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目 錄

中文摘要

本研究主要是針對雙子星晶圓廠環境提出一套生產支援決策模式。由於雙子星晶圓廠位於同一地理位置且產能配置通常具有差異，為了提高整體之績效表現，廠區之間必須透過產能互相支援解決暫時性產能缺口或機台負荷不平衡等問題。有鑑於此，雙子星晶圓廠的生產規劃有以下二個問題：投料分佈及產能支援決策。前者為投料量決策並規劃如何分配在各廠區；後者在搬運系統產能限制下，透過產能支援達到增加產出以及降低Cycle Time等目標。此外，在互相支援產能的影響下，個別系統增加了來自系統外的干擾，其績效預估將會較以往困難許多。

本計畫第一年針對生產規劃方面提出有關投料決策及產能支援決策之模式構建：投料決策包含生產系統產能與搬運系統產能的檢核，以及當產能不足時投料量的調整與重新分配；產能支援決策包含產能支援時間點與支援工作量。而第二年的部分則是針對在施行生產互相支援情況下其績效預估模式之建構：此階段從模擬實驗觀察雙子星廠WIP轉移至他廠之現象，並分析其分別對雙方廠內績效之影響表現，接著透過實驗得知其相關因子間之關聯性後，藉由修正吾人先前之研究概念以及傳統等候模型等手法，發展出針對不同情況下之績效預估模式。最後，透過這三個模式的發展以建立一套有效的決策模式，進而提昇雙子星晶圓廠之績效。

關鍵詞：雙子星晶圓廠，生產支援決策，自動搬運系統，績效預估模式

英文摘要

Semiconductor manufacturing is one of the most complicated industries in the world. In order to reduce installation cost and increase production flexibility, twin-fab concept has been established over the past decade, which means two neighboring fabs can be connected to each other by automatic transportation system. Through the design of twin-fab, manufacturing performance, such as total throughput and cycle time of products, can be improved conspicuously. However, if lacking of completed production planning and control models, the benefit of twin-fab will be decreased significantly. In this proposal, a completed production planning and control system will be developed.

The proposal will include job release policy, capacity backup model and performance estimation model sections. First year, a production supporting system will be established, which includes job release policy and capacity backup model. Production and transportation capacity of the twin-fab will be considered in job release policy to decide the product types, quantity and timing for job releasing. The function of capacity backup model is to relieve the load of the permanent and temporary bottlenecks. Due to permanent bottleneck is caused by capacity shortage, product mix and capacity analysis will be applied to the decision of backup quantity. The temporary bottlenecks occur by the uncertainties of factory, and result in increasing the cycle time. Hence, the backup quantity and timing for the temporary bottlenecks will be based on the analysis of machines' stability and the mechanism of buffer management. A performance estimation model will be developed in the second year. Due to capacity backup, the performance of individual fab, such as cycle time and throughput will be changed. A simulation model will be established to observe the relationship between batch transfer and performance indices. Based on these results, we will modify the queuing network model and develop an accurate performance estimation model precisely. According to completed production planning and control model, the machines blocking and starving phenomena will be avoided and it will result in reducing the cycle time of products and increasing the total throughput of twin-fab.

Key words: Twin-fab, Production planning and control, Transportation capacity, Performance estimation

報告內容

一、 前言

由於在半導體產業其特殊的產業生產特性下，使得半導體產業的生產作業管理與其他的產業相較起來相形複雜且困難，例如繁雜的生產步驟與流程、設備使用率的高度要求以及半成品之時間限制等製程條件【14】【15】。不論何種類型的產業，在建廠初期的產能規劃上，總是存在著一定程度的風險，然而就半導體產業的投資上，其所需必須承擔的風險，更是其他產業所不能比擬的，除了一般產業所必須面對之未來市場需求變化以及技術發展速度外，另一個造成其高度風險的原因在於其製程設備投資成本相當昂貴，往往每台機台設備動輒數百萬美金左右。而在半導體產業所有的建廠投資金額中，機台購置成本所佔有的比例往往高達70~80%，再加上為了因應市場需求變化快速的現象，以及為了使企業能達到經濟規模的效益等其他考量因素，迫使的半導體廠的管理者，對於在機台的設置選擇上難以抉擇，所以在為了能維持工廠的高度競爭力，雙子星工廠的建廠模式已是半導體產業中不可忽略的一種趨勢與概念。

所謂雙子星工廠型態，乃泛指在一棟工廠建築物內擁有兩條不同產能或技術之獨立生產線，各自擁有自己的投料組合與生產流程，換句話說，就像是在同一棟建築物內有兩間獨立的工廠，各有獨自的管控方式。而此型態工廠的概念之所以能廣泛的被現在的半導體產業者所接受，原因大致上可分為下列幾項考量因素：(1)共用基本設備，降低擴充產能之成本：以往的半導體廠大多是採取多廠且小規模的建廠思維，目的在於管理者期望透過此種方式，逐漸反應市場需求變動而擴充相關之產能，降低在擴充產能時之可能造成的投資風險。然而但在這樣的建廠思維模式中，不難發現一些基本的廠務設備，如氣體幫浦以及污水回收等系統，當每建一座新廠就必須建構一次，這對於在投資上無非是一種浪費。而在雙子星廠模式概念中，其即在規劃時則將其兩條生產線所能共用之基本廠務設備一並構建，藉此方式有效的降低擴充產能時，關於基本廠務設備方面的建置成本。(2) 縮短產能擴充之時程：在此方面的問題，承如上點所述由於雙子星廠在建廠規劃已將基本廠務設備一並建構，因此可以依循著市場需求與景氣的步調，逐步的建置所需之機台設備，這不僅可以快速的因應市場變化也可以避免侷限了自我製程能力的發展，此因素對於在產品組合(product mix)極為複雜的晶圓代工(Foundry)環境中，製程能力水準的調整方式也較為適合且有效。(3)即時性的產能支援(Capacity Backup)調配：雙子星廠模式的另一項優點，在於執行產能規劃時可以同時考量兩廠的產能，依據市場需求做彈性的調整。若以先前的建廠方式(小規模多廠)來進行產能支援的，其在執行方式上通常在一開始的投料階段即必須進行規劃與協調的動作，預先做好生產規劃與工件運輸的相關計畫，此種運作模式如遇到即時性的突發狀況，則難以做到產能支援的動作。然而對於雙子星晶圓廠來說，即時性的管控行為則較容易達到，主要是由於兩廠距離相當靠近，可以透過傳輸設備來達到所謂的即時性的產能支援管控。譬如當生產線發生預期外之生產狀況，像是產品大量的Hole/Release、機台嚴重當機；或是因受限於晶圓製程中逐漸增多的生產限制因素影響，如等候時間限制(Time constraint) 【6】【14】【23】、緊急工件(Hot lot)【11】【24】等，而可能導致產品良率(yield)下降；或是產線不平衡而導致產品生產週期時間(Cycle time) 之增加時，即可藉由即時傳輸方式來降低其突發事件發生時對於工廠績效所造成的傷害，亦或是進一步的來避免這樣的事件發生。除此之外，在平常的生產過程中也可以利用這樣的傳輸動作，來提高雙方兩廠的績效表現，像是提高加工站內機台使用率(Utilization)。

然而，雖然許多的半導體大廠對於雙子星廠的建廠模式已行之有年，但以往的雙子星廠管理方式，在執行上也逐漸的受到考驗與限制。由於在成本利潤與市場競爭力等環境壓力下，晶圓片的主流規格以從先前8吋大小逐漸演變到12吋。由於晶圓片尺寸大小的改變，使的12吋廠內的生產型態與管控模式

上產生了變化。就12吋晶圓廠的晶圓搬運方式而言，由於12吋的晶盒體積與重量相較於以往的8吋增加許多，為了避免人工搬運的不便所可能造成的人員傷害以及產品的安全性考量下。目前的12吋半導體現場管控趨勢，大多採取自動化物料搬運系統(Automatic MaterialHandling System, AMHS)的方式來進行搬運的動作。雖然以往8吋雙子星晶圓廠也是採取AMHS，只是當遇到傳輸系統派遣不及，或是生產排程臨時改變等狀況時，現場作業人員為了避免機台挨餓等狀況的發生，大多會直接以人工搬運的方式來進行處理，可惜的是此種處理方式對12吋雙子星晶圓廠的流程管控來說已經不太適用。所以對於12吋雙子星晶圓廠來說，如何運用雙子星廠可以同時考慮兩廠生產規劃之優點，對於產能支援以及傳輸系統產能的決策進行相互間的配合與考量，對於未來12吋雙子星晶圓廠的管理上勢必是一個必須面對的課題。

過去針對產能支援的問題，Tu et al.【25】提出利用保護性產能與機台產能負荷的概念，計算出合理的產能支援數量，而對於執行產能支援後的績效估計則是利用等候理論與Little’s Law的觀念，建構出一套有效的估計模式。雖然其研究環境的考量因素，是針對兩獨立工廠之間的產能支援問題進行研究，但對於產品backup的設定上，還只是針對單一產品進行研究。除此之外，對於傳輸系統方面仍未加以考量，也造成對於即時性反應的問題無法探討。

對於AMHS的研究，大部分的學者都針對單一工廠內的AHMS排程與指派方式進行探討；或者是對於單一12吋晶圓廠中，interbay與intrabay系統的AMHS的運作法則，亦或是AMHS與工廠設施規劃之間整合效力的研究【2】【3】【8】【12】【28】。在這些相關研究中，可以發現這些對於AMHS排程、指派或是規劃模式的探討，其判定模式好壞的衡量指標，大多著重傳輸系統的反應時間是否最短、是否能快速找到最短路徑，或者是傳輸時間能否準時(on-time delivery)等居多【9】【16】【18】，因為有學者認為能達到on-time delivery以及較短的反應時間，對於Cycle time或是機台使用率等績效指標，就會有較好的提升效果。但是這方面的研究中針對雙子星廠間之傳輸系統的文獻探討則較為缺乏，不僅如此，雙子星廠間之傳輸系統在排程、指派或是規劃上的考量，也必須跟兩廠的產能規劃同時配合，否則其傳輸後所帶來的效果，就無法有效的顯現出來，因此比起過去單一工廠傳輸系統的研究上，雙子星廠在考量與研究上也會的較為麻煩且複雜。而關於結合產能支援與AMHS這兩方面的研究，過去學者研究曾提出不少概念與方法，像是Tobaet al.【19】【20】【21】提出利用real time inter-fab dispatching rules以及segment-based approach的概念，探討加工物件允許可跨廠生產的環境中，對每一個加工物件進行製造流程上的指派，以期望達到較佳的績效表現。Wu and Chang【29】所探討的實驗環境，則是針對擁有夥伴關係之半導體廠，其之間產能支援的管控方式，以及如何選擇出較佳的搬運方案進行研究，其提出結合倒傳遞類神經演算法(BPN)與基因演算法(GA)的概念，找出較佳的傳送組合，來達到所謂move數提升之目標，進而使的廠內Cycle Time與產出量之績效有顯著提升。雖然Toba et al.以及Wu and Chang先前的相關研究，對於產能支援與AMHS兩方面結合，提出不錯的解決概念與模式，但卻也發現在這些學者的研究過程裡，對於傳輸系統的產能方面的限制卻都未加以考量，雖然理論架構與實驗結果都有不錯的表現，但如依據理論模式去執行，極可能造成過多且頻繁的傳輸動作，就現場說過多的傳輸動作可能增加晶圓破損的機率增加。除此之外，礙於廠內空間的限制下，傳輸系統的產能也勢必有限，而其過多的傳輸要求與動作是否都能達到，這都是在實際現場中會碰到的問題，所以在考慮傳輸系統產能有限的條件下，其產能支援與AMHS的互相結合的研究方面，仍有一些須要改善與考量的地方。

此外，在半導體產業中所關心的績效指標，不外乎是Cycle time與產出量(Throughput)，此兩項指標不僅顯示與評判其生產績效的好壞，更是生產規劃階段很重要的兩大指標。生產規劃人員通常會以預估的Cycle Time與Throughput來做為訂單交期允諾的因素，因此績效預估的準確與否在生產規劃上十分重要。雖然在過去的研究中不少的學者，提出不少相關的估算式【4】【5】【10】【13】【27】，

但其大多針對不同的環境條件下之單一晶圓廠。對於雙子星工廠的績效估算研究仍有所欠缺，主要是其雙子星廠在產能規劃時，可以將兩廠部份之產能同時合併考量，在加上其傳輸行為較為即時性，所以可能造成系統的Cycle time與Throughput有所變化。因此如採用先前學者所提出的績效估算模式於雙子星晶圓廠中，進行績效值的估算其結果必定存在某種程度上的不準確度，因此發展出一套合理且合適雙子星晶圓廠之績效估算模式，對於管理者來說是相當重要的一環。

綜合以上的分析，在雙子星廠內傳輸系統產能限制條件下，如何有效管控傳輸系統使機台設備發揮最大的效能，如何使管理者對於雙子星晶圓廠的管控做出較佳生產決策，以達到有效之Cycle time的下降與Throughput的提升，此乃當今晶圓製造中雙子星廠當務之急。有鑑於此，本研究將提出一系列的方法來解決晶圓製造中雙子星廠的生產決策以及績效估算之問題。

二、 研究目的

承如前言所述，隨著製程技術的進步、建廠成本之上升以及面臨市場需求的高度不確定性等環境因素，使得雙子星晶圓廠的興建勢必成為半導體產業的一種趨勢，因此如何決策雙子星廠內雙方產線之相關的生產管控機制，勢必也將是一個不可避免的問題。本研究目的在於考量雙子星晶圓廠在有限之傳輸系統產能中，從提升生產系統績效的角度下思考，發展出一套有效且合理的生產支援決策模式。此決策模式從兩廠內之生產情況以及傳輸系統產能限制進行著手，提供雙子星晶圓廠較佳的投料決策及產能支援決策機制。除此之外，由於雙子星晶圓廠的管控方式有別於傳統單一晶圓廠，因此也針對在此決策模式下之雙子星晶圓廠發展一套合適之績效預估模式，以便提供管理者在後續進行相關規劃與決策之用，遂而能有效的提高雙子星晶圓廠在管控上的效能。

三、 研究方法

本研究之主要目的為針對半導體雙子星晶圓廠環境提出一套生產支援決策模式。由於雙子星晶圓廠位於同一地理位置且產能配置通常具有差異，廠區之間經常必須透過產能互相支援解決暫時性產能缺口或機台負荷不平衡等問題。經分析整理，雙子星晶圓廠生產規劃應就以下幾點加以考慮：

1. 製程能力差異

檢視雙子星晶圓廠之建廠背景，由於機台設置時間點的差異，造成其製程技術能力也有所差異。因此，某些產品在不同的廠區可能會有不同的加工時間，甚至發生無法在某廠區加工的情形。在考慮加工路徑的同時，必須將製程能力差異及限制加以考慮。

2. 當機影響

在傳統決策模式中，通常以自身服務率降低表達當機。然而，在雙子星晶圓廠環境中，當機發生除了自身服務率降低之外，還有就是導致等候線異常累積，因此可能必須施行產能支援，而此時將會影響另一廠區的到達率，而造成一連串的干擾，所以此因子之影響也必須成為生產規劃決策中一環。

3. 跨廠傳輸系統產能限制

在產能支援或路徑選擇的相關研究中，經常使用動態及時路徑選擇的方法進行。然而，動態決策方法在每次加工完畢時皆有可能發生傳輸，此舉對於 AMHS 系統的產能預估上勢必有一定程度的影響，如果決策不對將可能造成傳輸系統負荷過重。因此，在支援決策上也必須將傳輸系統產能納入考量，以避免傳輸系統負荷過重而引起在製品在暫存區等候過久的情形發生。

綜合以上各項觀點，雙子星晶圓廠的生產規劃問題有著以下二個主要問題：投料分佈以及產能支援決策。前者為投料量決策並規劃如何分配在各廠區；後者在搬運系統產能限制下，透過產能支援達到增加產出以及降低 cycle time 等目標。除此之外，在互相支援產能的影響下，個別系統增加了來自系統

外的干擾，雙子星晶圓廠的績效預估將會較以往困難許多。因此，完整解決雙子星晶圓廠生產規劃問題必須包含以下三個方向：投料決策(job release policy)、產能支援決策(capacity backup)以及績效預估模式(performance evaluation model)，而以上各決策模式的詳細說明分述如下：

1. 投料支援決策

(A) 生產系統產能檢核

由於雙子星廠可以藉由自動化搬運系統(AMHS)來進行即時性的產能支援，因此初步上是將兩廠之機台產能合併起來進行生產系統產能的檢核與規劃，而本研究在此方面提出如下之參數計算並結合試算表的方式來進行檢核：

$$DC_{ij} = R_i \times PT_{ij}$$

$$MC_j = \sum_{k=1}^{2} A_{jk} \times MT_{jk}$$

DC_{ij} ：產品 i 所需之產能
R_i ：產品 i 投料比率
PT_{ij} ：產品 i 在加工機台 j 所需之加工時間
MC_j ：加工機台 j 所能提供之產能
A_{jk} ：廠區 k 中加工機台 j 之可用率
MT_{jk} ：廠區 k 中加工機台 j 之可用時間

如 $\sum_{i=1} DC_{ij}$ 與 MC_j 不相等時則代表其產品投料比率，對於在雙子星廠環境裡就算透過產能支援的方式仍無法滿足實際產能需求，如此在本階段的檢核結果上則必須將其產品投料比率加以改變，以期符合所需之產能需求，以免接下來的規劃上出現錯誤。

(B) 搬運系統產能檢核

經由前部份的生產系統產能檢核後，接下來將對於 AMHS 的產能進行檢核與規劃。上個階段的產能檢核是考量在雙子星廠實行跨廠的產能支援條件下，生產系統產能所能提供的最大產能情況，如何去規劃一個合適的 AMHS 車輛數，對於一個高度自動化的雙子星廠產線來說十分重要，過多或太少都會影響到 AMHS 的實際能提供的產能，因此接下來就針對 AMHS 產能的部份進行檢核。

AMHS 主要是在幫助生產流程更為流暢的一種手段，對於產品價值提升上並無直接的效益，因此對於 AMHS 的產能需求上，首先本研究先從機台運作的角度切入思考，但由於半導體現場機台種類繁多，因此本研究提出一套 adjust X-factor contribution 概念來做為選定關鍵機台的方式，而其細部過程與研究結果如附件一之文章所示，而本篇文章已被國際期刊 International Journal of Services Operations and Informatics (EI) 所收錄並於 2009 刊登。

而由於本研究是以提升生產系統績效為前提下進行相關之決策制定，因此關於 AMHS 的車輛數的規劃上，將從為了避免機台在加工作過程中，因為 AMHS 來不及送達工件而發生機台挨餓的情況進行思考，因此本計劃對於 AMHS 車輛數的考量上，運用 adjust X-factor contribution、保護性產能以及等候理論之相關概念，發展出一套 AMHS 車輛數的估算模式，其詳細的研究結論如附件二所示，此部份之研究已在 Global Business And Technology Association (GBATA)所舉辦之第 11 屆年度國際研討會(Business Strategies and Technological Innovations for Sustainable

Development: Creating Global Prosperity for Humanity)上發表之。

2. 產能支援決策

相關研究指出，工作負荷平衡可以達到減少WIP、降低cycle time以及更有效處理機台當機狀況等目標【1】【7】【17】。因此，除了支援對方產能不足的部分之外，平衡雙方工作負荷亦是產能支援決策一個很重要的目標。由於雙子星廠現場產能支援模式，現階段並沒有一套有效的管理模式，因而造成負責跨廠運輸的傳輸系統可能做了過多無意義的搬運行為，例如：管理者期望跨廠進行產品的加工，以降低產品的生產週期，但管控模式的邏輯錯誤，使的產品跨廠等候加工在未被加工前，又被送回原廠生產線等候加工，而導致傳輸系統之產能的浪費。至於產能支援的時機，以往研究大都以動態決定為主要作法，然而，此舉可能造成搬運系統產能需求很大。

