國立交通大學

管理學院(工業工程與管理學程)

碩士論文

生產線訂單履行週期之績效評比
-以微波通訊廠為例

Product Line Performance Assessment on Order Fulfillment Cycle Time
– A Case of Microelectronic Communication Company

研究生：劉育誠
指導教授：劉復華 教授

中華民國九十三年八月

博碩士論文授權書

本授權書所授權之論文為本人在 國立交通 大學(學院) 工業工程與管理 系所
________ 組 九十三 學年度第 一 學期取得 碩 士學位之論文。
論文名稱：生產線訂單履行週期之績效評比—以微波通訊廠為例
指導教授：劉復華教授

1.☑同意　□不同意

本人具有著作財產權之上列論文全文(含摘要)資料，授予行政院國家科學委員會科學技術資料中心(或改制後之機構)，得不限地域、時間與次數以微縮、光碟或數位化等各種方式重製後散布發行或上載網路。

本論文為本人向經濟部智慧財產局申請專利(未申請者本條款請不予理會)的附件之一，申請文號為:__________，註明文號者請將全文資料延後半年再公開。

2.☑同意　□不同意

本人具有著作財產權之上列論文全文(含摘要)資料，授予教育部指定送繳之圖書館及國立交通大學圖書館，基於推動讀者間「資源共享、互惠合作」之理念，與回饋社會及學術研究之目的，教育部指定送繳之圖書館及國立交通大學圖書館得以紙本收錄、重製與利用；於著作權法合理使用範圍內，不限地域與時間，讀者得進行閱覽或列印。

本論文為本人向經濟部智慧財產局申請專利(未申請者本條款請不予理會)的附件之一，申請文號為:__________，註明文號者請將全文資料延後半年再公開。

3.☑同意　□不同意

本人具有著作財產權之上列論文全文(含摘要)，授予國立交通大學與台灣聯合大學系統圖書館，基於推動讀者間「資源共享、互惠合作」之理念，與回饋社會及學術研究之目的，國立交通大學圖書館及台灣聯合大學系統圖書館得不限地域、時間與次數，以微縮、光碟或其他各種數位化方式將上列論文重製，並得將數位化之上列論文及論文電子檔以上載網路方式，於著作權法合理使用範圍內，讀者得進行線上檢索、閱覽、下載或列印。

論文全文上載網路公開之範圍及時間 –

本校及台灣聯合大學系統區域網路：　年　月　日公開

校外網際網路：　年　月　日公開

上述授權內容均無須訂立讓與及授權契約書。依本授權之發行權為非專屬性發行權利。依本授權所為之收錄、重製、發行及學術研發利用均為無償。上述同意與不同意之欄位若未鉤選，本人同意視同授權。

研究生簽名：劉育誠　　　　學號：9163511
（親筆正楷）　　　　　　　（務必填寫）

日期：民國 93 年 12 月 7 日

1.本授權書請以黑筆撰寫並影印裝訂於書名頁之次頁。

國家圖書館博碩士論文電子檔案上網授權書

本授權書所授權之論文為本人在 國立交通 大學(學院) 工業工程與管理 系所
＿＿＿＿組 九十三 學年度第 一 學期取得 碩 士學位之論文。
論文名稱： 生產線訂單履行週期之績效評比－以微通訊廠為例
指導教授： 劉復華教授

☑同意　　□不同意

本人具有著作財產權之上列論文全文(含摘要)，以非專屬、無償授權國家圖書館，不限地域、時間與次數，以微縮、光碟或其他各種數位化方式將上列論文重製，並得將數位化之上列論文及論文電子檔以上載網路方式，提供讀者基於個人非營利性質之線上檢索、閱覽、下載或列印。

上述授權內容均無須訂立讓與及授權契約書。依本授權之發行權為非專屬性發行權利。依本授權所為之收錄、重製、發行及學術研發利用均為無償。上述同意與不同意之欄位若未鉤選，本人同意視同授權。

研究生簽名： 劉育誠　　　　學號： 9163511
（親筆正楷）　　　　　　　（務必填寫）

日期：民國 93 年 12 月 7 日

---

1. 本授權書請以黑筆撰寫，並列印二份，其中一份影印裝訂於附錄三之一(博碩士論文授權書)之次頁；另一份於辦理離校時繳交給系所助理，由圖書館彙總寄交國家圖書館。

國立交通大學

研究所碩士班

論文口試委員會審定書

本校管理學院碩士在職專班工業工程與管理組劉育誠君

所提論文　生產線訂單履行週期之績效評比---以微波通訊廠為例

Production Line Performance Assessment on Order Fulfillment Cycle Time---A case of Microelectronic Communication Company

