrimination is related to the industry demand elasticity and generates more price dispersion if a market is closer to a monopoly. On the other hand, competitive-type discrimination is related to customers’ cross-elasticity of demand among different brands. Price dispersion becomes greater when a market is more competitive, since firms tend to offer deeper discounts when segmenting the customers based on demand elasticity across different brands. In their empirical study of the U.S. domestic airline market in 1986, price dispersion in terms of the GINI coefficient was found to be negatively related to market concentration, which was measured by the HHI (Herfindahl-Hirschman Index, defined as the square sum of the market shares in percentage). Thus, competitive-type price discrimination prevails over monopoly-type price discrimination.

Stavins (2001) conducted a regression analysis focused on the relationship between price dispersion and market condition in the U.S. domestic airline market, but with data that was collected in 1995. In addition, two ticket restrictions (Saturday-night stay-over and advance purchase) were included in the model. This was done because these two restrictions are very effective for segmenting the airline travellers based on their valuation of time and flexibility, and they are commonly used by the airlines in the RM system. Both discriminatory devices were found to be negatively related to airfares. In the basic (non-interaction) model, the restriction of Saturday-night stay-over was estimated to reduce the fare by 211.17 USD, and one day of advance-purchase gave a price reduction of 6.04 USD.

In the interaction model, Stavins (2001) examined the effect of the market condition on price discrimination further by including the product terms of these two ticket restrictions and the HHI in the regression model. The results showed that, for both restrictions, the higher the market concentration on a route, the lower the effect of price discrimination. For example, the estimated fare reductions for the restriction of the Saturday-night stay-over were 253, 233, and 165 USD for the 25th, 50th, and 75th percentiles of the HHI, when being sorted in increasing order (*i.e.*, from less to more concentration).

Using a regression model similar to that of Stavins (2001), Giaume and Guillou (2004) discussed the market for the intra-Europe flights originating from Nice, France based on the data collected in 2002.

Airfare was once again used as the dependent variable, and the key independent variables (Saturday-night stay-over, advance purchase, and market concentration represented by the HHI) remained the same. However, they introduced several new independent variables (such as the presence of low-cost carriers) to reflect the unique situation in the European market. Although the study area was geographically smaller, and the deregulation movement was slightly later, the results obtained by Giaume and Guillou (2004) focusing on Europe were similar to those of Stavins (2001) for the U.S. In particular, the signs for the coefficients of the major variables in the regression models were found to be the same, although the coefficient of determination (R^2) was lower (0.40 in Giaume and Guillou, 2004 vs. 0.77 in Stavins, 2001).

A local version of the "Open Sky" policy was initiated in Taiwan in 1987, and several new airlines were established to serve the domestic airline market, which was experiencing an unprecedented demand. However, fare was still under a very strict control scheme, under which tickets were sold at the fixed published fare. Only until 1994, airlines were authorized for the first time to adjust the ticket price within 10% of the published fare, and this permissible range was expanded several times later on. The fare-control regulations were further revised in 1999 such that the published fare became a price cap, and airlines were allowed to set a certain level of discount. Although several minor revisions have been made, the current regulations basically follow the form of the 1999 version (CAA, 2012).

To some extent, Taiwan has been following the global trend to deregulation, and the airlines gradually adopted the concept of revenue management. However, the liberalized domestic airline market in Taiwan was quite different from most markets in the literature. Taiwan is geographically a small country and has good infrastructure for most part of the island, but jet aircrafts (such as A320s, MD-80/MD-90s, B737s, and even B757s) are anyway used to serve many domestic routes. In addition, the fare regulations for the domestic airline market were only partially deregulated. Thus, it is of great interest to conduct an empirical study to examine the relationship between price discrimination and market condition and to conduct a comparative analysis with respect to different markets.

3. Framework of Empirical Analysis

Following the framework in Stavins (2001) and Giaume and Guillou (2004), this study established four linear regression models to perform the empirical analysis. The flights included in the analysis were operated by three airlines, Far Eastern Air Transport (FAT), TransAsia Airways (TNA), and UNI AIR (UNI), for the routes from Taipei, the capital and the economic center, to seven domestic airports. The basic information and the market condition of the routes are listed in Table 1. Given the airlines and the routes considered, the traffic volume included in the analysis accounted for 65% of the overall domestic airline traffic in Taiwan, or 82% of the traffic leaving or bound for Taipei in terms of the number of passengers (CAA, 2004). The information regarding the flights for a typical weekday in 2004 (Tuesday, August 10) was collected to serve as the data for the regression models from the website of a popular on-line travel agent, in which the above-mentioned airlines are suppliers for the domestic air markets.

Based on the fare-control regulations under the partially-deregulated scheme, an airline can discount fares within a regulated range for the flights it operates. Therefore, the discount for each flight was used as the dependent variable in all four models, and it was defined as (published fare - discount fare)/published fare (in percent). This dependent variable is different from the one (the airfare) used in Stavins (2001) and Giaume and Guillou (2004).

