行政院國家科學委員會專題研究計畫 成果報告

RFID 系統發展及產業應用--子計畫四：以 RFID 為基之半導體供應鏈監督與控制之研究(3/3)

研究成果報告(完整版)

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行政院國家科學委員會專題研究計畫成果報告

RFID 系統發展及產業應用

子計畫四：以 RFID 為基之半導體供應鏈監督與控制之研究(3/3)

Monitoring and Control of Semiconductor Supply Chains with RFID-based Information (3/3)

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摘要

半導體產業供應鏈具有高度垂直分工的特性，上下游不同的企業所追求的目標不一，再加上前端成員較為強勢，造成供應鏈內部各成員力量大小不同，導致整個供應鏈被分割為許多片段，而無法對顧客的訂單進行有效的監控。而隨著新技術的發展，例如 RFID 的導入，許多資訊可以更即時取得，因此如何運用這些即時的資訊來重新調整半導體供應鏈內各成員的作為，以提昇供應鏈內協同合作便成為一個重要的研究課題。

本三年計畫旨在以半導體產業為研究平台進行三大研究議題：(1)建立以 SCOR 與 RFID 為基礎之供應鏈績效監督指標；(2)建構描述供應鏈行為的監督模式；(3)發展以 RFID 為基礎的控制機制。第三年的重點在於結合 RFID 所提供的資訊與第二年所提出的層級監督模式，發展以前端為基礎之半導體供應鏈監控模式。已完成之具體的工作成果分為(1)建構以前端為主之二層級監控模式；(2) 發展 CONWIP 控制方式與模式求解；(3) 設計模擬情境與進行模式比較。

經由模式驗證結果可有下列結論：本研究以層級在製存貨取代階段在製存貨作為監控上界，使整體供應鏈系統於在製存貨量較低的情況下同時具有較佳的服務水準。

關鍵詞：無線射頻識別、半導體供應鏈、監控機制、層級在製存貨

Abstract

Semiconductor industry in nature has a fragmented supply chain and each member of supply chain with different power pursues for different goals. Therefore, there is a need to improve the performance of the whole supply chain and integrate the front-end and back-end to meet customer on-time delivery. As more real-time information such as RFID information is available, how firms adopt real-time information to improve collaboration in semiconductor supply chain has become an important research area.

The goals of this three-year research are to: (1) design SCOR-based and RFID-based supply chain performance monitoring metrics, (2) construct a RFID-based supply chain monitoring model, and (3) develop RFID-based control schemes. In the third year, we have completed three major tasks: (1) construct a forward echelon-based monitoring model, (2) develop CONWIP control method and solution procedures, and (3) design scenarios and conduct simulations to compare the performance of different control schemes.

Based on the validation results, we conclude that the proposed control scheme obtains a higher service performance compared to the traditional method.

Keywords: RFID, Semiconductor Supply Chain, Monitoring & Control, Echelon WIP Inventory

研究目的

在第三年的計畫中，旨在建立半導體供應鏈的監控模式，考量到半導體產業的生產特性與內部力量大小的不同後，結合 RFID 所提供的資訊與第二年所提出的層級監督模式，發展以前端為基礎之半導體供應鏈監控模式。而第三年的所完成的事項分別為：(1)建構以前端為主之二層級監控模式；(2) CONWIP 控制方式與二層級模式之求解；(3)設計模擬情境與進行模式比較。在發展第三年的供應鏈監督模式前，模式中所發展之監控方法必須藉由 RFID 所提供之資訊來完成。此外，模式建立中所需的一些資料亦必須藉由 RFID 來進行蒐集並且加以分析。根據第一年所規範出的資訊中，下列資訊為接下來發展之供應鏈監控模式所需之資訊：

1. Object ID、Route 以及 Location 之資訊：這些資訊為提供監督供應鏈中各個階段以及層級中的在製存貨水準所需之資訊。
2. Cycle time：提供每個階段或是每個層級中進行製造所需的週期時間資訊，主要做為模式的輸入用，從蒐集到的資料中來分析生產週期的分配為何以及所對應的參數，以及在製存貨水準與生產週期之間之關係。
3. Lot status：在模式應用時使用的資訊，記錄 lot 在供應鏈中的不同狀態，例如：在製程中、完成品、半完成品、被阻擋進入生產系統以及在途存貨等等。

有了這些資訊，接下來就可以建立以層級存貨與 CONWIP 系統這兩種概念為基礎而發展的供應鏈監控模式。第三年的研究中所完成的事項如下列所示：

成果 1：建構前端為主之二層級監控模式

以下所要建立的以前端為基礎之二層級監控模式為一以最小化整體之在製存貨為目標式，同時要滿足兩種服務水準之二層級監督模式[1]。層級(echelon)在製存貨的概念不同於以往傳統的階段(stage)存貨概念，從傳統的階段存貨只考慮某階段內的存貨量，並且進行監督與控制。然而層級存貨則是包含某階段到最終階段之內的所有存貨，兩者之間的關係如圖 1 所示：

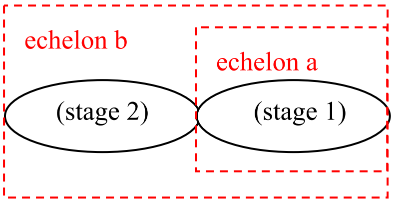

圖1　供應鏈階段點與層級關係圖

然而在半導體產業當中，前端製造廠中的製程相當繁雜同時所需的製造時間也很長，使得製造廠在晶圓生產上扮演著重要角色，相對來說就顯得較為強勢，也因此造成供應鏈內部成員控制力量大小不一，所以依照半導體的生產特性與前端力量較大的情況，由前端主導供應鏈的整合相對的會比較符合產業的情況。因此以前端為基礎的情況下，發展層級的概念如圖 2 所示：

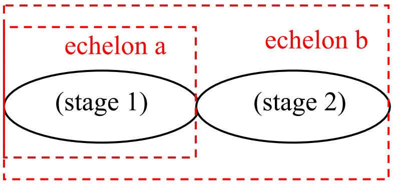

圖2　階段點與以前端為基礎之層級關係圖

接下來將生產路徑依照生產流程依序分成階段 1 晶圓製造與針測(Fab/CP)、階段 2 封裝測試(Assembly/FT)兩部分。而層級 a 包含階段 1，層級 b 包含階段 1, 2。模式所需之假設條件整理如下：

1. 單一生產路徑只生產一種產品類型，且將其視為多層級序列性生產系統。
2. 將時間分割成時間欄位並可根據情況調整時間單位。各階段之間在製品屬於非連續性傳遞，每期結束後會將在製品成批地移至下一階段。
3. 需求從顧客端產生且需求量服從常態分配，期與期之間的需求量相互獨立，但是階段之間的需求總量有可能會互相影響。
4. 在不同層級中在製存貨的生產週期時間與該層級中的在製存貨水準的關係採用 Chen et al.(2001)之假設，而分配之平均數以及變異數各為在製存貨水準之兩階段之片段線函數。於此模式中生產週期時間採用常態分配之假設，實際情況可依據由 RFID 所蒐集到之資訊進行調整。