本研究在此階段提出在製品門檻值(Threshold)以及在製品差異門檻值(Difference)二種觀點進行產能決策的管控。其中在製品門檻值之設定目的除了避免過多在製品(WIP)而導致生產績效的下降外，另一個目的在於避免機台發生缺料之情況。此數值設置過低除了可能造成本身機台的缺料外，也可能造成過多產能支援搬運動作，而導致自動化搬運系統(AMHS)產能浪費；反之則使的支援模式無法啟動。至於在製品差異門檻值的設定，其訂定的目的在於避免發生無效搬運之狀況。當兩廠可進行產能支援機台之WIP差異大於此設定值時，才正式啟動產能支援的動作進行運送。而所謂的無效搬運是指，當工件在原投料廠等候加工之時間小於跨廠來回搬運時間與跨廠後等候加工時間之總和條件下還進行搬運之行為。此設定過小會導致產能支援的效果下降，而浪費不必要的搬運系統產能，相反的設定過大則使的產能支援模式無法發揮其效用。本研究首先透過e-Mplant7.0模擬軟體建構雙子星晶圓廠，並利用實驗設計的方式進行實驗數據的收集與分析，找出這兩因子對於生產系統之影響情形，其中環境之設定分為有產能缺走與無產能缺口兩種，有產能缺口是指由於訂單變化所導致的短期產能短缺，而需要進行產能支援；另外一個無產能缺口則是由於無預期性之因素所導致之產能的損失，像是機台嚴重當機，而必須施行產能支援行為。此部份之詳細研究內容與結論已整理並發表在2010工程和商業管理學術會議(EBM2010)(附件三)。

至於在製品門檻值(Threshold)以及在製品差異門檻值(Difference)的設定，由於其在製品門檻值之數值的設定是為了避免機台挨餓導致機台產能損失所設置之管制點，因此吾人則以機台的保護性產能觀點進行公式之推導；而對於在製品差異門檻值的計算上，由於其數值主要的目的是為了避免過多的無效搬運，所以本研究從管理者期望搬運行為所能獲取之績效角度來進行公式的建構，以降低無效搬運的發生機會。而關於這兩方方面數值之公式推導細部資訊與介紹請詳見附件四，文章部分也已整理發表在 2010 IMS 國際研討會中。

3. 績效預估

在具有產能支援的雙子星晶圓廠中，由於其工作站到達率會遭受非常態外部到達的干擾，因此，其績效預估無法以一般等候模型、平均值分析(mean value analysis, MVA)等績效評估模式進行計算，必須針對雙子星晶圓廠特性加以修正。而在實行產能支援模式時，對於原先的生產系統會產生以下二項干擾：

(A) 對發出需求方而言:

其等候線中部份在製品不經過機台加工而離開本身之生產系統，而造成自身產線上之工件到達率下降。

(B) 對接受需求方而言：

除了原先本身生產系統的工件到達之外，還必須接受來自他廠工件到達，而且此種工件之到達率與期數量卻非固定與規律的發生。

所以由此可知在估算產能支援情況下之績效，勢必要從工件到達率的增減來進行考量，除此之外由

先前的一些相關研究發現，機台當機干擾因子對系統的影響是不可忽視的，因此在績效估算模式的建構方面，也結合吾人過去所提出之相關機台當機修正式【22】。此外在加上由於雙子星晶圓廠的產能支援環境大致上可分為，無產能缺口與有產能缺口兩種，其發生須要進行產能支援的情況也不同，因此關於績效預估方面的模式建構概念與方式也有所差異。在無產能缺口情況下，發生需要進行產能支援大多是現場出現無法預期之嚴重產能損失狀況，為了避免 WIP 迅速累積影響生產系統的整體績效所施行之手段，因此本研究將從機台產能合併角度下進行模式之建構，以虛擬合併機台的觀點估算得到，關於運用產能支援之決策管控下其績效的改善。至於在有產能缺口方面，由於此種情況的發生產能支援是可以預期的且也是必需的，因此關於這方面的績效預估模式，將藉由從過去吾人相關之研究【26】進行更進一步的修正，以符合雙子星晶圓廠之實際情況，關於這方面的詳細研究結論也以整理如附件五所示，本篇研究結果預計發表在 2011 年四月所舉辦之工程和商業管理學術會議(EBM2011)。

四、 結果與討論

在半導體產業面對雙子星晶圓廠的建廠模式中產能支援決策的制定，管理者必須在有限的傳輸系統產能，藉由不同的管控手法提升產能支援的效益，然而，在缺乏系統化的解決方法之下，管理者大多只能憑藉經驗法則找出合理的產能支援管控方式。而本研究所提出之產能支援決策模式，包含投料決策、產能支援決策以及績效預估模式三階段，透過在製品門檻值與在製品差異門檻值的制定，一方面確保機台設備之生產產能不會損失，另一方面也考量傳輸系統之負荷情況，最後再經由績效預估模式計算出預期之績效表現，進而提供管理者做下一步的管理考量。相信在此產能支援決策模式的幫助下，對於雙子星晶圓廠產能支援管控而言提供了一有系統且合理之參考依據，管理者定能更有效地解決雙子星廠晶圓廠的產能支援問題。

在半導體產業之中，唯有不斷的提升製程能力與提升生產之績效，方能在瞬息萬變的市場中佔有一席之地，然而前幾年的金融海嘯震驚了全世界，也帶給台灣半導體產業不少的衝擊，由於台灣的半導體公司大多是以代工為主，沒有訂單的就沒有收入，因此如何快速的因應市場的變動，調整到最事宜的生產步調，如何安排製程的導入時程，使的公司在轉換時仍然維持著一定的競爭水準，不至於導致更多的問題產生，實為後續相關研究可以進行探討之方向。

就本質而論，本計畫之研究成果同時具有實務及學術價值。在實務方面，本計畫之成果提供雙子星晶圓廠對於產能支援決策的制定上能有所憑藉；在學術上，本研究提供一套以等候理論應用於雙子星晶圓廠之車輛配置與產能支援決策之概念。此外，本研究亦已將研究成果發表於國際學術研討會以及國際學術期刊之中。

本研究之主要成果分述如下：

1.考量雙子星晶圓廠與自動化傳輸系統的負荷問題，並針對雙子星晶圓廠內之生產規劃，提供一個有系統化且合理化之思考與解決邏輯。

2.從生產系統績效的角度思考，對於傳輸系統產能的配置進行估算，避免過去及時性的傳輸決策，所可能導致的系統工作負荷過大問題。

3.提出以等候理論為基礎之雙子星晶圓廠產能支援績效預估模式

4.利用eM-Plant 7.0呈現與建構雙子星晶圓廠之製造過程與特性，以提供後續相關之研究平台。

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附 錄

附 件一

Model to determine a general X-factor contribution and apply to cycle time improvement for wafer fabrication

Model to determine a general X-factor contribution and apply to cycle time improvement for wafer fabrication

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Abstract: Shortening cycle time and maximising output are the major concerns of highly competitive industry. In this paper, an Adjusted X-Factor Contribution (AXFC) measurement is developed, which considers batching process, un-batching process and machine failure. A general model is established to determine the X-factor contribution for all types of machines. In this model, GI/G/m queuing theory is applied to estimate the aggregated cycle time. The machine downtime variability, lot arrival variability, batching and un-batching processing are considered. Finally, the effects of system performances by improving the workstations with high utilisation and high AXFC are explored. The results showed that the cycle time and cycle time variability of products could be affected by the relative locations of high utilisation and high AXFC workstations. Furthermore, the results also revealed that reducing failure frequency of high AXFC workstation will perform as good as high utilisation workstation on cycle time improving.

Keywords: X-factor; batching process; un-batching process; cycle time.

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1 Introduction

Semiconductor manufacturing is a capital, labour and technology intensive high-tech industry with complex processes. In order to maintain profitability, firms have to improve productivity, quality, cycle time and on-time delivery continuously. Many researchers believed that reducing variability of system can keep the low cycle time as the system approaching its maximum throughput rate. Many theories and methodologies were presented on performance improvement to reduce system variability from reducing mean cycle time and cycle time variance (Adams et al., 1988; Goldratt and Cox, 1996; Lee et al., 2002). For example, Theory of Constraint emphasises the importance of bottleneck and puts all efforts on the bottleneck of system (Goldratt and Cox, 1996). The theory of just-in-time is also used for management system of production efficiency. It was addressed to lower WIP in overall system, because the higher WIP resulted in bad production performance. Although many theories were presented for production managements (Enns, 1995; Srivatsan and Kempf, 1995; Sattler, 1996; Chung and Huang, 1999), they were hard to apply to the wafer fabrication due to some specific characteristics such as re-entry, complicate process flow and high utilisation rate of machines. Therefore, an useful and simple index was developed, which can measure and represent the performance of overall system in wafer fabrication. This index is called X-factor.

The basic X-factor was proposed by Martin (1996). It was defined as the total mean cycle time of system divided by the total Raw Process Time (RPT) of the production line. Besides, it showed the relationship between normalised cycle time and RPT in overall system. Therefore, in steady state, the concept of X-factor can be used to estimate the cycle time of each product when the product mix of wafer fabrication is stable. Unfortunately, product mix is changed frequently and enormously in wafer foundry. Afterward the extended application of X-factor was proposed by many researchers (Martin, 1996; Martin, 1997, Martin, 1998, Kishimoto et al., 2001). Martin's study used the extended X-factor exclusively as an alternative measure for identifying and monitoring machine group level characteristics. Moreover, Delp et al. (2005, 2006) also proposed a modificatory model of X-factor, which combined Kingman's equation with Martin's concept. In these studies, they both indicated that the X-factor can be used to determine the performance of each machine for the contribution of overall system. In other words, when engineers try to determine the priority of machines for performance improvement, they can not only use the utilisation of machines but also use the X-factor of machines.

Based on the description as above, X-factor is an index which can easily apply to wafer fabrication not only as an overall performance index but also on the selection of workstation for performance improvement. Unfortunately, there are some factors still being excluded from the X-factor model, such as batching process and un-batching process. Because these factors are common processes in wafer fabrication, they can not be ignored (Rulkens et al., 1998, Tu and Chen, 2006, Tu and Chen, 2008, Tu, 2008). Consequently, this paper presented a general X-factor determination model for wafer fabrication to determine the X-factor contribution of each work centre. Within this model, the machine failure was modified from other viewpoint. In addition, we extended the exploration of X-factor contribution for batch and un-batch machines to examine whether the conclusions of Delp's experiments still work when there are including batching and un-batching processes.

This paper was structured as follows. In Section 2, a general X-factor model for batching process and un-batching processes was proposed. In Section 3, a simulation model was established for model validation. In Section 4, an exploration research and its results were presented. Finally, in Section 5, the summary and future researches were included.

2 Methodology

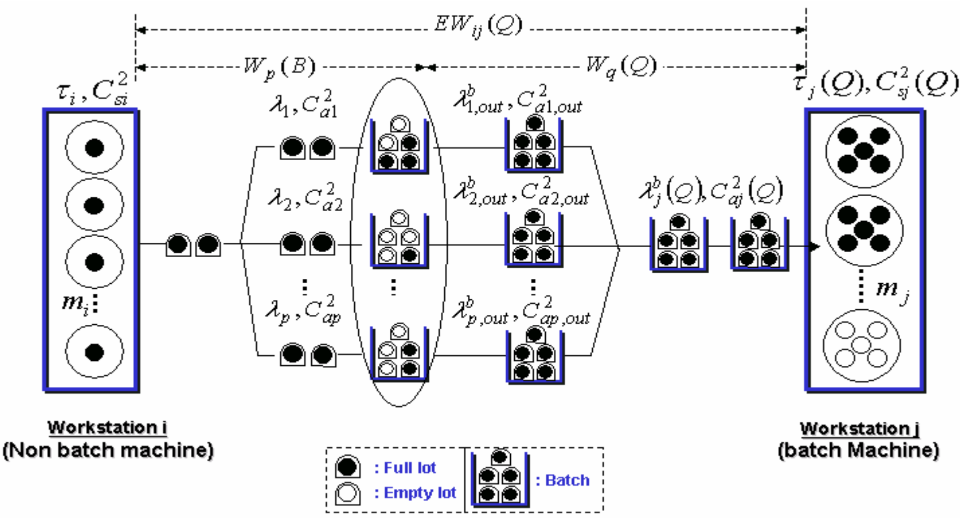
The basic X-factor presents the relationship between normalised cycle time and RPT in overall system. In general, the RPT has no high variation in any factory and the major variation of product cycle time comes from the queue time. Therefore, in order to take the factors of batch and un-batch into the concept of X-factor, a GI/G/m model for cycle time estimation is established in the following sections. Furthermore, machine failure issues are considered in this model as well.

2.1 Cycle time estimation of batching process

The factor of batch has to be taken into consideration in the queuing systems. In previous study, a frame of queuing system for batching process was presented (Fowler et al., 2002; Tu and Liou, 2006; Tu and Chen, 2008). There are two parts in this queuing system. The first one stands for the queue to form a batch and the second one is a queue to wait for processing. The parameters and performance measures of GI/G/m queue are modelled in Figure 1.

From Figure 1, $W_p(B)$ is the expected waiting time of any product to form a batch. $W_q(Q)$ is the expected waiting time of any product by batch type to wait for processing. The sum of $W_p(B)$ and $W_q(Q)$ can derive the total expected waiting time in GI/G/m queuing system of batching process denoted by $EW_{ij}(Q)$. Finally, the cycle time of batch workstation was derived from combining processing time of a batch product with $EW_{ij}(Q)$.

Figure 1 The diagram of batching behaviour (see online version for colour)



Based on GI/G/m queuing theory, there are five principal parameters within GI/G/m queuing model (Lazowska et al., 1984; Fowler et al., 2002): average arrival rate (λ), average service time (τ), squared coefficient of variation of arrival rate (C_a^2), squared coefficient of variation of service time (C_s^2) and number of servers (m). The modification of these five parameters can be captured by Tu and Liou (2006). However, this paper proposed a general model, which can apply to single lot or batch workstations. Therefore, the parameters of C_a^2 are modified as follows:

$$C_{ai}^2\,(\mathrm{Q}) = \left\{ \begin{array}{ll} (1-\varpi) + \varpi \times \left(\sum_{k=1}^{f} \dfrac{C_{ak,out}^2 \times \lambda_{k,out}^b}{\lambda_i^b(\mathrm{Q})} \right) & ,\ \mathrm{b} > 1 \\ C_{ai}^2 & ,\ \mathrm{b} = 1 \end{array} \right\} \tag{1}$$

$$\lambda_{k,out}^b = \frac{\lambda_k}{b} \tag{2}$$

$$C_{ak,out}^2 = \frac{C_{aj}^2}{b} \tag{3}$$

$$\lambda_k = \lambda \times R_k \tag{4}$$

$$\varpi = \left[1 + 4\left(1-\rho_j\right)^2 \left(v-1\right) \right]^{-1} \tag{5}$$

$$\rho_j = \frac{\lambda_j^b(\mathrm{Q}) \times \tau_j}{m_j} \tag{6}$$

Where

f	Number of products.
b_k	Batch size of product f, for $k = 1,2,3,\ldots,f$.
λ_k	Arrival rate(lot/time-unit), for $k = 1,2,3,\ldots,f$.
λ	Total arrival rate(lot/time-unit), that is $\lambda = \lambda_1 + \lambda_2 + \ldots\ldots + \lambda_f$.
$\lambda^b_{k,out}$	Arrival rate of batch (batch/time-unit) of product k, for $k = 1,2,3,\ldots,f$.
$\lambda^b_j(Q)$	Total arrival rate of batch (batch/time-unit).
$C^2_{ak,out}$	Squared coefficient of variation of arrival rate (batch/time-unit) of product k, for $k = 1,2,3,\ldots,f$.
$C^2_{aj}(Q)$	Squared coefficient of variation of form batch arrival rate of a single aggregate product.
ρ_j	Traffic intensity of the GI/G/m queue.

Moreover, this paper considered machine downtime variability into the model. The previous study presented that the different length of *MTTR* influences the accuracy of cycle time estimation, when machines have the same condition of utilisations (Tu and Chen, 2005). In terms of the machines downtime, it only impacts the system on the τ and $C_s^{\,2}$. Therefore, the modificatory τ and $C_s^{\,2}$ were represented in follow equations.

$$\tau_i(Q)=\frac{\sum_{k=1}^{f}\left(\frac{\lambda^b_{k,out}}{\mu_k}\right)+\sum_{l=1}^{m_i}\frac{MTTR_{il}}{MTTR_{il}+MTBF_{il}}}{\lambda^b_i(Q)+\sum_{l=1}^{m_i}\frac{1}{MTTR_{il}+MTBF_{il}}} \tag{7}$$

$$C^2_{si}(Q)=\frac{\sum_{k=1}^{f}\left(\frac{\lambda^b_{k,out}(C^2_{sk}+1)}{\mu^2_k}\right)+\sum_{l=1}^{m_i}\frac{MTTR^2_{il}}{MTTR_{il}+MTBF_{il}}(C^2_{sd_{il}}+1)}{\left(\lambda^b_i(Q)+\sum_{l=1}^{m_v}\frac{1}{MTBF_{il}+MTTR_{il}}\right)\times\tau^2_i(Q)}-1 \tag{8}$$

Where

$MTTR_{il}$	Mean time to repair of l machine in i workstation.
$MTBF_{il}$	Mean time between failures of l machine in i workstation.
$C^2_{si}(Q)$	Squared coefficient of variation of the process time for per batch including machine downtime.
$\tau_i(Q)$	Service time of per batch including machine downtime.

$C^2_{sd_{il}}$	Squared coefficient of variation of the machine downtime for *l* machine in *i* workstation.
C^2_{sk}	Squared coefficient of variation of the process time for product *k*.
μ_k	The rate of process time of product *k* in batching (batch/time-unit).

Whereas $W_q(Q)$ is the expected waiting time of any product by batch type to wait for processing. From Figure 1, $W_q(Q)$ was calculated by GI/G/m queuing model which was used with above modification of parameters. The approximation formula of GI/G/m model was referred to the revision queuing model which was modified from *EW*(*M*/*M*/*m*) by Whitt (1993).

$$W_q(Q) = \left(\frac{C^2_{aj}(\mathrm{Q}) + C^2_{sj}(\mathrm{Q})}{2} \right) \times EW_{ij}(M / M / m_j) \tag{9}$$

$$EW_{ij}(M / M / m) = \frac{\tau_j \left(\rho_j^{\sqrt{2(m_j+1)}-1} \right)}{(m_j(1-\rho_j))} \tag{10}$$

The expected waiting time $W_q(Q)$ was referred to the revision queuing model by (Tu and Liou, 2006, Tu and Chen, 2008). Fowler et al. (2002) shows that, in terms of batching behaviour, when the first lot arrives to the queue, it has to wait for the arrival of additional (b-1) lots. In the same situation, the second lot has to wait for the arrival of other (b-2) lots and so on. The last lot has not waited for any other lot. Thus, the expected waiting time of product to form a batch $W_q(Q)$ can be defined as follows.

$$W_p(B) = \frac{\lambda_1}{\lambda} \times \left(\frac{b-1}{2 \times \lambda_1} \right) + \frac{\lambda_2}{\lambda} \times \left(\frac{b-1}{2 \times \lambda_2} \right) + \ldots\ldots + \frac{\lambda_p}{\lambda} \times \left(\frac{b-1}{2 \times \lambda_p} \right) = \sum_{k=1}^{p} \left(\frac{\lambda_k}{\lambda} \times \frac{b_k - 1}{2\lambda_k} \right) \tag{11}$$

Based on the above descriptions, the cycle time of batch workstation is as follows.

