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The implementation of an activity-based costing collaborative planning system for semiconductor backend production

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While the market turns to an environment with low profit margins for semiconductor backend operations, it is hard for an independent firm to survive today. Forming strategic alliances or integrating an enterprise's internal firms by means of collaborative planning/operations to gain competitive advantage is inevitable. This paper presents the development of an activity-based costing collaborative production planning system (ABC/CPPS) to help production planners to estimate the manufacturing profit of semiconductor backend turnkey (combined IC assembly and testing) operational services at the early stage of order release to production line in a collaborative context. The estimation is under the real constraints of production resources. A predicate/transition net (Pr/Tr net) is used to simulate and implement the activity-based costing (ABC) model with the dynamic characteristics of a production line incorporated. A financial measure, profit, is used to supplement and indicate the consequence of the planning result and link the view to the enterprise's financial vision.

Keywords: Activity-based management (ABM); Collaborative production planning system (CPPS); Semiconductor backend; Operational turnkey service; Predicate/transition net

1. Introduction

Semiconductor firms are typically owned and managed independently by different enterprises, but it is hard for an individual firm to struggle in the semiconductor industry today. Recently, a business model has evolved from electronic commerce (EC) to collaborative commerce (CC) with the competitive advantage stemming from a collaborative planning/operation. The environment for semiconductor backend firms is becoming difficult, therefore, semiconductor backend enterprises are considering integrating their internal business units (firms) or strategic alliances with their partners, in order to provide a one-stop turnkey operational service to meet customer requirements.

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The entire supply chain of the semiconductor industry is linked by integrated circuit (IC) design, fabrication/probing, assembly and testing firms. The semiconductor backend turnkey service is composed of assembly and testing operations. Some but not all semiconductor backend enterprises own both assembly and testing firms. Due to the heavy investment required, most past research has focused on frontend (fabrication) instead of backend (Liu *et al*. 1997). Studies about production planning considered turnkey operational service had appeared infrequently. Though there were some studies related to the testing operations, most of them simplified the complexity of the manufacturing process on the testing floor (Liu *et al*. 1997, Yang and Chang 1998, Freed and Leachman 1999).

Two kinds of measures are used to evaluate system performance, financial and non-financial. Most past production research on semiconductor industry focused on a single firm's planning/improvement using non-financial measures, such as maximum throughput, maximum utilisation of workstations, minimum production cycle time, least tardiness or maximum wafer movements (Wein 1988, Glassy and Resende 1988, Spearman *et al*. 1990, Uzsoy *et al*. 1992, Johri 1993, Liao *et al*. 1996). But these measures do not closely or directly link to an enterprise's overall financial vision. Fisher (1992) stated that, one of the key difficulties of the non-financial system was its inability to change to dollars the amount of improvement in the non-financial measurements. The connection between improvements in the non-financial measures with profits was unclear. According to the research by Laitinen (2002), both financial and non-financial measures are important, but small technology firms appear to emphasise the importance of company-level profitability and other financial performance factors.

A pyramid model was proposed by Lynch and Cross (1991), they claimed that it is useful for describing how objectives are communicated down to the low levels and how measures can be rolled up to various higher levels in the enterprise. A production planning manager should not only ascertain the breakdown of objectives for each department but also know the consequences of the planned activities rolled up to the enterprise's overall objectives before a financial report is prepared. In addition to the non-financial measures commonly used in the semiconductor industry, this paper intends to supplement a financial performance measure by applying activity-based costing (ABC) for collaborative production planning (CPP).

The ABC system was first introduced in 1971. Basically, it is the concept that a product consumes activities and activities consume resources therefore the product cost can be derived. As suggested by Salafatinos (1996), ABC systems can be adapted to provide profitability information for enterprise activities. ABC has demonstrated that it is a suitable financial measure, and past research generally used spreadsheets to implement ABC in estimating product cost in a static way. However, as Pirttilä and Hautaniemi (1995) pointed out the data needed for ABC has to be handled with computers, small models can be created with spreadsheet programs, but large systems need more effective methods, a computer-based tool seems applicable to address the problem.

This paper aims at developing an activity-based costing collaborative production planning system (ABC/CPPS), to help a production planner to estimate the consequences of production planning, with a financial measure for semiconductor backend turnkey (combined IC assembly and testing) operational service at the early stage of the order release to the production line. In this paper, a collaborative production planning view is examined first, and then a system structure is proposed in section 2. A system structure composed of ABC data and a predicate/transition net (Pr/Tr net) model is used to simulate the resources consuming process. The study of the ABC model and the proposed two-stage approach for implementing an ABC/CPPS system are presented in section 3. A case, which includes the details of implementation of the ABC/CPPS model for semiconductor backend operation and calculation of the profit, is illustrated in sections 4 and 5. Finally, conclusions and future research possibilities are presented in section 6.

2. Collaborative production planning for semiconductor backend enterprise

2.1 *Collaborative production planning view*

Figure 1 depicts a conceptual view of collaborating entities. The dotted triangle across two firms represents a physical (or virtual) enterprise with an overall enterprise view, which considers integrating internal business units or forming strategic alliances with other trade partners by applying CPP to achieve an overall consensus goal, with benefits going to the integrated backend enterprise and/or to the individual firms simultaneously. Under this centralised collaborative planning scheme, resources owned by each firm will be co-planned together to configure the best arrangement for customer orders (COs).

Using the advantage of the Internet, the CPPS system can be designed as a web-based system, which is easily accessed by each member (Huang and Mak 1999). The COs processing procedure will have little if any change, COs were previously accepted and confirmed by each separate firm, now with the change to a single, integrated window of the integrated enterprise. Profit is important in such a cooperative initiative. Without profit, a firm cannot sustain its operations and thus will negatively impact on the cooperative relationship.

2.2 *A collaborative production planning system structure*

Two factors that significantly impact on the performance of a production system are the release policy and the dispatching rules. Release policy states the mix and release

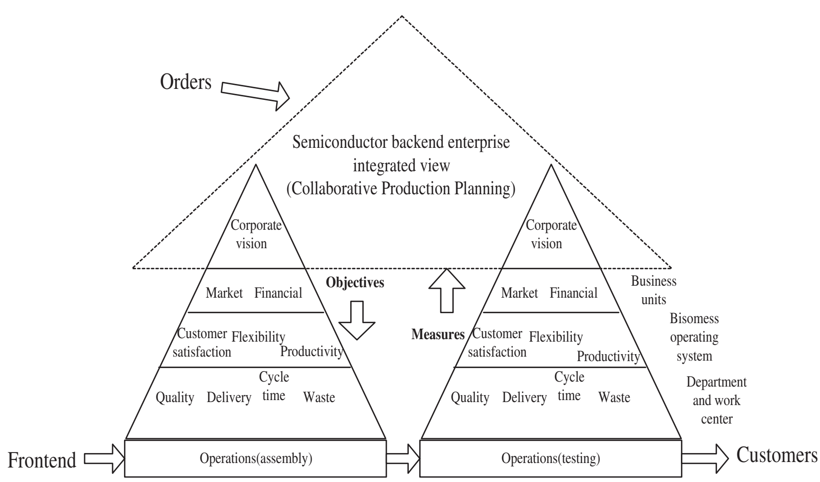

Figure 1. A conceptual view of collaborative entities.

