Developing a Data Model of Product Manufacturing Flow for an IC Packaging WIP System

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Abstract

The IC packaging industry heavily relies on shop floor information, necessitating the development of a model to flexibly define shop floor information and timely handle manufacturing data. This study presents a novel data model of product manufacturing flow to define shop floor information to effectively respond to accelerated developments in IC package industry. The proposed data model consists of four modules: operation template setup, general process setup, enhanced bill of manufacture (EBOMfr) setup, and work-order process setup. The data model can flexibly define the required shop floor information and decision rules for shop floor product manufacturing flow, allowing one to easily adopt changes of the product and on the shop floor. However, to handle floor dynamics of the IC packaging industry, this work also proposes a WIP (*i.e.* work-in-process) system for monitoring and controlling the product manufacturing flow on the shop floor. The WIP system integrates the data model with a WIP execution module. Furthermore, an illustrative example, the MIRL WIP System, developed by Mechanical Industrial Research Laboratories of Industrial Technology Research Institute, demonstrates the effectiveness of the proposed model.

Key Words: Product Manufacturing Flow, Shop Floor Information System, Manufacturing Execution System, Bill of Manufacture, IC Packaging, WIP System

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1. Introduction

Integrated circuit (IC) manufacturing can generally be divided into five major parts: design, fabrication, chip probing test, packaging and final testing. IC packaging transforms wafers into chips. Many different package types are available, including DIP, SOP, SOJ, QFP, and BGA. Managers within the IC packaging industry heavily rely on shop floor information to effectively handle variations in the product manufacturing flow as a timely response to customer requests. More specifically, customer specifications regarding product changes reflect the variation in information and decision support of product manufacturing flow. Therefore, enhancing a company's competitiveness largely depends not only on rapidly incorporating information related to product manufacturing flow to meet the floor dynamics, but also providing pertinent information to other systems and individuals.

A standard manufacturing flow of IC packaging consists of the following operations: wafer grinding, wafer saw, die bond, epoxy cure, wire bond, post-bonding inspection (PBI), molding, marking, dejunk/trimming, solder plating, forming/singulation, open/short (O/S) test, lead scan, final inspection, packaging, outgoing QC *et al.* as shown in Figure 1. Typically recorded on a run card, the production information of the manufacturing flow for a product lot is manually written down by floor personnel, and then later summarized by an assigned department. A run card is a formatted form, recording the materials and equipment used, as well as the operational conditions of a product lot. This card is filled out as the production batch arrives on the floor, recorded by the floor people based on the production facts at every operation, and completed as the production batch reaches completion. Although easy to process, the run card creates several problems: (1) Floors' exceptions can not be effectively handled since such information is difficult to obtain in real time; (2) The best resolving point of time is missed owing to the slow rate of accumulating time critical information; (3) The data is invalid owing to human error.

To overcome the above problems and ensure good customer service, an IC packaging WIP system must be developed. The WIP system should allow the user to perform the following tasks: (1) Define product information, e.g. related materials, equipment, and operational attributes, of each lot before production. Otherwise, consider possible setup changes in different materials, equipment used by the same product type, such as different molding temperature for different epoxies in the molding operation; (2) Handle the lot activities of customer orders in real time during production; (3) Rapidly incorporate information of each lot to fulfill changing product requirements and floor situations.

According to the hierarchical control architecture of CIM [1, 2], computer technology used in manufacturing in recent years has focused mainly on the planning level, i.e. the information system in the manufacturing sector is based on material requirements planning, and the control level, i.e. the plant automation system automates production equipment. Manufacturing information systems, largely having the function of planning, can not handle shop floor activities due to a lack of the function of real time feedback of production information. On the other hand, plant automation systems automate equipment to accumulate real time feedback information, but create the commonly referred to island of automation due to incompatible information format. The shop floor information system, therefore, becomes the bridge between planning level and control level. This system takes orders from the planning level, then coordinates, controls, monitors equipment in the control level and ultimately enhances plant productivity.

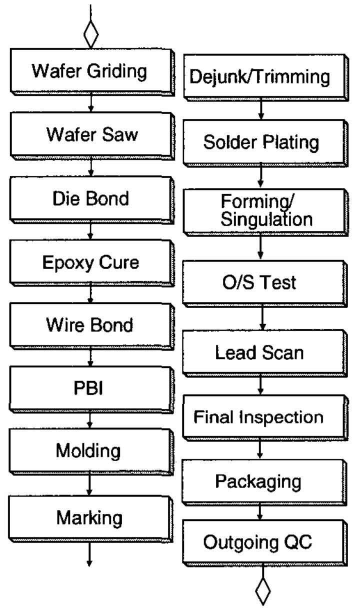

Figure 1. A standard manufacturing flow of IC packaging

Melnyk [3, 4] narrowly defined a shop floor information system as consisting of the following five functions: order review and release, detailed assignment, data collection and monitoring, feedback and corrective action, and order disposition. In addition to these functions, Vincent [5], Vollman, Berry and Whybark [6], and Sartori [7] cited scheduling, dispatching, and monitoring as well. The shop floor information system can also be broadly defined as a manufacturingexecution system (MES). Many investigations [1, 2, 8, 9, 10, 11] have emphasized the role of MES in bridging Manufacturing Resource Planning (MRPII) and the shop floor supervisory system together. This system not only integrates individuals, materials, machines, time, and cost via a relational database, but also provides operation tracking, feeds back information to the planning system, and produces managerial reports for decision support. The system architecture differs from nonintegrated partial solution. According to previous investigations [12, 13], MES has the following eleven functions: resource allocation and status, operation/detail scheduling, dispatching production units, document control, data collection/acquisition, labor management, quality management, process management, maintenance management, product tracking and genealogy, and performance analysis.

As narrowly defined, shop floor information system uses routes in the planning level, and is combined with shop floor reporting system to monitor the manufacturing flow. Thus, its application is limited owing to the lack of a flexibly described manufacturing flow data scheme capable of facilitating the user in defining what information to collect and how to handle exceptions. As broadly defined, shop floor information systems such as Promis [14], WorkStream [15], Poseidon [16] *et al.* provide a flexibly described manufacturing flow data scheme to support the user. However, the data scheme of such commercial systems is proprietary. Therefore, modifying the data scheme in these commercial systems for future requirements is difficult. Nevertheless, not many small, medium firms can afford it since such systems are highly complicated customization required, and costly.

Hastings and Yeh [17] indicated that the manufacturing management information system generally takes BOM and routing as two separate modules. Integrating these two modules into a single structure would enable MRP environments such as job shops not only to perform JIT manufacturing, but also to reinforce planning, costing, and transaction tracking functions. Those investigators also presented a data structure called the bill of manufacture (BOMfr), capable of integrating routing and BOM. BOMfr has the following features: (1) A product may have one or more operations; and (2) Materials required by an operation should be presented in the corresponding BOM as the next lower level component items; resources such as labor, machines and cost information can be added as well. A merit of BOMfr is its ability to incorporate a data structure with integrated manufacturing information into an operation at the planning level. However, it lacks the necessary information and decision rules to facilitate the shop floor activities, such as how to define the data items to be collected and the rules to handle exceptions. Therefore, its shop floor applications are limited.