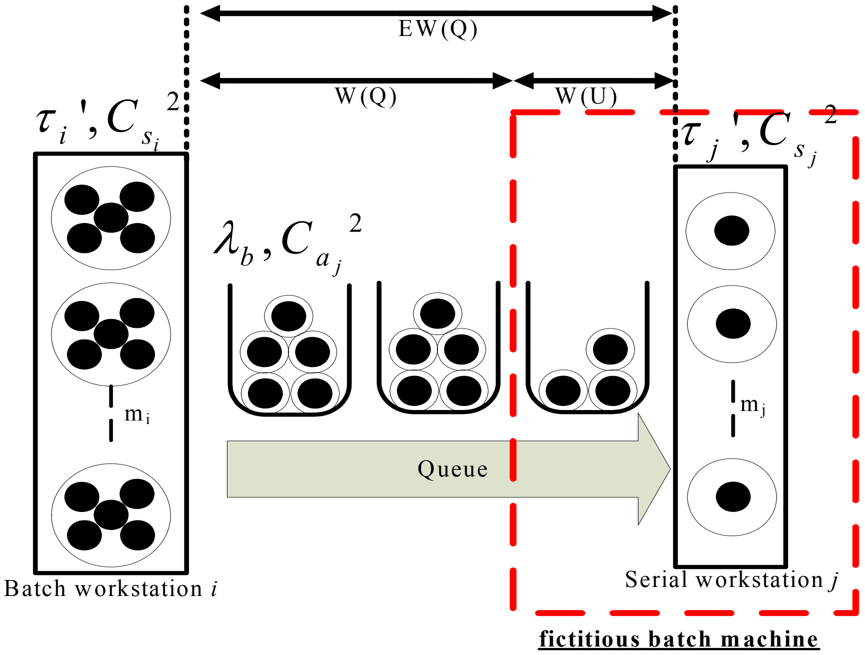
$$\begin{aligned} \mathrm{C\,T_B} &= W_p(B) + W_q(Q) + \tau_i(\mathrm{Q}) \\ &= \left(\tau_i(\mathrm{Q}) \times \frac{(C^2_{ai}(\mathrm{Q}) + C^2_{si}(\mathrm{Q})) \times \rho_i^{\sqrt{2(m_i+1)}\ -1}}{2m_i\ (1 - \rho_i\ )} \right) + \left(\sum_{k=1}^{f} \left(\frac{\lambda_k}{\lambda} \times \frac{b_k - 1}{2\,\lambda_k} \right) \right) + \tau_i(\mathrm{Q}) \end{aligned} \tag{12}$$

2.2 Cycle time estimation of un-batching process

The un-batch workstation always connects with the batch workstation. Because the un-batching process has different arrival pattern (Tu and Chen, 2006; Tu, 2008), a special model is proposed to fit its character. In this model, two series of queues are presented for the queuing system in front of un-batch machines. The first one stands for the queue to wait for un-batching; the second is a queue to wait for processing. The parameters and performance measures are diagrammed in Figure 2.

From Figure 2, *W*(*Q*) is the expected waiting time of any product by batch type to wait for un-batching. *W*(*U*) is the expected waiting time of any product to wait for processing. Summation of *W*(*Q*) and *W*(*U*) can derive the total expected waiting time in GI/G/1 queuing system denoted by *EW*(*Q*). The modification models of *W*(*Q*) and *W*(*U*) were presented as follows. In order to identify batching and un-batching processes clearly, the subscript index of batch workstation denoted by *i* and un-batch workstation was presented by *j* in this work.

Figure 2 The diagram of un-batching process (see online version for colour)



Based on Figure 2, it is obvious that *W*(*Q*) was the waiting time of the fictitious machine. Therefore, GI/G/1 queuing theory was applied to calculate *W*(*Q*). The equations were presented as follows. However, there were some parameters within GI/G/1 queuing model need to modify, such as average arrival rate (λ), average service time (τ) and so on. The details of the reasoning processes can refer to the research of Tu (Tu and Chen, 2006; Tu, 2008).

$$W(Q) = \left(\frac{C_{a_j}{}^2 + C_{s_b}^2}{2}\right) \times EW(M/M/1) \tag{13}$$

$$EW(M/M/1) = \tau_b' \frac{\rho_b}{1-\rho_b} \tag{14}$$

Where

$C_{a_j}^2$	Squared coefficient of variation of the arrival time for un-batch workstation *j*.
$C_{s_b}^2$	Squared coefficient of variation of the process time for un-batch workstation *j* including machine downtime.

τ_b'	The raw process time of fictitious workstation including machine downtime.
ρ_b	The utilisation of fictitious workstation.
$EW(M/M/1)$	The waiting time of *M/M/1* queuing theory.

For un-batching behaviour, the first lot of a batch arrives to the fictitious batch machine has not waited for processing. The last lot has to wait τ_b'. Thus, the average waiting time of any product to un-batch, $W(U)$, is:

$$W(U) = \frac{0+\tau_b'}{2} = \frac{\tau_b'}{2} \tag{15}$$

$$\tau_b' = \frac{\tau_j' \times b}{m_j} \tag{16}$$

$$\tau_j' = \frac{\tau_j \times b + \sum_{l=1}^{m_j} \frac{\tau_b \times MTTR_{jl}}{MTTR_{jl} + MTBF_{jl}}}{b + \sum_{l=1}^{m_j} \frac{\tau_b}{MTBF_{jl} + MTTR_{jl}}} \tag{17}$$

$$\tau_b = \frac{\tau_j \times b}{m_j} \tag{18}$$

Where

τ_j'	The raw process time of fictitious workstation including machine downtime.
τ_j'	The raw process time of un-batch workstation including machine downtime.
b	The batch size of *i* workstation.
m_j	Number of machine in un-batch workstation.
τ_j	The raw process time of un-batch workstation.
τ_b	The raw process time of fictitious workstation.
$MTTR_{jl}$	Mean time to repair of *l* machine in un-batch workstation *j.*
$MTBF_{jl}$	Mean time between fail of *l* machine in un-batch workstation *j.*

The final cycle time estimation equation of un-batching process was presented as follows.

$$\begin{aligned} \mathrm{CT_U} &= W(Q) + W(U) + \tau_j' \\ &= \left(\frac{C_{a_j}^{\ 2} + C_{s_b}^2}{2}\right) \times \left(\tau_b' \times \frac{\rho_b}{1-\rho_b}\right) + \frac{\tau_b'}{2} + \tau_j' \end{aligned} \tag{19}$$

2.3 *General X-factor determination model*

Finally, the goal of this paper is to propose the general X-factor contribution determination model. It combines the concept of X-factor with the modification cycle time estimation. The model of batch workstation and un-batch workstation was represented in follow equations.

$$\mathrm{AXFC_B} = \frac{\left(\tau_i(\mathrm{Q}) \times \left(1 + \dfrac{(C_{ai}^2(\mathrm{Q}) + C_{si}^2(\mathrm{Q})) \times \rho_i^{\sqrt{2(m_y+1)}\ -1}}{2m_i\ (1 - \rho_i\ )} \right)\right) + \left(\sum_{k=1}^{f} \left(\dfrac{\lambda_k}{\lambda} \times \dfrac{b\text{-}1}{2\,\lambda_k} \right)\right)}{\sum_{n=1}^{M} \mathrm{RPT}_n} \tag{20}$$

$$\mathrm{AXFC_U} = \frac{\left(\dfrac{C_{a_j}{}^2 + C_{s_b}^2}{2} \right) \times \left(\tau_b{}' \times \dfrac{\rho_b}{1-\rho_b} \right) + \dfrac{\tau_b{}'}{2} + \tau_j{}'}{\sum_{n=1}^{M} \mathrm{RPT}_n} \tag{21}$$

Where

$\mathrm{AXFC_B}$	The AXFC of batch workstation
$\mathrm{AXFC_U}$	The AXFC of un-batch workstation
M	The number of machine groups
$\sum_{n=1}^{M} \mathrm{RPT}_n$	Sum of the total raw process time of workstation n, $n = 1,2,\ldots,M$.

3 Model validation

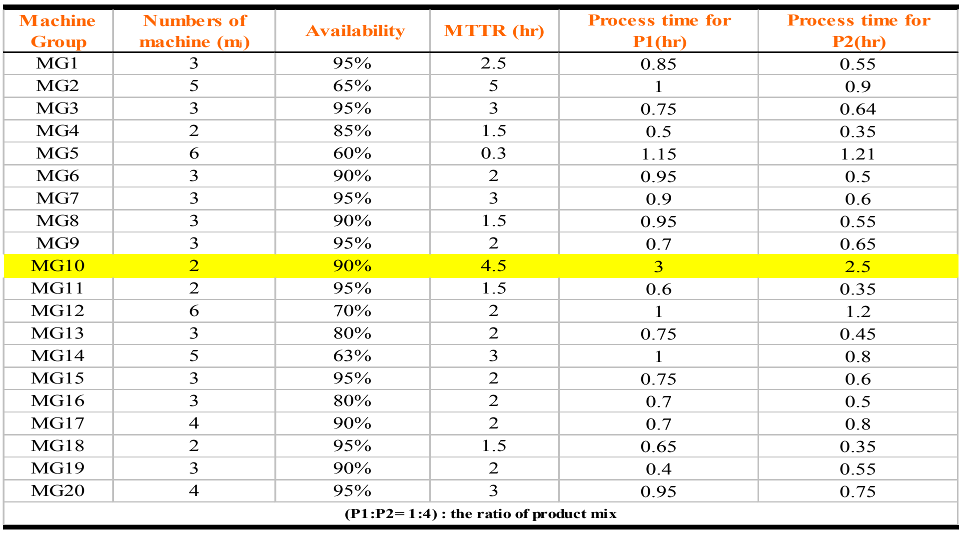
In this section, a simulation experiment was constructed to validate the accuracy of this approximation model, the difference between the simulation results and those obtained from the proposed model were compared. The simulation software, eM-Plant, was applied to build up the simulation model. Simultaneously, the *t*-test was applied by SPSS statistic software to proof that there is no significant difference between the results from simulation model and the proposed model.

3.1 *Simulation experiment*

Simulation model was performed under two products, and twenty machine group conditions. In addition, there are three different types of machine groups in the simulation experiment, serial, batching and un-batching processes. The batch machine group is MG10, which batch size is six. MG11 is un-batching process and the others are serial machines. Moreover, ‘Full load required’ were used for batching process.

Furthermore, this model was set up with an exponential distribution arrival. The mean inter-arrival time and the squared coefficient of variation of inter-arrival time were 22.86 min and 1 min, respectively. The process times obeyed the normal distribution and their standard deviation is assumed to be 0.01 hrs. The other important parameters and factors of the simulation experiment are listed in Table 1.

Table 1 System parameters (see online version for colour)



Machine Group	Numbers of machine (mᵢ)	Availability	MTTR (hr)	Process time for P1(hr)	Process time for P2(hr)
MG1	3	95%	2.5	0.85	0.55
MG2	5	65%	5	1	0.9
MG3	3	95%	3	0.75	0.64
MG4	2	85%	1.5	0.5	0.35
MG5	6	60%	0.3	1.15	1.21
MG6	3	90%	2	0.95	0.5
MG7	3	95%	3	0.9	0.6
MG8	3	90%	1.5	0.95	0.55
MG9	3	95%	2	0.7	0.65
MG10	2	90%	4.5	3	2.5
MG11	2	95%	1.5	0.6	0.35
MG12	6	70%	2	1	1.2
MG13	3	80%	2	0.75	0.45
MG14	5	63%	3	1	0.8
MG15	3	95%	2	0.75	0.6
MG16	3	80%	2	0.7	0.5
MG17	4	90%	2	0.7	0.8
MG18	2	95%	1.5	0.65	0.35
MG19	3	90%	2	0.4	0.55
MG20	4	95%	3	0.95	0.75

(P1:P2= 1:4) : the ratio of product mix

3.2 *Approximation result*

Through the steps of modifications in this research, the approximation of cycle time of this experiment should be calculated by the formulas in Section 2. The result of approximation is shown in Table 2.

Table 2 The result of approximation model (Unit: Hr)

Machine group	*Approximation model*	*Machine group*	*Approximation model*
MG1	0.83	MG11	1.17
MG2	1.34	MG12	1.62
MG3	0.94	MG13	0.90
MG4	0.78	MG14	1.18
MG5	1.88	MG15	0.89
MG6	0.85	MG16	0.98
MG7	0.92	MG17	1.09
MG8	0.90	MG18	0.64
MG9	0.88	MG19	0.91
MG10	5.23	MG20	0.96

3.3 *Simulation result and statistical analysis*

The simulation model is designed by eM-Plant and shown in Figure 3. The running horizon for each simulation was set at 365 days, 24 hrs a day. The first 60 days comprised a warm-up period. The simulation was run 30 times to obtain average results. Table 3 presents the compared result.

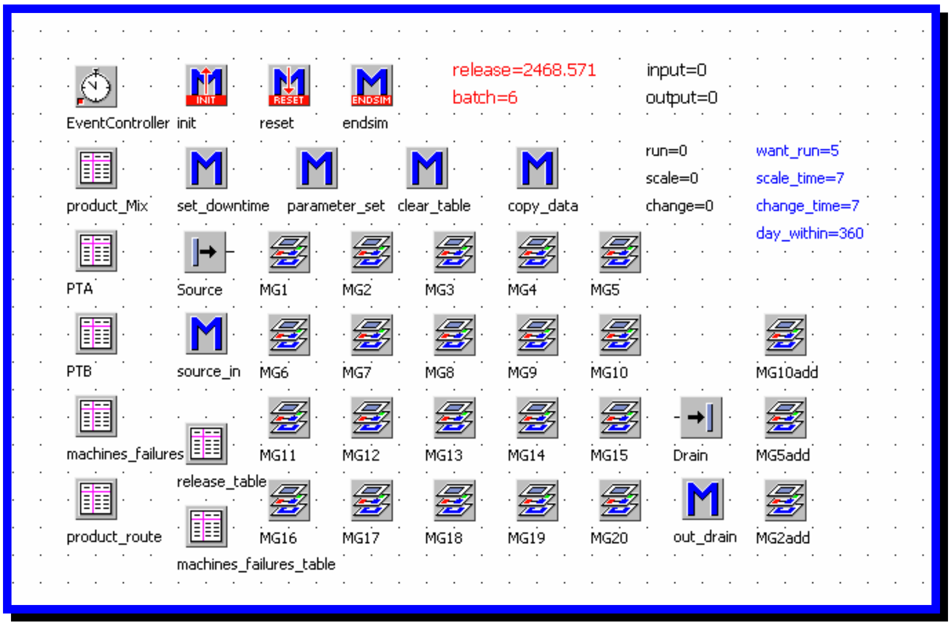
This simulation model is only considering the simple production activities which are without the activities of material handling, storages, or human operations. Furthermore, the dispatching rule of each machine is following the rule of first-in-first-out.

The designed experiment is analysed by SPSS software. To validate the performance difference of the cycle time estimation, a statistical analysis by *t*-test was conducted. The assumptions are as follows:

H_0: *The estimation of the cycle time between approximation and simulation are not significantly different in machine group i (i=1,2,3,….,20).*

H_1: *The estimation of the cycle time between approximation and simulation are significantly different in machine group i (i=1,2,3,….,20).*

Figure 3 The pattern of simulation environment (see online version for colour)



release=2468.571
batch=6
input=0
output=0
run=0
scale=0
change=0
want_run=5
scale_time=7
change_time=7
day_within=360

Table 3 The result of simulation model (Unit: Hr)

Machine group	*Simulation model*	*Machine group*	*Simulation model*
MG1	0.78	MG11	1.21
MG2	1.49	MG12	1.41
MG3	0.83	MG13	0.85
MG4	0.68	MG14	1.10
MG5	1.69	MG15	0.93
MG6	0.92	MG16	0.87
MG7	0.89	MG17	1.03
MG8	1.06	MG18	0.75
MG9	0.77	MG19	0.82
MG10	4.98	MG20	0.88

The *t*-test result is shown in Table 4. From Table 4, the overall *p*-values are actually over 0.05. It means all H_0 is accepted under the 95% confidence levels. This statistical analysis also proved that the approximation model can provide an accurate estimation of the cycle time.

Table 4 *t*-test result

Machine group	*p-value*	*Machine group*	*p-value*
MG1	0.3193	MG11	0.0793
MG2	0.1429	MG12	0.0981
MG3	0.2370	MG13	0.2061
MG4	0.2980	MG14	0.1740
MG5	0.1325	MG15	0.1114
MG6	0.1093	MG16	0.1420
MG7	0.2242	MG17	0.2430
MG8	0.0845	MG18	0.1296
MG9	0.1890	MG19	0.2230
MG10	0.0832	MG20	0.1425

4 System performance improvement

The previous studies (Delp et al., 2005; Delp et al., 2006) indicated that the Complete X-Factor Contribution (CXC) measure can identify the capacity constraining machine groups effectively and accurately for semiconductor manufacturing. They demonstrated the effectiveness of this measure, as compared with a typical utilisation measure. Nevertheless, CXC did not consider batching and un-batching processes, which are the common processes and cannot be ignored in wafer fabrication. Therefore, AXFC measure is developed, which includes batching and un-batching issue, to verify whether the conclusions of previous researches (Delp et al., 2005, Delp et al., 2006) are still workable or not. The eM-Plant simulation model was established to collect data. The structure of simulation model is shown in Figure 3.

4.1 Indicators and methodologies of system performance improvement

There are two different environments, UX and XU, designed in this experiment. UX means the position of the high utilisation machine group is in front of the high AXFC machine group in production line and vice versa. Under these two environments, two different indicators, utilisation and AXFC and two improving approaches were used to compare the performance of system improvement. The improving approaches included: (1) reducing the variability of machine group by increasing machine breakdown frequencies (2) additional capacity through increasing machines. Based on the different environments, indicators and approaches, the effects of mean cycle time and cycle time variability on the overall system are surveyed by the simulation model.

Table 5 The output target

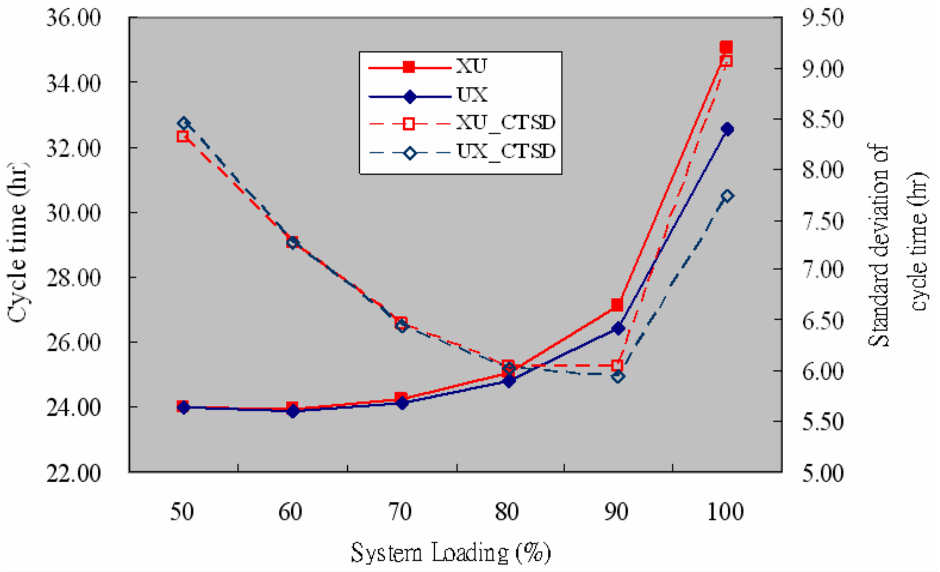
System loading	50%	60%	70%	80%	90%	100%
Product P1 (lot/month)	210	252	294	336	378	420
Product P2 (lot/month)	840	1008	1176	1344	1512	1680
Release rate (lot/day)	35	42	49	56	63	70

In this simulation model, an exponential arrival was set. Thus, the squared coefficient of variation of the arrival is equal to one. Furthermore, the service time was assumed to be the normal distribution and its standard deviation was set to be 0.01 hrs. The production unit of this experiment is 'lot' and 25 wafers per lot. The running horizon for each simulation was set at 365 days, 24 hrs a day. The first 60 days comprised a warm-up period. Each treatment was run 30 times to obtain average results. The other parameters are summarised in Tables 1 and 5.

4.2 The effects of bottleneck placement

As the heart of bottleneck of system is the highest utilisation machine group. In this section, the effects of the placement relation between high utilisation machine group and high AXFC machine group was investigated. The results of experiments are shown in Figure 4. In the Figure 4, it was the relationships between system capacity vs. cycle time and cycle time deviation. It shows that both cycle times raises as the release rate of products increasing. However, the product cycle times in XU environment are worse than those in UX environment, when system load approaches to 100%. Regarding the relationships between system loading and cycle time deviation, it shows the cycle time deviation is decreasing as system load increasing when system load is less than 90%. However, the relationship is reversed when system load is over 90%.

Figure 4 The relationship of system loading vs. cycle time and cycle time deviation under UX and XU environment (see online version for colour)



Therefore, if the shorter cycle time and lower variations of cycle time are wanted, the location of high utilisation machine group should be in front of high AXFC machine group in capacity planning stage.