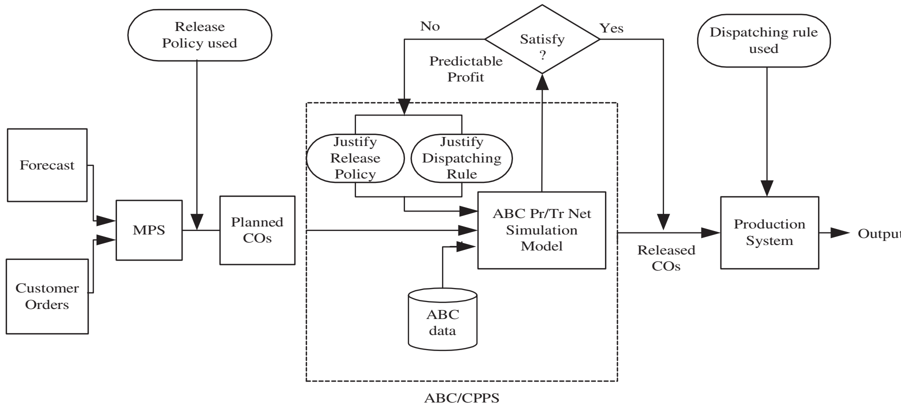

Figure 2. A collaborative production planning system structure.

of orders to start the manufacturing process at a certain point in time. Dispatching rules are used for deciding the next lot to be processed or which machine is to be assigned to process the lot on the shop floor. It is reasonable to assume that system performance (profit) will be positively impacted by these two factors in an integrated collaborative production endeavour. Most semiconductor firms use earliest due date (EDD) as release and dispatching rules to schedule and meet customer requirements (Kim *et al*. 1998). But how performance of EDD directly links to the enterprise's profit is usually unknown.

A system structure of collaborative production planning composed of ABC data and Pr/Tr net model to simulate the resource consuming process for semiconductor backend turnkey operational service is proposed as shown in figure 2. In the system structure, COs are selected by release policy from the master production schedule (MPS). Before the release to the production line, COs are transformed to the planned manufacturing orders (MOs). The activity-based costing collaborative production planning system (ABC/CPPS) is used to simulate and roll up all the activity costs by the consuming resources for the released COs. Profit for those released COs is calculated and reported to the production planner. If the expected outcome is acceptable then the planned MOs are released to production line for manufacturing. Otherwise, either justifies the release policy to have different release orders or changes in the dispatching rules used on the shop floor are investigated.

3. Methodology

3.1 *The ABC/M model*

ABC was introduced by George and Staubus in 1971. As shown in figure 3, the ABC model describes product (cost object) consumes activities and activities consume resources. Therefore, from the two-stage structure, product cost can be derived. Some researchers (Pirttilä and Hautaniemi 1995, Tsai 1996) pointed out that ABC offer more accurate product cost than the traditional cost system by using cost drivers to trace the costs of activities consumed by product/order.

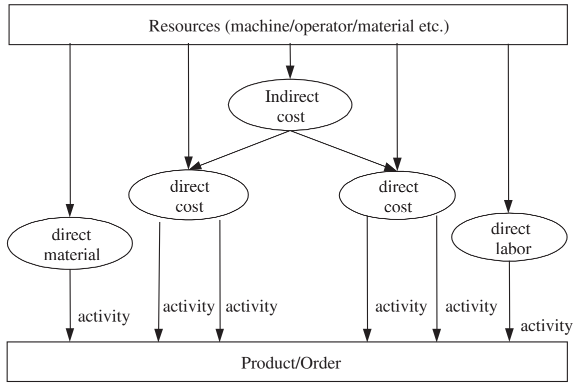

Figure 3. An ABC model.

Activities in ABC model are categorised into unit-level, batch-level, product-level and facility-level proposed by Cooper (1990). Unit-level cost is defined as inputs increase in proportion to the number of units processed, such as number of wafers to be grinded, numbers of dies to be wire bonded, number of dies to be tested, etc. Most of the activities occurring on the shop floor can be attributed to unit-level cost. Batch-level cost assumes that inputs vary in proportion to the number of batches processed, such as orders to be processed, set-up required whenever a batch of product is to be manufactured. Product-level cost assumes that inputs are necessary to support the manufacturing of each different type of product, such as inventory holding for all completed products. A facility-level cost is those costs related to sustaining a facility's general manufacturing process, such as a general administrative cost. The facility-level cost is more difficult to estimate (Cooper 1990, Foster and Gupta 1990, Ong 1995), the other three costs can be directly attributed to individual cost object.

Using another point of view, activity costs are classified into direct material, direct labour and some overhead costs. The core elements and types of costs in the ABC model are defined below:

- *Cost object:* The object that consumes activities, such as product or order, the costs of activities are calculated and rolled up as the cost object.
- *Cost driver:* The factors incur costs for a specific activity, such as the process time, the quantity of product or the quantity of material consumed.
- *Direct material:* The cost of purchased material, such as lead frame, gold wire, etc. directly consumed in the production line and attributed to the cost object. The direct material can use standard material cost data.
- *Direct labour:* The cost is determined by multiplying the standard time with the average mean hour salary rate in the production centre, such as a 'set up' by the operator.
- *Overheads:* In traditional accounting, overhead costs include variable and fixed costs. Variable overhead costs include repair, maintenance, supplies (tool service, quality control) and office-depreciation. Repair overhead costs occur stochastically on the shop floor. Fixed overhead cost includes salaries for staff personnel, rental for a building or a machine, utilities, water, indirect labour, planning, preparing, production administration and other remains. According to the ABC model, indirect activities

are re-conceptualised to direct activities and assigned to cost object (product/lots) as directly as possible (Armstrong 2002).