To overcome the above-mentioned problems, this study presents a novel manufacturing flow data scheme for the shop floor. The proposed scheme consists of four modules: operation template setup, general process setup, enhanced bill of manufacture (EBOMfr) setup and work-order process setup. This data model is characterized by its ability to flexibly define the shop floor product manufacturing flow, allowing one to effectively respond to fluctuations of the product and on the shop floor. In addition, the proposed model can cooperate with a WIP execution module to develop a WIP system for monitoring and controlling the manufacturing flow to handle floor dynamics and enhance the floor decision process. The rest of this paper is organized as follows. Section 2 describes in detail the proposed data model of shop floor product manufacturing flow. Section 3 discusses the WIP execution module of the shop floor product manufacturing flow data scheme. Next, Section 4 presents an illustrative example from the MIRL WIP System (Mechanical Industrial Research Laboratory Work-In-Process System), demonstrating the effectiveness of the proposed model. Conclusions are finally made in Section 5.

2. Construction of Product Manufacturing Flow Data Model in the IC Packaging Industry

Figure 2 schematically depicts the shop floor activities of the IC packaging industry. According to this figure, the proposed data model views the shop floor activities of IC packaging as an accumulation of sequenced operations. Applying the four basic modules of the data model, i.e. operation template, general process, enhanced bill of manufacture (EBOMfr), work-order process as shown in Figure 3, allows us to define the shop floor product manufacturing flow in a configurable manner.

Basically, a product, semi-product or a product family can own multiple sets of EBOMfr. Each EBOMfr contains available materials setup, available equipment setup and override attributes. A work-order process is a specific EBOMfr with corresponding available material assignments, available equipment assignments and override attributes based on customer requirements as a work order is about to be reviewed. Although a product, semi-product or a product family can own several sets of EBOMfr, an EBOMfr is commonly matched with only a product or a semi-product in a relatively uncomplicated industry. Each EBOMfr links to a general process. A general process, consisting of a group of sequenced operations, is used to control a manufacturing flow. An operation is a basic tracking unit of a shop floor. The contents of an operation are copied and modified from its corresponding contents of an operation template. The contents of an operation template can be defined by the user. For example, a user can set up attributes of an operation template, such as yield rate, input quantity; a user can also define exceptional rules, such as low-yield-rate rule and unmatched-input-quantity rule. Its contents are summarized according to shop floor activities. The concept of EBOMfr closely resembles that of BOMfr. However, the EBOMfr proposed herein is made after the general process and operation template. A user can easily alter the production conditions of a product manufacturing flow either by (1) adding, modifying or deleting the contents of an operation or an operation in the general process or (2) adding, modifying or deleting the contents of an operation template or an operation template to effectively responding to rapidly changing requirements and floor situations. This data model is characterized by its ability to provide users with the following functions: (1) to define manufacturing flows and the pertinent data consisting of items to be collected and action control rules through early standardization of an operation template, general process and EBOMfr. (2)

To set up related attributes, equipment and materials according to the customer requirements at the time of work order reviews through late customization of the work-order process. In the following subsection, we describe the proposed product manufacturing flow data model in detail.