As for the independent variables, the RM technique for price discrimination and the market condition were considered first. Taiwanese carriers do not use a complicated RM system for the domestic market, and they deal with the diverse demand simply by dynamically adjusting the price, a practice adopted by many low cost carriers worldwide. The price offered on-line remains the same from the beginning of the booking period to five days before departure. The price then subsequently increases and becomes the published fare on the day of departure. Given this price adjusting scheme, the number of days for advance purchase was taken as one of the key independent variables in the regression model. To quantify market condition, the Herfindahl-Hirschman Index was used as the other key independent variable.

Table 1: Information of the routes in the analysis

Route	Location (Distance)	Annual Traffic (Both ways)	Airlines	Market Condition	HHI
Kaohsiung	West coast (183 miles)	2,652,629	FAT, TNA, UIA	Oligopolistic	0.380
Tainan	West coast (164 miles)	1,242,933	FAT, TNA	Duopolistic	0.504
Pingtung	West coast (177 miles)	109,833	TNA	Monopolistic	1.000
Hualien	East coast (75 miles)	634,018	FAT, TNA	Duopolistic	0.508
Taitung	East coast (161 miles)	587,165	FAT, UIA	Duopolistic	0.516
Makung	Offshore (156 miles)	753,975	FAT, TNA, UIA	Oligopolistic	0.352
Kinmen	Offshore (196 miles)	818,895	FAT, TNA, UIA	Oligopolistic	0.349

In the four models developed in this study, the basic model includes only two independent key variables: the number of days for advance-purchase and the HHI. The enhanced model incorporates additional factors related to domestic airfares. In addition, the two interaction models introduce the product terms of independent variables. The basic model is as (1), where $DISC_{ijk}$ is the discount of the kth flight of airline j on route i, ADV_{ijk} is the number of days for advance purchase discount of the kth flight of airline j on route i, and HHI_i is the HHI for route i.

$$DISC_{ijk} = \beta_0 + \beta_1 ADV_{ijk} + \beta_2 HHI_i \tag{1}$$

In order to address the factors related to the pricing decision of the airlines, four dummy variables were used in the enhanced model. The first one is whether a flight is popular. Since all seven routes are short for air transportation, many passengers make the round-trip on the same day. Thus, popular flights are defined as those with a scheduled departure time within 7:00 a.m. to 9:00 a.m. or 6:00 p.m. to 8:00, as they provide the most benefit to short-haul passengers. The second one is whether a route is bound for an offshore island. The concern is that the alternative transportation service is unfavorable, as the boat trip can take more than 12 hours, and the service frequency and comfort leave a lot to be desired. The third and fourth ones are the dummy variables for two airline brands (UNI and TNA), given that the largest airline in the domestic market, FAT, was chosen as the base category. The regression model is shown as (2), where POP_{ijk} is equal to 1 if the kth flight of airline j on route i is popular, $ISLD_i$ is equal to 1 if route i is for off-shore islands, and UNI_j as well as TNA_j represents the airline brands.

$$DISC_{ijk} = \beta_0 + \beta_1 ADV_{ijk} + \beta_2 HHI_i + \beta_3 POP_{ijk} + \beta_4 ISLD_i + \beta_5 UNI_j + \beta_6 TNA_j \tag{2}$$

For the independent variables used in the model, the maximum absolute value in the correlation matrix is 0.375, indicating that the multicolinearity issue is not a serious problem. In addition, some other factors possibly related to airfare have been tested, such as destination population, market share, flight frequency etc. However, all of them were found to be suffering from the multicolinearity problem or insignificant in the regression analysis.

The first interaction model was designed to determine the influence of the market condition on the implementation of price discrimination. A product term of the first two independent variables was introduced into the model as (3). The second interaction model was used to understand the impact of the airline, the decision maker, on the level of advance purchase discount. Two product terms of the first variable, representing the days for advance purchase, and the two airline dummy variables were introduced into the model as (4).

$$DISC_{ijk} = \beta_0 + ADV_{ijk}(\beta_1 + \gamma_1 HHI_i) + \beta_2 HHI_i + \beta_3 POP_{ijk} + \beta_4 ISLD + \beta_5 UNI_j + \beta_6 TNA_j \quad (3)$$

$$DISC_{ijk} = \beta_0 + ADV_{ijk}(\beta_1 + \gamma_2 UNI_j + \gamma_3 TNA_j) + \beta_2 HHI_i + \beta_3 POP_{ijk} + \beta_4 ISLD + \beta_5 UNI_j + \beta_6 TNA_j \quad (4)$$

4. Results of Regression Models

Based on the collected data, the results of the regression models are listed in Table 2. The summary and the discussion of the results are presented as follows.