5. 模式中採用規劃生產時間(planned lead time)之概念，某階段之在製存貨只有在其規劃生產時間到達時，才會轉交給下一個階段並不會提前轉交。亦即假設規劃生產時間為 10 期，而在製存貨於第 9 期時完成，也會在第 10 期才轉交給下一階段進行皆下來的生產。
6. 假設當層級在製存貨之水準未到達該層級所設置的在製存貨上界時，系統中的生產週期不會超過設定之規劃生產時間。然而當系統中的在製存貨到達在製存貨上界時，會有一定比例之在製存貨的生產週期超過規劃生產時間。
7. 本模式採用 CONWIP 控制方式，當在製存貨欲進入下一個層級時，若是系統中的在製存貨會因此超過所設定之層級上界，多餘之部分會暫時無法進入該階段，而在下一個時期時優先進入下一個階段。

在模式中的相關的註標、參數和變數如下所示，其關係可以參考圖 3。

<u>註標說明</u>

t：時間註標

n：每個生產的階段註標

m：層級註標

<u>輸入變數說明</u>

D_t：在 t 時期時的需求，而且需求服從常態分配。

$D_t \sim N(\mu,\sigma^2)$

X_n：在規劃時間中階段 n 所需滿足的需求總和。

ρ：X_1, X_2 的相關係數。

l_n：階段 n 的規劃生產時間。

B：共同阻擋在製存貨的期望數量。

α：每段期間中，顧客需求可完全被滿足之比率。

γ：顧客需求量可以被滿足之累積數量比率。

ε：降低整體在製存貨上界之貢獻比率

<u>決策變數</u>

Z_m：以第二階段面對之需求 X_2 為基準標準化後之層級 n 之在製存貨上界

<u>其他符號</u>

ST_n：在階段 n 的在製存貨界線。

S_m：以層級觀點來看的層級 m 的在製存貨界線。

M：$\dfrac{\mu}{Var^{1/2}(X_2)}$

V：$\dfrac{Var^{1/2}(X_1)}{Var^{1/2}(X_2)}$

A：代換 ρ, V 所引入之代數

$\psi(\cdot,\cdot;\zeta)$：兩變數的相關係數為 ζ 之標準化二元常態累積機率密度函數

$\phi(\cdot)$：標準化常態機率密度函數

$\Phi(\cdot)$：標準化常態累積機率密度函數

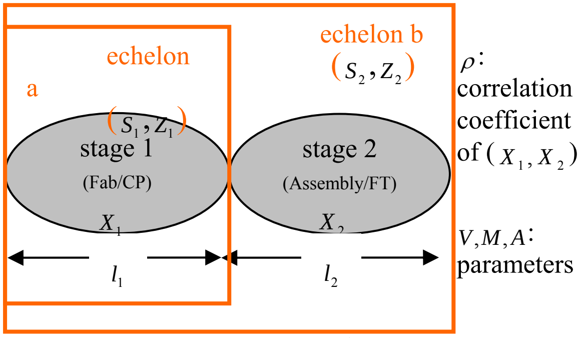

圖 3 模型參數

<u>二層級在製存貨監督模式</u>

Minimize

Z_2

Subject to

$$\overline{Z}_1 \le \overline{Z}_2 + l_2 \cdot M$$

$$\alpha \le \psi\left(\frac{f(\overline{Z}_1)}{V}, \frac{f(\overline{Z}_2)}{\sqrt{A}}; \frac{\rho+V}{\sqrt{A}}\right)$$

$$\begin{aligned}(1-\gamma)M \ge{}& \sqrt{A}\cdot\phi\left(\frac{f(\overline{Z}_2)}{\sqrt{A}}\right) - f(\overline{Z}_2)\cdot\left\{1-\Phi\left(\frac{f(\overline{Z}_2)}{\sqrt{A}}\right)\right\}\\ &- f(\overline{Z}_1)\cdot\left(\Phi\left(\frac{f(\overline{Z}_2)}{\sqrt{A}}\right)-\alpha\right)\\ &+V\phi\left(\frac{f(\overline{Z}_1)}{V}\right)\cdot\Phi\left(\frac{V\cdot f(\overline{Z}_2)-(\rho+V)\cdot f(\overline{Z}_1)}{V\sqrt{1-\rho^2}}\right)\\ &-V\left(\frac{\rho+V}{\sqrt{A}}\right)\cdot\phi\left(\frac{f(\overline{Z}_2)}{\sqrt{A}}\right)\left\{1-\Phi\left(\frac{A\cdot f(\overline{Z}_1)-V\cdot(\rho+V)\cdot f(\overline{Z}_1)}{V\cdot\sqrt{A}\cdot\sqrt{1-\rho^2}}\right)\right\}\end{aligned}$$

Where,

$$f(\overline{Z}_1) = \overline{Z}_1 - B - \left(1-\Phi\left(\frac{\overline{Z}_1}{V}\right)\right)\times\overline{Z}_1\times\frac{1}{8}erfc\left(\frac{\Phi^{-1}(\alpha_c)}{\sqrt{2}}\right)^2$$

$$f(\overline{Z}_2) = \overline{Z}_2 - B - \left(1-\Phi\left(\frac{\overline{Z}_2}{\sqrt{A}}\right)\right)\times\overline{Z}_2\times\frac{1}{8}erfc\left(\frac{\Phi^{-1}(\alpha_c)}{\sqrt{2}}\right)^2$$

$$B = V\cdot\phi\left(\frac{\overline{Z}_1}{V}\right)\cdot\left\{\Phi\left(\frac{\overline{Z}_2-\left(1+\frac{\rho}{V}\right)\cdot\overline{Z}_1}{\sqrt{1-\rho^2}}\right)\right\}$$

$$+\phi\left(\overline{Z}_2-\overline{Z}_1\right)\cdot\left\{1-\Phi\left(\frac{(1+\rho V)\overline{Z}_1-(\rho V)\cdot\overline{Z}_2}{V\sqrt{1-\rho^2}}\right)\right\}$$

$$+\sqrt{A}\cdot\phi\left(\frac{\overline{Z}_2}{\sqrt{A}}\right)\cdot\left\{1-\Phi\left(\frac{\frac{(\rho+V)\cdot V\overline{Z}_2}{\sqrt{A}}-\sqrt{A}\cdot\overline{Z}_1}{V\sqrt{1-\rho^2}}\right)\right\}$$

$$-\overline{Z}_1\cdot\left[\Phi\left(\overline{Z}_2-\overline{Z}_1\right)-\psi\left(\overline{Z}_2-\overline{Z}_1,\frac{\overline{Z}_1}{V},\rho\right)\right]$$

$$-\overline{Z}_2\cdot\left[1-\alpha-\Phi\left(\overline{Z}_2-\overline{Z}_1\right)+\psi\left(\overline{Z}_2-\overline{Z}_1,\frac{\overline{Z}_1}{V},\rho\right)\right]$$