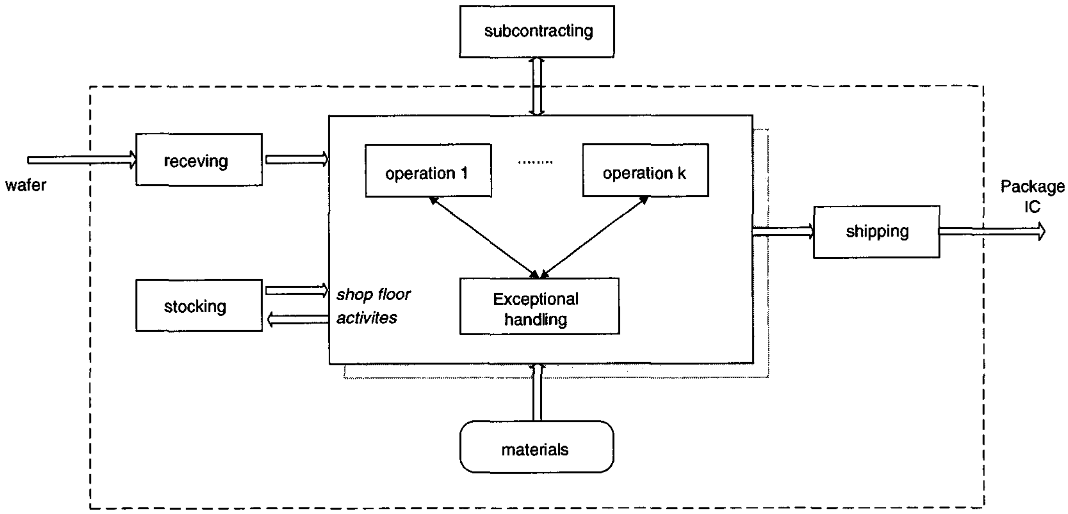

Figure 2. The shop floor activities of IC packaging industry

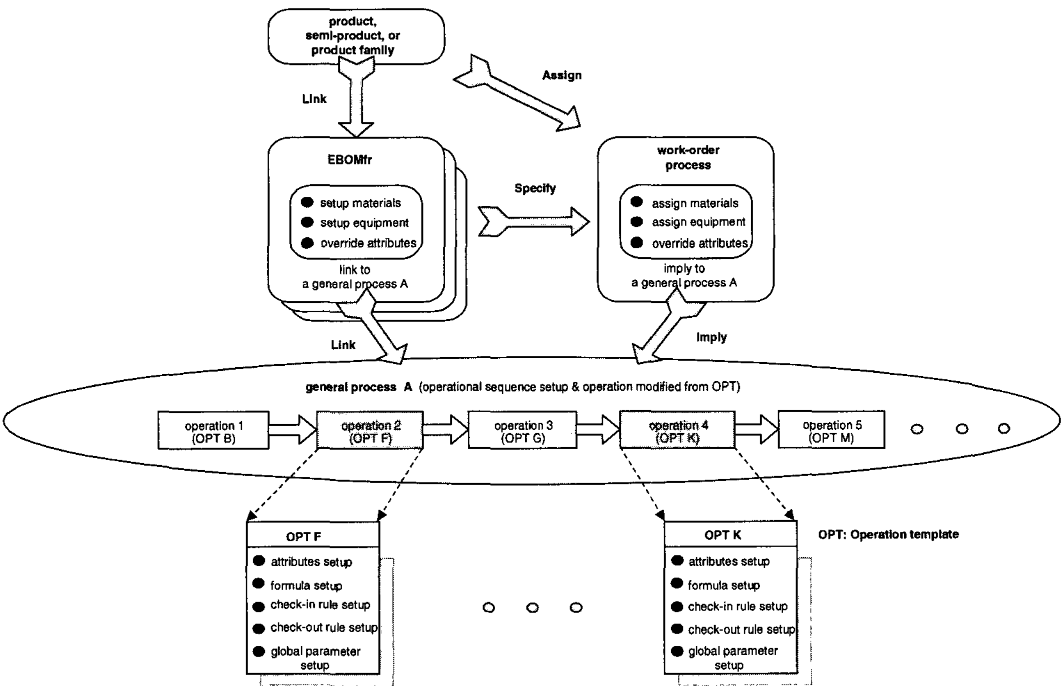

Figure 3. The proposed structure of shop floor product manufacturing flow

2.1 Operation Template

In general, the operation template can be differentiated as normal, inspected, and special operation template. A normal operation template, e.g. wafer grinding or wafer saw, is an ordinary task; a user can freely define its contents. An inspected operation template, on the other hand, is an inspecting product task. Meanwhile, a special operation template is a task requiring interface with the outside for special handling, such as subcontracting solder plating. The contents of an operation template include attribute setup, formula setup, check-in rule setup, check-out rule setup, and global parameter setup. These setups are also the basic components of EBOMfr and general process. Each setup is described as follows:

(1) Attribute setup: A user can set up different kinds of attributes, including the following:
   (a) Preset value: A default value for the shop floor is required for display or modification, e.g., a minimum yield rate of 99.5%.
   (b) Check-in value: Information or value for checking in, e.g., temperature and speed.
   (c) Check-out value: Information or value for checking out, e.g., good quantity, and scrape quantity.
   (d) Calculated value: Values calculated by a system in terms of the formula predefined by a user. e.g., output quantity = good quantity + lost quantity + scrape quantity.

(2) Formula setup: A user can define a formula to generate the calculated values for operation template.

(3) Check-in rule setup: The rule that a user used during checking in action. According to check-in value, calculated value, preset value, and the corresponding conditions defined by the user, the system can take actions such as transferring automatically, displaying a warning message, and performing exceptional handling. For example, "Error on input quantity" rule is as follows:

   If "key-in quantity" < > "move-in quantity",
   Then display the warning message "Error on input quantity".

(4) Check-out rule setup: The rule that the user used during checking out action. According to check-out value, calculated value, preset value, and the corresponding conditions defined by the user, the system can take actions such as transferring directly, displaying a warning message, and performing exceptional handling. For example; "Take defect causes" rule is as follows:

   If "defect quantity" < > 0,
   Then take the defect causes.

(5) Global parameter setup: Special attributes which must be transferred between different operations can be set up as global parameters for manufacturing flow control, e.g., transfer quantity,

Prior operation: transfer quantity = good quantity;
Current operation: move-in quantity = transfer quantity.

The data scheme of operation template can be described in IDEF1x [18] presentation as illustrated in Figure 4. Table tblWipOPData defines the name (OPNo) of each operation template. Table tblWipAttibData defines the name (AttibName), type and property of each attribute. The type of attribute can be classified as either user-defined or system-defined. The system-defined attribute, e.g., sample number and acceptance number of the inspection operation template, does not allow the user to do any editing. The property of an attribute, e.g., numerical number, date, bin, percentage and string, can be checked to observe whether or not the system legitimates the value.

(1) Attribute setup: The attribute setup of the operation template is displayed in Table tblWipTAttribOP. Its primary key consists of the operation name (OPNo) of Table tblWipOPData and the attribute name (AttribName) of Table tblWipAttribData. Among its basic data items, e.g., check-in value, calculated value, preset value, are set here.
(2) Formula setup: Table tblWipTMethodOut defines the equation to calculate calculated values. The equation is constructed by the calculated item (ObjAttribName), attribute name (AttribName), operand, and calculating sequence (MethodOrder).
(3) Check-in rule setup: The rule name of check-in rule of the operation template is defined in Table tblWipTRuleCheckIn. Each rule can own several conditions and one result. The condition is defined in Table tblWipTIfCheckIn. Each condition consists of the first attribute name (AttribName1), operand, and second attribute name (AttribName2). The logic operands (LogicOP) can be used to connect several conditions. The result (ThenOption) of the check-in rule is defined in Table tblWipTThenCheckIn. Actions of the result are to transfer automatically, to warn of errors, to perform exceptional handling.
(4) Check-out rule setup: The rule name of check-out rule of the operation template is defined in Table tblWipTRuleCheckOut. Each rule can own several conditions and one result. The condition is defined in Table tblWipTIfCheckOut. Each condition consists of the first attribute name (AttribName1), operand, and second attribute name (AttribName2). The logic operands (LogicOP) can be used to connect several conditions. The result (ThenOption) of the check-out rule is defined in Table tblWipTThenCheckOut. Actions of the result can be to transfer automatically, to warn of errors, and to perform exceptional handling.
(5) Global parameter setup: Table tblWipParameter defines the parameter name (ParameterName) of the setting. Table tblWipTPutParameter adopts the attribute value of the operation template and transforms it into a global parameter value. Meanwhile, Table tblWipTGetParameter adopts the global parameter value and transforms it into an attribute value of the operation template.