合於碩士資格水準、業經本委員會評審認可。

口試委員：

劉復華

陳文賢

指導教授：劉復華

工管組組長：＿＿＿＿＿＿教授

中華民國 93 年 9 月 28 日

生產線訂單履行週期之績效評比-以微波通訊廠為例

中文摘要

許多工廠經常以 KPI (key performance index)作為衡量生產績效的工具。本研究建議以資料包絡分析法(data envelopment analysis，簡稱 DEA)，透過公司內部 KPI 的訂定，用以評核具有相關生產績效的生產單位。資料包絡分析法之最大功能在能實際評估一群決策單位之績效，本研究利用四種效率的索引:總體效率(global technical efficiency)，技術效率(technical efficiency)，規模效率(scale efficiency)，和混合效率(mix efficiency) 來衡量台灣一微波通訊公司的九條生產單位。此法有別於傳統的績效評核方式，其考慮了產線的規模、管理方式及生產流程，將有效的建議公司改進的方向及改善的重點。

關鍵字：資料包絡分析法，KPI，訂單履行週期，供應練管理

Product Line Performance Assessment on Order Fulfillment Cycle Time -- A Case of Microelectronic Communication Company

Abstract

Key performance index (KPI) is a popular tool to evaluate production performance in a factory. The paper suggests data envelopment analysis (DEA) as a promising alternative technique to measure the relative efficiencies of production lines with several KPIs. We use four efficiency indexes: global technical efficiency, pure technical efficiency, scale efficiency, and mix efficiency to assess the performance of the nine production lines of a microwave communication company in Taiwan. The method is different from the traditional performance assessment and also considers the production line scale, management, operation and process.

Keywords*: Data Envelopment Analysis, Key Performance Index, Order Fulfillment Cycle Time, Supply Chain Management*

誌　謝

本論文的完成，首先必須感謝恩師　劉復華教授的悉心指導，使得學生在繁忙的工作壓力下，能夠掌握正確的論文架構及方向，並在預定的期間內完成論文的書寫。劉教授因了解學生公事的繁忙及時間的緊迫，常剝奪自己睡眠的時間為學生指導論文，並鼓勵學生投稿相關期刊，這雖然是一個艱難的過程，但在彼此的鼓勵聲中達成了。此良師益友得之不易，在此至上最誠摯的謝意。

另外在口試期間，承蒙口試委員大同大學黃遵鉅博士，交通大學彭文理博士及交通大學陳文智博士之指正，提供許多寶貴的意見，使本論文更臻完善，在此深表謝意。

在研究期間，由於工作繁忙，經常造成學業及研究無法兼顧。除感謝劉復華老師的體諒，另亦感謝工作上的長官陳志宏副總及李中平協理，在學業及工作上不斷的鼓勵及指教，使這一路走來雖辛苦但亦格外溫馨。希望兩年的所學能夠應用在工作上以答謝師長及長官的栽培。最後要感謝父母及家人，在研究所兩年的時間對我在學業及工作上的支持，讓我無後顧之憂的完成學業。

劉育誠　謹誌於
國立交通大學工業工程與管理研究所
中華民國九十三年八月

1 Introduction

Microelectronics Technology Inc. (MTI) is a high tech company specializing in wireless communication technology research, product development, and production. Its current assets and yearly global revenues are more than one hundred million US dollars. Based on 20 years of valuable experience, possessing microwave and RF technology core competence, MTI has established a global leading position in the fields of radio, VSAT (very small aperture terminals), satellite TV transceiver systems, and personal wireless communications system. MTI has strategic alliances with many global leaders of wireless solution like STXN, UTStarcom, etc.

Reduction of cost, enhancement of customer service, and decrease of order cycle are three important factors needed to be the winner in this field. In order to improve these three factors, MTI defines several critical KPI for performance assessment. The study shows how to define the KPI and how to evaluate the performance of MTI's nine production lines based on the KPIs.

This paper shows how MTI employed data envelopment analysis (DEA) to evaluate its nine production lines. This study will describe some critical KPIs for the company's order fulfillment process and evaluation of the performance of the nine production lines.