原本二層級的模式主要是應用在配銷系統以及存貨的背景上，所以其層級概念為由後端往前端推展；但是，考量了半導體生產特性與前端較為強勢的情況後，以前端為基礎的層級模式則是由前端往後端推展層級，同時再將生產週期與在製存貨水準的關係與 CONWIP 控制方法的影響等生產系統的特性納入模式之中，則以前端為基礎之二模式簡述如下：

1.在以前端為基礎發展層級概念之模式中，層級存貨與服務水準間的關係：

在α服務水準中，顧客需求主要是以最終產品來滿足，因此必須對後端在製存貨水準進行估計，而在以前端發展層級模式的情況下，前端層級本身會有層級在製存貨上界，而由於後端的在製存貨估計和前端層級的需求總量有相關，所以為了能夠提供後端一個合理的在製存貨估計指標，就必須將前端的層級在製存貨上界與前端層級裡需求總量的關係納入考量，因此α服務水準與在製存貨水準關係為$\alpha\le\Pr\left\{\left[X_1+X_2<\overline{S}_2\right]\cap\left[X_1<\overline{S}_1\right]\right\}$。

而γ服務水準表示需求量可被滿足的累積數量之比率，相反的$(1-\gamma)\cdot\mu$代表了未滿足之需求數量，也就是說只要層級的需求量超過其所對應的層級上界時，便會發生無法如期滿足客戶的需求。因此，γ服務水準與在製存貨水準關係為

$$(1-\gamma)\cdot\mu=E\left(X_1-\overline{S}_1\mid A_1\right)\cdot\Pr(A_1)+E\left(X_1+X_2-\overline{S}_2\mid A_2\right)\cdot\Pr(A_2)$$

$$A_1=[X_1>\overline{S}_1]\cap[X_1+X_2<\overline{S}_2],\ A_2=[X_1+X_2>\overline{S}_2]$$

2.為了將生產週期與在製存貨之間的關係納入考量，模式中以下列方程式來估計兩者間的關係：

$$\begin{cases} N(\alpha_1+\beta_1 x_i,\ a_1+b_1 x_i) & if\ x_i\le\omega \\ N(\alpha_2+(\beta_1+\beta_2)x_i,\ a_2+(b_1+b_2)x_i) & otherwise \end{cases},$$

上述方程式主要是從生產的觀點(production view)來表示在製存貨與生產週期的關係。而在給定欲達到的服務水準下，下列的方程式可用來估計當系統中的生產時間為l時，為了達成給定的服務水準系統所需的最小在製存貨水準：

$$l\cdot\mu_D+\phi^{-1}(\alpha)\cdot\sqrt{l}\cdot\sigma_D$$

此方程式是以需求觀點(demand view)來表示兩者之間的關係。因此，模式中採用解上述兩方程式之連立方程式做為模式規劃生產時間之適當估計值，其示意圖如圖 4。

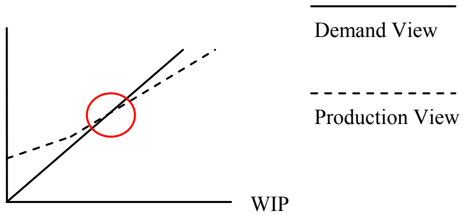

圖4　規劃生產時間之估計

3.由於模式採用 CONWIP 控制方式，所以當在製存貨到達監控上界時，多餘的在製存貨會被阻擋在生產系統之外，直到下一期會有優先的順序進入系統當中。而在以前端為基礎之模式中，當系統準備投料時所面對的是層級一與層級二的上界，也就是要分別計算投入的需求量會否造成層級一與層級二超過其所對應的層級上界。而當有多餘的在製存貨被阻擋再系統外時，會對後期預定進入系統的需求造成影響，所以必須將其納入模式考量，也就是利用$Max\left\{X_1-\overline{S}_1,X_1+X_2-\overline{S}_2,0\right\}$來進行估計；此外，當系統較為滿載時，部分在製存貨的生產週期可能超過規劃生產時間而留系系統中，因此也必須將此延遲的在製存貨所造成的影響納入考量。利用$1-\Phi(Z_n)$的部分來估計當在製存貨超過監督上界的機率，而當系統中的在製存貨水準到達監控上界時造成部分在製存貨之生產週期過長之影響，由$Z_n\frac{1}{8}erfc(\frac{l'}{\sqrt{2}})^2$ 進行估計。

成果 2：CONWIP 控制方式與二層級模式之求解

利用層級在製存貨上界作為監督指標，再結合 CONWIP 的控制方式，藉此控制系統的在製存貨水準維持在一定的水準之下。而為了使系統能滿足所需要的服務水準，可以增加在製存貨上界以包函更多的需求量進入系統進行生產以滿足客戶。然而，當在製存貨上界增加的同時，所包含的在製存貨水準也會逐漸提升，而過多的在製存貨會造成生產週期過長與變異的增加。因此，希望能以較低的整體在製存貨上界來滿足所需的服務水準，讓系統對生產週期有更好的掌控與降低在製存貨成本的積壓。

為了要降低整體之在製存貨控制上界，可以藉由將內部層級之服務水準設定高於整體之服務水準，使的整體之在製存貨水準降低。而在以前端為基礎之二層級模式當中，當有新的需求或是物料要進入系統時，所面對的監控機制就是必須同時考量展層級一和層級二的在製存貨上界，藉此來共同決定新的需求或是物料能夠進入系統的數量，所以對系統來說，可以先把安全的在製存貨配置到層級一，也就是說逐漸提高層級一的在製存貨上界，讓層級一產生阻擋需求的效果逐漸降低，而在這樣的情況下，這時候在配置層級二的安全在製存貨時，就比較不用考慮到層級一的阻擋影響而能專注在配置最小的安全在製存貨上界於層級二來滿足所需的服務水準。一般來說，由於半導體產業中前端製程相當複雜且製程時間較長，因此在半導體產品能否順利產出扮演著重要的角色，因此也就必須配置較多的安全在製存貨上界於前端，讓其能夠順利的產出以滿足客戶的需求。因此，藉由提升前端的層級之服務水準，有助於降低整體在製存貨監督上界。

然而，提高內部層級之服務水準的提升不只導致內部層級在製存貨監督上界的增加，同時也會增加內部層級之規劃生產時間。雖然提高內部之服務水準有助於降低整體之在製存貨水準，但是也並非無限制的增加內部層級之服務水準以及在製存貨上界。因此當增加內部層級的服務水準，對於降低較大層級的在製存貨水準之貢獻度小於ε時，我們將會停止增加內部服務水準來換取整體在製存貨水準之降低。

在求解二層級監督模式的部分，因為系統中的生產時間會受到系統中的在製存貨水準的影響，所以採用以下的流程來進行求解：

步驟一：藉由解下列之方程式以求得每一個層級初始的規劃生產時間來當作模型之輸入。

$$\begin{cases} l\cdot\mu_D+\phi^{-1}(\alpha)\cdot\sqrt{l}\cdot\sigma_D= \\ \alpha_1+\beta_1x_i+\phi^{-1}(\alpha_c)\sqrt{a_1+b_1x_i} & if\ x_i\le\omega \\ l\cdot\mu_D+\phi^{-1}(\alpha)\cdot\sqrt{l}\cdot\sigma_D= \\ \alpha_2+(\beta_1+\beta_2)x_i+\phi^{-1}(\alpha_c)\sqrt{a_2+(b_1+b_2)x_i} & otherwise \end{cases}$$