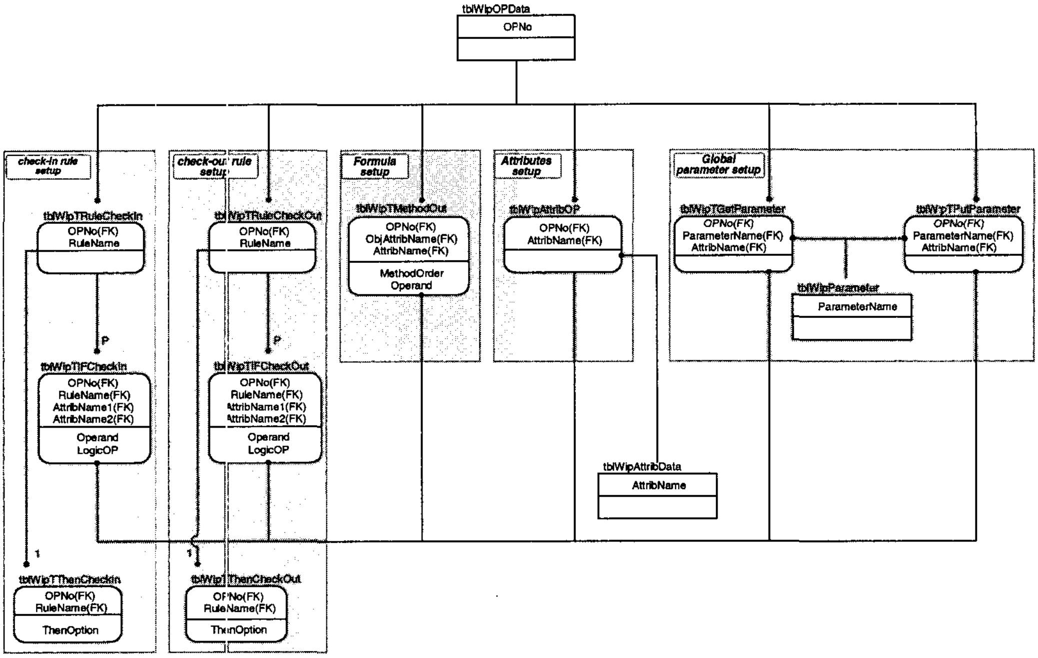

Figure 4. The data scheme of operation template

2.2 General Process

A general process is used to control a manufacturing flow and handle shop floor exceptions. This process consists of operations and operational sequence. Operational sequence is the order of an operation in a process. The contents of an operation in the general process, including attribute setup, formula setup, check-in rule setup, check-out rule setup, and global parameter setup, are copied from that of an operation template. According to the predefined operation template, a user can easily add on, modify, or delete an attribute, rule, or formula of the contents of an operation of the general process to create the manufacturing flow. Automatic transfer and exceptional handling of the shop floor are then performed based on the rule defined in each operation of the general process. According to Figure 5, the flow controls can be as (1) transfer to another operation: transfer is within the same general process, including back to the previous operation, rework at the same operation, forward to the next operation or go to the specific operation. (2) Transfer to another general process, including transfer to other general processes and start from its first operation or transfer to parts of another general process.

Figure 6 reveals that the possible general processes are (1) Sequential process: Operations in the general process are one operation following the other sequentially. Each operation in the process can be visited only once. (2) Alternate process: Conditional logic in the preceding operation of a general process specifies one of several successive operations to transverse.

(3) Checklist process: Every operation of the general process should be visited once, but without any specific order. (4) Reentry process: Some operations of the process can be visited several times under various production conditions. (5) Non-returnable process: The manufacturing flow can shift from one process to another process, but cannot return to the original process. (6) Returnable process: The manufacturing flow can shift from one process to another one and, then, return to the original process again.

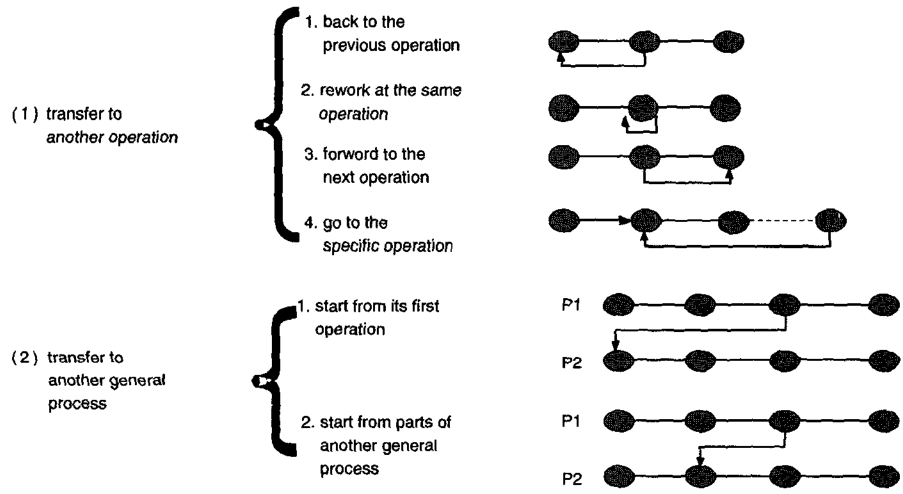

Figure 5. Possible flow controls in each operation of the general process

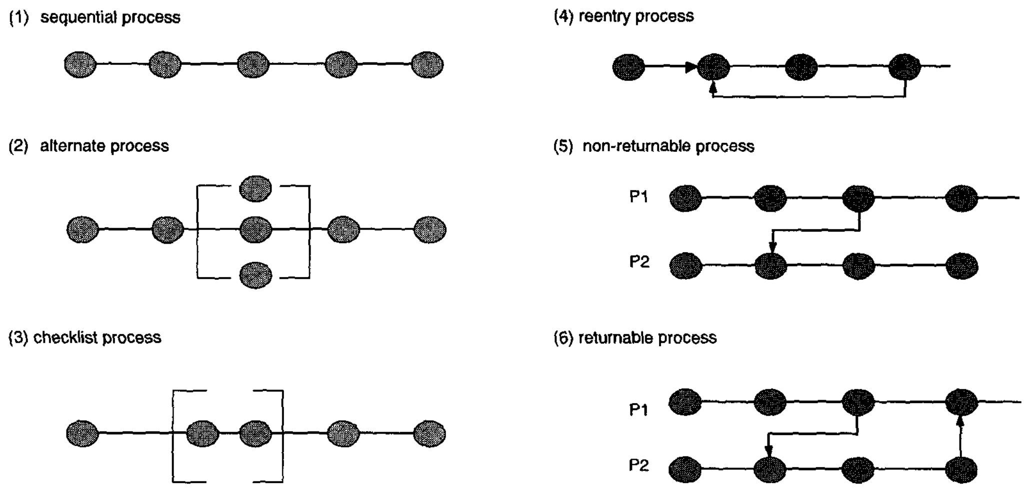

Figure 6. The possible general processes

Figure 7 depicts the data scheme of general process which can be described in IDEF1x presentation. Table tblWipProcessData defines the name (ProcessNo) and related information of each general process. Each record in tblWipProcessData corresponds to several records of tblWipProcessOP. The ProcessOPPK, consists of process name (ProcessNo), operation name (OPNo), and order (OPOrder) of the operation in the process, is the primary key of table tblWipProcessOP. As mentioned earlier, major contents of the operation in the general process (except primary key, including attribute setup, formula setup, check-in rule setup, check-out rule setup, and global parameter setup) are copied from the operation template. The user can also modify above data through addition, modification, or deletion. The operational sequence is set up in the field (OPOrder) of tblWipProcessOp. In addition, Table tblWipProcessOP can also define the properties of an operation, such as alternate operation, checklist operation, option of check-in, and check-out. The result (ThenOption) of rules in operations defines the flow controls.