Among these costs, the allocation of overhead costs as a percentage of direct labour cost and/or machine usage by traditional accounting may not accurately reflect the actual product cost, and the more complex, low-volume and small batch products tend to be underestimated by traditional accounting methods (Cooper and Kaplan 1988, Dhavale 1990). Many companies therefore have improved their cost accounting by developing an ABC system. Lea and Fredendall's research (2002) found that ABC provides higher profit, lower inventory and better overall service across multiple manufacturing systems than throughput accounting. Recently, ABC has been expanded to the management area in the form of activity-based management (ABM). It is an area of decision support that can directly connect to operational planning in order to provide useful financial information. In contrast to ABC, the traditional accounting system is designed mostly to meet financial accounting purposes and therefore focuses on creating a balance sheet and an income statement. ABC is a more powerful tool in the decision-making area.

A seven-step methodology for designing an ABC system has been studied by Pirttilä and Hautaniemi (1995). The steps proposed by them in that paper are:

1. Scope of interest.
2. Documenting the manufacturing process.
3. Define activities/resources.
4. Analyse activities/resources.
5. Select cost drivers.
6. Activity costs.
7. Cost object costs.

3.2 *ABC/CPPS*

Though Pirttilä and Hautaniemi (1995) provided a seven-step methodology, it was discovered that most past implementation of ABC used only the static method at the early stage of product design, without considering the actual constraints and competition of resources in the dynamic production environment. Moreover, it was noted, that even though activities with the same cost driver will result in different cost values impacted by the specific type of resources actually consumed in the shop floor. A static procedure may not treat the actual cost appropriately. Therefore, applying a computer-based tool that incorporates the ABC model along with a simulation methodology seems applicable to effectively address these problems.

As shown in figure 2, the dotted rectangle including two core components, the ABC data and the ABC Pr/Tr net simulation model, is defined as the scope of the ABC/CPPS. Therefore, a two-stage approach with detailed steps is proposed to implement the ABC/CPPS.

Stage 1: Analyse the ABC data

1. *Define the domain of application:* Firstly, we should define the scope we are interested in applying, and the collaborative entities must be identified.
2. *Understand the processes of the application domain:* According to the domain of the application, the operational processes for the collaborative entities must be investigated.

3. *Analyse the activities/resources from the processes:* Extract activities and analyse the resources used for each activity from the processes, and then assign an activity code to each activity in order to be traced by the simulation model in stage 2.
4. *Analyse the cost drivers and decide the cost object:* After extracting the activities in the previous step, cost drivers and activity cost for each activity are analysed, and then a cost object must be decided.

Stage 2: Develop the ABC Pr/Tr Net simulation model

1. *Analyse the activity transition:* In order to simulate the sequence of activities for rolling up cost, an activity transition diagram is proposed as a tool in this step. As shown in figure 4, an example is illustrated for two collaborative entities with a sequential activity transition, where activities a_1 to a_p belong to entity A and activities a_{p+1} to a_q belong to entity B. Therefore, a universal set $X = \{a_1, a_2, \ldots, a_p, a_{p+1}, a_{p+2}, \ldots, a_q\}$ can be derived.
2. *Group the activities into activity sets:* Analyse the activities in the universal set X and respectively categorise them into sets Y and Z, each contains subsets. Each subset in Y is used to control the trigger of a specific transition and transit lots to use resource(s). On the other hand, each subset in Z is used to control the trigger of a specific transition and transit lots end of resource(s) usage. The purpose of grouping the activities into different subsets by similar characteristics is that we can control the similar activities to be sent by a specific transition, which embedded with specific treatment for this group. X, Y and Z sets will be used in the next step and are defined as follows:

   X is the universal set and consists of all activities; $X = \{a_1, a_2, \ldots, a_p, a_{p+1}, a_{p+2}, \ldots, a_q\}$.

   Y is a set constructed by subsets Y_i; $Y = \{Y_i; I = 1, m\}$, Y_i is a subset that consists of activities with the same characteristic to trigger a specific transition which transits tokens (orders) to use resource(s). The definition of characteristic depends on the application requirement or concern; activities that require resource(s) supply might therefore be defined as a subset, or activities requiring a setup operation might be grouped into one subset, etc. Note that the exclusive relationship $Y_1 \cup Y_2 \cup \cdots \cup Y_m = X$ holds.

   Z is a set constructed by subsets Z_j; $Z = \{Z_j; j = 1, n\}$, Z_j is a subset that consists of activities with the same characteristic to trigger a specific transition which transits tokens (orders) end of resource(s) usage. The definition of characteristic depends on application requirement or concern. Activities which require a merge process after resource usage might be grouped into one subset, etc. Again, note that the exclusive relationship $Z_1 \cup Z_2 \cup \cdots \cup Z_n = X$ holds.
3. *Develop the simulation model:* A generalised ABC Pr/Tr net with a loop structure is proposed as shown in figure 5 to simulate the dynamic and iterative consuming process.

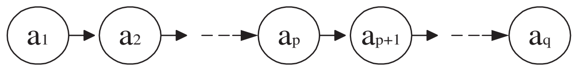

Figure 4. An example of an activity transition diagram.

Pr/Tr net is a high-level petri net, which possesses higher abstraction and aggregation properties for modelling. Basically, Pr/Tr net is a directed graph (P, T, A) where P is the set of predicates ('first-order' facts), T is the set of transitions, A is the set of arcs and some other components, logical formulas, labels are used to constitute the Pr/Tr net. For the detailed definition of Petri net and Pr/Tr net please refer to Genrich and Lautenbach (1986), Murata (1989), and Lee *et al.* (1994). Components of the proposed ABC Pr/Tr net model are defined below:

- Predicate: $P = \{O, W, R, U, F, E\}$ are predicates to state the facts.
  O: There is an order.
  W: Want to use resource; an order is ready to consume the resource(s).
  U: Using resource; describe the consuming process, and rolling up the cost.
  R: There is a resource.
  F: Finish using resource; the consuming process is complete.
  E: Exit system; all activities for an order are complete.
- Transition: $T = \{T1, T2, T3, T4, T5\}$ are transitions to transit predicates.
  $T1$: Transit lots from O (There is an order) to W (Want to use resource) predicate.
  $T2$: $T2 = \{T2_i;\ I = 1, m\}$ transit lots from W predicate to U (Using resource) predicate.
  $T3$: $T3 = \{T3_j;\ j = 1, n\}$ transit lots from U predicate to F (Finish using resource) predicate.
  $T4$: Transit lots from F predicate to W predicate (Want to use).
  $T5$: Transit lots from F predicate to E (Exit system) predicate.
- Logical formula: A formula expressed by logic syntax inscribed in a transition. Such as $a \in X$ is a logical formula with a value of 'true' only if a, belongs to set X. A set of formulas $LF = \{LF1, LF2_{i=1,m}, LF3_{j=1,n}, LF4, LF5\}$, is used in the net, contents for each logical formula depend on application. $LF1$ is the logical formula which states the condition to release an order into production, $LF2_{i=1,m}$ are logical formulas used to control the triggers of the transitions $T2_{i=1,m}$ and transit a lot to U predicate for resource(s) consuming, $LF3_{j=1,n}$ are the logical formulas used to control the triggers of transitions $T3_{j=1,n}$. Similarly, $LF4$ is a logical formula used to