In order to promote the company's operation efficiency and improve the inventory level to become the leader in the field, the company established an effective corporate structure and formulated sound strategies to orient employees in the proper use of resources. In this stage, the company set the company target by orientation and determination declaration. It then analyzed and defined the critical success factors by comparing the benchmark in the same field and similar fields; this also helps the company become aware of the advantages by elimination.

The target of the key performance indices (KPIs) is evaluating the implementation of the company goals and strategies. KPI is also a standard system for business activities; the purpose is setting a common language to evaluate the process performance.

DEA, first introduced by Charnes et. al (1978) is a mathematical programming approach to determine the relative efficiency company against a set of similar units. A unit with "efficiency score" one is on the "efficiency frontier" and the score less than one indicates the unit is not on the frontier. DEA provides detailed information about these possibilities by calculating the projection of each observation upon the frontier. The projection points are called "best practice". Comparing the actual performance with the projected ones can provide the direction for improvement. In this paper, each production line of the company represents as a unit in DEA. We use four efficiency indexes: global technical efficiency, pure technical efficiency, scale efficiency, and mix efficiency to assess the performance of the nine production lines. The four indices were determined by three DEA models: CCR, BCC, and SBM.

The CCR model (Charnes et al. 1978) is used to measure the efficiency of the process that incorporates multiple input and output modes. This type of relative efficiency rating is designated as the global technical efficiency. (Banker et al. 1984) adjoined the convex constrain ($\sum \lambda_j = 1$) to CCR model and get BCC model which is the one calculated under variable returns of scale. This type of relative efficiency rating is designated as the pure technical efficiency. SBM model (Tone 2002) which is non-radial and deals with input/output slacks directly. The SBM returns an efficiency measure between 0 and 1, and gives unity if and only if the decision-making unit (DMU) concerned is on the frontiers of the production possibility set with no input/output slacks.

This type of relative efficiency rating is decomposition into global technical efficiency and mix efficiency (Banker et al. 1984).

2 Order fulfillment cycle and the key performance indices (KPIs)

Fulfilling customer orders is the first priority of any company. The cycle for fulfilling customer order is depicted in Figure 1. When a customer places an order, MTI precedes three processes: 1. Demand Management, 2. Making and Sourcing, 3. Logistic Management. In the customer-oriented environment, how to obtain feedback and ship product more rapidly than other competitors is always the key factor to get more orders. How to shorten lead time and increase production efficiency are the topics in this corporate reengineering process.

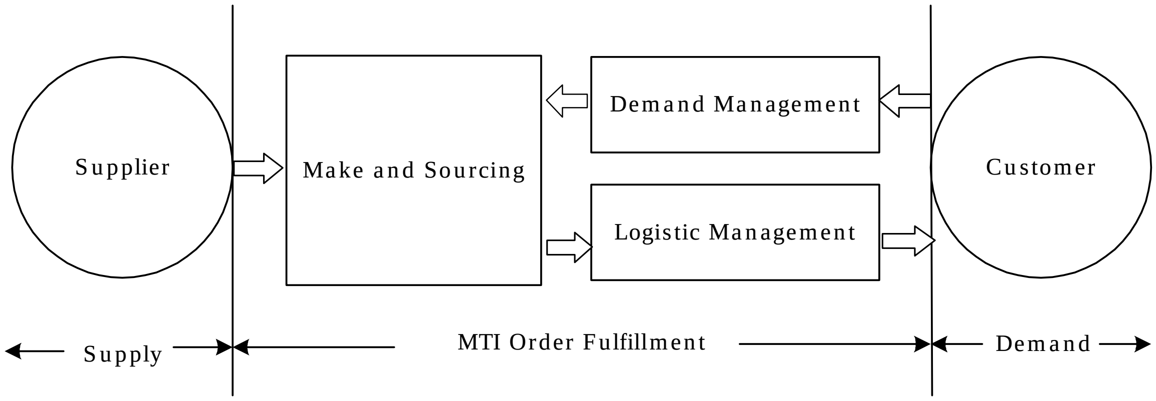

Figure 1 Order Fulfillment Cycle

Demand Management process always involves the processing and confirming the order with the customers. It is the beginning of the order fulfillment cycle. It includes items such as customer service, customer management, sales management, quotation service, order change process, available to promise, product price management, and product management.