4.3 The effects of variability reduction under UX and XU environments

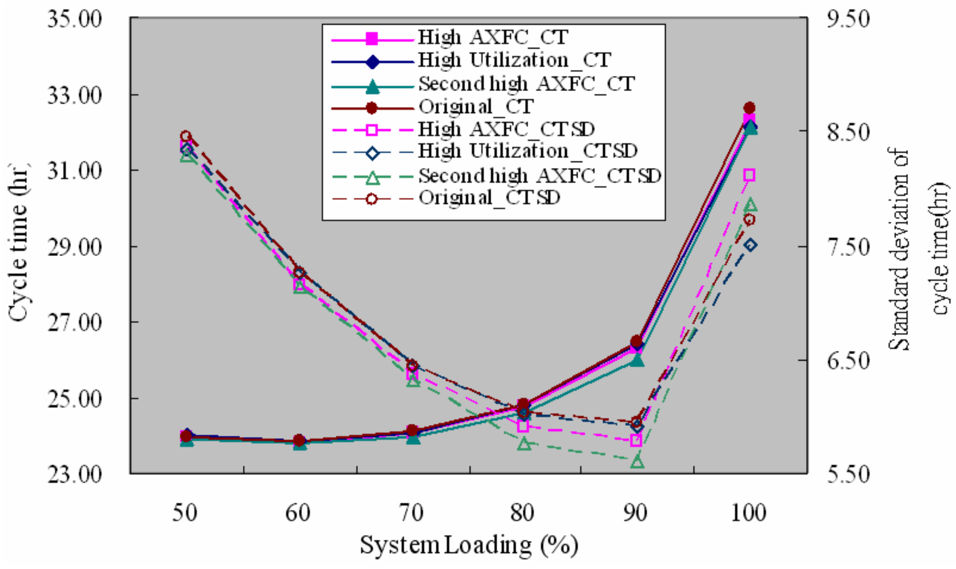
4.3.1 UX environment

Figure 5 presents the improvement results of mean cycle time and cycle time deviation by decreasing the variability of machine group under UX environment. In this stage, the improved effects of cycle time and cycle time deviation were validated by different improving indicators. The assumptions are as follows:

H_0: The reducing of mean cycle time (or cycle time deviation) is not significant by increasing machine breakdown frequency.

H_1: The reducing of mean cycle time (or cycle time deviation) is significant by increasing machine breakdown frequency.

Figure 5 The result of variability reduction for machine of high AXFC, high utilisation and second high AXFC under UX environment (see online version for colour)



From Table 6, all p-value are great than 0.05, hence H_0 is accepted under 95% confidence level. It can be made the conclusion that there is no significant reduction on cycle time and cycle time deviation either on different system loading conditions or different selection of improved machine groups by reduction the frequency of machine breakdown.

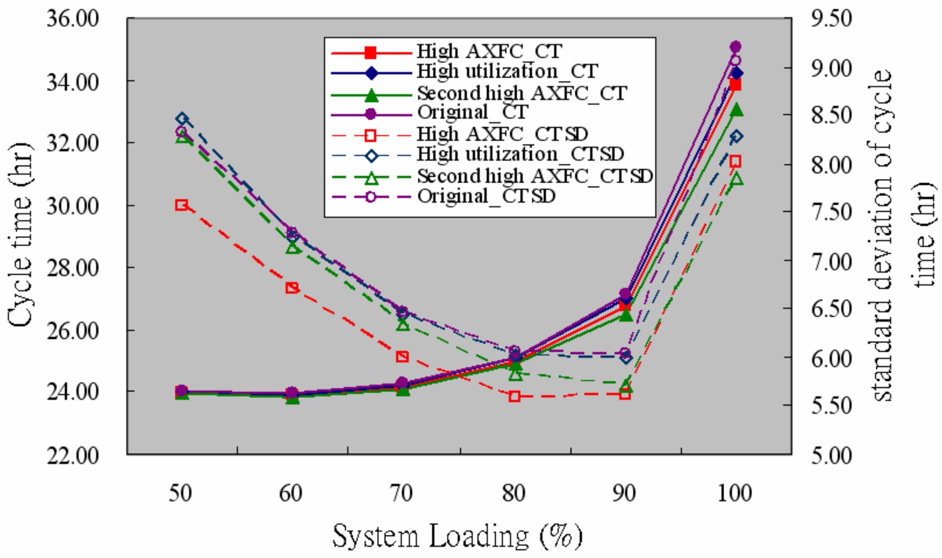
Table 6 *t*-test result of Figure 5 (α = 0.05)

	Improvement of machine group	*High utilisation*	*High AXFC*	*Second high AXFC*
C/T	Loading 90%	0.158	0.137	0.249
	Loading 100%	0.097	0.085	0.105
C/T Deviation	Loading 90%	0.252	0.179	0.105
	Loading 100%	0.184	0.086	0.063

4.3.2 *XU environment*

Figure 6 presents the improvement results of mean cycle time and cycle time deviation by decreasing the variability of machine group under UX environment. The results are also verified by *t*-test and *t*-test results are showed in Table 7.

Figure 6 The result of variability reduction for machine of high AXFC, high utilisation and second high AXFC under UX environment (see online version for colour)



From Table 7, it shows that there is no significant reduction on mean cycle time except the second high AXFC was chose as an improvement indicator under system full load. Under XU environment, the increasing machine breakdown frequency will reduce the cycle time deviation significantly except the high utilisation machine group was chose under 90% of system load.

Table 7 *t*-test result of Figure 6 (α = 0.05)

	Improvement of machine group	*High utilisation*	*High AXFC*	*Second high AXFC*
C/T	Loading 90%	0.219	0.131	0.195
	Loading 100%	0.084	0.076	0.041
C/T Deviation	Loading 90%	0.248	0. 031	0.045
	Loading 100%	0.026	0.013	0.021

4.4 The effects of additional capacity under UX and XU environments

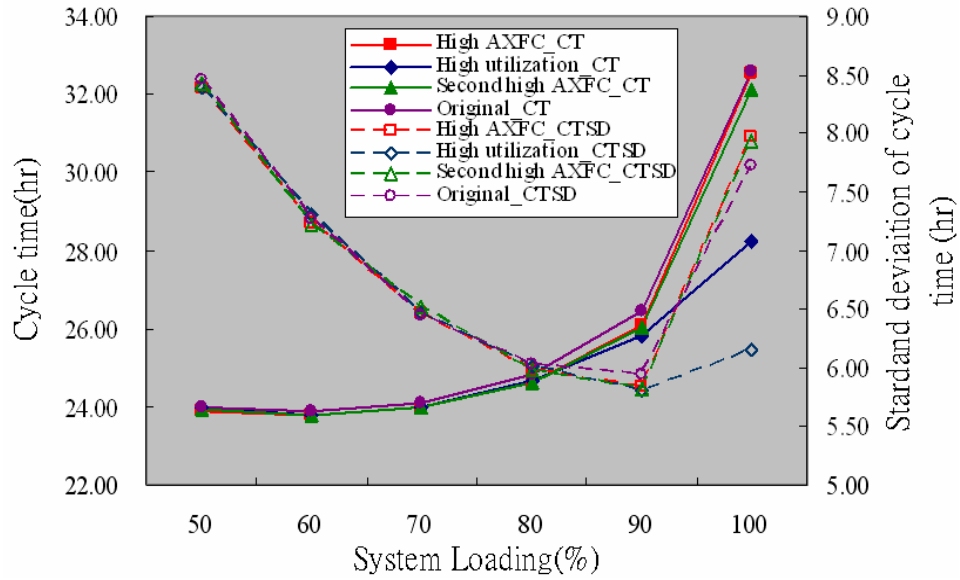
4.4.1 UX environment

Figure 7 presents the improvement results of mean cycle time and cycle time deviation by decreasing the variability of machine group under UX environment. The results are also verified by *t*-test as showed in Table 8.

Table 8 *t*-test result of Figure 7 (α = 0.05)

	Improvement of machine group	*High utilisation*	*High AXFC*	*Second high AXFC*
C/T	Loading 90%	0.099	0.168	0.227
	Loading 100%	0.007	0.062	0.069
C/T Deviation	Loading 90%	0.358	0.125	0.195
	Loading 100%	0.037	0.094	0.113

Figure 7 The result of adding supplemental capacity for machine of high AXFC, high utilisation and second high AXFC under UX environment (see online version for colour)

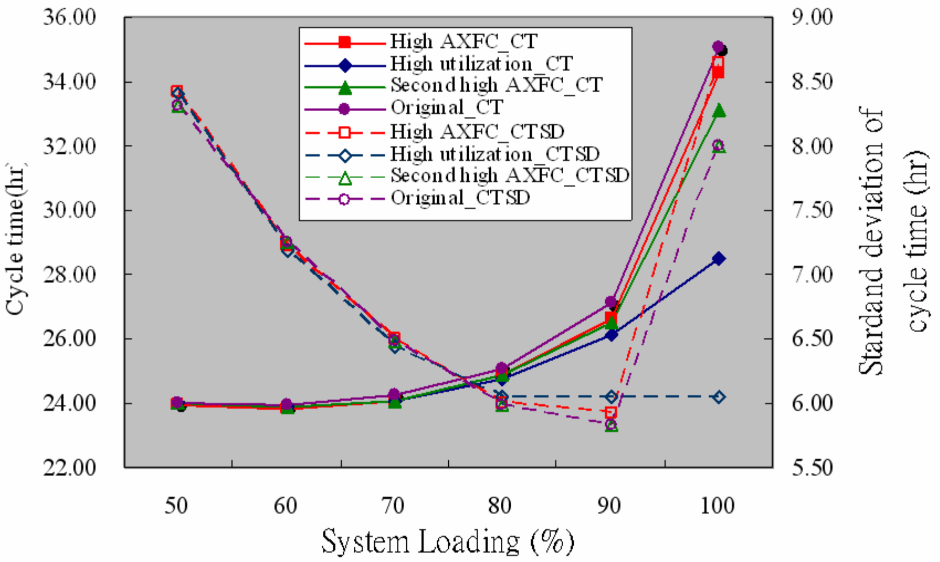


From Table 8, all *p*-value are great than 0.05 except the high utilisation machine group chose under system full load. It means that the supplemental capacity can not significant reduce cycle time and cycle time deviation significantly except the supplemental capacity is added on high utilisation machine group under system full load.

4.4.2 XU environment

Figure 8 presents the improvement results of mean cycle time and cycle time deviation by decreasing the variability of machine group under UX environment. The results are also verified by *t*-test as showed in Table 9.

Figure 8 The result of adding supplemental capacity for machine of high AXFC, high utilisation and second high AXFC under XU environment (see online version for colour)



From Table 9, it shows that there is no significant reduction on mean cycle time and cycle time deviation under 90% of system load. Under system full load, the adding supplemental capacity will reduce the mean cycle time and cycle time deviation significantly except the high AXFC machine group chose.

Table 9 *t*-test result of Figure 8 (α = 0.05)

	Improvement of machine group	*High utilisation*	*High AXFC*	*Second high AXFC*
C/T	Loading 90%	0.093	0.112	0.253
	Loading 100%	0.019	0.147	0.032
C/T Deviation	Loading 90%	0.269	0.249	0.311
	Loading 100%	0.006	0.047	0.017

4.5 The summary of performance improvement

The results of simulation experiments were summarised in Tables 10 and 11. Based on these tables, they show that the improvement performance under XU environment is better than or equal to UX environment no matter which improvement indicator and approach are selected. It means that the production line designed as XU environment will get a better performance. In addition, the improvement performance of second high AXFC is better than that of high AXFC. In order to prove the AXFC indicator worked well under batching process environment, a batch machine group was design as high AXFC machine group. However, this experiment shows that the results are under expectation and the AXFC value should be modified under batching environment. The modification is as follows.

$$\text{AXFC}' = \frac{\text{AXFC}}{b} \tag{22}$$

Where

b: batch size of machine

After modification, AXFC will be a good indicator for performance improvement.

Table 10 Performance improvement by variability reduction

Improved machine group	*High AXFC*	*High utilisation*	*Second high AXFC*
Mean CT	No difference under UX and XU	No difference under UX & XU	Lower under XU
CT variance	Lowered under XU (High system loading)	Lowered under XU(High system loading)	Lowered under XU(High system loading)

Table 11 Performance improvement by additional capacity

Improved machine group	*High AXFC*	*High utilisation*	*Second high AXFC*
Mean CT	No difference under UX and XU	Lowered under XU & UX(High system loading)	Lowered under XU(High system loading)
CT variance	Lowered under XU(High system loading)	Lowered under XU & UX	Lowered under XU(High system loading)

5 Conclusion

X-factor is an important index of performance, which is accepted extensively in production management of wafer fabrication. However, there is no any X-factor model can describe all types of processes especially for batching and un-batching processes. In this work, a general X-factor determination model, AXFC, for all types of machines in wafer fabrication is developed. GI/G/m queuing theory is applied into this model for the aggregated cycle time estimation. The machine downtime variability, lot arrival variability, batching processing and un-batching processing are taken into account. Furthermore, a simulation model is established to validate the feasibility of model. By this model, X-factor of each work centre can be easily and accurately calculated.

In addition, a different view of cycle time improvement is explored in this work as well. Generally, system bottleneck is regarded as an improvement target and it is indeed can improve product cycle time by adding supplemental capacity or reducing machine variability. However, this approach is expensive mostly. In this work, some findings were explored through simulation experiment. In order to shorten cycle time and lower variations of cycle time, the location of high utilisation machine group should be in front of high AXFC machine group in capacity planning stage. Furthermore, reducing machine variability to the high AXFC machine groups will reduce product cycle time and cycle time variability in XU environment significantly. Providing more capacity to bottleneck machine will reduce product cycle time and cycle time variability significantly.

Nevertheless, adding supplemental capacity to high AXFC machine groups will get the same effect in XU environment.

Regarding the future works, there are two things can be discussed. First, the factor of budget should be considered in the stage of selecting the improved machines. When budget factor can be taken into account, an effective and money-saving choice can be made. Second, the product priority should be considered, such as hot run. Generally, product priority will impact on overall cycle time performance certainly. If the priority behaviour can be incorporated into this model, it will be more complete.

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附 件二

MODEL TO DETERMINE AMHS CAPACITY FOR WAFER FABRICATION

MODEL TO DETERMINE AMHS CAPACITY FOR WAFER FABRICATION

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ABSTRACT

Automatic Material Handling System (AMHS) is getting more important in 300mm wafer fabrication factory (Fab). An effective and efficient design and control of AMHS became more critical in 300mm fab. Capacity planning is one of the major factors of AMHS design. Generally, surplus capacity can not increase throughput but reduce ROI (Return On Investment). On the other hand, if the AMHS capacity is insufficient, the throughput will be impacted seriously. Therefore, how to determine an adequate capacity level is a key point for 300mm fab.

The major concept of AMHS capacity determination model is to maintain the original designed production performance. In order to maintain fab's performance, the WIP portfolio of constraint machines should be kept. Based on this concept, a GI/G/m queuing model is applied to represent the AMHS and to determine the required numbers of vehicles. It assumed that products should be transported to next processing equipment by finishing the processing part of next equipment, thus the WIP in front of this constraint machine can be kept the same. Under this condition, the probability that transportation time exceeds part processing time under a certain transportation capacity level can be calculated by proposed model. Hence, we can get the required capacity of AMHS which can achieve the probability target set in advance.

Due to the capacity of AMHS will be set according to the acceptable probability of non-exceeding processing time of constraint machines, the level of WIP in front of constraint machines can be kept. It also can be ensured that AMHS will not affect the production performance as well as keep on a reasonable investment level.

INTRODUCTION

Semiconductor manufacturing is a capital, labor and technology intensive high-tech industry with complex processes, consisting of thousands of process steps, re-entrant flows and batch processing. The technology and efficiency of manufacturing have to be improved continuously to increase profitability (Tu and Liou, 2006; Driessel and Mönch, 2007; Tu, 2008). Generally, 300 mm manufacturing is a common and necessary technique in recent wafer fabrication. In order to achieve high cost-effective production and avoid the possible injury of employees due to carrying the heavy weight of 300 mm wafers, a highly automated material transfer system should be established in 300 mm semiconductor fabs (Liao and Fu, 2004). Accordingly, Automatic Material Handling System (AMHS) plays an important and significant role for 300 mm wafer fabrication fab. The AMHS acts as a connector among workstations to assist to deliver the products to the right place, at the right time. Hence, an effective and efficient design and control of AMHS became more critical factor in 300 mm fab. Capacity planning is one of the major factors of AMHS design. Generally, surplus capacity can not increase throughput but reduce ROI. On the other hand, if the AMHS capacity is insufficient, the throughput will be impacted seriously. Therefore, how to determine an adequate capacity level is a key point for 300mm fab.

Abundant researches with methods to design the quantity of AMHS. The primary method is based on minimizing some functions of acquisition costs (Egbelu, 1993; Herrmann, et al., 1999; Kuo, 2002; Steele, 2002; Liao and Fu, 2004). However, the acquirement of cost data is difficult and some performance data is hard to transfer to cost index. Furthermore, from the literature, it shows that simulation and queuing theory are usually applied in the determination of AMHS capacity (Bozer and Park, 2001; Benjaafar, 2002; Nazzal and Bodner, 2003; Raman, et al., 2008). Simulation approach is just an evaluation model. It can only provide the result under certain conditions. Moreover, it is usually expensive and time-consuming. Regarding to the queuing approach, although the inherent stochastic nature of the manufacturing system has been considered into the performance factors, very few method of the researches is optimizing the quantity of MHE with respect to production performance factors, like production throughput time and cycle time of products. The objectives of these researches focused on the performance of AMHS, such as the minimum the response time, empty traveling time, maximum utilization of AMHS and throughput of AMHS in different dispatching rule. However, it is not sure that the optimal performance of AMHS results in a better performance of overall production system. The AMHS is only an auxiliary system for the production system. The operations of AMHS can not create any additional value for products. Nevertheless, surplus or insufficient AMHS capacity all indeed hurts production performance. Hence, an adequate capacity level is crucial to 300 mm fab. Moreover, the objectives of AMHS design should be linked to the performance of production system directly. Otherwise, the optimization is out of value.

In this study, a GI/G/m queuing model is applied to represent the AMHS and to determine the required numbers of vehicles. The major concept of AMHS capacity determination model is to maintain the original designed production performance of fab. In order to maintain fab's performance, the WIP portfolio of constraint machines should be kept. Based on this concept, it assumed that products should be transported to the next processing equipment by finishing the processing part of next equipment, thus the WIP in front of this constraint machine can be kept the same. Under this condition, the probability that transportation time exceeds part processing time under a certain transportation capacity level can be calculated by proposed model. Hence, we can get the required capacity of AMHS which can achieve the probability target set in advance.

This paper was structured as follows. In section 2, a process of solution for AMHS capacity was proposed. Next section, an illustrative example was presented. The conclusion and future researches were included in the final section.

CAPACITY DETERMINATION MODEL FOR AMHS

In this section, the capacity determination model for AMHS in wafer fab will be described. The capacity determination model proposed by this work utilized the GI/G/m queuing model to represent the AMHS and to determine the required numbers of vehicles. The objective of this model is to establish a minimum necessary capacity level that enables managers to ensure the production performance will not be impact by AMHS. In other words, we hope the fab can perform as well as without consideration of the transportation when the AMHS is included. The procedure of capacity determination is as follows.

Step 1 Define the constraint machine

The initial step of this procedure would be defining the constraint machines for whole system. This kind of machines is usually expensive and hard to augment capacity in wafer fabrication. In other words, managers will not allow the controllable factor, like the capacity of AMHS, which leads to the capacity loss of constraint machine. This work assumes that the all products move between workstations by material handing system. Therefore, our notion will prevent the constraint machines from idling, that is the material handing system always serving at the right moment.

From pervious studies indicated that the concept of X-factor contribution can be used to determine the performance of each machine for the contribution of overall system. Hence, when engineers try to define the constraint machines for whole system, it can use the X-factor contribution of machines (Delp, et al., 2005; Delp and Fowler, 2006; Tu and Lu, 2008).