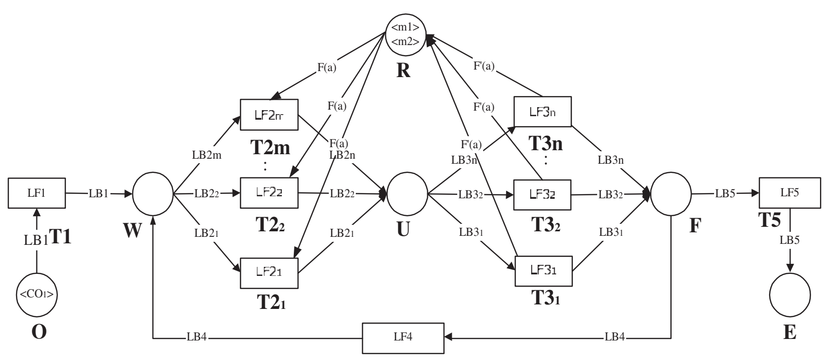

Figure 5. A generalised ABC Pr/Tr net model.

control the trigger of transition $T4$ and $LF5$ is used to judge the trigger of transition $T5$.

- Label: Are labels of formal sum for some arcs in the Pr/Tr net, for example, $\langle B \rangle$ is a label, and $\langle A, T \rangle$ is another label, a formal sum may be expressed by $\langle B \rangle + \langle A, T \rangle$. In the label, B, A and T are attributes (like a variable) used in these labels. A set of labels $LB = \{LB1, LB2_{i=1,m}, LB3_{j=1,n}, LB4, LB5\}$ is used in the net, contents for each label depend on application.
- Firable: A transition is defined 'firable' whenever its preconditions and logical formula are satisfied. For example, $T1$ is firable, if the token $O\langle CO_1 \rangle$ exists, resources determined by functor $F(a)$ are available (for activity a) and logical formula $LF1$ is satisfied. After $T1$ fired, order token $O\langle CO_1 \rangle$ will be sent to token $W\langle CO_1 \rangle$ (CO_1 want to use).

This paragraph describes the details of the running of the ABC Pr/Tr net model. First, COs reside at O predicate, all resources such as operators, machines, etc. reside at R predicate. The resources constitute the production capacity of the system. Moreover, the COs and the resources initially reside at O and R predicates respectively form the initial markings of the net. When the model begins to run, customer orders (or 'tokens') selected by the release policy are sent (by transition $T1$) to predicate W with the initial activity code ($a = 1$). At W, if a lot is selected by a dispatching heuristic rule (such as EDD) and acquires all the required resources allocated by functor $F(a)$, then transition $T2_i$ will be fired (depends on whether $LF2_i$ is satisfied) and the lot is sent to U predicate for operation. After completing this operation, $T3_j$ will then be fired (depends on $LF3_j$ being satisfied) and resource(s) will be returned to R predicate by functor $f'(a)$. Finally, the lot is checked at F predicate by $LF5$ to make sure all activities are completed, then the lot will be sent to E (Exit) predicate, otherwise the lot will be sent back to W predicate and recycled again for the next activity. When all lots reach E predicate (all lots are finished), the model then stops and concludes the profit.

4. *Profit calculation:* In the previous step, the ABC Pr/Tr net is used to simulate the resources consuming. In essence, there are two kinds of predicates in the ABC Pr/Tr net simulation model, 'activity' predicates (U) and 'state' predicates (W, R, O, F, E). Only at activity predicates U, lots may hold and consume resource(s). Other 'state' predicates only show a state of the lots. As illustrated by figure 6, the waiting time (WT) and using time (UT) of each activity can be simulated and therefore the cost can be estimated

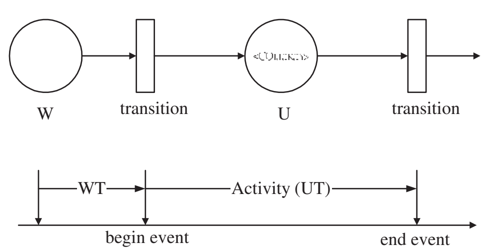

Figure 6. WT and UT of an activity.

according to the activity cost drivers. Finally, the total manufacturing cost (TMC) can be derived when all orders are completed.

Manufacturing net profit (MNP) of the released COs is calculated by subtracting the total manufacturing cost (TMC) from total sales revenue (TSR). TSR is derived by multiplying sales order quantity by unit prices per piece for all the released orders. The manufacturing cost considered in this paper includes direct labour cost, direct material cost, and some overhead costs driven directly by the cost drivers, which were defined in section 3.1. Some overhead costs, such as repair that occurred stochastically and other overhead costs (like water, electric, insurance, office depreciation, maintenance, administrative cost and other remains), which are minor or not impacted by the release policy and/or dispatching rules, are neglected and not included.

4. Implementation: Analyse the ABC data

A case is given in this study to illustrate the application of the methodology. In this section, we focus on the ABC data analysis.

4.1 *Define the domain of application*

This case is based on W Corporation, an enterprise which owns both assembly and testing business units and focuses on producing DRAM, located in Taiwan. Three kinds of product types, assembly only, testing only and turnkey products are considered in this case. The process needed for each order depends on product type. Assembly only product type needs only assembly processing, both testing only and turnkey product must perform the testing process.

4.2 *Understand the process of semiconductor backend operation*

An Oracle enterprise resource planning (ERP) system initiates order processing (O/P), manufacturing orders (MOs) are created from COs. Before the MOs are released, the material check (M/C) and program/tool check (PT/C) activities are performed to make sure of the production feasibility. After order release (O/R), an inventory retrial (I/R) is conducted to access materials and wafers for releasing to the production line.