Making and Sourcing are the manufacturing activities, which include material planning, capacity planning, material purchasing, material outsourcing and production line efficiency.

Logistic Management is defined as making the product available and ready to ship. The process includes shipping inspection, package, combine delivery, and transportation arrangement.

2.1 Purposes of KPI

There are four major purposes for setting up KPIs. The first is to set up a common language for measuring company performance; based on these indices, one finds a way to practice global supply chain management. Second, to help employees to understand the situation discrepancy of supply chain management between company and other competitors within the same industry, and in the process of planning and managing supply chain, try to select the hottest focus area, so as to work together with suppliers and partners to take immediate action and improve continuously. The third is to provide a baseline for performance measurement and comparison between the company and other companies within the same industry, so as to recognize the advantages and disadvantages of Supply Chain Management（SCM）. The last purpose is to provide tools for the company to do the comparison and analysis on the current internal supply chain management and other competitively strategic supply chain management, so as to help the company set up a target position inside the highly competitive market.

2.2 KPI implementation Steps

The process of adopting KPIs in the order fulfillment cycle is critical to reengineer a company. With reference to the element’s capabilities, a target is set for each KPI. Data collection is set and in case performance is not up to target, a review process is in place to rectify the situation. This consists of five following steps; these steps are designed to breakdown the company wide supply chain operational KPI to element level measurements. It includes clarification, review, matching, and confirmation with supply chain and production of a set of KPIs.

Step 1: Review new company wide SCM KPI definitions

Discuss with supply chain manager any supply chain definition that requires clarifications and reconciliation.

Step 2: Breakdown into element’s requirements

After the supply chain KPI definitions are clarified, review the impact area in terms of management and operational area, external interface, and activity content to define the functional/element’s requirements.

Step 3: Design supporting element’s KPI

After understanding the order fulfillment element’s business and process requirements, design the supporting logistics KPI, detailing the definition, calculation formula, frequency of measure, and measurement method, etc.

Step 4: Confirm KPI with process owners

Communicate the element’s KPI definition with the process owner of the impacted area and confirm the rationality and feasibility, and finalize the KPI details including any extra system or business resource requirement.

Step 5: Confirm SCM related element’s KPI with supply chain manager

Confirm with the supply chain manager the SCM related element’s KPI for supply chain control and measurement monitoring.

2.3 Key Performance Index Description

The six KPI indices used by MTI are depicted in Table 1. The six processes are described as follows:

Table 1 Key Performance Index Description

KPI #	KPI name	KPI Definition	To-Be KPI Sponsor
Y_1	Percentage of order confirmed	The percentage of purchase orders confirmed that could be delivered within 3 days.	PC, MC,
Y_2	Percentage of inbound operation complete	The number of inbound orders/lines that are operated divided by the total inbound orders/lines in the measurement period	WH
Y_3	Percentage of work order material planning & kitting orders/lines processed (planning, picking & material kitting) complete	The number of work order material kitting orders/lines that are kitted on-time to demand requirements divided by the total work order material kitting orders/lines requested in the measurement period	WH

Y_4	Percentage of delivery performance to first committed date	The percentage of orders that are fulfilled on or before the first committed date.	All
X_1	ECO (engineering change order) cycle time	The total time for request for change from customer engineering, production or quality control to revising a blueprint or design released by engineering, and implement the change within the make operation.	SM and Engineer
X_2	Total build time	Total build time is the average time for MTS, MTO semi-products from when production begins on the released work order until the build is completed and unit is ready to be inspected.	PH

Y_1: Purchase order (PO) schedule evaluation

MTI is set up in such a way that each customer order should be fulfilled within no more than three days. The production controller (PC) is informed of any order coming into the sales department. PC would commit the order if work-in-process (WIP) status and production capacity available for the required order. Then PC informs order administration (OA) and the order evaluation process is completed. Otherwise, PC will pass the work order to material control (MC) and purchasing section. Purchasing section will confirm the material schedule and make a feedback to MC.

Y_2: Inbound operation

The inbound operation process starts as the warehouse receives an arrival material. Time spent on the material for unloading, receiving, inspecting, and moving to points to be used and storage locations are recorded. The necessary bookkeeping for system control is also performed.

Y_3: Work order preparation and W/H material hand over

Stopwatch is pressed as PC releases a work order to warehouse. Then, W/H spends time for launching the plan for material kitting task, generating dispatching assignment, picking, kitting, packing, and handling the material to production lines.