步驟二：先藉由設定$\overline{Z}_1=\Phi(\alpha_1)\cdot V$與$\alpha_1=\alpha$來求解$\gamma$限制式。

而讓$\overline{Z}_1=\Phi(\alpha_1)\cdot V$的原因是因為由$\alpha$限制式可看出對層級一而言必須要$Vx_1\le\overline{Z}_1$，其中$x_1$是本身層級一標準化過後的數值，所以由層級一的角度來看，滿足層級一達到α_1的累積機率所對應的 Z 值為$\Phi(\alpha_1)$，所以可以知道$x_1\le\dfrac{\overline{Z}_1}{V}=\Phi(\alpha_1)$，也因此先設定$\overline{Z}_1=\Phi(\alpha_1)\cdot V$為初始值來代入$\gamma$限制式求解。而由於要藉由提升內部服務水準來降低整體在製存貨水準，所以一開始的內部服務水準就以整體的服務水準作為初始值，也就是$\alpha_1=\alpha$。而在逐漸增加內部服務水準的過程當中，不能無限制地增加，而由於從存貨累積機率來看，當超過 3.5 時對累積機率增加的貢獻度很少，所以限制$\Phi(\alpha_1)$小於 3.5，也就是$\overline{Z}_1\le 3.5\cdot V$。藉此來求解對應$\gamma$限制式之下的$\overline{Z}_2$。

步驟三：利用步驟二的初始結果，以二元搜尋法來逐步增加$\overline{Z}_1$以降低$\overline{Z}_2$，同時計算其貢獻度。

首先設定初始內部服務水準為下界，1 為上界，以$New\ probability=0.5\cdot(upper\ bound+lower\ bound)$的方式得到新的內部服務水準，接著計算$\gamma$限制式求得$\overline{Z}_2$。並藉由

$$Contribution\ percentage=\frac{\left(\dfrac{Decrease\ WIP\ quantity}{Overall\ WIP}\right)}{New\ probability-lower\ bound}$$

之方法計算其貢獻比率，如果貢獻比率大於 0.01 或是服務水準的上下界差距大於 0.005 的時候，則繼續增加$\overline{Z}_1$以降低$\overline{Z}_2$，反之則停止提升內部服務水準而以下界作為最佳的內部服務水準。而在得到所求的$\overline{Z}_1$與$\overline{Z}_2$後，接著進一步檢查α限制式是否滿足，如果α滿足，則跳到步驟四;若沒有滿足，則代表要增加$\overline{Z}_2$，也就是要配置較多安全在製存貨上界於層級二，所以固定$\overline{Z}_1$後代入α限制式求出$\overline{Z}_2$值。

步驟四：由標準化之$\overline{Z}_1$與$\overline{Z}_2$來計算對應之在製存貨上界(S_m)。藉由下列之方程式來計算在此在製存貨上界所對應的生產週期時間

$$\begin{cases} N(\alpha_1 + \beta_1 x_i, a_1 + b_1 x_i) & if\ x_i \le \omega \\ N(\alpha_2 + (\beta_1 + \beta_2) x_i, a_2 + (b_1 + b_2) x_i) & otherwise \end{cases},$$

若是結果小於原模式求解之規劃生產時間則求得之在製存貨上界即為所求。反之，則將對應之層級規劃生產時間加 1，重新計算所需之參數回到步驟二重新計算。

成果 3：設計模擬情境與進行模式比較

根據上述之模式以及假設建立了一個模擬模式，並且依據上述模式所求出的在製存貨上界作為監督指標並進行 CONWIP 之控制，以幫助半導體供應鏈的整合與監控整體供應鏈之績效與服務水準。而由模式中所求出之在製存貨上界的結果如表 1 所示，而在半導體產業中，就生產特性而言，前端成員控制力量較大，且較為強勢，因此由前端來成員來主導供應鏈的整合會比較符合其產業的狀況；相對於傳統層級存貨的概念而言，主要是討論零售產業，所以以配銷系統為基礎，由後端發展層級存貨。所以由表 1 可以知道，在半導體產業中，由於前端製程時間比較長，後端比較短，所以由前端進行控制時，前端在製存貨水準就會比較高，且整體的在製存貨水準會比由後端進行控制的方式來的高一點，但是，藉由高一點的在製存貨上界來進行 CONWIP 的監控方式可以達到所需的服務水準與符合產業的特性。

而根據求出之在製存貨上界所進行模擬之結果如表2所示。藉由本研究所提出的以前端為基礎來發展層級存貨之監控模式，可以在相同或是更低的在製存貨水準下，達到較高的服務水準。這主要是因為以往傳統以階段為觀點之控制與監督，主要是各階段進行各自局部的資訊(local information)進行監督與控制。然而藉由RFID所提供之資訊，以層級觀點的監督與控制，是以供應鏈整體之資訊(global information)來進行監督與控制，因此能有較佳之結果。此外，從模擬的結果來看，在層級一配置之在製存貨水準相較於以階段觀點配置之在製存貨水準為高，這部份主要是利用前面所提的提高內部層級之服務水準，以降低整體的在製存貨監督上界概念之結果。

表 1: 在製存貨監督上界

Settings	$D_t \sim N(497.556, 112.2^2)$； $l_1 = 36, l_2 = 11$；$\alpha \ge 0.9$			
	ST$_1$	ST$_2$	S_1	S_2
Stage Based	18775 (100%)	5951 (100%)	18775 (100%)	24726 (100%)
Forward Echelon Based	19421 (103.44%)	5109 (85.56%)	19421 (103.44%)	24530 (99.2%)
Echelon Based	6184 (103.92%)	18284 (97.39%)	6184 (103.92%)	24468 (98.96%)

表 2: 模擬結果

	Forward-Echelon			Stage	
Echelon	WIP	Planned lead time	Stage	WIP	Planned lead time
1	19421	36	1	18775	36
2	24530	47	2	5951	11
Total WIP	24530	47	Total WIP	24726	47
Service level	alpha service level	gamma service level	Service level	alpha service level	gamma service level
Mean	0.91121	0.94657	Mean	0.79023	0.89245
Std	0.04424	0.03608	Std	0.05756	0.04911

參考文獻

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計畫成果自評

研究內容與原計畫相符
達成預期目標
研究成果適合在學術期刊與國際會議發表

經由模式驗證結果可有下列結論：本研究以層級在製存貨取代階段在製存貨作為監控上界，使整體供應鏈系統於在製存貨量較低的情況下同時具有較佳的服務水準。

2006 亞太工業工程與管理系統會議

郭瑞祥

台灣大學工商管理學系暨商學研究

一、參加會議經過

APIEMS (Asia Pacific industrial engineering and management systems conference)委員會是由36個來自澳洲、臺灣、中國、香港、日本、韓國、菲律賓和泰國等8個不同地區、國家的委員組成，成立的目的在提供亞太地區的學術界與實務界的交流平台，一方面讓學術界人士能夠有相互切磋、學習、討論彼此研究，以激盪出新研究主題的機會，另一方面也提供了學術界與實務界人士能夠相互對談的場合，藉以碰撞出許多研究的新火花，因此APIEMS為亞太地區頗負盛名的作業管理與管理科學界學術研討會。