As shown in figure 7 (which illustrates the transformation of material in process) and figure 8 (which gives details of the process), the assembly process is somewhat of a flow type process. The entire assembly manufacturing process can be divided into pre-assembly and assembly processes. The pre-assembly process consists of wafer grinding (W/G) and wafer saw (W/S) operations, the others belong to the assembly process. After dies have been sawed out during the pre-assembly process, the batch (lot) is moved to the assembly process. A series of operations, including die bonding (D/B), wire bonding (W/B), moulding (M/D), dambar cutting (D/C), solder plating (S/P) and trim and forming (T/F) are performed to assemble and package the dies. The W/B operation usually becomes the bottleneck during the assembly process. Therefore, after the D/B operation, the MOs will be split into sub-lots for production efficiency. Finally, a visual inspection (V/I) operation is performed to ensure the

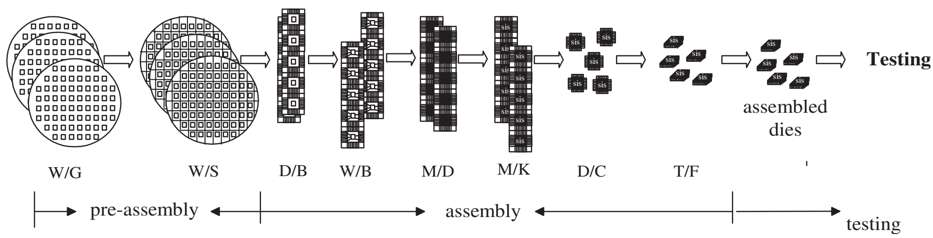

Figure 7. Transformation of material in process.

appearance quality, if the product type for the lot is assembly only, then lots for the same customer will be combined, packed (A/P) and shipped out (S/O) to the customer, otherwise they will be transferred to the testing firm.

On the testing shop floor, the dies will go to burn-in (B/I) operation, after burn-in, dies go to low temperature testing (FT1), according to the testing results, dies will then be classified to pass bin, fail bin, etc. Dies might need to rework FT1 if high defect results come out. After FT1, dies go to high temperature testing (FT2), when this operation is finished, speed test (FT3) is conducted and bin classes are set for classifying the dies (split). After the speed test, dies of each bin are marked (M/K). An engineering quality assurance (EQA) gate is set to determine pass or fail after the marking operation. If passed, then a lead scan (L/S) operation is performed to make sure all leads of dies are the same level. After a lead scan, a visual inspection (VI) is conducted to check the dies appearance. When no problem occurs, a baking (B/K) operation is performed to dry the dies. After this operation, if package type for this lot is 'tape and reel' then the dies will move to tape and reel operation (T&R), otherwise the lot will be forwarded to packing operation (P/K) directly. Within 6 hours of the baking operation, dies must be completely packed (P/K). A final quality assurance (FQA) is performed to ensure the outgoing quality.

4.3 *Analyse the activities/resources from the process*

Based on the manufacturing processes described in the previous section, the activities and resource(s) required and released for each activity are listed in tables 1, 2 and 3, each for indirect manufacturing activities, assembly and testing firm respectively. An activity code is assigned for each activity.

4.4 *Analyse cost driver and cost object*

The cost object used in this case is CO, figure 9 displays the analysed results of cost drivers and activity costs for semiconductor backend turnkey operations in a collaborative environment. Each activity is likely to have a different cost driver that represents the consumption of the resources. Different cost drivers will create different ways of calculating the costs. But it should be noted, values of activity costs vary with the type of resource actually consumed even though those activities have the same cost driver. Take the W/B activity as an example, the process cycle time per die depends on what type of wire-bonder machines are actually used, therefore, the cost value result is different.

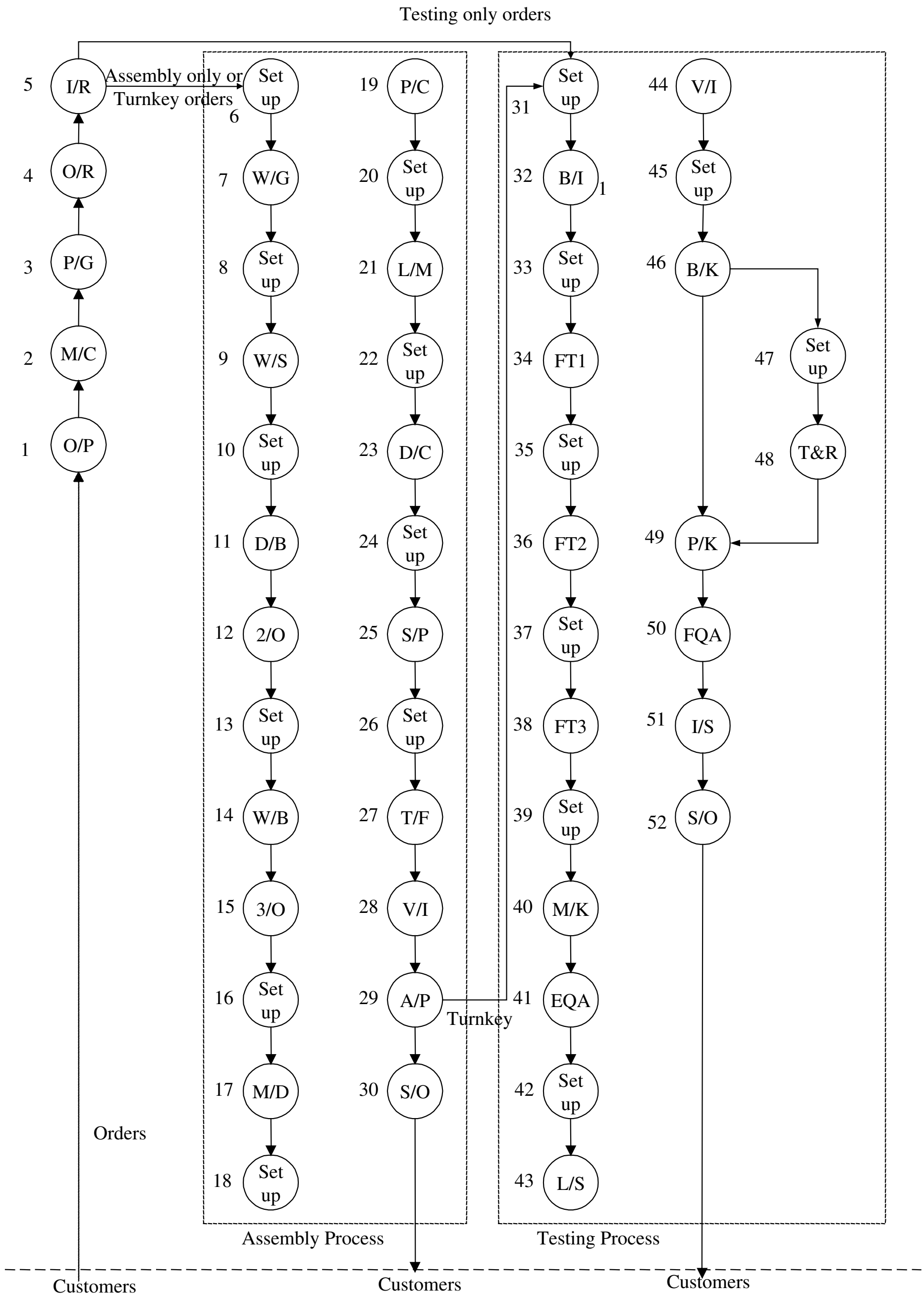

Figure 8. Assembly and testing process.

