行政院國家科學委員會補助專題研究計畫成果報告

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執行單位：國立交通大學工業工程與管理學系

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行政院國家科學委員會專題研究計畫成果報告

具應用性與優異性之晶圓針測排程問題演算法設計研究

Design of Algorithms with Applicability and Effectiveness for Solving the Wafer Probing Scheduling Problem (WPSP)

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一、中文摘要

在晶圓針測廠，工作可依產品類型分群組，並須在交期之前完成晶圓測試，其所使用的測試機台可視為多個群組的平行機台。此外，工作的處理時間隨產品而異，機台設置時間與所處理工作的次序是順序相關。晶圓針測排程問題因為具有順序相關之設置時間、工作產品群組、工作產品別相關之處理時間、交期、產能等限制，其求解比典型的平行機台排程問題更加困難。

為快速求解晶圓針測排程問題，本研究透過網路轉換方法，將此問題轉換為具時窗限制之車輛路線規劃問題，並應用車輛遞送演算法中的節約、插入等類型演算法，發展九種演算法可快速求解晶圓針測排程問題。並藉由文獻與實務四組問題的測試發現：待排程之工作的交期鬆緊度、工作的群聚性（產品群組），影響排程演算法求解的績效。當排程問題的交期較鬆時，可採用配對為基礎之節約演算法；當排程問題的交期較緊時，可採用配對為基礎之合併節約演算法，且這兩個演算法的績效並不受工作是否具有群聚性的影響。

此外，為驗證本研究的演算法之排程解接近最佳解，本研究已發展符合晶圓針測排程問題特性的整數規劃模式，並以求解整數規劃問題的軟體(Cplex)求得此問題的最佳解，並在面對較大之問題時，藉由不同的參數設定以在可接受的時間內找到績效不錯的可行解，本研究採用節點數限制以限制求解時間，透過節點選擇策略(depth-first)與變數選擇策略(strong branching rules)的參數組合，以在較短的時間求得較好的可行解。

關鍵詞：晶圓針測、平行機台排程問題、順序相關設置時間、演算法、整數規劃

Abstract

In the wafer probing factories, the jobs are clustered by their product types, which must be processed on groups of identical parallel machines and be completed before the due dates. The job processing time depends on the product type, and the machine setup time is sequentially dependent on the orders of jobs processed. Since the wafer probing scheduling problem involves constraints on job clusters, job-cluster dependent processing time, due dates, machine capacity, and sequentially dependent setup time, it is more difficult to solve than the classical parallel machine scheduling problem.

To solve the wafer probing scheduling problem (WPSP) in a short time, we transfer the wafer probing scheduling problem (WPSP) into the vehicle routing problem with time windows (VRPTW) and develop the savings and insertion algorithms with

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applicability for solving the WPSP quickly. We proposed nine algorithms for solving WPSP, based on the concept of network transformation, and the computational results of these nine algorithms are provided on four testing problems including one real-world WPSP case. The performance comparison of these nine algorithms on four testing problems reveals that the optional choice of either matching-based algorithm or matching-based with compound-savings algorithm proposed in this research, shall lead to relatively good schedule performance in the problems with due dates or job-cluster characteristics.

Besides, to ensure the solutions obtained from the algorithms being close to the optimal solution, we formulate the WPSP as an integer programming problem to minimize the total machine workload. With the help of integer programming software (Cplex), we can derive the optimal solution for WPSP. However, since the computation time relates to the system parameters of Cplex, we investigated the best combination for parameters setting to shorten the computation time for solving the optimal solution. We implement the depth-search strategy by choosing the most recently created node, incorporating with the strong branching rule causing variable selection based on partially solving a number of sub-problems with tentative branches to find the most promising branch. The implementation thus allows us to set various limits on the number of memory nodes so that feasible solutions may be obtained efficiently within reasonable amount of computer time.

