An Algorithm for Exchanging Capacity in IC Foundry

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Abstract

Short-term capacity unbalance problem happens frequently in IC manufacturing. In order to meet the demand of new order, how to transfer the capacity of prescheduled orders to new order, and to achieve a triple-win situation among manufacturer, customers of prescheduled orders and new order is an important issue.

For this type of capacity exchange problem, the key is to develop a procedure to compute the degree of similarity between new order and prescheduled order, based on which the orders to be exchanged are determined. The similarity index proposed in this paper is computed as follows:

(1) For each workstation, calculate a score to indicate the similarity of load distributions between new order and given order.

(2) Degree of similarity between new order and prescheduled order is obtained by summing up the scores in (1) over all workstations.

The order with largest degree of similarity is chosen to exchange with new order. If the capacity of new order is not yet satisfied, the order with second largest similarity score is taken to exchange, etc.

1. Introduction

For accelerating the products to market and thus sharing marketplace as early as possible, the rush orders are frequently placed by the customers of an IC manufacturer. In consequence, the need of production rescheduling and capacity adjusting within a given period of time has arisen. Facing the problem of capacity shortage, traditional methods of capacity planning and production smoothing, such as overtime, stocking up, subcontracting, capacity expanding, etc. [1][3][4][5], are not applicable or difficult to cope with due to the distinctive nature of IC manufacturing systems.

In a close communication with an IC foundry in Hsin-Chu Science Park, we consider that exchanging capacity between new order and prescheduled orders could act as an alternative to alleviate the unbalanced problem of short-term capacity for a given planning horizon. It is necessary to point out that the capacity exchange defined here refers to the transfer of capacity of prescheduled orders into rush order in the same foundry, not the mutual relief among various plants in a multi-plant company as discussed in Bitran and Gilbert [1], and Gendron and Crainic [2]. For this type of capacity exchange problem, the key is to develop an algorithm to measure the degree of similarity between new order and prescheduled orders, based on which the orders to be exchanged are determined. For simplicity and practicability, the similarity between new order and prescheduled order is measured in accordance with their manufacturing processes for the products specified in orders. That is, we will utilize the load (processing time) projections at each time bucket in every workstation derived from manufacturing processes as the underlying criterion for the computation of degree of similarity. The detailed procedure of the algorithm is described in Section 2.

2. The Algorithm

In this section, an algorithm is presented for evaluating the degree of similarity between new order and a given prescheduled order based on their respective manufacturing process. At first, notations used in the algorithm are defined as follows:

m = number of time buckets.

n = number of workstations.

$\rho_{i,j}$ = load rate (i.e., the total processing time projected for all prescheduled orders divided by the total available time) of workstation i at time bucket j.

$p_{i,j}^{(k)}$ = accumulated processing time at time bucket j in workstation i for order k.

$d_i^{(k)}$ = workload difference for workstation i between new order and prescheduled order k.

$s_i^{(k)}$ = degree of similarity in workstation i between new order and prescheduled order k.

$s^{(k)}$ = degree of similarity between new order and prescheduled order k.

The algorithm is described as follows:

Step 1. Compute workload difference $d_i^{(k)}$*:*

We begin by comparing the load projection between order k and new order at each time bucket in workstation i. Define $\Delta p_{i,j}^{(k)}$ as the following:

$$\Delta p_{i,j}^{(k)} = \begin{cases} 0 & if \quad p_{i.j}^{(new\ \ order)} \le p_{i,j}^{(k)} \\ p_{i.j}^{(new\ \ order)} - p_{i,j}^{(k)} & if \quad p_{i.j}^{(new\ \ order)} > p_{i,j}^{(k)} \end{cases},$$

The values of $\Delta p_{i,j}^{(k)}$ are weighted by the corresponding load rate of workstation i at time bucket j and then are summed up over j to obtain the workload difference between order k and new order in workstation i. That is,

$$d_i^{(k)} = \sqrt{\sum_{j=1}^{m} w_{i,j}\left(\Delta p_{i,j}^{(k)}\right)^2}, \tag{1}$$

where,

$$w_{i,j} = \frac{\rho_{i,j}}{\sum_{l=1}^{m} \rho_{i,l}},$$

$$\rho_{i,j} = \frac{t_{i,j}}{TB},$$

$t_{i,j}$ = the total of accumulated processing time in workstation i on time bucket j for all prescheduled orders, i.e., $t_{i,j} = \sum_k p_{ij}^{(k)}$,

TB = the length of time bucket.

It is evident that $d_i^{(k)} = 0$ implying the load of new order can be fully satisfied in workstation i by deleting order k.

Step 2. Compute $s_i^{(k)}$

Let $\overline{d_i} = \sqrt{\sum_{j=1}^{m} w_{i,j} \left(p_{i,j}^{(new\ \ order)}\right)^2}$

then $\overline{d_i} \geq d_i^{(k)}$ for all k

We calculate the degree of similarity between order k and new order in workstation i as follow:

$$s_i^{(k)} = \left(1 - \frac{d_i^{(k)}}{\overline{d_i}}\right) \times 100\% \cdot \tag{2}$$

Step 3. Compute. $s^{(k)}$

In this step, the similarity scores between order k and new order in workstations are weighted by relative utilization rate of workstations, and then are summed up over all workstations to obtain the degree of similarity.

$$s^{(k)} = \sqrt{\sum_{i=1}^{n} w_i \left(s_i^{(k)}\right)^2}\ , \tag{3}$$

where,

$$w_i = \frac{\overline{\rho_i}}{\sum_{l=1}^{n} \overline{\rho_l}}\ ,$$

$\overline{\rho_i}$ = average utilization rate for workstation i.