Based on the description as above, the adjusted X-factor contribution (AXFC) measurement is applied to this paper. This measurement is developed for wafer fabrication, which considers batching process, un-batching process and machine failure. The detail information can refer to Tu and Lu (2008). The equations of measurement are given below:

$$\text{AXFC}_{\text{B}} = \frac{\left(\tau_i(\text{Q}) \times \left(1 + \left(\frac{(C_{ai}^2(\text{Q}) + C_{si}^2(\text{Q})) \times \rho_i^{\sqrt{2(m_y+1)}\ -1}}{2m_i\ (1 - \rho_i\ )}\right)\right)\right) + \left(\sum_{k=1}^{f} \left(\frac{\lambda_k}{\lambda} \times \frac{b-1}{2\lambda_k}\right)\right)}{\sum_{n=1}^{M} \text{RPT}_n \times b} \tag{1}$$

(2)
$$\mathrm{AXFC_U} = \frac{\left(\frac{C_{a_j}{}^2 + C_{s_b}^2}{2}\right) \times \left(\tau_b' \times \frac{\rho_b}{1-\rho_b}\right) + \frac{\tau_b'}{2} + \tau_j'}{\sum_{n=1}^{M} \mathrm{RPT}_n}$$

Where

$\mathrm{AXFC_B}$	The AXFC of batch workstation
$\mathrm{AXFC_U}$	The AXFC of un-batch workstation
M	The number of machine groups
$\sum_{n=1}^{M} \mathrm{RPT}_n$	Sum of the total raw process time of workstation *n*, *n* = 1,2,…,*M*
$C_{si}^2(Q)$	Squared coefficient of variation of the process time for per batch including machine downtime
$\tau_i(Q)$	Service time of per batch including machine downtime

Step 2 Compute the minimum permissible arrival time of product

In our research experiment, the products have to move to the next workstations by MHS. The workstation will be idle, if products can not arrive in the right time by MHS. Besides, we assume there is a good WIP management rule to define the WIP level in front of constraint machines. Consequently, we will set a threshold value for the cycle time of MHS transportation that can keep the same WIP level and avoid constraint machines in an idle situation. The value was obtained from the following equation:

(3)
$$Q = \sum_{i=1}^{N} w_i \frac{pt_i}{b_i}$$
$$\sum_{i=1}^{N} w_i = 1$$

Where

Q	the minimum permissible arrival time of product
w_i	the weight of workstation *i*
pt_i	processing time of step *i*
b_i	Batch size of workstation *i*

Step 3 Calculate the parameters of the material handing system

In this step, the mean service time ($E(S_t)$) and service time variation ($Var(S_t)$) of material handing system are calculated. Form pervious research, there are two kinds of traveling time in the transportation service. One is the material-handling device travels empty from the workstation location of its last delivery to the workstation location of the current request. The other is material-handling device travels full to the workstation location of goal. The detailed process can refer to Benjaafar (2002). The equations of parameters are represented as follows.

(4)
$$E(S_t) = \sum_{r=1}^{N}\sum_{i=1}^{N}\sum_{j=1}^{N} p_{rij} t_{rij} = \tau_t$$
$$P_{\mathrm{rij}} = \sum_{\mathrm{k=1}}^{\mathrm{n}} P_{\mathrm{kr}} P_{\mathrm{ij}}$$
$$t_{rij} = \sum_{\mathrm{r=1}}^{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}}\sum_{\mathrm{j=1}}^{\mathrm{N}} (d_{ri} + d_{ij})/v$$

(5)
$$E(S_t{}^2) = \sum_{r=1}^{N}\sum_{i=1}^{N}\sum_{j=1}^{N} p_{rij} (t_{rij})^2$$

(6)
$$Var(S_t) = E(S_t{}^2) - E(S_t)^2$$

p_{rij} is the probability distribution which an empty trip from r to i followed by a full trip from i to j. The p_{ij} is the probability of a full trip from department i to department j. d_{ij} is the distance between locations i and j. v is the speed of the MHS. t_{rij} is the travel time among of any three workstations r to i and i to j.

Step 4 Determine the initial capacity

In this section, the minimum capacity that can meet system's basic requirement was determined, which was defined as "initial capacity". From the definition of Queuing Theory, the traffic intensity (ρ) must be smaller than one to keep the steady-state of the system. Therefore, the initial capacity would be the smallest integer m that greater than arrival rate divided by service rate, it can be presented as follows:

$$\rho = \frac{\lambda \tau}{m} < 1 \qquad (7)$$

$$m = \lfloor \lambda \tau \rfloor + 1$$

Step 5 Compute the variation of inter-arrival time and service time of the transportation request

In GI/G/m model, two kinds of important parameters are applied. First, the parameters of service time are calculated in setp3. In addition, the variation of the service time and inter-arrival time can be obtained from the following equations. They refer the method proposed by Whitt's (1993) and Benjaafar (2002).

$$C_{at}^2 = \frac{(\sum_{i=1}^{N} \pi_i \rho_i^2 C_{si}^2 + \sum_{i=1}^{N} \pi_i (1-\rho_i^2)(1-\pi_i) + \sum_{i=1}^{N} \pi_i^2 (1-\rho_i^2) \rho_t^2 C_{st}^2 + \pi_0 (1-\rho_0^2) C_{a0}^2)}{(1-\sum_{i=1}^{N} \pi_i^2 (1-\rho_i^2)(1-\rho_t^2))} \qquad (8)$$

$$\pi_{\mathrm{i}} = \lambda_i / \lambda_t \ , \ C_{st}^2 = Var(S_t)/(E(S_t))^2$$

Where

λ_t	the workload for MHS
λ_i	the workload for workstation i
ρ_t	Traffic intensity at MHS
ρ_i	Traffic intensity at workstation i
N	the numbers of workstations
C_{at}^2	the SCV of arrival rate of transfer request for MHS
C_{si}^2	the SCV of service time of workstation i
C_{st}^2	the SCV of service time of MHS

Step 6 Calculate the mean waiting time of product waiting for the service of MHS

In this study, we assume that MHS is an independent workstation. WIP will be put in a virtual buffer to wait for the transportation to next process equipment when they finished the current process. In addition, the dispatching of MHS selects first come first serve (FCFS). Based on this concept, the expected waiting time was referred to the revision queuing model which was modified from *EW*(*M/M/m*) approximation formula to *GI/G/m* model by Whitt (1993).The equations are showed as follows.

$$Q_{Te} = \phi(\lambda_t, C_{at}^2, C_{st}^2, \tau_t, m_t) \times \frac{C_{at}^2 + C_{st}^2}{2} \times \frac{\tau_t (\rho_t^{\sqrt{2m_t+1}-1})}{m_t (1-\rho_t)} \qquad (9)$$

$$\lambda_t = \sum_{i=1}^{N} \sum_{j=1}^{N} \lambda_{ij}$$

Where

Q_{te}	the mean waiting time of product waiting for MHS service
λ_t	the workload for MHS
τ_t	mean service time of product k at workstation j,

ρ_t	traffic intensity at MHS
m_t	Vehicle numbers at MHS
C_{at}^2	the SCV of arrival rate of transfer request for MHS
λ_{ij}	the product flow rate for workstation *I* to workstation *j*
C_{st}^2	the SCV of service time of MHS

Step 7 Obtain the probability function

From step 1 to step 5, the maximum time, X, that a product waits for MHS can be derived. Therefore, the probability that the waiting time of products is less than X can be calculated. It can be obtained as follows:

$$\begin{aligned} P(Q_{Te} \le \mathrm{X}) &\approx 1\text{-}\alpha \mathrm{e}^{-\eta \mathrm{X}} \\ \mathrm{X} &= Q\text{-}E(S_T) \\ \alpha &\approx \eta \times Q_{Te} \\ \eta &= 2m_t \times (1\text{-}\rho_t) \big/ (C_{at}^2 + C_{st}^2) \end{aligned} \tag{10}$$

Where

X	the maximum time that a product waits for MHS
Q_{te}	the mean waiting time of product waiting for MHS service
m_t	Vehicle numbers at MHS
C_{at}^2	the SCV of arrival rate of transfer request for MHS
C_{st}^2	the SCV of service time of MHS

Step 8 Determine the required capacity for MHS

In this step manager should set a target probability which MHS can deliver the WIP to the constraint machins in the right time. Due to the probability function is complicated, the determination of MHS quantity can only use the trial and error. The minimum of MHS quantity which can meet the target probability will be the best quantity of MHS.

NUMERICAL EXAMPLE

In this section, a numerical illustration is presented to demonstrate the procedures of our proposed approach. There were five workstations associated with three product families with reentry production flows in this example. The products include 24 and 34 process steps and the demands of products per month were 900 and 300 lots respectively. The arrival rate of system is equal to demand rate and set up with an exponential distribution arrival. The other assumption and experimental parameters of example are shown as follow:

1. Each workstation has two infinite buffer which are loading and unloading ports.
2. Each vehicle moves one load at one time operating under the dispatching rule of first-come-first-served (FCFS).
3. Vehicle's travel times is given by $t_{ij} = d_{ij}/v$; where d_{ij} is the distance between any two workstation *i* and *j* and "*v*" is the MHS's speed.
4. The system in this example is indexed from Wi= 0 to 7, where i = 0 and 7 denotes the release and shipping workstations, respectively.
5. Load/unload of the vehicle is determination.

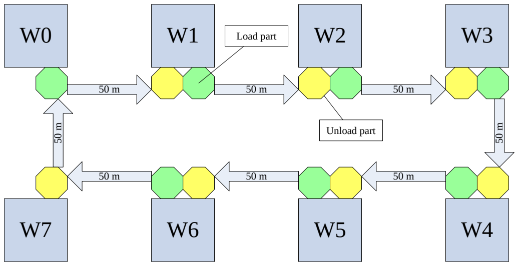
Table 1: Information of product

product	Process routing
P1	W1-W2-W3-W4-W5-W6- W1-W2-W3-W4-W5-W6- W1 -W2-W3-W4-W5-W6- W1-W2-W3-W4-W5-W6
P2	W1-W2-W3-W4-W5-W6-W1-W2-W3-W4-W5-W6-W1-W2-W3-W4- W1-W2-W3-W4-W5-W6- W1-W2-W3-W4-W5-W6- W1-W2-W3-W4-W5-W6

Table 2: Information of workstation

Workstation	Numbers of machine	availability	MTTR	Batch size	Avg. process time for P1	Avg. process time for P2
W1	3	0.96	2	1	0.25	0.189
W2	9	0.97	3	6	5.75	5.611
W3	6	0.91	3	1	0.738	0.608
W4	2	0.96	2	1	0.175	0.172
W5	5	0.92	2	1	0.554	0.547
W6	2	0.94	3	1	0.15	0.143

Figure 1: Information of layout



Step 1 Define the constraint machine

AXFC concept is applied to define the constraint machine in this step. The result of AXFC is shown in table 3.

Table 3: The result of AXFC value for each workstation

	W1	W2	W3	W4	W5	W6
AXFC	0.043	0.158	0.313	0.048	0.129	0.045

Step 2 Compute the minimum permissible arrival time of product

From the result of step 1, it shows that W3 is the constraint machine. Hence, the minimum permissible arrival time of product can be calculated for this constraint machine. The approximation is calculated as follows.

$$Q = \sum_{i=1}^{N} w_i pt_i = 0.75 \times 0.738 + 0.25 \times 0.608 = 0.706$$

Step 3 Calculate the parameters of the material handing system

The material flow rate is estimated from product demand and routing. Table 4 shows the material flow rate "λ_{ij}" between the workstation. The probability of vehicle availability (P_{kr})at workstations 1–7 are 0.164, 0.164, 0.164, 0.164, 0.155, 0.155, 0.036, separately. Accordingly, this stage the mean service time ($E(S_t)$) and service time variation ($Var(S_t)$) of material handing system could be calculated as follows.

$$E(S_t) = \sum_{r=1}^{N}\sum_{i=1}^{N}\sum_{j=1}^{N} p_{rij} t_{rij} = \tau_t = 0.503$$

$$E(S_t^2) = \sum_{r=1}^{N}\sum_{i=1}^{N}\sum_{j=1}^{N} p_{rij} (t_{rij})^2 = 0.3$$

$$Var(S_t) = E(S_t^2) - E(S_t)^2 = 0.3 - (0.503)^2 = 0.21$$

Table 4: Material flow rate between workstations (λ_{ij})

j i	W_0	W_1	W_2	W_3	W_4	W_5	W_6	W_7
W_0		-	-	-	-	-	-	-
W_1	1.667		-	-	0.417	-	5.417	-
W_2	-	7.5		-	-	-	-	-
W_3	-	-	7.5		-	-	-	-
W_4	-	-		7.5		-	-	-
W_5	-	-	-	-	7.083		-	-
W_6	-	-	-	-	-	7.083		-
W_7	-	-	-	-	-	-	1.667	

Step 4 Determine the initial capacity

$$m = \lfloor \lambda \tau \rfloor + 1 = \lfloor 45.833 \times 0.503 \rfloor + 1 = 24$$

Step 5 Compute the variation of inter-arrival time and service time of the transportation request

The two important parameters of queuing system, the SCV of inter-arrival time and SCV of service time, are calculated as follows.

$$\lambda_t = \sum_{i=1}^{N}\sum_{j=1}^{N}\lambda_{ij} = 45.833,\ C_{a0}^2 = 0$$

$$\rho_t = \lambda_t \tau_t / m = 45.833 \times 0.503/24 = 0.96$$

$$C_{st}^2 = Var(S_t)/(E(S_t))^2 = 0.21/(0.503^2) = 0.832$$

$$(\pi_0,\ \pi_1,\ \pi_2,\ \pi_3,\ \pi_4,\ \pi_5,\ \pi_6) = (0.036,\ 0.164,\ 0.164,\ 0.164,\ 0.164,\ 0.155,\ 0.155)$$

$$(\rho_0,\ \rho_1,\ \rho_2,\ \rho_3,\ \rho_4,\ \rho_5,\ \rho_6) = (0,\ 0.597,\ 0.816,\ 0.949,\ 0.679,\ 0.847,\ 0.556)$$

$$(C_{s0}^2,\ C_{s1}^2,\ C_{s2}^2,\ C_{s3}^2,\ C_{s4}^2,\ C_{s5}^2,\ C_{s6}^2) = (0,\ 0.081,\ 0.002,\ 0.046,\ 0.006,\ 0.006,\ 0.065)$$

$$C_{at}^2 = \frac{(\sum_{i=0}^{N}\pi_i\rho_i^2C_{si}^2 + \sum_{i=1}^{N}\pi_i(1-\rho_i^2)(1-\pi_i)\sum_{i=1}^{N}\pi_i^2(1-\rho_i^2)\rho_t^2C_{st}^2 + \pi_0(1-\rho_0^2)C_{a0}^2)}{(1-\sum_{i=1}^{N}\pi_i^2(1-\rho_i^2)(1-\rho_t^2))} = 0.417$$

Step 6 Calculate the mean waiting time of product waiting for the service of MHS

In this step, we will use Gi/G/m queuing theory to calculate the mean waiting time of product waiting for the service of MHS. The other modification of parameters can refer step1-4. The result is shown as fallow:

$$Q_{Te} = \phi(\lambda_t,\ C_{at}^2,\ C_{st}^2,\ \tau_t,\ m_t) \times \frac{C_{at}^2 + C_{st}^2}{2} \times \frac{\tau_t(\rho_t^{\sqrt{2m_t+1}-1})}{m_t(1-\rho_t)} = 0.168$$

Step 7 Obtain the probability function

Finally, the probability of capacity achieve of constraint machine can be obtained.

$$X = Q - E(S_T) = 0.706 - 0.503 = 0.203$$

$$P(Q_{Te} \leq\ 0.203) \approx 1 - \alpha e^{-\eta X}$$

Step 8 Determine the required capacity for MHS

Assume the target probability set by manager is 1. The number of HMS and the probability that waiting time of WIP for HMS within 0.203 hour are as Table 5. Based on the result of Table 5, the best quantity of vehicles is 31 sets.

Table 5: Probability checking table

Number of vehicle	24	25	26	27	28	29	30	31
probability	0.810	0.933	0.969	0.984	0.991	0.995	0.997	0.999

CONCLUSION

In this work, a capacity determination model for AMHS based on GI/G/m queuing model was proposed. The major concept of this model is linking the AMHS capacity determination to production performance. Therefore, the best quantity of vehicles would be determined through this model. Under this configuration, the production system can be performed well with lower investment of MHS. Furthermore, the stochastic nature of manufacturing systems and the relationship between the processing facilities and MHS are properly and realistically described.

Regarding to the future work, the failure behavior of HMS can be considered. HMS can be treated as a workstation. In this point of view, failure behavior will increase the required capacity of HMS and should be taken into account. In addition, the congestion of HMS is another important issue in the capacity determination and can be considered in the future work.

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附 件三

Factors Analysis of Capacity Backup Policy for Twin Fabs

Factors Analysis of Capacity Backup Policy for Twin Fabs

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Abstract: In order to reduce some facility costs and increase production flexibility, twin-fab concept has been established over the past decade. Through the concept of twin-fab, the manufacturing capacity of two fabs, such as total throughput and utilization of machines, can be improved and enhanced effectively by different capacity backup policies. However, if lacking of completed backup control policies, the benefit of twin-fab will be decreased significantly. Therefore, it is necessary to find out the factors which will influence the performance of capacity backup policies. The purpose of this research is to observe and analyze the factors, which can affect the production performance in twin-fab capacity backup model. The simulation model is established and the experimental design is applied. The capacity backup environments were divided into two parts and named as permanent and temporary capacity shortage separately. Furthermore, three more factors were taken into account, which included WIP (Working In Process) level, the difference of WIP amount and stability of backup machine. By simulation, the analytical data is collected and analyzed its significance in these two environments. According to the results, they reveal that the significance of factors under different environments. Based on these results, the managers can conclude an appropriate shop floor control policy in twin-fab environment, which will help to reduce the cycle time of products and increase the total throughput of twin-fab.

Keywords: Twin-fab, Capacity backup policy, Simulation model, Experimental design

雙子晶圓廠產能支援決策因子分析

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【摘要】由於雙子晶圓廠可以減少建廠時基本設施的成本以及提高生產上的靈活性，因此雙子晶圓廠的概念在晶圓製造產業過去的十年以來已廣泛被接受。在此環境架構下，兩廠之產能可很容易透過不同的產能支援策略而有效的改善與提升。然而缺少一套完整的產能支援控制策略，反而會造成兩廠產能績效明顯下降。本研究的目的希望藉由模擬模型的建構以及實驗設計的應用，找出雙子星廠產能支援決策模式中之影響因子。此研究將雙子星廠產能支援情況分為短暫性與永久性產能缺口兩種，而考量的影響因子包含在製品門檻值、在製品差異門檻值與機台的穩定度。透過模擬實驗與結果分析，希望可以使管理者了解到當面對不同的現場環境下，要注意且管控的因子究竟為何，進而制定出有效的產能支援決策模式，以提升改善雙子星晶圓廠的生產績效。

【關鍵詞】雙子星廠；產能支援策略；模擬模型；實驗設計

1 前言

相較於其他產業 晶圓製造產業的製造過程是極為複雜且需要高度技術，像是製程回流現象、時間限制以及批量加工特殊的製程[1][2]。為了保持高競爭力，擴大生產能力和先進的生產技術是必要的。然而，管理者卻必須面對許多不確定且變動的環境挑戰，因此擴展與投資產能的動作對於半導體業來講必然存在一定程度之風險[3]。為了在如此動態的半導體市場與產業環境下降低投資的風險，在過去幾十年來，許多半導體製造公司逐漸接受雙子星工廠概念。所謂的雙子星工廠意指在同一建築物中有著兩種不同世代的製程能力生產線，而其建構概念的優勢大致上有下列三點：

1. 共用基本設備，降低擴充產能之成本
2. 縮短建構新廠時的建構時間
3. 可即時性的執行兩廠間之產能支援動作

由於這些特點，雙子星晶圓廠的生產線對於市場波動的適應性比單一晶圓廠更為靈活。然而卻很少有研究從雙子星晶圓廠生產系統績效的角度來研究其產能規劃與管控。過去許多針對產能規劃的探討上，大多採取線性規劃的方式，結果顯示都有不錯的成效[4][5][6][7]，然而這些模式實際運用在雙子星廠上，除了則成效有限外在計算上也較為複雜。因此有部分學者將線性規劃與類神經網路(ANN)以及基因演算法(GA)結合，用來解決雙子星廠之產能支援路徑規劃問題[8][9]，可是此研究對於支援時機點的制定以及其他可能的干擾因子都未詳細加以考量，而此舉可能導致此模式在現場運用上產生成效不足的地方。Chen et al. [10][11]則針對雙子星廠提出一套產能需求規劃系統（capacity requirements planning system , CRP)，其系統分為了四個大部份，從晶圓的投料控制到物料上機加工都有其判斷邏輯，但此研究較為可惜的是其假設條件為產能無限之環境，這對於目前業界的情況來說在實行上必然會較為不適。

從過去的研究發現，對於雙子星晶圓廠來說一個良好的能支援管控模式是相當缺乏，因此在發展雙子星廠之產能支援模式前，事先了解哪些因子會對廠內之生產績效造成影響是必須的。本研究將利用模擬軟體與實驗設計的方式，進行實驗數據的收集與分析，其研究結果將可提供管理者在制定產能支援決策上能有所參考與依據，進而訂定一合適之雙子星廠現場產能支援管控策略，使得雙子星晶圓廠之生產績效得以改善提升。