Y_4: Outbound operation

The outbound operation KPI is initialized by the production line releasing the packing list and transferring to OA. OA will follow the packing list to generate the shipping notice and then transfer to logistic department. After the logistic department gets the shipping notice they arrange transportation and prepare all the freight information and documentation. When everything is ready, they will pass all related documents to W/H. The shipment is ready when W/H gets the product from the production line and documentation from logistic department. Total KPI is responsibility by Production line, OA, Logistic and W/H. The other KPI for manager review are OTD for first commit date and customer required date. The OTD is the most important index for customer satisfaction and should be tracked monthly.

X_1: Engineering change order

The purpose of this KPI is evaluating the engineering change process (ECP). The process is initiated as a customer releases engineering change request to document control center (DCC). The process is completed as OA feedbacks to the customer.

X_2: Production & testing

This KPI is to evaluate the efficiency and productivity of a production line. The collection of KPI is from shop floor control and analyzed by the system. Two separate sets of data are collected: 'total build time' and 'work order completed ratio'. 'Total building time' is the average time for the line spends on production of customer orders. The process includes surface mount technology (SMT) production, semi-product staging, product integration, test, packaging, shipping inspection to put away finished goods in the assigned staging area. We can evaluate the test time and efficiency for each work center and test station. "Work order complete ratio" begins on the released work and end by the work order been closed. The work order completed ration will impact the on time delivery (OTD).

3 The performance data

The nine production lines of MTI are denoted as *Line* 1, 2,.., and 9. Their data on the six indices are depicted in the following table. For each line, say *Line j*, y_{rj} denotes the data on index Y_r, r = 1, 2, 3 and 4, and x_{ij} denotes the data on index X_i, i = 1 and 2. As the six KPIs are defined, larger values at Y_1, Y_2, Y_3 and Y_4 smaller values on X_1 and X_2 indicate the better performance of the production line. Therefore, one may use the following equation to measure the efficiency of each *Line j*.

$$P_j = \sum_{r=1}^{4} y_{rj}u_r \Big/ \sum_{i=1}^{2} x_{ij}v_i \qquad (1)$$

The notations u_r and v_i are the weights that should be assigned to index Y_r and X_i, respectively.

It is a challenge to have a set of proper weights of the indices to measure the relative performance of production lines. We employ the theory of DEA to assess the relative efficiencies of the nine lines.

Table 2 KPI data for the production lines

KPI *Line j*	y_{1j}	y_{2j}	y_{3j}	y_{4j}	x_{1j}	x_{2j}
1	56%	56%	65%	95%	45	78
2	50%	87%	55%	76%	33	67
3	45%	54%	83%	55%	30	56
4	67%	76%	65%	66%	21	45
5	53%	66%	83%	55%	30	22
6	60%	45%	45%	56%	56	23
7	44%	93%	77%	76%	12	28
8	87%	88%	96%	87%	34	22
9	53%	78%	76%	55%	12	21

4 Implement Data Envelopment Analysis models

The relative efficiency of *Line k* is evaluated by following input-oriented CCR-I model.

[CCR-I-FP$_k$]

Maximize $P_k = \sum_{r=1}^{4} y_{rk} u_r / \sum_{i=1}^{2} x_{ik} v_i$

Subject to: $P_j = \sum_{r=1}^{4} y_{rj} u_r / \sum_{i=1}^{2} x_{ij} v_i \leq 1, \quad j = 1,\ldots,9$;

$u_r \geq \varepsilon > 0,\ r = 1,2,3,4$; $v_i \geq \varepsilon > 0, \quad i = 1,2$

ε is an Archimedean infinitesimally small number.

[CCR-I-FP$_k$] tries to maximize the efficiency score for the object *Line k* while keeping the efficiency scores for each *Line j* being no greater than one. [CCR-I-FP$_k$] is a fractional programming model and is transformed into a linear programming model as shown below. The lower bound conditions for the decision variables u_r and v_i would guarantee the proper transformation given the data of a line are non-negative and at least one is positive.