Keywords: Wafer probing, Parallel-machine scheduling, Sequence-dependent setup time, Algorithms, Integer programming

二、緣由與目的

IC 測試廠的製程接續在 IC 封裝之後,其前置時間受封裝廠將 IC 送達之到達時間的影響,不同緊急程度的訂單插入勢必影響其它訂單的生產排程。所以最終測試廠必須有系統化之產能規劃與排程方法,在產能規劃/機台群組設定時即考慮緊急訂單的處理,才能避免緊急訂單對系統的干擾與衝擊。

針測機台是最終測試廠的主要製程機種,由於價格昂貴,機台產能利用率的高低是重要的績效指標。針測機台通常可處理多種產品,但處理不同的產品可能需要進行相關軟硬體的設置作業,並且測試批量的順序亦將影響設置時間的長短。

此外,晶圓針測廠的測試機台數目可能達到數十部,所包含的工作數量有上百個,如此複雜的排程問題,如何快速求得排程解是十分具有挑戰性的。因此如何發展求解晶圓針測排程問題的演算法,可在很短的時間內獲得可行解,並且減少設置次數與提高機台利用率之成效,是本計畫之研究動機。

因此,本研究的目的在於構建具有應用性與優異性的針測廠排程問題演算法之設計,重要工作內容列示如下:

1. 發展解決晶圓針測排程問題(WPSP)之具時窗限制之車輛路線規劃問題(vehicle routing problem With time window constraint; VRPTW)的近似解演算法,並對演算法內之函數重新設計,以縮短解題時間並提高排程解之品質。

2. 將晶圓針測廠之現場問題特性,在機台產能與服務時窗限制下,建構晶圓針測排程問題之整數規劃模式,以求得最小總機台負荷之最佳排程解。

3. 調整 Cplex 軟體內之各項參數,縮短利用整數規劃模式求得最佳解的時間。

三、結果與討論

本研究提出一網路轉換方法,將晶圓針測排程問題轉換為具時窗限制之車輛路線規劃網路問題;並且以一個實例說明此網路轉換過程。根據本研究所提出的轉換方法,我們成功的應用九個具時窗限制之車輛路線規劃問題的演算法,有效的求解晶圓針測排程問題。這九個演算法的績效也藉由學術上以及實務上的問題進行測試。當排程問題的交期較鬆時,可採用配對為基礎之節約演算法;當排程問題的交期較緊時,可採用配對為基礎之合併節約

演算法,且這兩個演算法的績效並不受工作是否具有群聚性的影響。

發展晶圓針測排程問題的數學規劃模式,在考慮工作產品群組、工作產品別相關之處理時間、交期、順序相關之設置時間、產能等因素下,提出目標函數為最小化總工作負荷之晶圓針測排程問題的整數規劃模式。

為測試所發展之整數規劃模式的可應用性,本研究以數學規劃軟體 CPLEX,結合有效的運算策略,求解一實務之晶圓針測排程問題,結果發現在可接受的時間內,此模式可求得此問題的可行解。以節點數限制以限制求解時間,透過節點選擇策略 (depth-first) 與變數選擇策略 (strong branching rules) 的參數組合,以在較短的時間求得較好的可行解。

四、計劃成果自評

1. 研究內容與原計畫相符程度
   90%
2. 本研究達成預期目標情況
   實驗原型或系統之建立、理論的推導或模式建立、人才培育、技術之新應用
3. 本研究成果之學術或應用價值
   極高
4. 本研究成果是否適合在學術期刊發表或申請專利之說明
   本研究成果可發表於國內外之期刊,但由於本研究成果非工程技術之研究,其成果不適宜申請專利。
5. 主要發現或其他有關價值
   本計畫主要探討晶圓針測的排程問題,針對現場每個工作群組包含多個工作、在工作的交期限制與包含工作處理時間及機台設置時間的產能限制之環境下安排排程,使其模式更接近實務狀況。
6. 綜評
   本計畫將指出如何將晶圓針測排程問題轉換為一個整數規劃(Inter Program)模式與一個具時窗限制的車輛路線規劃模式 (the vehicle routing problem with time windows; VRPTW)。藉由此兩種方式可得到由整數規劃所得之最佳解與車輛路線規劃其所發展的演算法之近似解,並衡量其求解之速度與求解之品質。對於現場之排程人員,本計畫將能迅速提供一個良好的排程判斷法則。

目前國內外對於針測廠排程問題的探討尚少,更缺乏針對針測廠特殊生管特性的排程演算方式。本研究對於針測廠特殊生管特性詳加考量,再運用整數規劃(Inter Program)模式與具時窗限制的車輛路線規劃模式 (the vehicle routing problem with time windows; VRPTW)針對排程問題的最佳解與近似解進行探討,務求解題時間的縮短及排程解的良好品質保證。因此本研究除在排程解的提供上可保證其準確性外,對針測廠的排程問題更有實務上的幫助。

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