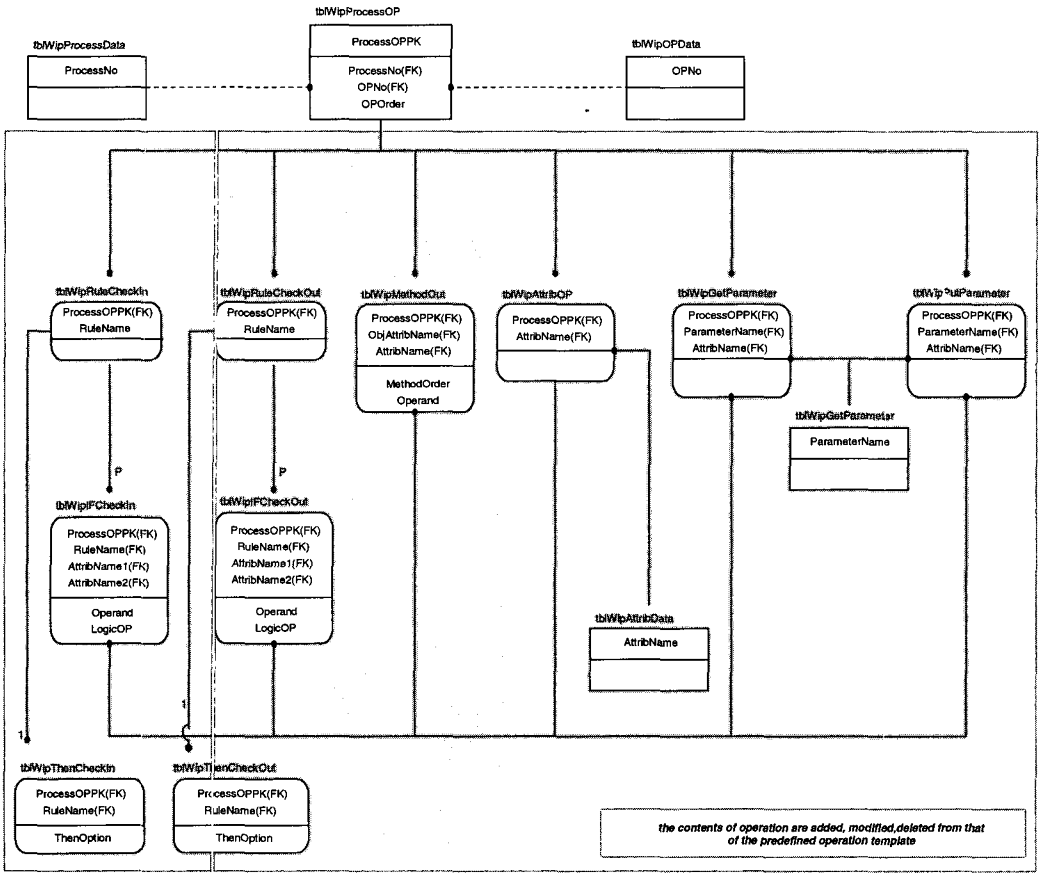

Figure 7. The data scheme of general process

2.3 Enhanced Bill of Manufacture (EBOMfr)

The primary key of EBOMfr (MBomNo) is defined in Table tblWipMBom. Its foreign keys consist of a product name (ProductNo) from Table tblWipProduct, and a general process name (ProcessNo) from Table tblWipProcessData. Those keys imply that we can define several different processes for a specific product, or a process for several different products. Figure 8 illustrates the data scheme of EBOMfr. In EBOMfr, its associated factors can be further divided into two categories: (1) Factors related to the product and operation of a process and (2) Factors related only to the product.

(1) Factors related to the product and operation of a process as shown in the shaded portion of Figure 8:

(a) Available materials setup: Table tblWipMBomMaterialOP, which defines the available materials of operation in EBOMfr, contains the name of EBOMfr (MBomNo), operation and operational sequence in the process (ProcessOPPK), available material (MaterialNo) in each operation. Available materials must first appear in Table tblMstMaterial.

(b) Available equipment setup: Table tblWipMBomEquipmentOP, which defines the available equipment of operation in EBOMfr, contains the name of EBOMfr (MBomNo), operation and operational sequence in the process (ProcessOPPK), available equipment (EquipmentNo) of each operation. Available equipment must first be defined in Table tblMstEquipment.

(c) Override attributes: Table tblWipMBomAttribOP, which defines the override attributes of operation in EBOMfr, contains the name of EBOMfr (MBomNo), operation and operational sequence in the process (ProcessOPPK), value to overrides the same attribute (AttribName) of each operation. Override attributes must first be shown in Table tblWipAttribOP first.

(2) Factors related only to the product:

(a) Available packing specifications setup: Table tblWipMBomPackage, which defines available packing specifications of the packing operation in EBOMfr, contains the name of EBOMfr (MBomNo) and the name of available packing specification (PackageNo) of the product. The available packing specifications must first be defined in Table tblWipPackageData.

(b) Available marking specifications setup: Table tblWipMBomPrinting, which defines available marking specifications of the marking operation in EBOMfr, contains the name of EBOMfr (MBomNo), and the name of available marking specification (PrintingNo) of the product. The available marking specification must first be defined in Table tblWipPrintingData.