[CCR-I-LP$_k$]

Maximize $P_k = \sum_{r=1}^{4} y_{rk} u_r$

Subject to $\sum_{r=1}^{4} y_{rj}u_r - \sum_{i=1}^{2} x_{ij}v_i \le 0, \quad j=1,\dots,9;$

$$\sum_{i=1}^{2} x_{ik}v_i = 1;$$

$$u_r \ge \varepsilon > 0,\ r=1,2,3,4;\quad v_i \ge \varepsilon > 0, \quad i=1,2$$

The dual of [CCR-I-LP$_k$] can be written:

[CCR-I-DLP*k*]

Minimize $\theta_k - \varepsilon\left(\sum_{i=1}^{2} s_i^{-} + \sum_{r=1}^{4} s_r^{+}\right)$

Subject to $\sum_{j=1}^{9} x_{ij}\lambda_j + s_i^{-} = \theta_k x_{ik},\ i=1,2;$

$$\sum_{j=1}^{9} y_{rj}\lambda_j - s_r^{+} = y_{rk},\ r=1,2,3,4;$$

$$\text{all} \quad \lambda_j, s_i^{-}, s_r^{+} \ge 0$$

s_i^- and s_r^+ are the *excess* of the to-be-minimized index X_i and *shortfall* of the to-be-maximized index Y_r of this expression, respectively, and are called *slacks*. We add the superscript “*” on the variable to represent its optimal value of the model. According to the solution of the model *Line k*’s performance could be one of the following categories.

Pure efficient: $\theta_k^* = 1$ and $\left(\sum_{i=1}^{2} s_i^{*-} + \sum_{r=1}^{4} s_r^{*+}\right) = 0$

Pure inefficient: $\theta_k^* < 1$ and $\left(\sum_{i=1}^{2} s_i^{*-} + \sum_{r=1}^{4} s_r^{*+}\right) = 0$

Mixed inefficient: $\theta_k^* < 1$ and $\left(\sum_{i=1}^{2} s_i^{*-} + \sum_{r=1}^{4} s_r^{*+}\right) > 0$

Weak efficient: $\theta_k^* = 1$ and $\left(\sum_{i=1}^{2} s_i^{*-} + \sum_{r=1}^{4} s_r^{*+}\right) > 0$

The [CCR-I-FP$_k$] model assumes constant returns-to-scale. To identify the property of *Line k*, increasing or decreasing returns-to-scale, Banker, Charnes, and Cooper (BCC) (1984) proposed a model that measures so-called pure technical efficiency and scale efficiency. It is called the BCC model. Starting out from Shephard’s definition of a production possibility set, BCC-I assumes that this set satisfies basic axioms of convexity, inefficiency, ray unbounded and minimum extrapolation, $\lambda_j \ge 0, \quad j=1,2,\dots,9$ and $\sum_{j=1}^{9} \lambda_j^* = 1$.

BCC-I used the axioms and Shephard’s distance function to drive a model that measures ***Pure Technical Efficiency***.

[BCC-I-DLP$_k$]

Minimize $\eta_k - \varepsilon(\sum_{i=1}^{2} s_i^{-} + \sum_{r=1}^{4} s_r^{+})$

Subject to $\sum_{j=1}^{9} x_{ij}\lambda_j + s_i^{-} = \eta_k x_{ik}, \; i = 1,2;$

$\sum_{j=1}^{9} y_{ij}\lambda_j - s_r^{+} = y_{rk}, \; r = 1,2,3,4;$

$-\sum_{j=1}^{9} \lambda_j = -1$ and all $\lambda_j, s_i^{-}, s_r^{+} \geq 0$

The dual form of above [BCC-I-DLP$_k$] is expressed as follows:

[BCC-I-LP$_k$]

Maximize $\sum_{r=1}^{4} u_r y_{rk} - u_{0k}$

Subject to $\sum_{r=1}^{4} y_{rj}u_r - \sum_{i=1}^{2} x_{ij}v_i - u_{0k} \leq 0, \quad j = 1,2,\ldots,9;$

$\sum_{i=1}^{2} x_{ik}v_i = 1;$

$u_r \geq \varepsilon > 0, r = 1,2,3,4$ and $v_i \geq \varepsilon > 0, i = 1,2;$ u_{0k} free in sign

Measure by the intercept u_{0k}^{*} its sign, positive or negative, allows one to determine the magnitude of the returns-to-scale whether *Line k* currently evaluated is operating under increasing or decreasing returns-to-scale. Thus $u_{0k}^{*} > 0$, $u_{0k}^{*} = 0$ and $u_{0k}^{*} < 0$ imply *Line k* is operating under conditions of decreasing (DRS), constant (CRS), and increasing (IRS) returns-to-scale, respectively.