Table 2: Results of the estimations in four models

	Basic Model	Enhanced Model	Interaction Model I	Interaction Model II
Intercept	-1.86 (1.33)	-0.41 (0.99)	-2.79 (1.69)	0.88 (1.10)
ADV	2.21 (0.21) ***	2.87 (0.16) ***	3.66 (0.49) ***	2.42 (0.22) ***
HHI	12.66 (2.12) ***	10.13 (1.68) ***	15.15 (3.33) ***	10.91 (1.66) ***
ADV×HHI			-1.67 (0.96) *	
POP		-0.81 (0.64)	-0.81 (0.63)	-0.58 (0.62)
ISLD		-6.31 (0.68) ***	-6.76 (0.72) ***	-6.29 (0.67) ***
UNI		-3.00 (0.59) ***	-3.00 (0.58) ***	-6.98 (1.43) ***
TNA		-1.16 (0.64) *	-1.17 (0.64) *	-2.90 (1.55) *
ADV×UNI				1.00 (0.33) ***
ADV×TNA				0.48 (0.38)
Adjusted R^2	0.498	0.750	0.754	0.763
Observations	140	140	140	140

Numbers in parenthesis are standard errors. * significant at 10% level, ** significant at 5% level, *** significant at 1% level.

The basic model is not very satisfactory, since its R^2 is only 0.498. However, the *t*-statistics of both independent variables (the number of days for advance-purchase and the HHI) are large, indicating that the relation between ticket discount and each of these two dependent variables is significant. As expected to be positive, the coefficient of the variable ADV shows that the advance-purchase discount is about 2.21% per day.

The coefficient of the other independent variable HHI is 12.26%, and its positive sign indicates that the more concentrated a market is, the higher the ticket discount is. This result probably does not support the standard notion that market concentration raises fare level, or it is not in agreement with the conclusion in the first empirical study (Borenstein and Rose, 1994) that competitive-type price discrimination prevails over monopoly-type price discrimination. However, it is consistent with the results of the two later empirical studies, Stavins (2001) and Giaume and Guillou (2004).

Stavins (2001) did not discuss the cause of this result, but Giaume and Guillou (2004) provided an explanation in light of the unique features of the European air market. Airline deregulation in Europe had not come into effect for a long time, and there was a significant market share inequality for many routes. For example, in a duopoly market, it is common that one of the players is a large (flag-carrying national) airline and the other one is a small (new) regional airline. In that market the associated HHI are very high. Lowering the price appears to be the best strategy for the big one to drive out the new comer and for the small one to penetrate the crucial new market. Thus, the average fares are likely to lower than those in the markets with comparable market share among players.

As for the domestic airline market in Taiwan, this counter-intuition result is most likely caused by the demand level of the routes. As shown in Table 1, the HHI and the annual traffic are strongly correlated, and the correlation coefficient is -0.53. A high value of the HHI is sometimes an indication of insufficient demand (possibly due to a small population or favorable alternative transportation services). It is possible that, in order to maintain an acceptable load factor, airlines have to constantly offer deep-discount tickets, which make the airfare level low.

By including four more independent variables, the R^2 is raised to 0.750 in the enhanced model. The coefficient of the advance-purchase discount increases slightly to 2.87% per day, and the coefficient of the market concentration (HHI) remains positive. As for the new independent variables, the coefficient of the dummy variable for popular flights is -0.81%, but it is not very significant (p-value = 0.20). At the same time, the coefficient of the dummy variable for offshore-island routes is -6.31%, suggesting that airlines decrease the discount considerably for the inelastic travellers lacking alternative transportation modes. As for the dummy variables for the airline brands (UNI and TNA), the values are -3.00% and -1.16% respectively. The fact that the smallest discount offered by UNI Air may be partially attributed to the fact that it is the only airline in the analysis with a giant parent company (EVA Airways as well as Evergreen Marine Corp.), and its brand awareness is relatively strong.

For the first interaction model, the coefficient of the product term (γ_1) is significant, and the sensitivity of the discount to the advance purchase is as (5). The negative value of γ_1 (-1.67) implies that the advance-purchase discount is reduced if the market concentration increases. This result is consistent with those in Stavins (2001) and Giaume and Guillou (2004), although the three studied markets are significantly different in terms of market size, geographic location, transportation infrastructure, and airline industry development. The product term of the advance purchase and the market concentration in the interaction model provides a good way to understand how market condition affects the implementation of RM and the air fare. To give a numerical example for the relation of (5), consider the cases of one, two, and three players with equal market share. The HHIs are 1.00, 0.50, and 0.33 respectively. The discount per day for advance-purchase increases from 1.99% to 2.83% if the market condition changes from monopoly to duopoly and becomes 3.11% per day for oligopoly.