接下來下一章節將對本研究之環境與概念進行介紹，在第三章節部分則是本研究之結果分析與探討，最後為本文之總結與未來研究方向與建議。

2 模式概念與實驗設定

2.1 模式概念

由於雙子星廠的概念導致兩廠之製程水準在建構時即存在著差異，因此現階段的管理上大多採取各自管理模式，所以大多擁有各自的投料與指派法則，而雙子星晶圓廠發生產能支援行為之原因大致可分為兩種：

1. 無預期的因素所導致之產能的損失
2. 訂單變化所導致的短期產能短缺

有鑑於產能支援決策模式對於雙子星晶圓廠來說是相當重要且必須的，本研究將以實驗設計的方式，從提升整體系統生產績效的角度出發，找出雙子星晶圓廠在實行產能支援的生產管控下，探討在製品門檻值(Threshold)、在製品差異門檻值(Difference)與產能支援機台之穩定度(Stability of Capacity Support Equipment)，三項產能支援管控因子對於雙子星晶圓廠生產績效之影響關係，而生產績效指標方面則是以產品生產週期時間(CT)與總產出量(TH)作為評量之標準。

首先，在製品門檻值之設定目的除了避免過多在製品(WIP)而導致生產績效的下降外，另一個目的在於避免機台發生缺料之情況。此數值設置過低除了可能造成本身機台的缺料外，也可能造成過多產能支援搬運動作，而導致自動化搬運系統(AMHS)產能浪費；反之則使的支援模式無法啟動，所以希望透過本研究結果找出之間的相關性，以幫助管理者在制定此門檻值時有所參考。接著關於在製品差異門檻值的設定上，其訂定的目的在於避免發生無效搬運之狀況。當兩廠可進行產能支援機台之WIP差異大於此設定值時，才正式啟動產能支援的動作進行運送。而所謂的無效搬運是指，當工件在原投料廠等候加工之時間小於跨廠來回搬運時間與跨廠後等候加工時間之總和條件下還進行搬運之行為。此設定過小會導致產能支援的效果下降，而浪費不必要的搬運系統產能，相反的設定過大則使的產能支援模式無法發揮其效用。第三項實驗因子為產能支援機台的穩定度，由於在過去的研究中發現[12]，機台的穩定度對於整體系統績效存有一定程度的影響，因此本研究也將此列為考量因子，而實驗中以機台的平均修復時間(MTTR)為其調整之方式。

2.2 實驗環境設定

本實驗架構分別以A、B來代表其雙子星廠的兩個生產模組其假設如圖1所示。A、B兩廠之間的產能備份動作則透過自動化物料搬運系統來達到其效果，而各廠內加工站間之搬運方式則暫時不在本研究考量範圍中。此外，當工件完成產能支援之加工模式後，必須回到原投料廠進行下一道的加工流程，如圖2所表示之。

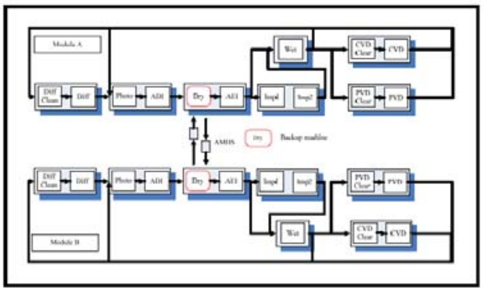


Figure 1. The concept of system layout

本研究實驗環境將分成兩部分，一為 A、B 兩廠之可相互支援的機台產能皆為充足之生產環境，此環境造成產能支援的原因主要來自機台當機；二則是 A 廠可相互支援的機台產能不足夠，B 廠可相互支援的機台有過

剩之產能，在這種環境中導致產能支援的因素，除了機台當機外，另一個原因在於 A 廠所面臨之產能不足問題。

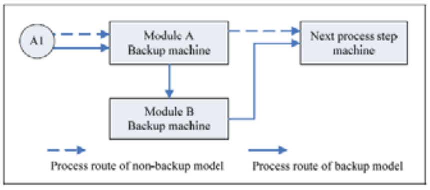


Figure 2. The concept of lot move for capacity backup model

實驗分析之數據則是利用模擬軟體 eM-plant 所建構之簡易雙子星廠收集取得之。此次實驗環境包含半導體產業常見的製程現象，如批量加工與回流製程。

3 實驗分析結果與討論

3.1 產能缺口不存在

圖3表示在不同MTTR(Mean Time to Repair)水準下，產品生產週期時間(cycle time)的變化趨勢。不管在何種MTTR水準下，B廠產品之cycle time(CTB)皆隨著在製品門檻值(T)上升而向上攀升，最後甚至高於CTA，導致此現象的原因在於門檻值(T)過高使得產能支援不易發生，且在無產能缺口環境設定下，B廠可相互支援的機台為相對產能較小的一方。另外在信賴水準95%的ANOVA檢定分析中，也驗證了不同的門檻值(T)對於CTA與CTB都有顯著影響。

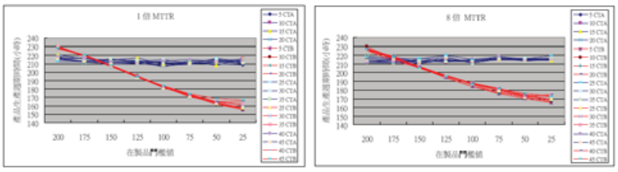


Figure 3. The performance of cycle time in capacity sufficient

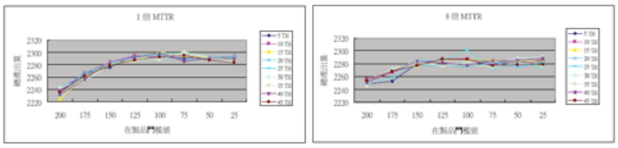


Figure 4. The performance of total throughput in capacity sufficient

接著從兩廠總產出之角度觀察(如圖4)，在相同MTTR條件下門檻值(T)上升，對於不同的差異值(D)水準下之曲線皆呈現相同的趨勢，且在T<125時總產出開始有趨於平緩的現象；但就不同MTTR的角度來看，MTTR倍率愈大時對於總產出量來說則是下降的趨勢且轉折點也較不明顯，而從ANOVA檢定的結果發現，在製品門檻值對於TH的影響是顯著的。

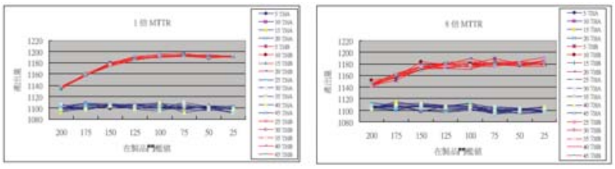


Figure 5. The performance of Individual throughput in capacity sufficient

如果分別從各廠產出的角度來看，A廠的產出量(THA)大致維持在一定的水準，而B廠產出量(THB)的表現則隨著門檻值(T)下降而有所增加，在T<125時產出開始維持一定水準。而B廠會有這樣的現象出現，主要在於當沒有產能缺口時，在本研究假設之的環境設定下，B廠產能支援機台為產能相對較少的一方，所以當門檻值愈大時產能支援的動作較不易發生，因此導致這樣的趨勢。此外在ANOVA的檢定中，也顯示不同水準的門檻值對於THA與THB是有顯著的差異。

3.2 有產能缺口存在

當雙子星廠發生某個廠有產能短缺現象時，從圖6發現，在MTTR相同下CTA與CTB的表現各自成為一個集群並未有發生交集的現象，且CTA皆大於CTB；此外隨著MTTR上升CTA與CTB也皆隨之升高。從ANOVA分析結果中，也發現到在不同的門檻值(T)水準對於CTA與CTB有顯著的影響。

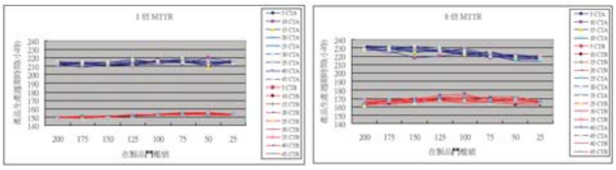


Figure 6. The performance of cycle time in capacity insufficient

對於就總產出量方面來說，從圖7的趨勢看來不管門檻值(T)在何種水準下，總產出量似乎沒有太大的變化，但從信賴水準95%的ANOVA檢定報告中，卻發現在MTTR較小的情況下，不同水準的門檻值(T)對於TH是有顯著的差異，但對於MTTR較大時則沒有此現象的產生。其原因可能是當MTTR越大時，雙方產能支援機台皆呈現較不穩定的狀態，導致在製品門檻值之因子變化不足以影響總產出量。

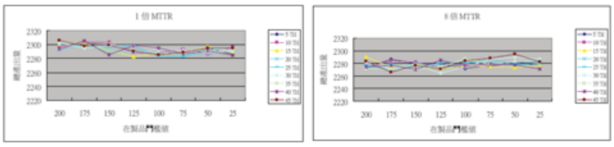


Figure 7. The performance of total throughput in capacity insufficient

從圖8之各廠產出量中發現，A廠產出量(THA)與B廠產出量(THB)大致維持在一定的水準，並沒有發生如無產能缺口情況下之現象。而進一步的ANOVA的檢定中發現，在相同的MTTR下不同的門檻值設定對於THA與THB是有顯著的影響。

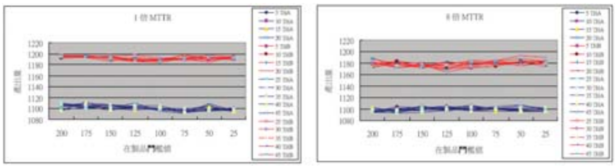


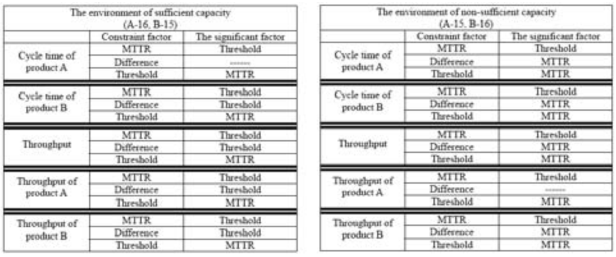
Figure 8.The performance of individual throughput in capacity insufficient

4 結論

4.1 總結

在目前半導體機台設備投資採購成本日益上升且產品毛利率日益縮減的情況下，雙子星廠的概念已逐漸的被業界管理者所接受，因此如何有效的運用與管理其特性，以增加公司整體競爭力是一件極為重要的挑戰。由表 1 的實驗結果整理得知，整體上產能支援機台的穩定度對於整個生產系統績效佔有很大的影響程度，而門檻值的影響則是次之。本實驗的結果提供管理者在雙子星廠的環境裡施行產能支援模式時，首先必須對於可進行產能支援機台的穩定度加以嚴格管控，如此接下來再進行其他產能支援的管控時，對於整體生產系統的績效才會是較有效率的。

Table 1. The level of experiment factor



The environment of sufficient capacity (A-16, B-15)

	Constraint factor	The significant factor
Cycle time of product A	MTTR	Threshold
	Difference	------
	Threshold	MTTR
Cycle time of product B	MTTR	Threshold
	Difference	Threshold
	Threshold	MTTR
Throughput	MTTR	Threshold
	Difference	Threshold
	Threshold	MTTR
Throughput of product A	MTTR	Threshold
	Difference	Threshold
	Threshold	MTTR
Throughput of product B	MTTR	Threshold
	Difference	Threshold
	Threshold	MTTR

The environment of non-sufficient capacity (A-15, B-16)

	Constraint factor	The significant factor
Cycle time of product A	MTTR	Threshold
	Difference	MTTR
	Threshold	MTTR
Cycle time of product B	MTTR	Threshold
	Difference	MTTR
	Threshold	MTTR
Throughput	MTTR	Threshold
	Difference	MTTR
	Threshold	MTTR
Throughput of product A	MTTR	Threshold
	Difference	------
	Threshold	MTTR
Throughput of product B	MTTR	Threshold
	Difference	MTTR
	Threshold	MTTR

4.2 未來研究方向與建議

在未來研究方向上，由於本實驗的產能支援路徑模式為單站來回，因此如能夠在此控制模式上增加彈性，相信對於 AMHS 的使用上會更有效率。另外，在未來之研究可以從本研究所發現之因子上著手，發展出一套屬於雙子星廠產能支援相關的管控因子估算式，例如兩廠間搬運車數量或是更明確的門檻值的設定，藉以達到雙子星廠生產系統整體之改善與提升。

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附 件四

Capacity Backup Model for Twin Fabs of Wafer Fabrication

Capacity Backup Model for Twin Fabs of Wafer Fabrication

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Abstract: The twin-fab concept has been established over the past decade due to the considerations of cheaper facility build up, faster equipment move in and more flexible productivity management. However, if lacking of completed backup control policies, the benefit of twin-fab will be decreased significantly particularly in production flexibility as well as effectiveness.

In this work, the control policy of capacity backup was established that two control thresholds were developed. The first one is the WIP (Working In Process) amount threshold which is the trigger for backup action. Nonetheless, the concept of protective capacity is also applied to set this threshold. When the WIP level in front of the workstation which needs capacity support is over the threshold, the action of capacity support is triggered. In order to endorse the effectiveness of WIP transfer between twin-fab, the threshold of WIP amount difference (D) is set as a control gate. When the WIP level in front of the workstation which needs capacity support is over the threshold and the difference of WIP amount in the twin fabs is over than D, the coming WIP will be transferred to the other fab. The design of the threshold of WIP amount difference is based on the concept of the coverage of transportation time and the benefit should be got when backup action is occurred. Through these two control rules, WIP can be well arranged among the twin fabs and be processed more efficiently and effectively. Finally, the production performances of twin fabs will be improved under the capacity backup policy.

Keywords: Twin-fab, Capacity backup policy, Protective capacity, Transportation time

I. Introduction

Compare with other industries, wafer fabrication is more complicated and scientific, particularly in manufacturing processes, such as re-entrant flows, time constraints between operations, and batch processing [1]], [2]. In order to keep high competitiveness, the capacity expansion and manufacturing of advanced technology are necessary. The managers, however, have to suffer many difficulties in such a circumstance, for instance, the market demand is changed rapidly, equipment cost is increased and the technology is upgraded frequently. Hence, if the managers try to expand capacity under such dynamic environment, it will be at high risk [3].

Over the past decades, many semiconductor manufacturing companies tend to accept twin-fab concept. The notion of twin-fab means two neighboring fabs are not only installed in the same building, but also connect to each other through AMHS (Automatic Material Handling System). There are some advantages of twin-fab as follows.

1. To reduce the cost of capacity expansion through sharing the essential facilities, such as gas pumps system and recycling system of polluted water.
2. Due to the building and basic facilities established in the beginning stage, the construction time of the second fab will be shortened.
3. As the twin-fab is two neighboring fabs, the real-time capacity backup can be achieved to each other by AMHS.

Because of these features, the adaptability of production line of twin-fab is more flexible than single fab. However, there are few of researches focus on capacity support between twin-fab from the viewpoint of the whole performance of the production system, such as cycle time of products and throughput. In previous studies, linear programming (LP) is used to solve the capacity allocation problem in general environment, which assumed each product should be manufactured completely within single-fab [4], [5], [6], [7]. However, the LP model is hard to apply to twin-fab configuration. Because of the computational scale becomes more complex and enormous, artificial neural network (ANN) and genetic algorithm (GA) are combined with LP model by other researchers [8], [9]. These models were used to solve the route planning of capacity backup between twin-fab. Unfortunately, the influences of the time point of backup on production performance were not taken into account. In addition, some possible issues which will result in low performance were ignored. Chen et al. [10], [11] announced a capacity requirements planning system (CRPS) for twin-fab, four modules were developed to control wafer release time and start processing time in machines. However, due to applying the infinite loading of capacity plan, the performance measurements of these models were only identified the percentage of extra capacity and utilization for equipment and AMHS. This does not conform to the current situation of wafer fabrication.

Based on previous studies, a model to decide the capacity support in twin-fab environment is desired for semiconductor manufacturing. Furthermore, this control model should be connected to the whole production performance and easy to implement. Hence, in this work, a capacity backup control model is developed. Under this control model, managers can well control the shop floor activities in twin-fab environment, which will help to reduce the cycle time of products and increase the total throughput of twin-fab.

This paper is organized as follows. Section 2 explains the important factors of this control model. The model structure and control procedures are described in the next section. In the final section, this paper concludes with the summary and direction of future research

II. FACTORS IN CAPACITY SUPPORT CONTROL MODEL

In this work, we assumed the workstations needed capacity backup and provided capacity backup are selected. The major task should be done is to set up a model to well control the capacity backup activities. Based on the simulation experiments of previous study [12], it revealed that WIP amount and WIP amount difference between two capacity backup equipment are the most affected factors upon the production performance under the capacity support environment between twin fabs. Therefore, the following sections will focus on these two factors and develop their control thresholds.

A. NOTATION

The following terminology is required for the capacity support control model.

T :	Threshold of WIP amount
ECL_q :	Expected capacity loss by quantity
ECL'_q :	Modified expected capacity loss by quantity
CL_i :	Capacity loss of workstation i
μ_i :	Average service rate of workstation i
μ_c :	Average service rate of constraint workstation(capacity supported)
$MTBF_{ij}$:	Mean time between failure of machine j in workstation i
$MTTR_{ij}$	Mean time to repair of machine j in workstation i
$MTTR_i$:	Mean time to repair of workstation i
$MTTR_F$	Average mean time to repair of feeder workstations of constraint workstation
$MTTR_s$:	Average mean time to repair of supporting workstations
$MTTR_c$	Average mean time to repair of constraint workstations
A_{ij} :	Availability of machine j in workstation i
A_i :	Availability of workstation i
A_s :	Availability of supporting workstation
PT_{ip} :	Processing time of product p in workstation i
PT_c :	Average processing time in constraint workstation
g :	Number of product types
m :	Number of feeder workstations
m_i :	Number of machines in workstation i
m_c :	Number of machines in constraint workstation
X :	Loading amended factor
α :	Confidence level
β :	Number of runs
TT :	Transportation time
MF :	Machine failure time
Dis :	Distance between constraint workstation and supporting workstation
V_T :	Speed of AMHS vehicle
DMF :	Difference of machine failure time between constraint workstation and supporting workstation
WIP_c :	WIP amount in front of constraint workstation

B. THRESHOLD OF WIP AMOUNT (T)

The queue length in front of bottleneck machine implies the length of queue time and the sufficiency of machine capacity. If the queue length is too long, it reveals the queue time will be long and maybe the machine capacity is insufficient. Hence, WIP amount can be a trigger factor to decide the backup action should be launched or not. Based on this concept, a threshold of WIP amount which launches the backup program should be setup. In order to setup the threshold of WIP amount, the essentiality of WIP should be examined. The positive side of WIP provides for resources to be put to full economical use and prevents unpredictable events from disturbing maximum output rate. This maximum output rate is particularly prevalent in capital intensive factories such as a semiconductor fab. The negative aspects of WIP are an increase in cycle time, impaired delivery performance and quality degradation [13], [14], [15], [16]. From this viewpoint, WIP level should be set as the amount used to protect against statistical fluctuation (breakdowns, late receipts of material, quality problems, and others) from the feeder machines. Generally, machine breakdowns are the major statistical fluctuation in fab and it is taken as the only one factor in this work.

Based on the above concept, WIP threshold can be set as the level to protect the breakdowns of feeder machines. Therefore, WIP threshold is defined as equation (1) in a balanced line

$$ECL_q = \sum_{i=1}^{m} (CL_i \times \mu_i) \tag{1}$$

$$CL_i = \sum_{j=1}^{m_i} ((1 - A_{ij}) \times MTTR_{ij}) \tag{2}$$

$$A_{ij} = \frac{MTBF_{ij}}{MTBF_{ij} + MTTR_{ij}} \tag{3}$$

$$\mu_i = \frac{1}{\sum_{p=1}^{g} (PT_{ip} \times r_p)} \tag{4}$$

Usually, the machines need to request for backup are defined as a constraint machine. It means the capacity of feeder machines is more than the constraint machine. The lost capacity of feeder machines will not fully affect on the constraint machine. Therefore, WIP in front of constraint machine should be the loss from the breakdowns subtracting the surplus capacity of feeder machines. Under this circumstance, WIP threshold can be modified as equation (5).

$$ECL_q' = Max\{ECL_q - X \ ,0\} \tag{5}$$

$$X = \left(\sum_{i=1}^{m} (\mu_i \times A_i) - \sum_{k=1}^{m_c} (\mu_k \times A_k) \right) \times MTTR_F \tag{6}$$

$$MTTR_F = \frac{\sum_{i=1}^{m} MTTR_i}{m} \tag{7}$$

Besides, MTTR is the mean value of machine's downtime; that is to say, around 50% of the machines will fail to surpass this mean value. In order to determine the WIP threshold, a confidence level must be incorporated to ensure that the constraint machine is fully protected. The following equation is the modified WIP threshold by confidence level α.

$$T = \ln\left(\frac{1}{1-\alpha}\right) \times ECL_q' \tag{8}$$

C. THRESHOLD OF WIP AMOUNT DIFFERENCE

Although WIP threshold is the signal of backup launch, it doesn't mean that the backup action is always effective. If the WIP in front of the supporting machines is more than those of the supported machines, WIP transferring is useless and ineffective for production performances. Hence, a gate to verify the effectiveness under capacity support is necessary.