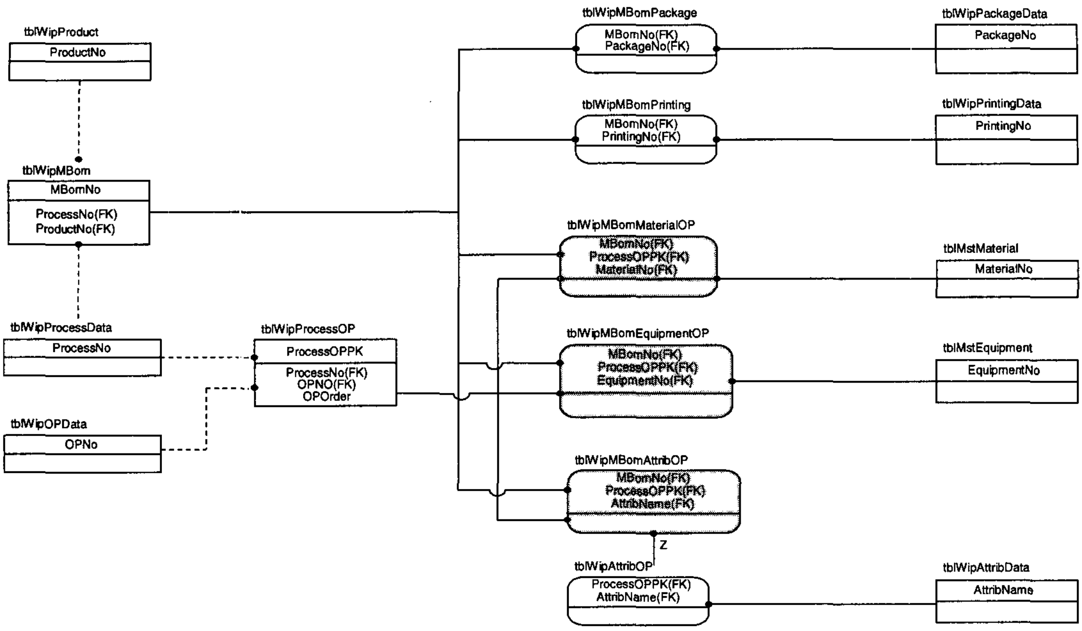

Figure 8. The data scheme of EBOMfr

2.4 Work-order Process

The primary key of work-order process (WoNo) is defined in Table tblWOData. The foreign keys consist of only a product (ProductNo) from Table tblWipProduct, and an EBOMfr (MbomNo) from Table tblWipMBom. Those keys imply that, during order review, the production planner can specify an appropriate EBOMfr for the product according to the special product requirement and, then, reassign the related product factors, including (1) Factors related to the product and operation of the process; (2) Factors related only to the product. The information used by work-order process is modified exactly from those of EBOMfr. The work-order process then carried by a lot, i.e. a basic tracking quantity on the floor, and the manufacturing flow is guided all the way on the floor. Figure 9 depicts the data scheme of work-order process. The production planner according to the corresponding EBOMfr can modify the following items:

(1) Factors related to the product and operation of a process as shown in the shaded portion of Figure 9:

(a) Available material assignments: Table tblWipWoMaterialOP, which defines the assigned materials of operation in a work-order process, contains the name of work-order process (WoNo), operation and operational sequence in the process (ProcessOPPK), as well as assigned material (MaterialNo) in each operation. The assigned materials must first be defined in Table tblWipMBomMaterialOP.

(b) Available equipment assignments: Table tblWipWoEquipmentOP, which defines the assigned equipment of operation in work-order process, contains the name of work-order process (WoNo), operation and operational sequence in the process (ProcessOPPK), assigned equipment (EquipmentNo) in each operation. Assigned equipment must first be defined in Table tblWipMBomEquipmentOP.

(c) Override attributes: Table tblWipWoAttribOP, which defines override attributes of operation in a work-order process, contains the name of work-order process (WoNo), operation and operational sequence in the process (ProcessOPPK), value to overrides the same attribute (AttribName) of each operation. Override attributes should first appear in the table tblWipMBomAttribOP.

(2) Factors related only to the product:

(a) Available packing specification assignments: Table tblWipWoPackage, which defines the assigned packing specifications of the packing operation in work-order process, contains the name of work-order process (WoNo), and the name of assigned packing specification (PackageNo) of the product. The assigned packing specifications must first be defined in Table tblWipMBomPackage.

(b) Available marking specification assignments: Table tblWipWoPrinting, which defines the assigned marking specifications of the marking operation in work-order process, contains the name of work-order process (WoNo), and the name of assigned marking specification (PrintingNo) of the product. The assigned marking specifications must first be defined in the Table tblWipMBomPrinting.

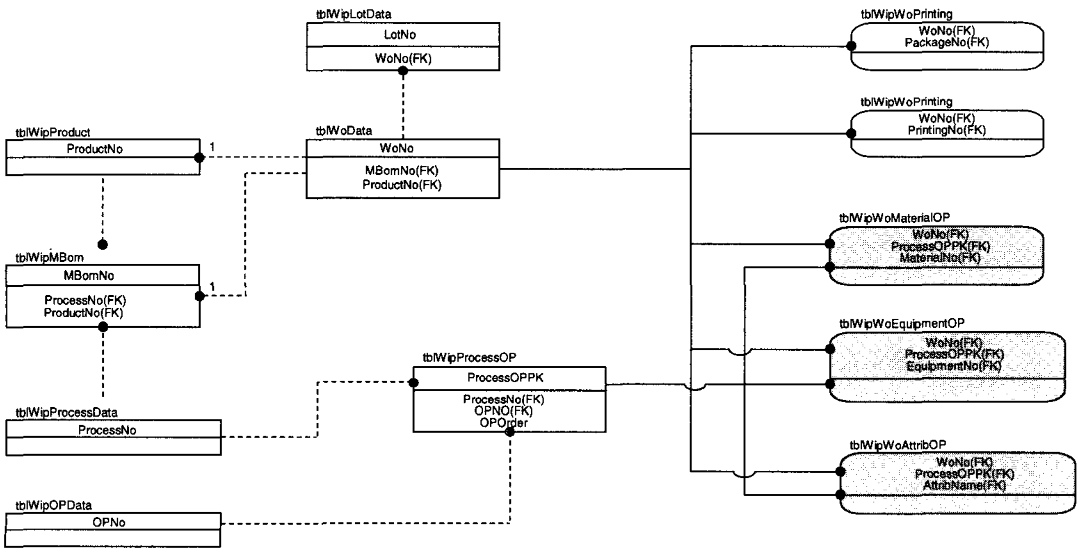

Figure 9. The data scheme of work-order process

3. Execution of Product Manufacturing Flow Data Model in the IC Packaging Industry

Through its early standardization of operation template, general process and EBOMfr, and late customization of work-order process, the data model of shop floor manufacturing flow provides the user with a flexible descriptive mechanism to define the relevant production information and action control rules of shop floor activities. However, to master floor dynamics in IC packaging industry, the data model incorporates with a WIP (*i.e.* work-in-process) execution module to develop a WIP system to monitor and control the product manufacturing flow on the shop floor as illustrated in Figure 10. Its major function is to take the work order from planning level, ensure that the work order can be delivered in the right amount and in adequate quality, and feedback the corresponding information to the planning level for proper management decisions. The WIP execution module can be vary based on the floor focus of tracking in each industry. Based on floor tracking unit of quantity, the WIP execution module can be classified into four different types:

(1) Lot-based WIP execution module. A lot is a basic unit of quantity for transferring from one operation to another operation, such as in IC packaging or IC testing industry;
(2) Unit-based WIP execution module. A single quantity is a basic unit for transferring from one operation to another operation, such as in printed board, hard disk, and notebook making industry;
(3) Order-based WIP execution module. Any amount of the same work order can be grouped and transferred from one operation to another one; and
(4) Product-based WIP execution module. Any amount of the same product can be grouped and transferred from one operation to another operation freely.

Under normal conditions, the WIP execution module tracks any transferred quantity from the first operation to the final operation according to the predefined work-order process, and monitor the following events in each operation. (1) During check-in, the module can assess whether or not an action can be executed based on the user check-in attributes and the predefined check-in rules. (2) During check-out, the module knows what the next operation is based on the user check-out attributes and the predefined check-out rules. If exceptional production problem occurs in a certain operation, the WIP execution module enters the predefined handling procedure. To accumulate information regarding shop-floor production lots at every operation, e.g. its associated material, equipment, people, quality, and time, we need an additional data scheme, called lot-based tracking process, to record lot status and course. In this section, we present (1) the Lot-based tracking process and (2) the Lot-based WIP execution module in the IC packaging industry.