「2006 亞太工業工程與管理系統會議（APIEMS2006）」於 12 月 17 日至 12 月 20 日在泰國曼谷舉行。此次會議輪由 Asian Institute of Technology (AIT)主辦，由 The Industrial Engineers Network (IENET) Thailand、Thai Researchers Consortium of Value Chain Management and Logistics (Thai VCML) 以及 Operations Research Network (ORNET) of Thailand 協辦。約有來自美、日、亞、歐等地的專家學者 300 餘人出席與會。本次會議共有 465 篇論文投稿，而最後共接受 308 篇論文。台灣大學計有 5 篇論文獲選，其中筆者有 4 篇論文獲選。

本次會議總計約有50餘位來自台灣的學界代表。筆者獲國科會同意補助與會，於12月17日下午赴美。12月18日起三天參加學術研討會，總計三天的會議中，全程參加大會各項分組會議，收穫頗為豐盛。筆者於12月20日晚會議結束後隨即搭機返國。

二、與會心得與建議

1.Keynote 演講部份

本屆共安排了四位Keynote講員，分別就下面主題發表演講:

- "Engineering School Accreditation in the United States of America: From Analysis of Curriculum Content to Assessment of Program Objectives and Outcomes - An American Experience and its Worldwide Applications" by Professor Mike Leonard, Mercer University, USA

- "Role of Industrial Engineers in Service Industry"

  by Dr. Ajva Taulananda, Vice Chairman of Chareon Pokphan Group and Vice Chairman of True Corporation, Thailand

- "Achieving Business Performance Excellence through a Comprehensive Quality Approach"

  by Mr. Ambrish K. Maheshwari, President, Thai Acrylic Fibre Company Limited, Thailand

- "Toyota Production System"

  by Mr. Kenji Miura, General Manager, Operation Management Consulting Division, Toyota Motor Corporation, Japan

2.論文分組部份

由於本屆發表論文眾多，因此分組的主題含括了：

- Computer Integrated Manufacturing
- Decision Modeling and Theory
- Demand Chain Management
- DSS and Expert Systems
- E-Business/Information Technology
- Engineering Economy
- Enterprise Resource Planning
- Ergonomics
- Flexible Manufacturing Systems
- Fuzzy Logics
- Group Technology
- Health Care Systems

- Industrial Automation
- Industrial Engineering Education
- Knowledge and Information Management
- Logistics and Supply Chain
- Management of Technology and Innovations
- Managing Global Supply Networks
- Mathematical Models
- Metaheuristics
- New Manufacturing Technology
- Operations Research
- Optimization/Artificial Intelligence
- Product Design and Development
- Production and Operation Management
- Quality Management
- Queuing Theory and Applications
- Reliability and Maintenance
- Scheduling and Sequencing
- Search Algorithms
- Simulation
- Supply Chain Management
- Sustainable Production & Development
- Tourism
- Transportation

等多個主題，筆者以參與的Session為主，心得如下：

(1). Supply Chain Management: Semiconductor Industry

在半導體供應鏈管理與方面，台灣大學共提出了3篇論文，引起許多討論與迴響。

(2). Supply Chain Management: Collaboration and Contracts

供應鏈的協同合作與契約設計方面，台灣大學也提出了2篇論文，也引起廣泛討論。

(3). Product Design & Development

在產品設計與開發方面，學者從不同面向切入，提出結合理論與實務的系統系思考方式，可供台灣業界與學界參考。

(4). 建議

a) APIEMS 目前為亞太地區工業工程與管理系統的重要的會議，為了提昇台灣的學術研究能量與研究能見度，應多鼓勵台灣學者專家參與此一盛事，與來自世界各地的學者交換意見與經驗。
b) APIEMS 2007 將由台灣雲科大主辦於高雄舉行，應廣為宣傳，吸引更多的學者能前來共襄盛舉。

三、攜回資料名稱及內容

1. APIEMS會議論文集之CD-ROM一片。

Monitoring Semiconductor Supply Chain based on Echelon WIP Inventory and CONWIP System

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Abstract. As the semiconductor industry faces more and more fierce competition, it is essential for semiconductor supply chain to integrate back-end and front-end to provide better service to customers. This research develops a semiconductor supply chain monitoring scheme based on the concept of echelon WIP inventory and CONWIP system. The first step in the proposed scheme is to construct a two-echelon model with the goal of minimizing the echelon WIP inventory control limits under target service levels. Next, this two-echelon model is extended to a multi-echelon model. The proposed scheme has been validated through simulation study. Based on the simulation validation results, conclusions are drawn as follows: 1) The proposed scheme can derive the multi-echelon WIP inventory limits effectively; 2) Compared to the traditional stage-based inventory monitoring scheme, the proposed echelon-based monitoring scheme can obtain higher service levels with lower inventory levels.

Keywords: Semiconductor Supply Chain, Multi-Echelon WIP Inventory, CONWIP

1. INTRODUCTION

The semiconductor supply chain has a vertical disintegration feature, and each member of supply chain chases for different goals which leads to the inefficiency of supply chain performance and the difficulty in monitoring it. Facing fierce competition along with the need to upgrade the service levels and improve the performance of the whole supply chain, it is necessary for all members to share their inventory information and synchronize their operations.

In a typical supply chain management, the supply chain network is designed and configured in the beginning. Once a supply chain routing is decided, the performance in each routing needs monitoring and control (Chiang *et al*. 2005). There are several performance metrics which can be developed for the needs of semiconductor supply chain. These include cycle time, WIP level, product throughput, delivery performance, capacity utilization, yield rates, and so on. However, from the entire supply chain point of view, WIP inventory is mostly easy to monitor and control.

There are two types of inventory control in supply chain management. In a stage-based inventory control system, inventory is managed at each stage only and inventory limits are determined by individual stage. However, in an echelon-based inventory control system, inventory is counted from the current stage to the last stage’s inventory and the inventory limits are determined by considering different stages altogether rather than a single stage. As shown in Fig. 1, echelon inventory takes the supply chain inventory into account and provides a better basis for supply chain coordination. However, most of the literature related to echelon inventory control has been focused on the logistics and distribution systems, in which lead time is usually fixed without considering of production constraint. This assumption is not applicable under a manufacturing-oriented supply chain such as in the semiconductor industry, in which lead time is dependent on the factory loadings (VoB *et al*. 2005). As a result, this research extends the traditional echelon inventory control method and applies it to the semiconductor manufacturing. In addition, the concept of CONWIP (Ovalle *et al*. 2005) is adopted for WIP monitoring and control. By combining the above concepts, this research is aimed to develop an effective supply chain echelon inventory control scheme in semiconductor manufacturing.