There are three factors included in the development of the threshold of WIP amount difference, WIP transportation time between twin fabs, machine breakdowns and expected performance increasing. Generally, WIP transfers to the other fab for backup should be transferred back when backup process finished. If the queue time reducing can not cover the transportation time, the action of backup is ineffective. Besides, there is the possibility that machines breakdown for a long time. Under this situation, the queue time of WIP will be worse than it just waits in the original fab. Therefore, the factor of machine breakdowns should be taken into account in the setting of WIP difference threshold. Finally, the factor of performance increasing should be included, otherwise, the backup action will be got nothing. Usually, one run of time save will be taken by managers. It means the queue time of WIP transferring should be saved one of processing time at least. In this work, the processing time is set as a unit, and how many times of processing time will be a variable decided by managers. Based on the above concepts, the threshold of WIP amount difference (D) is expressed by the following equations.

$$D = (2 \times TT + MF + \beta \times PT_c) \times \mu_c \tag{9}$$

$$TT = Dis \times V_T \tag{10}$$

$$MF = Max(DMF, 0) \tag{11}$$

$$DMF = \frac{WIP_c}{\mu_c} \times (1 - A_s) \times MTTR_s - \frac{WIP_c}{\mu_c} \times (1 - A_c) \times MTTR_c \qquad (12)$$

III. CONTROL MODEL OF CAPACITY SUPPORT

The control model of capacity support can be implemented when the factors T and D have been decided. The flow chart of this control model is represented as the following figure.

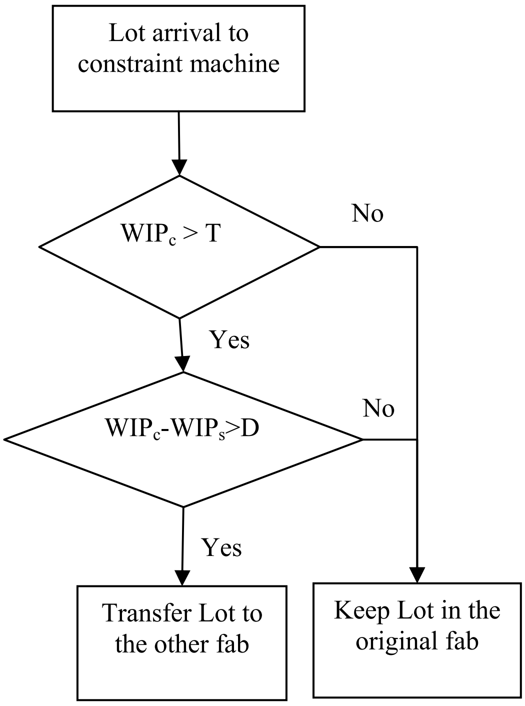

Figure 1: Flow chart of the capacity support control model

Based on the above flow chart, the decision point and control rules are as follows.

1) Decision points

The decisions should be made at the time of lot arrival at the constraint machine.

2) Control rules for capacity support

a. *Check the WIP amount in front of the constraint machines.*

   If, the WIP amount in front of the constraint machines is over the threshold (T), then go to the next step.

   Else, keep this lot in the original queue in front of constraint machines.

b. *Calculate the WIP amount difference between constraint machines and supporting machines*

   If, the WIP amount difference between the constraint machines and supporting machines is over the threshold D, then transfer this lot to the queue in front of supporting machines in the other fab.

   Else, keep this lot in the original queue in front of constraint machines.

III. CONCLUSION

In this work, a control model is established to well manage the issues of capacity support. There were two control thresholds, WIP amount threshold and difference of WIP amount threshold, developed in this control policy. One is the trigger for backup action and the other is set as a control gate. Through these two control rules, WIP can be well arranged among the twin fabs and be processed more efficiently and effectively. Finally, the production performances of twin fabs will be improved under the capacity backup policy.

Regarding to the future works, there are two points can be considered.

The first on is the selection of backup workstations. It is obvious that capacity backup will be occurred on bottleneck machines. However, capacity backup is necessary for the unstable workstations. How to identify the unstable workstation and put them into the backup machines list are very important. Finally, the performance under capacity backup should be estimated. Based on the estimation results, some important planning such as order scheduling, wafer out date projecting can be well done.

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附 件五

Performance Estimation Model of Twin Fabs under Capacity Backup

Performance Estimation Model of Twin Fabs under Capacity Backup

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Abstract: This study proposed an effective model for performance estimation of twin fabs under a real time capacity backup environment. The notion of twin-fab means two neighboring fabs are not only installed in the same building, but also connect to each other through AMHS (Automatic Material Handling System). In order to increase the whole performance, the capacity backup should be performed between twin fabs.

In this study, the performance estimation model is established under two situations, temporary and permanent capacity shortage. The queuing theory and Little's Law is applied in both two situations to develop the estimation model. Besides, in temporary capacity shortage, the performance estimation is based on the concept of capacity mergence of capacity backup workstation. In the other words, the twin fabs are taken as a single fab for the capacity backup machines to estimate the performance. Based on this model, managers can obtain an appropriate estimation of capacity backup performance in twin-fab environment, which will help to get a reliable information for decision making.

Keywords: Twin-fab; performance evaluation; capacity backup

雙子星晶圓廠產能相互支援下之績效評估模式

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【摘要】本研究主要是針對雙子星晶圓廠環境提出一套生產績效預估模式。由於雙子星晶圓廠位於同一地理位置且產能配置通常具有差異，為了提高整體之績效表現，廠區之間必須透過產能互相支援解決暫時性產能缺口或機台負荷不平衡等問題。因此，本研究分為無產能缺口與有產能缺口兩種狀態來構建其績效預估模式，並且透過等候理論與Little's Law兩者理論的結合來預估雙子星晶圓廠在產能互相支援下生產週期時間與產出的改變。除此之外，在無產能缺口情況下，並從合併加工機台站之產能的觀點來進行其產能支援下之績效估算。期望藉由此模式的建立使管理者在兩廠產能相互支援下能夠擁有一套準確的績效估算系統，以獲得充足且可以信賴之資訊做為決策之依據。

【關鍵詞】雙子星廠；績效預估；產能支援

1 前言

晶圓製造產業相較於大多數的製造產業而言，其製造過程所需之步驟極為複雜，例如高度重複的回流特性、工件等候時間之限制以及特殊的批量加工製程[1][2]。為了保持高競爭力，擴大生產能力和先進的生產技術對於此產業是必要的。然而在面臨投資產能擴展與新製程引進的抉擇上，管理者除了要考量投資計畫所帶給公司的利益大小外，也必須要顧慮瞬息萬變的市場環境可能帶來的投資風險[3]，所以半導體製造業為了因應這樣的產業生態以及降低投資上的風險，近幾十年來許多公司紛紛逐漸採用雙子星工廠概念來建廠，這樣的特性解決半導體製造公司期望快速且更有彈性的因應市場需求變動的訴求。除此之外，相較於單一晶圓廠的管控模式，其雙子星廠架構在管控上也增添了不少的優勢[4]。面對一個相當動態且詭譎多變的市場，各式各樣的顧客要求隨時都可能發生。而在半導體產業的建廠計劃過程中，對於未來要生產的產品組合大多有一定的預估與規劃，也使的其所需採購的機台種類與數量也都被規範在一定的程度內。然而，即使有再好的規劃與預估，在任何一個穩定的生產系統裡，仍有會造成短期的產能不足的情形發生。而導致這樣的情況不外乎兩種情況，第一種為當廠內機台發生嚴重當機，此種非預期的因素所導致的短期產能損失；第二則是由於顧客的要求而導

致短期產能的短缺，像是緊急訂單或是原先訂單數量的增減。為了保有與增加公司的競爭力，並在預定的交貨期限下順利完成顧客的訂單，因此必須去尋求可能的產能支援。而這對於單一晶圓廠的管理者來講是相當棘手的，管理者除了必須額外規劃與協調產品運輸上的問題外，對於解決問題的時效性上仍有一定程度的挑戰。但對於雙子星晶圓廠的環境而言，這些問題皆可透過自動化物料搬運系統(AMHS)得到一個完善的解決。然而對於這樣的產能支援行為，接收方是否該全盤接受抑是選擇性接受，對於管理者著實為決策的一個難題，實因接受方本身已有既定之生產排程，如果貿然執行，將可能造成雙方兩廠生產績效的變化與衝擊。

在半導體產業中所關心的績效指標 不外乎是產品生產週期時間(Cycle time)與產出量(Throughput)，這兩項績效指標不僅僅可顯示產線的表現好壞，更可做為在做生產規劃時的依據。在執行生產規劃時管理人員常以預估的Cycle Time與Throughput，來當做給定訂單交期的考量因子，因此績效指標的預估準確與否在生產規劃上就顯得十分重要，也使得很多學者針對這方面進行研究。雖然先前的研究中不少的學者，提出不少相關的估算式[5][6][7][8]，但其大部分都針對不同環境條件下之單一工廠進行探討。對於雙子星工廠的績效估算研究仍有所欠缺，主要是雙子星廠在產能規劃時，雖其生產運作上是各自獨立且各有自己的投料與排程，但卻可在某些條件情況下進行所謂的即時性產能支援，因此進而可以在規劃生產時期將兩廠相同之機台產能同時加以考量與運用，但此舉將對這兩產線原先的Cycle Time與Throughput造成一定程度的影響與變化，如採取過去學者所提出之績效估算模式，直接用來進行雙子星廠產能支援下生產績效值的估算，其估算的最後結果在運用上必定存有某種程度的誤差，因此關於在實行產能支援的雙子星廠下其生產績效預估研究必定存在著一定的研究價值，建構出一套準確且合理的估算模式對於往後的雙子星廠管控是相當必要且必須 的。

接下來第二章將針對本研究所提出之概念進行介紹，然後緊接著在第三章的部分，則是本研究對在不同環境條件下，所提出之雙子晶圓廠產能支援績效評估模式，最後則是本研究的總結部分，以及未來可能之研究方向與建議。

2 環境概念與參數設定

2.1 環境概念

就如前言中所提所到，會有需要執行產能支援行動大多發生在，非預期性因素導致之產能的損失與訂單變化所引起之短期產能短缺，因此本研究將分別以兩種型態來進行模式的建構，分別為無產能缺口與有產能缺口兩種狀況，其進一步的介紹將在下一章詳細說明之。

在實行產能支援模式時，對於原先的生產系統會產生以下二項干擾：

1. 對發出需求方而言，其等候線中部份在製品不經過機台加工而離開本身之生產系統，而造成自身產線上之工件到達率下降。
2. 對接受需求的一方來講，除了原先本身生產系統的工件到達之外，還必須接受來自他廠工件到達，而且此種工件之到達率與期數量卻非固定與規律的發生。

所以由此可知在估算產能支援情況下之績效，勢必要從工件到達率的增減來進行考量，因此本研究將透過工件到達率的修正與等候理論相關公式進行相互之結合，並以Tu & Lu[4]研究中所提出之雙子星產能支援之行為模式為基礎，從中推導與建構雙子星晶圓廠之產能支援績效評估模式。除此之外由於根據以往的研究顯示，在製品門檻值以及機台當機對於產能支援決策的影響佔有關鍵性的因素[4][9][10][11]， 因此除了從上述所提及之到達率角度進行估算式的修正外，本研究還將考量此兩項干擾因素，並將其修正加入模式中，進而使本模式在估算使用上能更為全面與完善。

2.2 參數設定

本小節將先行對於在評估模式中所使用到之相關參數進行定義與介紹：

λ_{ik}	i廠中產品k之到達率
λ_i'	實行產能支援後i廠產能支援機台站之到達率
m_i	i廠產能支援機台站之機台數
μ_{ik}	i廠中產品k之服務率
μ_i	i廠產能支援機台平均服務率
f	產品種類
n_i	i廠產能支援機台站之上游機台站數
τ_c	虛擬合併機台之加工時間
τ_i	i廠產能支援機台站之加工時間
$MTTR_l$	機台l之平均當機修復時間
$MTBF_l$	機台l之平均當機間隔時間
C_{cs}^2	虛擬合併機台之加工時間變異係數平方
$\mathrm{C}_{\mathrm{ca}}^2$	虛擬合併機台之到達率變異係數平方
$\mathrm{C}_{\mathrm{aj}}^2$	產能支援機台上游機加工站j之到達率變異係數平方

C_{sik}^2	*i*廠中產品*k*之服務變異係數平方
$C_{sd_l}^2$	機台*l*之當機變異係數平方
$\mathrm{THV_i}$	*i*廠之在製品門檻值(單位：個)
$\mathrm{Q_{iL}}$	*i*廠之等候線平均長度(單位：個)
$\mathrm{TTHV_i}$	*i*廠之在製品門檻值(單位：時間)
$\mathrm{TQ_{iL}}$	*i*廠之等候線平均長度(單位：時間)
ρ	虛擬合併機台之使用率
TT	產能支援之來回搬運時間
T	總觀察時間
CT_0	未實行產能支援前之機台 cycle time
CT	實行產能支援後之機台 cycle time
C_s^2	產能支援機台之加工時間變異係數平方
$\mathrm{C_a^2}$	產能支援機台之到達率變異係數平方
ρ_i	實行產能支援後*i*廠產能支援機台之使用率

3 績效評估模式

3.1 無產能缺口

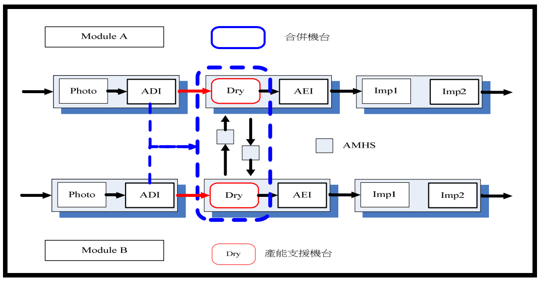

图 1. 合併機台概念圖

所謂的無產能缺口指的是兩廠可互相進行產能支援之機台，在本身投料節奏不變之情況下，其原先之機台產能是足夠的，可是一但在無預警情況下機台發生相當嚴重之當機，此時勢必導致機台前短期間內累積過多的在製品(WIP)，而管理者為了避免此情況造成產線績效傷害擴大，因此才產生需要尋求產能支援的需求。

由於此類因素是無法預先得知發生與否，因此本研究將從合併機台產能的角度來切入(如圖1所示)，原本的各廠之到達率為實線的部分，合併來看後其虛擬合併機台的到達率則為虛線線段之部分，除此之外並考量先前學者所提出之其他影響因子在製品門檻值(THV)以及機台當機，最後結合等候理論中Cycle time之估算與相關機率概念，推導出在無能缺口環境下之績效估算模式。

首先藉由公式(1)的計算，我們可以計算出虛擬合併機台之到達率，然後參考Tu & Chen[12]將當機時間修正加入工件加工時間的模式，修正出虛擬合併機台的加工時間、加工時間變異係數平方以及到達率變異係數平方，如公式(2)-(4)。接著利用Tu & Hung[9]所提出之計算式求得各自產線之THV，以及利用等候理論計算出各產線之平均等候線長度$\mathrm{Q_L}$，然後再使用公式(5)分別將此兩項參數單位，由個數轉換成為時間單位(TTHV與$\mathrm{TQ_L}$)，以便於後續之計算使用。由於在無產能缺口的環境中會產生產能支援搬運的機率發生在當$\mathrm{TQ_L}$>TTHV時，因此透過等候理論之相關機率公式計算可得知其發生之機率，然後利用期望值的概念計算出平均搬運時間，接著再利用等候理論Gi/G/M估算出虛擬合併機台之Cycle time，最後結合兩者而推導出公式(6)，其所計算之數值即是在無產能缺口情況下，實行產能支援機台之機台cycle time。

$$\lambda = \sum_{i=A,B} \lambda_i\,,\quad \lambda_i = \sum_{k=1}^{f} \lambda_{ik} \tag{1}$$

$$\tau_c = \frac{\displaystyle\sum_{i=A,B}\sum_{k=1}^{f}\left(\frac{\lambda_{ik}}{\mu_{ik}}\right) + \sum_{l=1}^{M}\frac{MTTR_l}{MTTR_l + MTBF_l}}{\displaystyle\lambda + \sum_{l=1}^{M}\frac{1}{MTTR_l + MTBF_l}},\qquad M = \sum_{i=A,B} m_i \tag{2}$$

$$\mathrm{C_{ca}^2} = \alpha + \sum_{j}^{N} \beta \mathrm{C_{aj}^2},\qquad N = \sum_{i=A,B} n_i \tag{3}$$

$$C_{cs}^2 = \frac{\displaystyle\sum_{i=A,B}\sum_{k=1}^{f}\left(\frac{\lambda_{ik}(C_{sik}^2+1)}{\mu_{ik}^2}\right) + \sum_{l=1}^{M}\frac{MTTR_l^2}{MTTR_l + MTBF_l}(C_{sd_l}^2+1)}{\displaystyle(\lambda + \sum_{l=1}^{M}\frac{1}{MTBF_l + MTTR_l})\times\tau^2} - 1 \tag{4}$$

$$\mathrm{TTHV_i} = \mathrm{THV_i} * \frac{1}{\mu_i},\ \ \mu_i = \sum_{k=1}^{f}\mu_{ik},\qquad \mathrm{TQ_{iL}} = \mathrm{EW(Gi/G/m)} * \lambda_i \tag{5}$$

$$CT = (\tau * \frac{(\mathrm{C_{ca}^2} + \mathrm{C_{cs}^2})\rho^{\{\sqrt{2(M+1)}-1\}}}{M*(1-\rho)} + \tau\ ) + \sum_{\mathrm{i=A,B}} \mathrm{P(TQ_{iL} > TTHV_i) * TT} \tag{6}$$

而至於產能支援之績效表現上的探討，則可從所推導出之Cycle time著手，結合Tu et al.[13]所發表之相關研究論點進行計算，其計算概念簡述如下：其中Throughput部份，則是利用Little's law的概念(L=λ*W)來進行估算。