5. Implementation: Develop the ABC Pr/Tr Net

When the ABC data analysis is completed, the simulation model is developed to simulate the manufacturing process and roll up the cost for each order.

Table 1. Define and analyse the indirect manufacturing activities.

Activity code (a)	Activity	Resource(s) required $F(a)$	Resource(s) released $F'(a)$
1	O/P	Production planner	Production planner
2	M/C	Production planner	Production planner
3	PT/C	Production planner	Production planner
4	O/R	Production planner	Production planner
5	I/R	Operator	Operator
	Facility level activities		

Table 2. Define and analyse the activities/resources for assembly firm.

Activity code (a)	Activity	Resource(s) required $F(a)$	Resource(s) released $F'(a)$
7	W/G	Grinder, tape, wheel	Grinder
9	W/S	Sawing machine, dicing tap	W/S cost
11	D/B	Die bonder, lead frame magazine	Die bonder
12	Second optical	Inspector	Inspector
14	W/B	Wire bonder, gold wire heat block	Wire bonder
15	Third optical	Inspector	Inspector
17	M/D	Molder, compound, carrier	Moulder, magazine
19	P/C	Oven	Oven
21	L/M	Laser marker	Laser marker
23	D/C	Dambar cutter	Dambar cutter
25	S/P	Solder plating, solder ball	S/P machine
27	T/F	Trim/form machine, tray/tube	Trim/form machine, carrier
28	VI	Inspector	Inspector
29	P/K	Operator, packing box	Operator
30	S/O	Ship out	Operator
Sa	Set-up	Operator, machine	Operator, machine

$Sa = \{6, 8, 10, 13, 16, 18, 20, 22, 24, 26\}$

Table 3. Define and analyse the activities/resources for testing firm.

Activity code (a)	Activity	Resource(s) required $F(a)$	Resource(s) released $F'(a)$
32	B/I	Burn-in board, program	Burn-in board, program
34	FT1	Tester, hi-fix, program, gas	Tester, hi-fix, program
36	FT2	Tester, hi-fix, program	Tester, hi-fix, program
38	FT3	Tester, hi-fix, program	Tester, hi-fix, program
40	M/K	Laser marker	Laser marker
41	EQA	Tester, inspector	Tester, inspector
43	L/S	Lead scanner	Lead scanner
44	VI	Inspector	Inspector
46	B/K	Oven	Oven
48	T&R	T&R machine	T&R machine
49	P/K	Operator	Operator
50	FQA	Inspector	Inspector
51	I/S	Storage space	Storage space
52	S/O	Operator	Operator
St	Set-up	Operator, Machine	Operator, Machine

$St = \{31, 33, 35, 37, 39, 42, 45, 47\}$

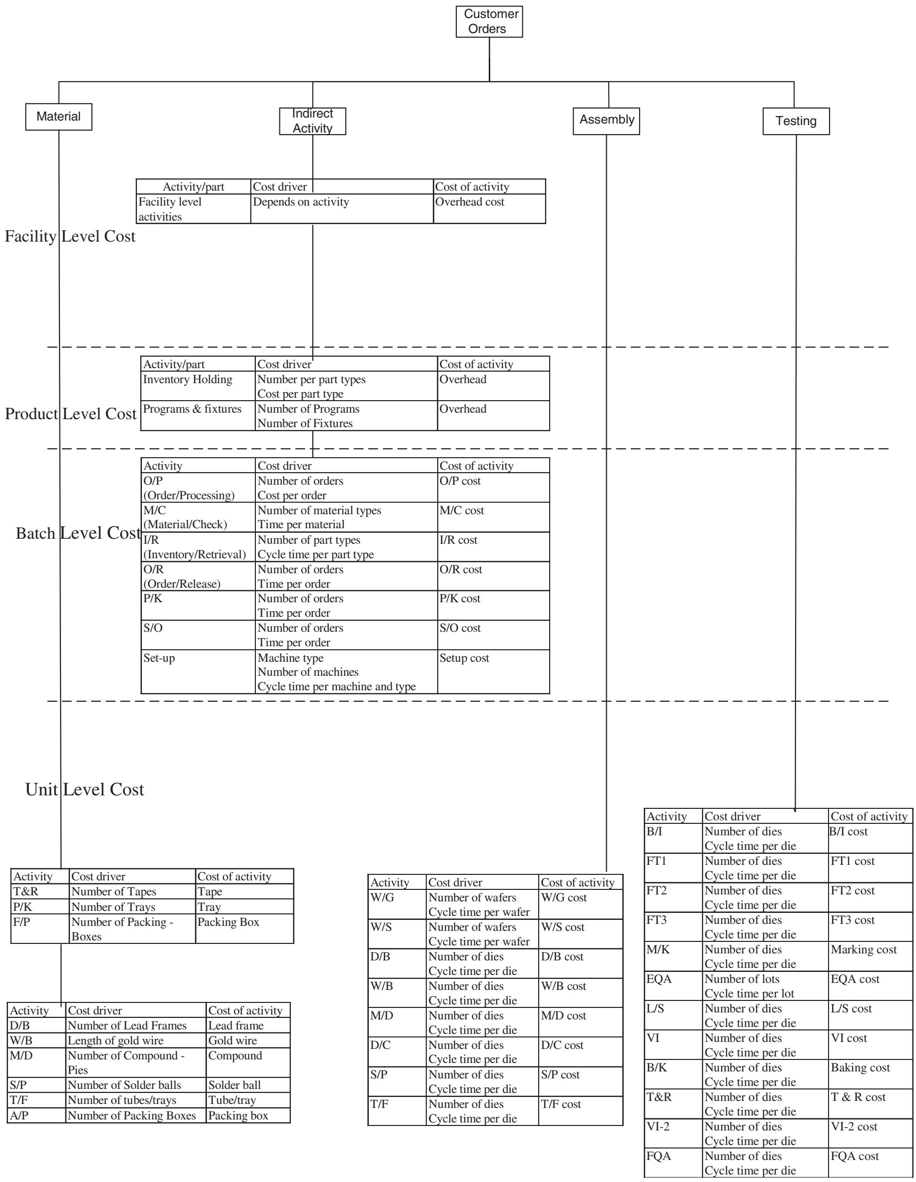

Figure 9. Cost driver and activity cost for assembly and testing firm.