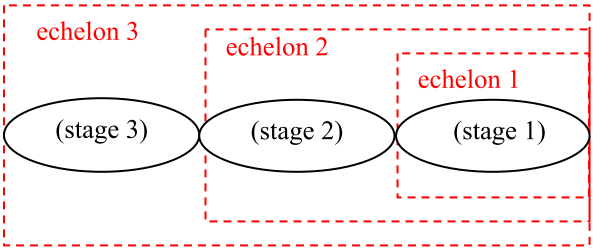

Fig.1: Definitions of stage and echelon inventory

In the following sections, we will first construct a two-echelon model with the goal of minimizing the echelon WIP inventory control limits under target service levels. Next, this two-echelon model is extended to a multi-echelon model. The proposed scheme is finally validated through simulation study. Based on simulation results, conclusions are then provided.

2. MODEL CONSTRUCTION AND SOLVING

Consider a typical semiconductor supply chain with three echelons and three stages as shown in Fig.2. We assume the following situations.

1. A production route, treated as a multi-echelon serial production system, manufactures one kind of product family.
2. Demands generate from the customer side and follow Normal distribution with correlations.
3. The mean and variance of the cycle time are functions of WIP level in each echelon (Chen *et al.* 2001).
4. Planned lead time，which means that the finished parts are transferred in fixed time after releasing into system, is related to the relationship between WIP level and cycle time and the required serviced level.
5. When the WIP level is below the upper limit, products can be manufactured within the planned lead time. If WIP level reaches the upper limit, production cycle time may exceed the planned lead time.
6. The control scheme adopts the CONWIP policy, so a lot cannot be released to the next stage if the WIP's upper limit is reached. The blocked lot has the highest priority to enter the system in the next period.

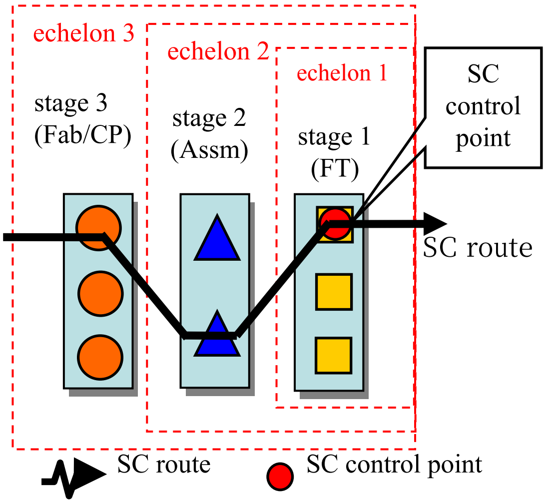

Fig.2: Supply chain network and routes

Indices and notations

t: time index.

n: the index of stage or echelon. In two echelon model, *n*=1 represents the stage that is close to customer side and *n*=2 represents the farer stage.

$\overline{\ }$: the index represents the echelon view.

D_t: the demand quantity in period t，which is also the quantity that must be delivered to customers. Assume that $D_t \sim N(\mu, \sigma^2)$.

ρ : the demand correlation coefficient.

x: WIP level.

l: cycle time.

l_n : the planned lead time of stage *n*.

$\overline{l_n}$: the planned lead time of echelon *n*.

S_n: WIP limits of stage *n*.

$\overline{S_n}$: WIP limits of echelon *n*.

$\overline{Z_n}$: Standardized WIP limits of echelon *n*.

α_c : the probability the cycle is less than the given value.

α : the fractions of periods in which the demand can be all satisfied.

γ : the fractions of demand quantities which the demand can be all satisfied.

$\Phi^{-1}(\cdot)$: the inverse function of the standardized normal distribution and the result is *Z* value.

$\phi(\cdot)$: the standardized p.d.f. of Normal distribution.

$\Phi(\cdot)$: the standardized c.d.f. of Normal distribution.

$\psi(\cdot,\cdot;\zeta)$: the standardized c.d.f. of bivariate Normal distribution with the correlation coefficient ζ .

erfc(x) : $\frac{2}{\sqrt{\pi}}\int_{x}^{\infty} e^{-t^2}\,dt$.

$\overline{Z_n}$: the standardized echelon WIP limit of stage *n*

2.1 Two-echelon Model

The multi-echelon is constructed based on a two-echelon model. Unlike the assembly and distribution systems, the production features are introduced by modifying the two-echelon model (Lagodimos *et al.* 1995) and adopting a load-dependent lead time relationship.

Minimize $\overline{Z_2}$

Subject to

$$\alpha \le \psi\left(f(\overline{Z_1}), \frac{f(\overline{Z_2})}{\sqrt{A}}; \frac{\rho \cdot V + 1}{\sqrt{A}} \right) \tag{1}$$

$$\begin{aligned}
&(1-\gamma)M \ge \sqrt{A}\cdot\phi\left(\frac{f(\overline{Z_2})}{\sqrt{A}}\right)\times \\
&\left[1-\Phi\left(\frac{f(\overline{Z_2})(\rho\cdot V+1) - f(\overline{Z_1})A}{V\sqrt{1-\rho^2}\sqrt{A}}\right)\right] - \rho\cdot\phi\left(\frac{f(\overline{Z_2}) - f(\overline{Z_1})}{V}\right)\times \\
&\left[1-\Phi\left(\frac{f(\overline{Z_1})(V+\rho) - \rho\cdot f(\overline{Z_1})}{V\sqrt{1-\rho^2}}\right)\right] + \phi\left(f(\overline{Z_1})\right)\times \\
&\Phi\left(\frac{f(\overline{Z_2}) - f(\overline{Z_1})(\rho\cdot V+1)}{V\sqrt{1-\rho^2}}\right) - f(\overline{Z_2})\cdot(1-\alpha) \\
&+ (f(\overline{Z_2}) - f(\overline{Z_1}))\times \\
&\left[\Phi\left(\frac{f(\overline{Z_2}) - f(\overline{Z_1})}{V}\right) - \psi\left(\overline{Z_1}, \frac{f(\overline{Z_2}) - f(\overline{Z_1})}{V}; \rho\right)\right]
\end{aligned} \tag{2}$$

$$\overline{Z_2} - \overline{Z_1} \ge 0 \tag{3}$$

Where

$$\overline{Z_1} = \frac{\overline{S_1} - (l_1)\mu}{Var^{1/2}(X_1)},\ \overline{Z_2} = \frac{\overline{S_2} - (l_1 + l_2)\mu}{Var^{1/2}(X_1)} \tag{4}$$

$$V = \frac{Var^{1/2}(X_2)}{Var^{1/2}(X_1)},\ M = \frac{\mu}{Var^{1/2}(X_1)} \tag{5}$$

$$A = V^2 + 2\rho\cdot V + 1 \tag{6}$$

$$\begin{aligned}
&f(\overline{Z_1}) = \overline{Z_1} - \left(1-\Phi(\overline{Z_1})\right)\times \\
&\left[\frac{e^{-\frac{\overline{Z_1}^2}{2}}}{\sqrt{2\pi}} - \frac{1}{2}erfc(\frac{\overline{Z_1}}{\sqrt{2}})\cdot\overline{Z_1} + \overline{Z_1}\cdot\frac{1}{8}erfc(\frac{\Phi^{-1}(\alpha_c)}{\sqrt{2}})^2\right]
\end{aligned} \tag{7}$$

$$\begin{aligned}
&f(\overline{Z_2}) = \overline{Z_2} - \left(1-\Phi(\frac{\overline{Z_2}}{\sqrt{A}})\right)\times \\
&\left[\frac{\sqrt{A}\cdot e^{-\frac{\overline{Z_2}^2}{2A}}}{\sqrt{2\pi}} - \frac{1}{2}erfc(\frac{\overline{Z_2}}{\sqrt{2A}})\cdot\overline{Z_2} + \overline{Z_2}\cdot\frac{1}{8}erfc(\frac{\Phi^{-1}(\alpha_c)}{\sqrt{2}})^2\right]
\end{aligned} \tag{8}$$