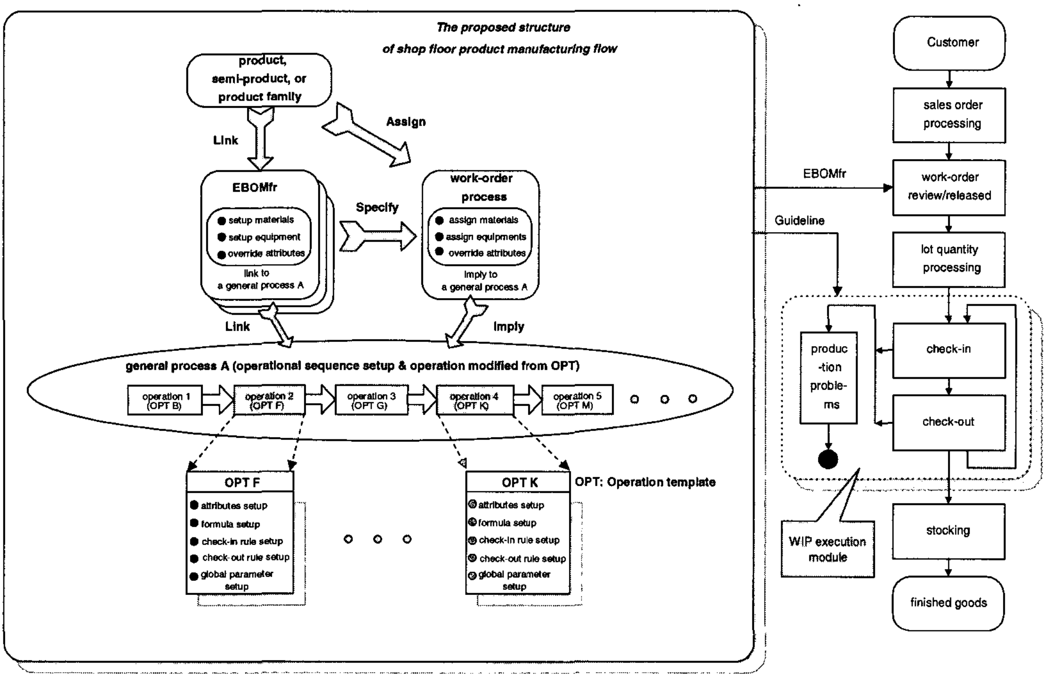

Figure 10. The framework of work-in-process system

3.1 Lot-based Tracking Process

Since the basic tracking unit is a lot in the IC packaging industry, assume that each individual in the lot contains the same status. According to Figure 11, if the lot status is "ready for release", the WIP execution module modifies the lot status to "released". The released lot can then have its status changed to "ready for check-in", "ready for check-out", "exception", or "ready for stocking". Moreover, when the lot is put into stock, the lot status is changed to "finished". Figure 12 illustrates the IDEF1x presentation of lot-based tracking process. The name of the lot (LotNo) is defined in Table tblWipLotData. When the lot status is "ready for release", the WIP execution module creates a record of lot in Table tblWipLotState, and adds a corresponding record (LotSerial) in the table tblWipLotTracking. In addition, the module records the material (MaterialNo) used in the table tblWipLotMaterialContent, takes down the equipment (EquipmentNo) used in the table tblWiplotEquipmentContent, and documents the name of attribute (AttribName) and value (AttribValue) used in the table tblWipLotAttribContent. If there are defects, the number of defects, defective lot, and defective reasons (ErrorNo) are recorded in Table tblWipLotFailContent. Under normal conditions, the lot travels from the first operation to the final operation according to the predefined work-order process. If abnormal situation occurs in specific operation, a record (LotErrorSerial) will be added into Table tblWipLotErrorLog, the cause of error (ErrorNo) will be inserted into Table tblWipLotErrorContent. The lot will then be put in the exceptional handling procedure. According to our results, the lot-based tracking process reflects exactly what occurred on the floor and, simultaneously, monitors the information and events. Tables of the lot-based tracking process can be described as follows:

(1) Table tblWipLotState records every processing lot in the plant about its current operation (CurOpNo), current number (CurNum), current status (CurStatus), such as "ready for check-in", "ready for check-out", "exception", or "ready for stocking", "finish".

(2) Table tblWipLotTracking documents each processing lot on how many operations the lot has gone through, the status of the each operation as it goes along, check-in time, and check-out time it encountered. The tables, for recording attributes, materials, equipment it used, and the defective lot, defective reason (ErroNo), defective quantity (ErrQty) it encountered, has been described in the previous section.

(3) Table tblWipLotErrorLog records the violated rule name (RuleName), starting time (StartTime), handling procedure (Result), and completion time (EndTime). Meanwhile, Table tblWipLotErrorContent records the errors of an abnormal lot.

(4) Table tblWipLotLog records the information of attributes, including good quantity, bad quantity, and lost quantity for user look-ups.