Tone (2000) introduced the slack-based measurement model. We consider an expression for describing the data for *Line k* as

$$y_{rk} = \sum_{j=1}^{9} y_{rj}\lambda_j - s_r^{+} \qquad (2)$$

$\lambda_j \geq 0, \; j = 1,2,\ldots,9, \; and \; s_r^{+} \geq 0, \; r = 1,2,3,4.$

From the conditions, $x_{ij} > 0$ and $\lambda_j \geq 0$, it holds

$$x_{ik} \geq s_i^{-} \qquad (3)$$

Using s_i^{-} and s_r^{+}, we define the SBM efficiency as follows:

$$\rho_k = \frac{1-\frac{1}{2}\sum_{i=1}^{2} s_i^- / x_{ik}}{1+\frac{1}{4}\sum_{i=1}^{4} s_r^+ / y_{rk}}. \tag{4}$$

It can be verified that ρ_k satisfies properties (i) units invariant and (ii) monotone decreasing in input/output slack. Furthermore, from (1), it holds $0 < \rho_k \leq 1$.

Another variation of SBM model [SBM-I] is also introduced to estimate the efficiency of *Line k*.

[SBM-I]

Minimize $\rho_k^* = 1-\frac{1}{2}\sum_{i=1}^{2} s_i^- \ / x_{ik}$

Subject to $x_{ik} = \sum_{j=1}^{9} x_{ij}\lambda_j + s_i^-$;

$y_{rk} = \sum_{j=1}^{9} y_{rj}\lambda_j - s_r^+$;

$\lambda_j \geq 0,\ j = 1,2,...,9,\ s_i^- \geq 0,\ i = 1,2,\ s_r^+ \geq 0\ and\ r = 1,2,3,4.$

[SBM-I] can be transformed into a linear program using the Charnes-Cooper transformation in a similar way to the CCR model. Refer to Tone (2001) and Cooper et al. (2000) for details.

Let and optimal solution for [SBM-I] is $(\rho_k^*, \lambda_j^*, s_i^{-*}, s_r^{+*})$. Based on this optimal solution, we define *Line k* as being *SBM-efficient* as follows:

(*SBM-efficient) Line k* is efficient if $\rho_k^* = 1$. This condition is equivalent to $s_i^{-*} = 0$ and $s_r^{+*} = 0$, i.e. no excesses and no shortfalls in any optimal solution.

Cross-sectional results

Banker, Charnes and Cooper (1984) suggested splitting the overall CCR efficiency-global technical efficiency (θ_k^*) into two factors, pure technical efficiency (η_k^*) and scale efficiency (S_k^*) in the following manner:

$$\theta_k^* = \eta_k^* \times (\theta_k^* / \eta_k^*) = \eta_k^* \times S_k^* \tag{5}$$

The BCC efficiency used the axioms and Shephard's distance function to drive a model that measures pure technical efficiency. The scale efficiency (S_k^*) can't exceed one. When the scale efficiency of a line is less than one, a further step can be taken to decide whether it is located at a stage of increasing returns-to-scale or decreasing returns-to-scale.

The calculations of economies of scale u_{0k}^* have a direct interpretation in terms of the underlying dynamic evolution. In an obvious sense, a production line with decreasing returns-to-scale has pushed its expansion too far, and management can be expected to consider the possibility of downsizing and reducing its scale of operation. Conversely, a production line with increasing returns-to-scale will typically be engaged in rapid economic growth. The mix efficiency, M_k^*, is not great than one and we have a decomposition of the non-radial efficiency into radial and efficiency as

$$\rho_k^* = \theta_k^* \times M_k^* \tag{6}$$

Based on (3), we have the decomposition of the non-radial technical efficiency ρ_k^* into M_k^*, pure technical efficiency (θ_k^*) and scale efficiency (S_k^*)

$$\rho_k^* = \theta_k^* \times M_k^* = \eta_k^* \times S_k^* \times M_k^* \tag{7}$$

5 Interpretation to the efficiency scores

Apply the models, **[CCR-I-LP$_k$], [BCC-I-LP$_k$] and [SBM-I]** for the data depicted in table 2, the objective function values and the cross section results are listed in table 3.