In the two-echelon model, the goal is to minimize the overall WIP limits under target service level. Notice that (1) and (2) describe the relationship between the WIP limits and the service levels. Equation (3) represents that the WIP limit of the larger echelon should exceed that of the smaller echelon. Equations (4)-(8) define relationships among some variables that will be used in the model.

Notice that in Equations (7) and (8), the probability that the WIP level reaches the WIP limit is estimated by the part as shown in (9), the expected quantities into the system which are blocked in the previous periods are estimated by the part as shown in (10), and the expected quantities which remain in the system because of their longer cycle time than the planned lead time are estimated by the part as shown in (11).

$$1-\Phi(\overline{Z_n}) \tag{9}$$

$$\frac{e^{-\frac{\overline{Z_n}^2}{2}}}{\sqrt{2\pi}} - \frac{1}{2}erfc(\frac{\overline{Z_n}}{\sqrt{2}})\overline{Z_n} \tag{10}$$

$$\overline{Z_n}\cdot\frac{1}{8}erfc(\frac{\Phi^{-1}(\alpha_c)}{\sqrt{2}})^2 \quad . \tag{11}$$

Because lead time is dependent on the loading condition in a manufacturing system, the initial planned lead time is estimated from two perspectives: production view and demand view. The production view, as shown in (12), shows the relationship between the WIP level and cycle time, where ω represents a critical value beyond which cycle time will increase at a higher rate.

The demand view defines the required WIP level to satisfy the service level, which is estimated by (13). By solving (12) and (13), the initial planned lead time is obtained (Fig. 3).

$$\begin{cases} N(\alpha_1+\beta_1 x, a_1+b_1 x) & \text{, if } x\le\omega \\ N(\alpha_2+(\beta_1+\beta_2)x, a_2+(b_1+b_2)x), & \text{otherwise} \end{cases} \tag{12}$$

$$x=\mu_D+\Phi^{-1}(\alpha)\cdot\sigma_D$$
$$\text{where } \mu_D = l\cdot\mu \;\; ; \; \sigma_D = Var(\sum_l X) \tag{13}$$

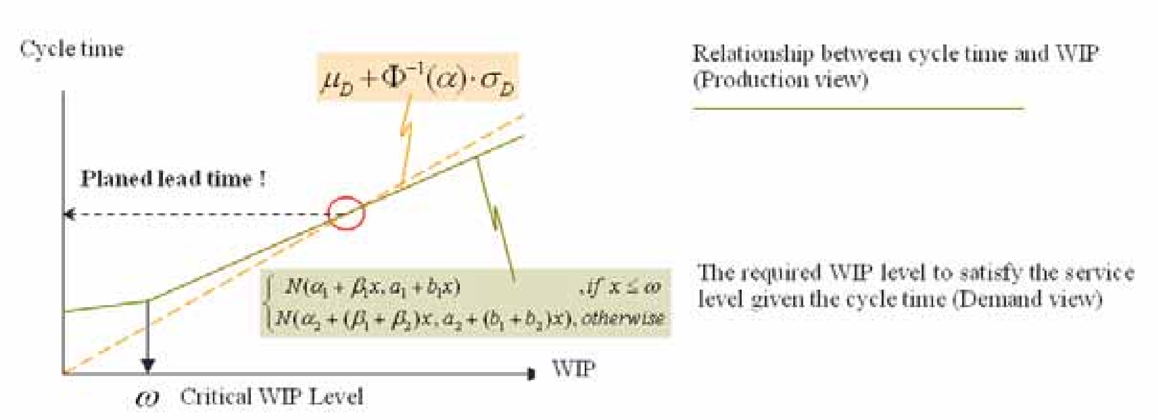

Fig. 3: Estimation of planned lead time

2.2 Solving Two-echelon Model

The model is solved by solving service constraints and then we check if the cycle time exceeds the corresponding lead time. After obtaining the WIP limits for both echelons from the two constraints, the corresponding cycle time is derived from equation (12). If the cycle time exceeds the planned lead time, the lead time is increased by one period and the model is resolved again. Details of the algorithm are shown below:

Step 1: Solve Equations (12) and (13) for each echelon and obtain the initial lead time as the model input.

Step 2: Solve $\alpha\le\psi\left(f(\overline{Z_1}),\frac{f(\overline{Z_2})}{\sqrt{A}};\frac{\rho\cdot V+1}{\sqrt{A}}\right)$ by setting $\overline{Z_1}=\overline{Z_2}$. If the derived $\overline{Z_1}$ is larger than a pre-determined number *c*, set $\overline{Z_1}$ = *c*. The equation is solved again to obtain the new $\overline{Z_2}$.

Step 3: Use results from step 2 to check if the γ constraint is satisfied. If γ constraint is satisfied, go to Step 4. If not, then change the values of $\overline{Z_1}$ and $\overline{Z_2}$ based on the value of ρ :

(1) If $\rho\ge 0$, decrease $\overline{Z_1}$ by *d* and solve

$$\alpha=\psi\left(f(Z_a),\frac{f(Z_b)}{\sqrt{A}};\frac{\rho\cdot V+1}{\sqrt{A}}\right)$$

to obtain new $\overline{Z_2}$. Repeat the procedure until the γ constraint is satisfied.

(2) If $\rho<0$, increase $\overline{Z_1}$ and $\overline{Z_2}$ by *d* and check if the γ constraint is satisfied. Repeat the procedure until the γ constraint is satisfied.

Step 4: Calculate the WIP monitoring limit ($\overline{S_n}$) from $\overline{Z_n}$. Check the corresponding cycle times for each echelon. If the corresponding cycle time (production view) is smaller than the lead time (demand view) in the model, the WIP monitoring limit is obtained. Otherwise, increase the lead time by one period and go back to step 1.

2.3 Multi-echelon Model

Next, this two-echelon model is extended to a multi-echelon model through a backward iteration algorithm and searching for the proper internal service level. This is illustrated in Fig. 4. By solving a two-echelon model (echelons 1 and 2), WIP limits can be obtained. Then by solving the model iteratively (echelons 2 and 3), the WIP limits for multi-echelon can be obtained. It should be mentioned that when extending to a multi-echelon model, the service level in a smaller echelon (echelon 1) should be set higher than that of a larger echelon (echelon 2) (Fig. 5). This is due to the fact that the downstream stage which has to face and absorb the uncertainty from upstream usually has tighter tolerances to meet customers' demands.