The process is iterated from step 1 to step 3 until all prescheduled orders have been evaluated. Flow chart of the algorithm is depicted in Fig. 1. Based on the results of the algorithm, the prescheduled orders will be arranged in descending sequence in line with the similarity scores. The order with largest similarity score is chosen to exchange with new order. If capacity of new order is not yet satisfied, the order with second largest similarity score is taken to exchange, etc. The process is iterated in the same way until the capacity quantity required by new order is met.

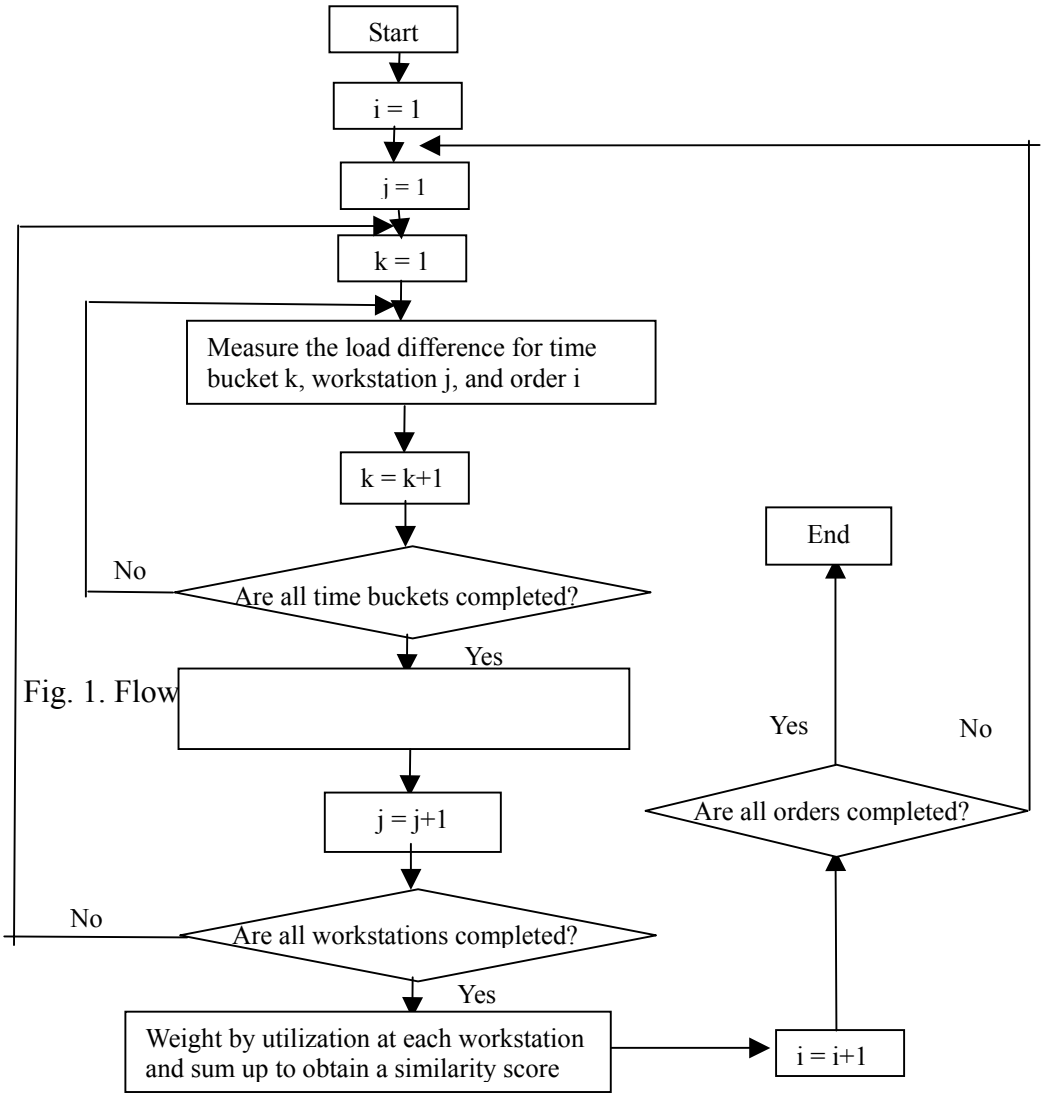

Fig. 1. Flow

3. Concluding Remarks

In this paper, a practical and simple algorithm for evaluating the degree of similarity between prescheduled order and new rush order, based on manufacturing process data, is developed. The main purpose of doing so is to assist production managers in IC foundry to solve the short-term unbalance problem when capacity demand exceeds supply, and thus the goal of "triple-wins" among capacity holder, capacity demander and manufacturer can be expected. That is, the capacity demander could obtain the capacity for production and speed up the time to market, the capacity holders could receive compensation from demander and cover its potential loss from giving up the capacity, and the manufacturer could achieve better capacity utilization and customer service.

ACKNOWLEDGEMENT

The research is jointly supported by National Science Council, Taiwan, R.O.C. and United Microelectronics Corp. under contract no. NSC-90-2622-E-009-001.

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