1. Cycle time 的變化部分(ΔCT)：

$$\Delta CT = CT_0\ \text{-}\ CT \tag{7}$$

2. Throughput 的變化部份(ΔOutput)：

$$\Delta Outpot = \frac{\mathrm{T}}{CT_0} - \frac{\mathrm{T}}{CT} \tag{8}$$

3.2 有產能缺口

關於有產能缺口之環境，其主要是指其一條生產線之投料量短期間有所增加，例如對公司來說極為重要之顧客臨時增加訂單量，為了能夠盡可能提供顧客訂單彈

性進而提升公司競爭力，但此時可能造成一方某些機台產能短時間發生不足的現象，而為了達成訂單之需求，管理者因此必須借助產能支援之運作來滿足顧客需求。

由於這種的情況的發生對於管理者來說其不足之產能是可以計算的，也就是說其所需要進行產能支援量是已知的，此種情況下之雙子星晶圓廠的績效估算上，如同Tu et al.[13]所提出之模式概念相同，因此可以利用其績效估算過程來計算雙子星廠的產能支援績效，只是其所採用之等候理論架構為M/M/S，在使用上必須符合產品來到間隔時間與服務時間皆爲指數分配之型態，因此在實際運用上還是略顯不便，本研究將之概念擴展至Gi/G/m等候理論模式，以期更能方便現實環境的使用，而其所增加之參數設定與修正為服務率變異係數平方與到達率變異係數平方，除此之外對於當機因子也以Tu & Chen[12]所提出之觀點一併考量加入修正，而以下的推導介紹以提供支援站(B廠)一方為例，也就是A廠會將多餘的工件送至B廠進行加工，其相關的修正式如下所示，△C為其可支援量：

$$\tau_B = \frac{\sum_{k=1}^{f}\left(\frac{\lambda_{Bk}}{\mu_{Bk}}\right) + \frac{\Delta \mathrm{C}}{\mathrm{T}\times\mu_{\mathrm{A}}} + \sum_{l=1}^{m_B}\frac{MTTR_l}{MTTR_l + MTBF_l}}{\lambda_B{}' + \sum_{l=1}^{m_B}\frac{1}{MTTR_l + MTBF_l}}, \lambda_B{}' = \lambda_B + \frac{\Delta \mathrm{C}}{\mathrm{T}} \tag{9}$$

$$\rho_B = \frac{\lambda_B{}'}{m_B}\times\tau_B \tag{10}$$

$$\mathrm{C}_{\mathrm{a}}^2 = \alpha + \sum_{j}^{n_B}\beta \mathrm{C}_{\mathrm{aj}}^2 \tag{11}$$

$$C_s^2 = \frac{\sum_{k=1}^{f}\left(\lambda_{Bk}(C_{sBk}^2+1)\times\tau_B^2\right) + \sum_{l=1}^{m_B}\frac{MTTR_l^2}{MTTR_l + MTBF_l}(C_{sd_l}^2+1)}{(\lambda_B{}' + \sum_{l=1}^{m_B}\frac{1}{MTBF_l + MTTR_l})\times\tau_B^2} - 1 \tag{12}$$

$$CT = (\tau_B * \frac{(\mathrm{C}_{\mathrm{a}}^2 + \mathrm{C}_{\mathrm{s}}^2)\rho_B^{\{\sqrt{2(m_B+1)}-1\}}}{m_B*(1-\rho_B)} + \tau_B) \tag{13}$$

4 結論

4.1 總結

藉由本研究所提出之修正模式，管理者可以輕易且快速的取得當實行產能支援控制下其可能之績效表現為何，史的管理者可早先一步去調整與改善相關之管控參數，以達到本身所設定之期望績效成果，除此之外也可以使得雙子星廠在訂單允諾交貨日的安排上更為準確，進而使公司之競爭優勢可以更為提升。

4.2 未來研究方向與建議

至於在未來的研究方向上，有以下幾點可以做進一步之考量，首先關於產能支援的運作路徑模式，本模式建構在單站來回之管控上，這對於AMHS的負荷是相當大的，因此如為了提高AMHS的使用效率，跨多站來回之路徑運作模式勢必是有需要的，此改變必定會造成績效估算產生誤差。另外，關於AMHS的產能也是一值得研究之因子，因為雙子星廠的工件運輸都倚賴AMHS，如果不能有效的管控，其對於產能支援績效的表現上必定存在某種程度的干擾與影響。

致谢

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行政院國家科學委員會補助國內專家學者出席國際學術會議報告

99年 8月 23日

附件三

報告人姓名	杜瑩美	服務機構 及職稱	工業管理學系 副教授
會議時間 地點	民國99年8月12日 至 民國99年8月19日 Urumchi & Kashi, China	本會核定 補助文號	NSC97-2221-E-216-031-MY2-2
會議 名稱	（中文）資訊與管理科學第九屆國際會議 （英文）The Ninth International Conference on Information and Management Science (IMS2010)		
發表 論文 題目	（中文） （英文）Capacity Backup Model for Twin Fabs of Wafer Fabrication		

表 Y04

報告內容應包括下列各項：

一、參加會議經過

The Ninth International Conference on Information and Management Sciences was held in Urumchi & Kashi, China. The purpose of the conference is to push the development and applications of information and management sciences in business, engineering, economics, medicine, and other related disciplines. The conference Organizing Committee also wishes to foster the international collaborations among scholars in the related areas.

In the conference, I presented a paper entitled “Capacity Backup Model for Twin Fabs of Wafer Fabrication” and the topic attracted the attention of attendants because the issue has not been researched a lot in the past. In addition, some other topics about management have been presented and they were all impressed me very much.

二、與會心得

The conference will serve as an important forum for the exchange of ideas and information to promote understanding and cooperation among the information and management science. This year's conference This year's conference combined with another international conference names “The First International Conference on Uncertainty Theory”. Therefore, the papers regarding to the uncertainty theory were presented in this conference. Due to this conference was hold in China, there were some of authors came from China’s Universities. It is a good chance to exchange the ideas and teaching experiences between Taiwan and mainland China. Besides, the conference arranged a plenary talk for a whole day to present and discuss some better topics. It is a way to make a large discussion for a special topic.

This is a rich and colorful trip not only in the research field but also to find a history and charm region, Xinjiang. In the finally, I would like to thank the budgets support from National Science Council.

三、考察參觀活動(無是項活動者省略)

None.

四、建議

The Ninth International Conference on Information and Management Sciences was a large conference and 132 papers were presented in this conference. As we know that international conference is a good way not only to get new ideas quickly but also to face to discuss with the authors. Therefore, I suggested that National Science Council and school should review the funding policy and increase the funding amount to encourage and support the teachers and graduate students to attend these conferences. Besides, to arrange the plenary talk for best paper is good way for all participators. It is worth following for the future conference hold in Taiwan.

五、攜回資料名稱及內容

1. Conference Program :
    The Ninth International Conference on Information and Management Sciences
    The First International Conference of Uncertainty Theory
2. CD of the proceedings.

六、其他

None

Capacity Backup Model for Twin Fabs of Wafer Fabrication

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Abstract: The twin-fab concept has been established over the past decade due to the considerations of cheaper facility build up, faster equipment move in and more flexible productivity management. However, if lacking of completed backup control policies, the benefit of twin-fab will be decreased significantly particularly in production flexibility as well as effectiveness.

In this work, the control policy of capacity backup was established that two control thresholds were developed. The first one is the WIP (Working In Process) amount threshold which is the trigger for backup action. Nonetheless, the concept of protective capacity is also applied to set this threshold. When the WIP level in front of the workstation which needs capacity support is over the threshold, the action of capacity support is triggered. In order to endorse the effectiveness of WIP transfer between twin-fab, the threshold of WIP amount difference (D) is set as a control gate. When the WIP level in front of the workstation which needs capacity support is over the threshold and the difference of WIP amount in the twin fabs is over than D, the coming WIP will be transferred to the other fab. The design of the threshold of WIP amount difference is based on the concept of the coverage of transportation time and the benefit should be got when backup action is occurred. Through these two control rules, WIP can be well arranged among the twin fabs and be processed more efficiently and effectively. Finally, the production performances of twin fabs will be improved under the capacity backup policy.

Keywords: Twin-fab, Capacity backup policy, Protective capacity, Transportation time

I. Introduction

Compare with other industries, wafer fabrication is more complicated and scientific, particularly in manufacturing processes, such as re-entrant flows, time constraints between operations, and batch processing [1]], [2]. In order to keep high competitiveness, the capacity expansion and manufacturing of advanced technology are necessary. The managers, however, have to suffer many difficulties in such a circumstance, for instance, the market demand is changed rapidly, equipment cost is increased and the technology is upgraded frequently. Hence, if the managers try to expand capacity under such dynamic environment, it will be at high risk [3].

Over the past decades, many semiconductor manufacturing companies tend to accept twin-fab concept. The notion of twin-fab means two neighboring fabs are not only installed in the same building, but also connect to each other through AMHS (Automatic Material Handling System). There are some advantages of twin-fab as follows.

1. To reduce the cost of capacity expansion through sharing the essential facilities, such as gas pumps system and recycling system of polluted water.
2. Due to the building and basic facilities established in the beginning stage, the construction time of the second fab will be shortened.
3. As the twin-fab is two neighboring fabs, the real-time capacity backup can be achieved to each other by AMHS.

Because of these features, the adaptability of production line of twin-fab is more flexible than single fab. However, there are few of researches focus on capacity support between twin-fab from the viewpoint of the whole performance of the production system, such as cycle time of products and throughput. In previous studies, linear programming (LP) is used to solve the capacity allocation problem in general environment, which assumed each product should be manufactured completely within single-fab [4], [5], [6], [7]. However, the LP model is hard to apply to twin-fab configuration. Because of the computational scale becomes more complex and enormous, artificial neural network (ANN) and genetic algorithm (GA) are combined with LP model by other researchers [8], [9]. These models were used to solve the route planning of capacity backup between twin-fab. Unfortunately, the influences of the time point of backup on production performance were not taken into account. In addition, some possible issues which will result in low performance were ignored. Chen et al. [10], [11] announced a capacity requirements planning system (CRPS) for twin-fab, four modules were developed to control wafer release time and start processing time in machines. However, due to applying the infinite loading of capacity plan, the performance measurements of these models were only identified the percentage of extra capacity and utilization for equipment and AMHS. This does not conform to the current situation of wafer fabrication.

Based on previous studies, a model to decide the capacity support in twin-fab environment is desired for semiconductor manufacturing. Furthermore, this control model should be connected to the whole production performance and easy to implement. Hence, in this work, a capacity backup control model is developed. Under this control model, managers can well control the shop floor activities in twin-fab environment, which will help to reduce the cycle time of products and increase the total throughput of twin-fab.

This paper is organized as follows. Section 2 explains the important factors of this control model. The model structure and control procedures are described in the next section. In the final section, this paper concludes with the summary and direction of future research

II. **FACTORS IN CAPACITY SUPPORT CONTROL MODEL**

In this work, we assumed the workstations needed capacity backup and provided capacity backup are selected. The major task should be done is to set up a model to well control the capacity backup activities. Based on the simulation experiments of previous study [12], it revealed that WIP amount and WIP amount difference between two capacity backup equipment are the most affected factors upon the production performance under the capacity support environment between twin fabs. Therefore, the following sections will focus on these two factors and develop their control thresholds.

A. NOTATION

The following terminology is required for the capacity support control model.

T : Threshold of WIP amount

ECL_q : Expected capacity loss by quantity

$ECL_q^{'}$: Modified expected capacity loss by quantity

CL_i : Capacity loss of workstation i

μ_i : Average service rate of workstation i

μ_c : Average service rate of constraint workstation(capacity supported)

$MTBF_{ij}$: Mean time between failure of machine j in workstation i

$MTTR_{ij}$ Mean time to repair of machine j in workstation i

$MTTR_i$: Mean time to repair of workstation i

$MTTR_F$ Average mean time to repair of feeder workstations of constraint workstation

$MTTR_s$:Average mean time to repair of supporting workstations

$MTTR_c$ Average mean time to repair of constraint workstations

A_{ij} : Availability of machine j in workstation i

A_i : Availability of workstation i

A_s : Availability of supporting workstation

PT_{ip} : Processing time of product p in workstation i

PT_c : Average processing time in constraint workstation

g : Number of product types

m : Number of feeder workstations

m_i : Number of machines in workstation i

m_c : Number of machines in constraint workstation

X : Loading amended factor

α : Confidence level

β : Number of runs

TT : Transportation time

MF : Machine failure time

Dis : Distance between constraint workstation and supporting workstation

V_T : Speed of AMHS vehicle

DMF : Difference of machine failure time between constraint workstation and supporting workstation

WIP_c : WIP amount in front of constraint workstation

B. THRESHOLD OF WIP AMOUNT (T)

The queue length in front of bottleneck machine implies the length of queue time and the sufficiency of machine capacity. If the queue length is too long, it reveals the queue time will be long and maybe the machine capacity is insufficient. Hence, WIP amount can be a trigger factor to decide the backup action should be launched or not. Based on this concept, a threshold of WIP amount which launches the backup program should be setup. In order to setup the threshold of WIP amount, the essentiality of WIP should be examined. The positive side of WIP provides for resources to be put to full economical use and prevents unpredictable events from disturbing maximum output rate. This maximum output rate is particularly prevalent in capital intensive factories such as a semiconductor fab. The negative aspects of WIP are an increase in cycle time, impaired delivery performance and quality degradation [13], [14], [15], [16]. From this viewpoint, WIP level should be set as the amount used to protect against statistical fluctuation (breakdowns, late receipts of material, quality problems, and others) from the feeder machines. Generally, machine breakdowns are the major statistical fluctuation in fab and it is taken as the only one factor in this work.

Based on the above concept, WIP threshold can be set as the level to protect the breakdowns of feeder machines. Therefore, WIP threshold is defined as equation (1) in a balanced line

$$ECL_q = \sum_{i=1}^{m} (CL_i \times \mu_i) \tag{1}$$

$$CL_i = \sum_{j=1}^{m_i} ((1 - A_{ij}) \times MTTR_{ij}) \tag{2}$$

$$A_{ij} = \frac{MTBF_{ij}}{MTBF_{ij} + MTTR_{ij}} \tag{3}$$

$$\mu_i = \frac{1}{\sum_{p=1}^{g} (PT_{ip} \times r_p)} \tag{4}$$

Usually, the machines need to request for backup are defined as a constraint machine. It means the capacity of feeder machines is more than the constraint machine. The lost capacity of feeder machines will not fully affect on the constraint machine. Therefore, WIP in front of constraint machine should be the loss from the breakdowns subtracting the surplus capacity of feeder machines. Under this circumstance, WIP threshold can be modified as equation (5).

$$ECL_q^{'} = Max\left\{ECL_q - X \;, 0\right\} \tag{5}$$

$$X = \left(\sum_{i=1}^{m} (\mu_i \times A_i) - \sum_{k=1}^{m_c} (\mu_k \times A_k) \right) \times MTTR_F \tag{6}$$

$$MTTR_F = \frac{\sum_{i=1}^{m} MTTR_i}{m} \tag{7}$$

Besides, MTTR is the mean value of machine's downtime; that is to say, around 50% of the machines will fail to surpass this mean value. In order to determine the WIP threshold, a confidence level must be incorporated to ensure that the constraint machine is fully protected. The following equation is the modified WIP threshold by confidence level α.

$$T = \ln\left(\frac{1}{1-\alpha}\right) \times ECL_q^{'} \tag{8}$$

C. THRESHOLD OF WIP AMOUNT DIFFERENCE

Although WIP threshold is the signal of backup launch, it doesn’t mean that the backup action is always effective. If the WIP in front of the supporting machines is more than those of the supported machines, WIP transferring is useless and ineffective for production performances. Hence, a gate to verify the effectiveness under capacity support is necessary.

There are three factors included in the development of the threshold of WIP amount difference, WIP transportation time between twin fabs, machine breakdowns and expected performance increasing. Generally, WIP transfers to the other fab for backup should be transferred back when backup process finished. If the queue time reducing can not cover the transportation time, the action of backup is ineffective. Besides, there is the possibility that machines breakdown for a long time. Under this situation, the queue time of WIP will be worse than it just waits in the original fab. Therefore, the factor of machine breakdowns should be taken into account in the setting of WIP difference threshold. Finally, the factor of performance increasing should be included, otherwise, the backup action will be got nothing. Usually, one run of time save will be taken by managers. It means the queue time of WIP transferring should be saved one of processing time at least. In this work, the processing time is set as a unit, and how many times of processing time will be a variable decided by managers. Based on the above concepts, the threshold of WIP amount difference (D) is expressed by the following equations.

$$D = (2 \times TT + MF + \beta \times PT_c) \times \mu_c \tag{9}$$

$$TT = Dis \times V_T \tag{10}$$

$$MF = Max(DMF, 0) \tag{11}$$

$$DMF = \frac{WIP_c}{\mu_c} \times (1 - A_s) \times MTTR_s - \frac{WIP_c}{\mu_c} \times (1 - A_c) \times MTTR_c \qquad (12)$$

III. CONTROL MODEL OF CAPACITY SUPPORT

The control model of capacity support can be implemented when the factors T and D have been decided. The flow chart of this control model is represented as the following figure.

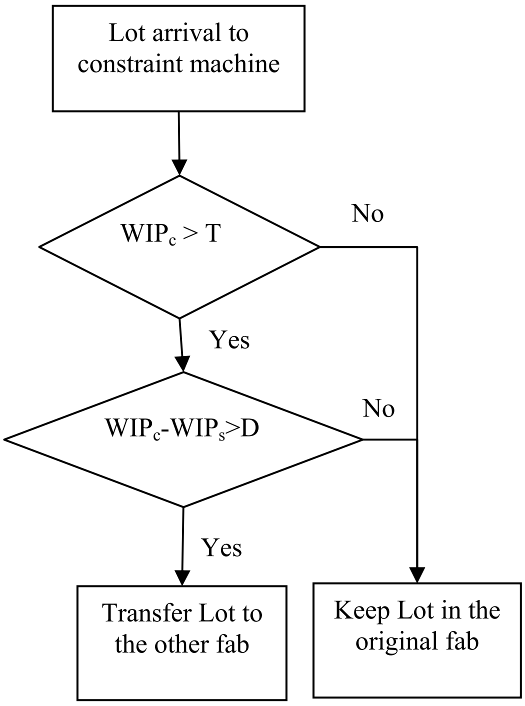

Figure 1: Flow chart of the capacity support control model

Based on the above flow chart, the decision point and control rules are as follows.

1) Decision points

The decisions should be made at the time of lot arrival at the constraint machine.

2) Control rules for capacity support

a. *Check the WIP amount in front of the constraint machines.*
   If, the WIP amount in front of the constraint machines is over the threshold (T), then go to the next step.
   Else, keep this lot in the original queue in front of constraint machines.
b. *Calculate the WIP amount difference between constraint machines and supporting machines*
   If, the WIP amount difference between the constraint machines and supporting machines is over the threshold D, then transfer this lot to the queue in front of supporting machines in the other fab.
   Else, keep this lot in the original queue in front of constraint machines.

III. CONCLUSION

In this work, a control model is established to well manage the issues of capacity support. There were two control thresholds, WIP amount threshold and difference of WIP amount threshold, developed in this control policy. One is the trigger for backup action and the other is set as a control gate. Through these two control rules, WIP can be well arranged among the twin fabs and be processed more efficiently and effectively. Finally, the production performances of twin fabs will be improved under the capacity backup policy.

Regarding to the future works, there are two points can be considered.

The first one is the selection of backup workstations. It is obvious that capacity backup will be occurred on bottleneck machines. However, capacity backup is necessary for the unstable workstations. How to identify the unstable workstation and put them into the backup machines list are very important. Finally, the performance under capacity backup should be estimated. Based on the estimation results, some important planning such as order scheduling, wafer out date projecting can be well done.

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國科會補助計畫衍生研發成果推廣資料表

日期:2010/11/29

國科會補助計畫	計畫名稱：雙子星晶圓廠之生產支援決策模式	
	計畫主持人：杜瑩美	
	計畫編號：97-2221-E-216-031-MY2	學門領域：生產系統規劃與管制

無研發成果推廣資料

97 年度專題研究計畫研究成果彙整表

計畫主持人：杜瑩美	**計畫編號：**97-2221-E-216-031-MY2
計畫名稱：雙子星晶圓廠之生產支援決策模式	

成果項目			量化			單位	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）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	1	1	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	4	4	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	1	1	100%	人次	
		博士生	2	2	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	0	0	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

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。)	無

	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）

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）

本研究所提出之產能支援決策模式，包含投料決策、產能支援決策以及績效預估模式三階段，對於雙子星晶圓廠產能支援管控而言提供了一有系統且合理之參考依據，管理者定能更有效地解決雙子星廠晶圓廠的產能支援問題。

在半導體產業之中，唯有不斷的提升製程能力與提升生產之績效，方能在瞬息萬變的市場中佔有一席之地，因此如何快速的因應市場的變動，調整到最事宜的生產步調，如何安排製程的導入時程，使的公司在轉換時仍然維持著一定的競爭水準，不至於導致更多的問題產生，實為後續相關研究可以進行探討之方向。

在實務方面，本計畫之成果提供雙子星晶圓廠對於產能支援決策的制定上能有所憑藉；在學術上，本研究提供一套以等候理論應用於雙子星晶圓廠之車輛配置與產能支援決策之概念。

本研究之主要成果分述如下：

1.考量雙子星晶圓廠與自動化傳輸系統的負荷問題，並針對雙子星晶圓廠內之生產規劃，提供一個有系統化且合理化之思考與解決邏輯。2.從生產系統績效的角度思考，對於傳輸系統產能的配置進行估算，避免過去及時性的傳輸決策，所可能導致的系統工作負荷過大問題。3.提出以等候理論為基礎之雙子星晶圓廠產能支援績效預估模式。4.利用 eM-Plant 7.0 呈現與建構雙子星晶圓廠之製造過程與特性，以提供後續相關之研究平台。