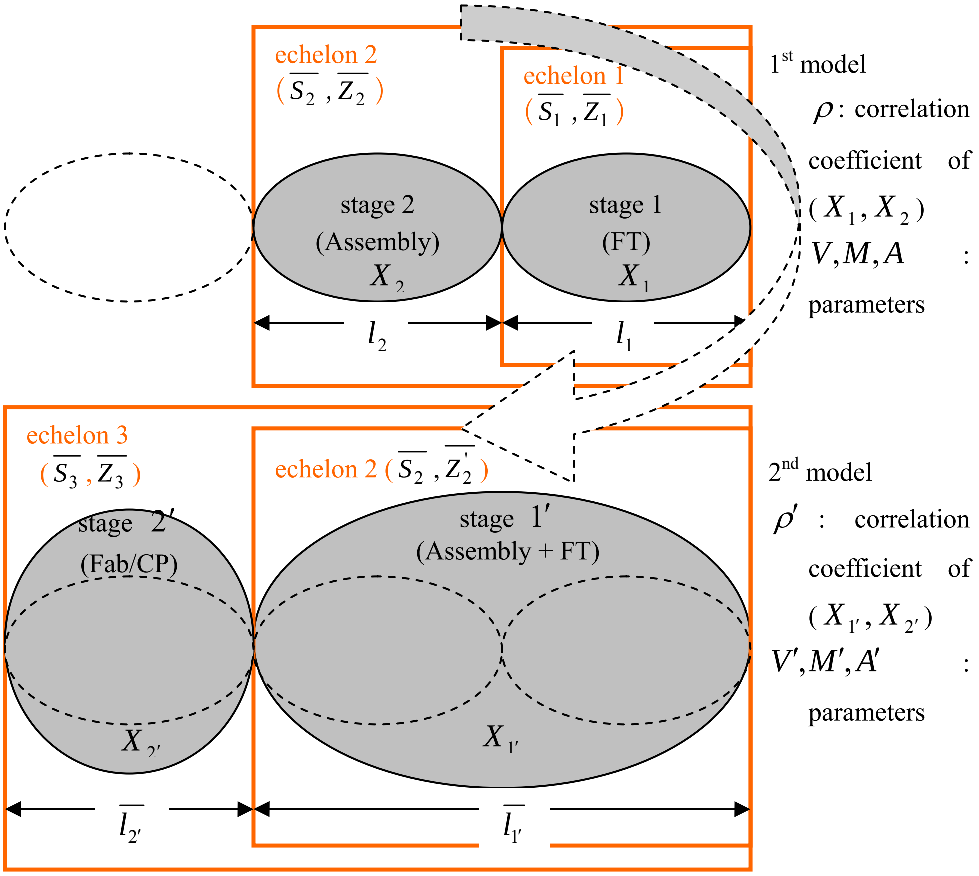

Fig. 4: Extending a two-echelon model to a multi-echelon model

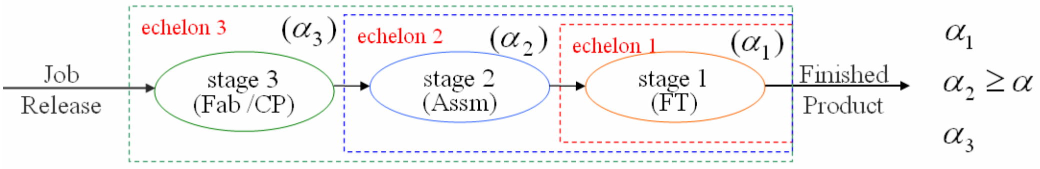

Fig. 5: Setting internal service level

3. SIMULATION VALIDATIONS

The proposed monitoring scheme has been validated through simulation study. In the simulation study, a scenario is designed which consists of three stages and demand is defined as $D_t \sim N(497.6, 112.2^2)$. Also we design $\alpha \geq 0.9$, $\gamma \geq 0.95$, and $\alpha_c = 0.97$. The relationships between WIP level and cycle time at three echelons are defined as:

$$1\text{st.}\begin{cases} N(2.5+0.0005\cdot x, 0.0002+0.000007\cdot x), x \leq 4000 \\ N(1.3+0.0008\cdot x,, 0.00025+0.00013\cdot x), \mathit{otherwise} \end{cases}$$

$$2^{\text{nd}}.\begin{cases} N(5+0.000565\cdot x, 0.00025+0.00002\cdot x),\ x \leq 7462 \\ N(2.5+0.0009\cdot x, 0.00064+0.00032\cdot x),\ \mathit{otherwise} \end{cases}$$

$$3\text{rd}.\begin{cases} N(20+0.00035\cdot x, 0.0003+0.000035\cdot x),\ x \leq 15271 \\ N(2.5+0.0015\cdot x, 0.00065+0.0005\cdot x),\ \mathit{otherwise} \end{cases}$$

With these settings the corresponding WIP limits are calculated by using stage-based monitoring scheme and echelon-based monitoring scheme. Table 1 shows the results of the calculated WIP limits. There are several findings in analyzing Table 1.

The echelon WIP inventory based on the proposed echelon-based monitoring scheme is lower than the echelon inventory by the stage-based monitoring scheme. The inventory positions at each stage are quite different by both schemes. For example, in stage 1, inventory position by echelon scheme is higher than that by stage-based scheme.

Next we perform simulations with both monitoring schemes and the CONWIP control scheme. Results of the simulation are shown in Table 2. As can be seen in Table 2, with a lower supply chain inventory, the proposed echelon-based inventory control scheme can achieve higher service levels than the stage-based inventory control scheme. This result is due to the fact that echelon inventory is derived based on the global information of the whole supply chain while the stage-based scheme considers only the individual situation.

In addition, a careful study confirms that inventory in stage 1 in the echelon-based scheme has a higher inventory position and results in a lower blocking probability. Although the overall WIP limits are not significantly different between stage-based and echelon-based schemes, we could obtain better service levels in echelon-based scheme. This is due to the fact that more WIP limits are allocated to the smaller echelon, and these limits can still be shared in larger echelons.

Table 1: WIP limits of different schemes

	Stage-based scheme		Echelon-based scheme	
No.	Stage limits	Echelon limits	Stage limits	Echelon limits
1	3338	3338	3676	3676
2	2809	6147	2508	6184
3	18774	24921	18284	24468

Table 2: Simulation results

View	Stage-based scheme	Echelon-based scheme
Total WIP	24921	24468
Service level	α service level	
Mean	0.698	0.878
Service level	γ service level	
Mean	0.873	0.918

4. CONCLUSIONS

According to the validation results, we conclude that: (1) The proposed scheme can be used effectively to derive the multi-echelon WIP inventory limits; (2) Compared to the traditional stage-based inventory monitoring scheme, the proposed echelon-based monitoring scheme can obtain higher service levels under the same inventory levels. This is the result of reallocating the WIP limits and the utilizing overall information.

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