5.1 *Analyse the activity transition*

Some specific characteristics of the testing process, which impact on the normal process flow are described as follows:

- If high defect results come out from FT1 operation, then rework it.
- After drying the dies (B/K operation), if the package type for this lot is tape and reel, then the dies will move to the tape and reel operation (T&R), otherwise the lot will be forwarded directly to the packing operation (P/K).

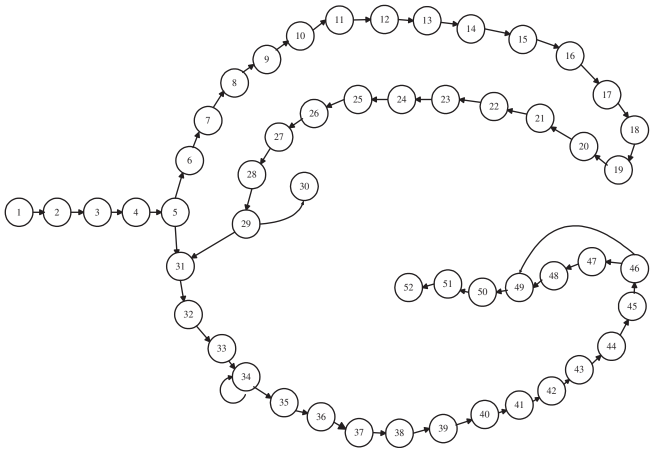

Figure 10. Activity transition diagram.

According to the above analysis, an activity transition diagram illustrated in figure 10 is used to describe the possible transition state for each activity.

5.2 *Group the activities into activity sets*

Refer to tables 1, 2 and 3, which describe the resource(s) required and released for each activity. Functor $F(a)$ is used to supply the resource(s), $F'(a)$ is used to return resource(s). Moreover, it shows that all activities need resource(s) for operation and after an activity is done, resource(s) must be returned. Split lot happened when activities 4 (Order release), 11 (Die bond) and 37 (FT3) finished, and merge lots occurred after activities 29 and 48 (Packing), therefore special treatment is necessary for lots after these activities (three kinds of activity sets for Z needed to be defined). According to the methodology we defined in section 3.2, three sets; X, Y, Z can be derived:

$X = \{1, 2, \ldots, 52\}$; the universal set of the activities.

$Y = \{Y_i;\ I = 1, m\}$, in our application, we are only concerned about whether activity needs resource(s) supply, and since all activities need resource supply, therefore, one set is sufficient for modelling, we set $m = 1$, hence $Y = \{Y_1\}$. Since the exclusive relationship $Y_1 \cup Y_2 \cup \cdots \cup Y_m = X$ hold, we have $Y_1 = X = \{1, 2, \ldots, 52\}$.

$Z = \{Z_j;\ j = 1, n\}$, in our application, we are concerned with three different changes of lots after some activities, i.e. the split, merge and neither split nor merge. Therefore, activities are categorised into three subsets, given $j = 3$, hence $Z = \{Z_1, Z_2, Z_3\}$. Each subset in Z is defined as follows:

$$Z_1 = \{4, 11, 37\}; \quad \text{the split set}$$
$$Z_2 = \{29, 48\}; \quad \text{the merge set}$$

and since the exclusive relationship $Z_1 \cup Z_2 \cup Z_3 = X$ holds, therefore

$$Z_3 = X - Z_1 - Z_2 = \{1, 2, \ldots, 52\} - \{4, 11, 37\} - \{29, 48\};$$

neither split nor merge set.

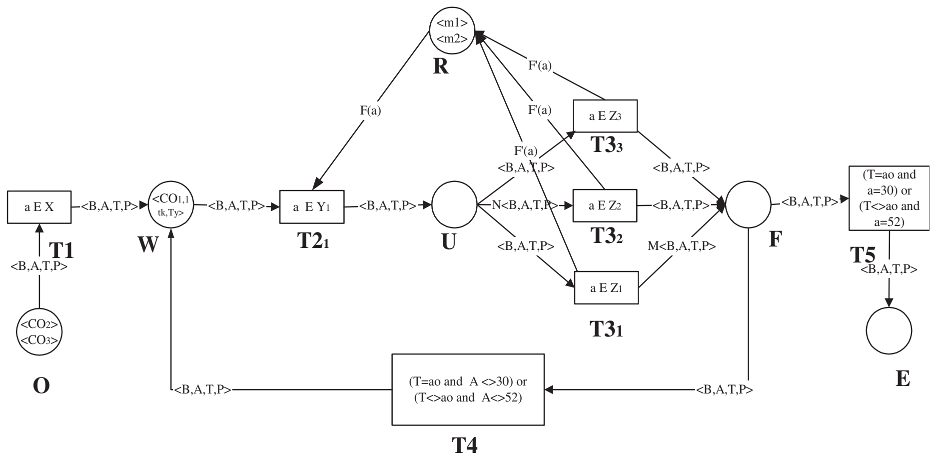

Figure 11. ABC Pr/Tr net model.

The X, Y and Z set will be used to construct the simulation model in the next section.

5.3 *Develop the simulation model*

By applying the core components defined below, as depicted in figure 11, an ABC Pr/Tr net was constructed to simulate a dynamic resources consuming process for semiconductor backend operations.

- Predicate: $P = \{R, O, W, U, F, E\}$
- Transition: $T = \{T1, T2_1, T3_{j=1,3}, T4, T5, T6\}$ are transitions with a logical formula.
- Label: the labels used in this case are $\langle B, A, T, P\rangle$ for $LB1$, $LB2_1$, $LB3_{j=1,3}$, $LF4$ and $LB5$. Four attributes are used in this label, each are defined as below:
  B: Batch number
  A: Activity code; values for $A = \{1, 2, \ldots, 52\}$
  T: Product type; values for $T = \{ao, to, tk\}$
    ao: assembly only
    to: testing only
    tk: turnkey
  P: Package type; values for $P = \{Ty, T\&R\}$
    Ty: Tray
    T&R: Tape and Reel
- Logical formula: in this case, logical formulas are defined as:
  $LF1$: $a \in X$; is the logical formula used to describe the logic condition to release and order into production.
  $LF2_1$: $a \in Y_1$; is the logical formula used to control the trigger of the transition $T2_1$ and transit a lot to U predicate for resource(s) consuming.
  $LF3_1$: $a \in Z_1$; is the logical formula used to control the trigger of transition $T3_1$ which split and transit lots from U to F predicate (for split activity set).
  $LF3_2$: $a \in Z_2$; is the logical formula used to control the trigger of transition $T3_2$ which merge and transit lot from U to F predicate (for merge activity set).