Table 3 Efficiency scores

Line k	θ_k^*	η_k^*	S_k^*	ρ_k^*	M_k^*	u_{0k}^*	RTS
1	0.423	1.000	0.423	0.393	0.929	-2.609	IRS
2	0.413	0.447	0.923	0.407	0.984	-0.706	IRS
3	0.436	0.632	0.690	0.423	0.971	-2.572	IRS
4	0.722	1.000	0.722	0.656	0.908	-1.051	IRS
5	0.893	0.970	0.920	0.783	0.877	0.782	DRS
6	0.660	0.922	0.715	0.539	0.817	0.845	DRS
7	1.000	1.000	1.000	1.000	1.000	0.000	CRS
8	1.000	1.000	1.000	1.000	1.000	0.000	CRS
9	1.000	1.000	1.000	1.000	1.000	0.000	CRS

From table 3, we can see *Lines 7, 8,* and *9* exhibit high efficient performances at any scale. The three production lines could be the benchmark of all the others. Scale efficiency S_k^* is equal to (θ_k^* / η_k^*). If S_k^* =1, then the *Line k* is operating at constant returns-to-scale which is the optimal level.

Line 1 and *Line 4* have a fully efficient η_1^* and η_4^* score and low efficiency of θ_1^* (0.423) and θ_4^* (0.722). The low efficiency is caused by scale $0 < S_k \leq 1$. The lines operate at an inappropriate scale either increasing or decreasing returns-to-scale. The values of u_{01}^* and u_{04}^* for production *Line 1* and *Line 4* are negative, indicating that they are increasing return-to-scale; this shows that it is possible for them to improve their efficiency by scaling up their production activities.

It is observed that production *Line 5* with low ρ_5^* (0.783) is caused by M_5^* (0.877), and S_5^* (0.920). Also, it is observed that production *Line 6* with low ρ_6^* (0.539) is caused by M_6^* (0.817), and S_6^* (0.715). Both u_{05}^* and u_{06}^* values are positive, which indicate that they are decreasing return-to-scale, showing that they can improve their efficiency by scaling down their production activities.

The production *Line 2* low efficiency of ρ_2^* (0.407) is caused by S_2^* (0.923) and η_2^* (0.447). The production *Line 3* low efficiency of ρ_3^* (0.423) is caused by S_3^* (0.690) and η_3^* (0.632). Both of u_{02}^* and u_{03}^* values are negative ones show that they have a possibility to improve their efficiency by scaling up their production activities. η_k^* is pure technical efficiency and low efficiency caused by technical and management. So, we can improve the efficiency by increasing scale, improving operation and management.

6 Conclusions

In this paper, we illustrate the KPI target and definition in the order fulfillment cycle. We list several KPIs and evaluate the nine production lines of MTI. The method introduced can also be used in assessing the performance of different companies. We provide example and interpretation intending to indicate direction of improvement. We decompose the efficiency score of each production line into technical, pure, scale, and mix efficiencies. DEA is successfully implemented on the assessment of the production lines. It can also be provided to assess the efficiency of management and other operation processes.

References

Banker, R.D., Charnes, A. and Cooper, W.W., 1984, Some Models for Estimating Technical and Scale Inefficiencies in DEA, *Management Science*, **30**(9), 1078-1092.

Callan, S.J., 1991, The Sensitivity of Productivity Growth measures to Alternative Structural and Behavioural Assumptions: An Application to Electric Utilities, 1951-1984, *Journal of Business and Economic Statistics*, **9**(2), 207-213.

Chavas, J.P. and Cox, T.L., 1990, A Non-Parametric Analysis of Productivities: The Case of U.S. and Japanese Manufacturing, *American Economic Review*, **80**(3), 655-666.

Cooper, W.W., Seiford, L.M., Tone, K., 2000, Data Envelopment Analysis – A Comprehensive Text with Models, Applications, References and DEA-Solver Software, *Kluwer Academic Publishers*, Dordrecht.

Farrell, M.J., 1957, The Measurement of Productive Efficiency, *Journal of the Royal Statistical Society*, **120**, 253-281.

Gaves, D.W., Christensen, L.R. and Diewert, W.E., 1982, The Economic Theory of Index Numbers and The Measurement of Input, Output, and Productivity, *Econometrica*, **50**(6), 1393-1414.

Tone, K., 2002, A slacks-based measure of super-efficiency in data envelopment analysis, *European Journal of Operational Research*, **143**, 32-41.