$$\partial DISC_{ijk} \big/ \partial ADV_{ijk} = (3.66 - 1.67 HHI_i)\% \tag{5}$$

For the second interaction model, the coefficient of the product term for UNI (γ_2) is significant; however, the other coefficient for TNA (γ_3) is basically insignificant (p-value = 0.21). The sensitivity of the discount to the advance purchase is as (6), in which the positive value of 1.00 for γ_2 suggests that, in addition to the base discount of 2.42%, UNI AIR (UIA) offers extra 1% per day for advance purchase. On the other hand, the sensitivity of the discount can also be addressed from the viewpoint of the airline as shown in (7). The base discount of -6.98% is once again an indication of the strong brand of UNI AIR, as it provides significantly less discount in general. However, at the same time, it adopts an aggressive approach in exercising the RM technique by offering more advance purchase discount.

$$\partial DISC_{ijk} \big/ \partial ADV_{ijk} = (2.42 + 1.00 UNI_j)\% \tag{6}$$

$$\partial DISC_{ijk} \big/ \partial UNI_j = (-6.98 + 1.00 ADV_{ijk})\% \tag{7}$$

5. Conclusions

Price discrimination is a core technique of RM, and results in price dispersion in the market. At the same time, the implementation of price discrimination is closely related to the market condition. The objective of this study is to conduct an empirical study to examine the relationship between revenue management and the market condition, based on the example of the domestic airline market in Taiwan. The study established four linear regression models to conduct this empirical study. Ticket discount was chosen as the dependent variable given the partially-deregulated environment for fare control.

The basic model, consisting of only the independent variables related to revenue management (advance purchase) and market condition (HHI), was found to be insufficient. After introducing four more variables, the enhanced model was better able to explain the pricing decision of the airlines. Based on the first interaction model, the discount for advance purchase was reduced if market concentration increases. With an aim to conduct a comparative analysis, it has been found that the result is in general consistent with those in the prior empirical studies earlier empirical studies focusing on other areas (Stavins, 2001; Giaume and Guillou, 2004). In the second interaction model, a specific airline (UNI AIR) was identified by its aggressive role in the implementation of revenue management. We believe this study provides more evidence from the practical viewpoint regarding the pricing decision of the airlines under the influence of RM and market condition

During the past several years, there has been a critical impact on the domestic airline industry in Taiwan: the high-speed rail, which was inaugurated on January 5th, 2007. The maximum speed of the trains is 300 kilometers per hour and the frequency of the service is high. The high-speed rail system carried 15.56 millions passengers for the first year, and the rate of growth is very promising (THSRC, 2012). All the domestic airline services for the west coast have been terminated thereafter. The business environment of the domestic airline market in Taiwan has been changed permanently. The airlines now have to focus on the services for the east coast and the offshore islands, where alternative transportation services are not competitive. An analysis of the pricing decisions of the airlines for these routes can be an extension to this study, but the issue must also be addressed from a public domain point of view. Government intervention is required for these potentially unprofitable routes, as the mobility of the people living in those remote areas should be protected.

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國科會補助計畫衍生研發成果推廣資料表

日期:2012/10/28

國科會補助計畫	計畫名稱: 以導引式螞蟻演算法求解運輸與運籌領域之排序問題
	計畫主持人: 黃寬丞
	計畫編號: 100-2221-E-009-124- 學門領域: 交通運輸

無研發成果推廣資料

100 年度專題研究計畫研究成果彙整表

<table>
<tr><td colspan="3">計畫主持人：黃寬丞</td><td colspan="5">計畫編號：100-2221-E-009-124-</td></tr>
<tr><td colspan="8">計畫名稱：以導引式螞蟻演算法求解運輸與運籌領域之排序問題</td></tr>
<tr><td colspan="3" rowspan="2">成果項目</td><td colspan="3">量化</td><td rowspan="2">單位</td><td rowspan="2">備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）</td></tr>
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其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	個人已將根據兩次會議所獲得意見，進一步改善論文內容，並增加數值測試的深度與廣度，近期投稿英文期刊。

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

本案研究成果包含碩士論文一篇(國立交通大學運輸科技與管理學系)，並發表於在韓國釜山所舉辦的國際會議 International Conference on Transport and Logistics (T-LOG 2012)。此外，本研究修正後已投稿 101 年運輸學會年會，獲邀在會議進行口頭報告。個人已將根據兩次會議所獲得意見，進一步改善論文內容，並增加數值測試的深度與廣度，以利於近期投稿英文期刊。

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

本案之研究課題「船席指派問題」是目前海運研究的重要課題之一，近年仍有許多相關研究論文的發表。本案所發展的解答方法，與文獻之方法有明顯的差異性，且在求解時間、演算法的複雜度、求解品質均較參考文獻之演算法良好。因此，在實務上的應用空間，以至學術上對於研究文獻的補充，應有其貢獻，個人也計畫進行後續的海運研究。