$LF3_3$: $a \in Z_3$; is the logical formula used to control the trigger of transition $T3_3$ and transit the lot from U to F predicate (for neither split nor merge set).
$LF4$: (T = '*ao*' and $A < 30$) or ($T \langle \rangle$ '*ao*' and $A < 52$); is a logical formula to judge the condition for lots transit to W predicate for the next activity (transit from F to W predicate).
$LF5$: (T = '*ao*' and $A = 30$) or ($T \langle \rangle$ '*ao*' and $A = 52$); is a logical formula to judge the condition for lots to exit the system (transit from F to E predicate).

5.4 *Profit calculation*

The manufacturing cost considered in this case includes direct labour cost, direct material cost, and some overhead costs driven directly by the cost drivers, which were defined in section 3.2. The manufacturing net profit may be expressed as follows:

$$\begin{aligned} MNP &= TSR - TMC = (ATR + TTR + KTR) - [(ATC + TTC + KTC) - DM] \\ &= \left(\sum_{i=1}^{m} A_i Q_i + \sum_{i=1}^{p} B_i Q_i + \sum_{i=1}^{s} C_i Q_i\right) \\ &\quad - \left[\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o} Q_{ij} C_{ijk} + \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{r} Q_{ij} C_{i_{jk}} + \sum_{i=1}^{s}\sum_{j=1}^{t}\sum_{k=1}^{u} Q_{ij} C_{i_{jk}}\right)\right. \\ &\quad \left. \times \left(\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{o} Q_{ij} M_{i_{jk}} + \sum_{i=1}^{p}\sum_{j=1}^{q}\sum_{k=1}^{r} Q_{ij} M_{i_{jk}} + \sum_{i=1}^{s}\sum_{j=1}^{t}\sum_{k=1}^{u} Q_{ij} M_{i_{jk}}\right)\right] \end{aligned}$$

Variables defined below:

MNP: Manufacturing net profit
TSR: Total sales revenue
TMC: Total manufacturing cost
ATR: Assembly total revenue
TTR: Testing total revenue
KTR: Turnkey total revenue
ATC: Assembly total cost
TTC: Testing total cost
KTC: Turnkey total cost
DM: Direct material cost
i: ith Customer order (CO)
j: jth Manufacturing order (MO)
k: kth activity
m: Number of customer orders for assembly only
n: Number of manufacturing orders per customer order for assembly only
o: Number of activities per lot for assembly only
p: Number of customer orders for testing only
q: Number of manufacturing orders per customer order for testing only
r: Number of activities per lots for turnkey
s: Number of customer orders for turnkey
t: Number of manufacturing orders per customer order for turnkey
u: Number of activities per lots for turnkey
A_i: Sales price of customer order i per piece for assembly only
B_i: Sales price of customer order i per piece for testing only

C_i: Sales price of customer order i per piece for turnkey
Q_i: Quantity of customer order i
Q_{ij}: Quantity of manufacturing order j for customer order i
C_{ijk}: Cost value of cost driver for activity k, manufacturing order j and customer order i. C_{ijk} is determined by resource available dynamically in shop floor.
M_{ijk}: direct material cost of activity k for manufacturing order j and customer order i.

It should be noted that C_{ijk} is dynamically determined, and finally, the costs can be rolled up to the cost object and MNP can be indicated.

6. Conclusion and future research directions

While the market confronts an environment of low profit margin for semiconductor backend, creating a strategic alliance or integrating the enterprise's internal firms by means of collaborative planning/operations mechanism to gain competitive advantage is inevitable. Consequences of non-financial measures used in the past alone are always weak and vague when connected to the enterprise financial objectives, therefore it can be considered to supplement the non-financial measures by a financial one in the collaborative environment.

In this paper a system structure of ABC/CPPS for semiconductor backend is proposed. After combining the cost data with an ABC model constructed by Pr/Tr net, a computer-based tool was established to simulate the resources consuming process with the dynamic characteristics in the production line were considered. Based on this system structure, costs of the released customer orders (COs) can be rolled up and the MNP can be estimated and reported to the production planner for justifying the release policy and/or the dispatching rule before the COs release to production. Though the MNP we defined in this paper did not include all the overhead cost incurred in an enterprise, but a relative MNP index is enough to evaluate the impacts of release or dispatching rules. Other previous research (Ong 1995) shared this same point of view.

Some studies established that a Pr/Tr net model could be transferred to a rule-based system (Giordana and Saitta 1987, Murata and Zhang 1988). The computer-based ABC/CPPS tool is under construction currently and seems useful for investigating such areas:

- *Release policy:* Some studies indicated that the order release policy is the dominant factor in determining most of the production system performance (Ragatz and Mabert 1988, Wein 1988). Most semiconductor firms use EDD to release COs, but usually the consequence on profit is unknown. Therefore, a study about release policy is needed for practical purposes. The ABC/CPPS system structure proposed in this paper provides a tool to investigate this topic.
- *Dispatching rule:* The dispatching rule used on the shop floor impacts the system performance secondary. Therefore, except the EDD, other dispatching rule results that better profit can be explored in the future.
- *Long term planning:* Though Bakke and Hellberg (2002) and Kee and Schmid (2000) found that ABC generates higher profits in the long term. But another research conducted by Lea and Fredendall (2002) pointed out that ABC

generates higher profits for both the short and long term. How time horizon impacts on profit can be examined.

- *Profit sharable analysis:* From the collaborative planning/operation, profit might be improved, how to share the profit for each member in a collaborative environment also appears as another interesting study subject.
- *Partner alliance:* The Honolic Manufacturing System (HMS) concept has been discussed by Huang *et al*. (2002), under the HMS structure, the cooperative partners changes rapidly, thus how to select right ones to collaborate in order to achieve better competence or overall profit, is a challenging topic. The model and methodology proposed in this paper might provide a useful approach connected to this subject.

In addition, a dynamic integrated performance measure system that combines both financial and non-financial factors and fits to the semiconductor industry is worth investigating on a continuous basis. The unique feature of such a system is, according to planner's weighting on the financial and non-financial, it is adjustable. Finally, we have to emphasise, though the investment in semiconductor backend industry is far less than in the frontend, firms in the semiconductor backend are vital and critical in the supply chain. Thus, more studies are needed since backend firms find it harder to survive.

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