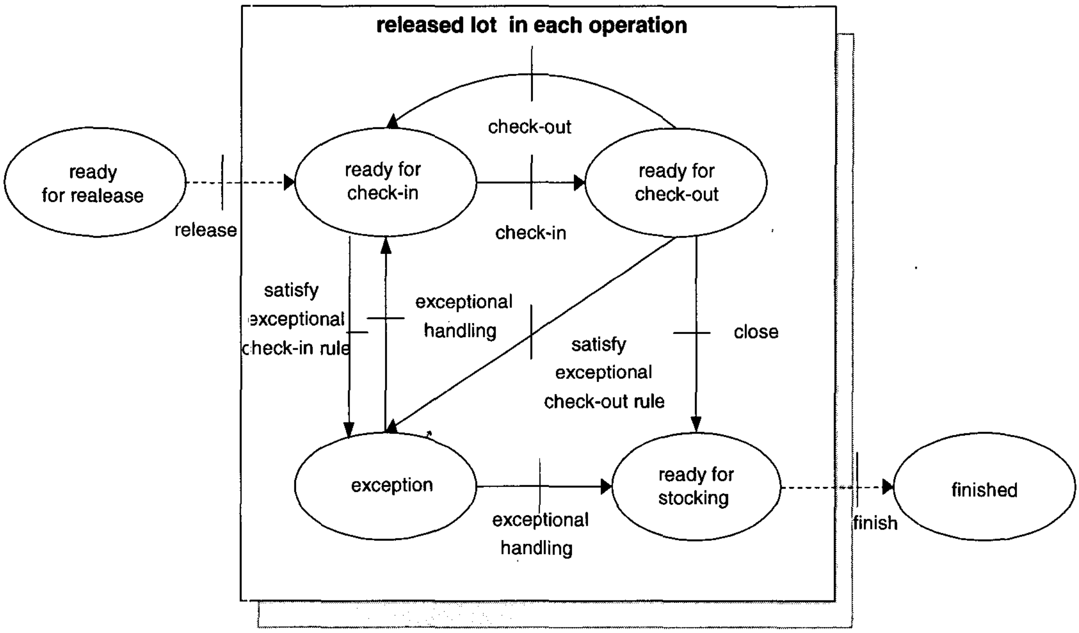

Figure 11. Lot status in each operation

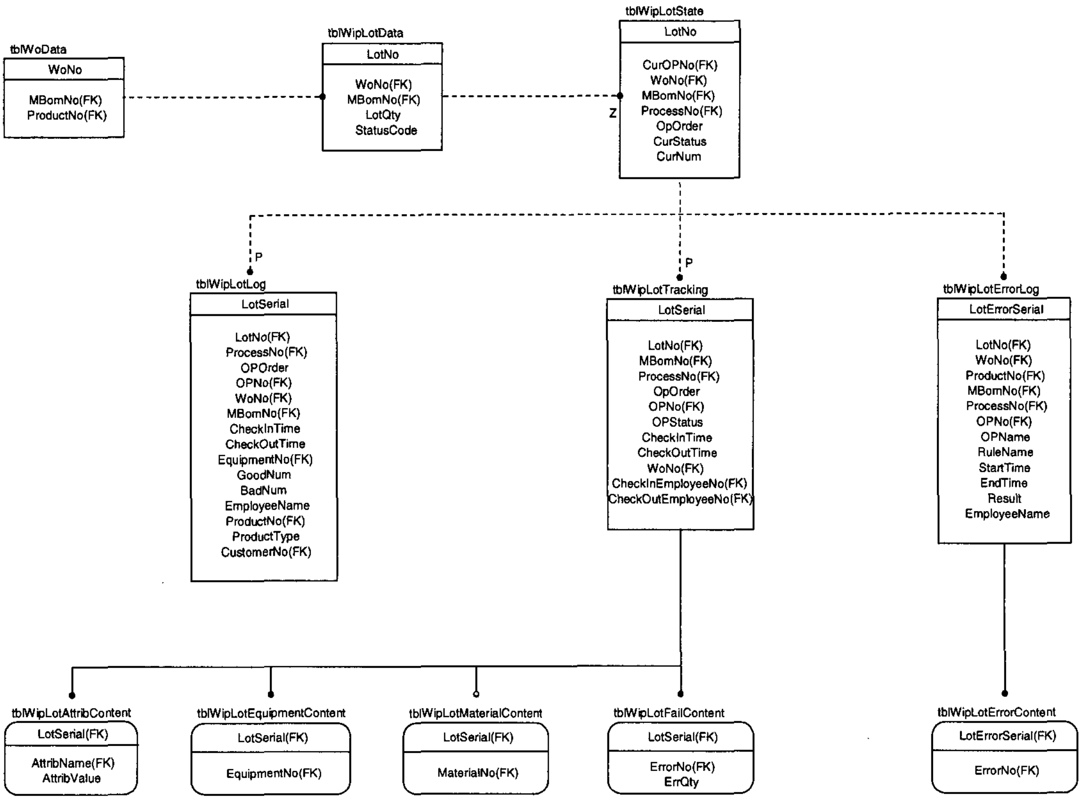

Figure 12. The data scheme of lot-based tracking process

3.2 Lot-based WIP Execution Module

Based on the setup of work-order process, EBOMfr, general process a lot used, the WIP execution module performs related events, such as "release lot", "check-in lot", "check-out lot", rule processing, exceptional handling, "close lot", "finish lot", according its lot status in each operation as depicted in Figure 11. When the floor operator keys in or barcodes in its user identity and lot number during login, the execution module updates the corresponding information in the following tables according to the status of the lot appearing in Table tblWipLotData:

(1) If the lot status (StatusCode) in Table tblWipLotData is "ready for release", the execution module updates the lot status (StatusCode) to 'released', adds a record to Table tblWipLotState, and marks the record's current status (CurStatus) in Table tblWipLotState as "ready for check-in" and call check-in procedure at the same time.

(2) If the lot status (StatusCode) in Table tblWipLotData is "released", the execution module reacts differently, depending on the current status (CurStatus) in Table tblWipLotState. The execution module calls for the check-in procedure when the current status

(CurStatus) is "ready for check-in". In addition, the execution module calls on the check-out procedure when the current status (CurStatus) is "ready for check-out".

- The check-in procedure is based on the setup of work order process, EBOMfr, general process and allows the floor operator to (a) select the material and equipment; (b) confirm preset value; (c) Key in check-in value. The execution module also (d) examine the validity of the check-in value; (e) review whether or not the check-in rule is satisfied,
  (i) If the check-in rule is not satisfied, the status (CurStatus) is changed to "ready for check-out"; in addition, check-in time, employee identity, check-in values are also recorded;
  (ii) If the check-in rule is satisfied, different actions are taken according to what the rule states. For instance, a warning signal is issued; otherwise, the status (CurStatus) is changed to "exception". Moreover, the corresponding rule name, time, employee identity is recorded as well.
- The check-out procedure is based on the setup of work order process, EBOMfr, general process. In addition, the floor operator is made available to (a) identify the material and equipment; (b) key in the check-out value. The execution module also (c) examine the validity of the value; (d) calculate the predefined formula's value; (e) review whether or not the check-out rule is satisfied,
  (i) If the check-out rule is not satisfied, the status (CurStatus) is changed to "ready for check-in" or "ready for stocking", and check-out time, employee identity, check-out values are also recorded;
  (ii) If the check-in rule is satisfied, different actions are taken according to the rule. For instance, generating warning messages, recording defects, reason, and number, or changing the status to "exception", and the corresponding rule name, time, employee identity are also recorded. In an exceptional status, typically the responsible engineer attempts to identify what the rule corresponds to, determine the next action, and record the outcome take down the reason and outcome.

(3) When the lot status (CurStatus) in Table tblWipLotState is "ready for check-out" and the operation is the final of the process, the execution module calls for a close lot procedure and then changes the lot status to "ready for stocking".

(4) When the lot status (CurStatus) in Table tblWipLotState is "ready for stocking", the module calls for the finished procedure to let the operator select finished lot and stock quantity. If the lot quantity is completely moved to stock, the lot is deleted from Table tblWipLotState. In addition, the status (StatusCode) of the corresponding record in Table tblWipLotData is updated to 'finished'.

3.3 Example

Figure 13 presents the post-bonding inspection (PBI) operation (this PBI operation can originate from the PBI operation template set up previously) of the manufacturing flow of a certain product in the packaging industry. The setup of the operation is shown in the lower portion of this figure. The attribute setup determines the characteristics of "key-in quantity", "good quantity", "scrape quantity", "lost quantity", "output quantity", "move-in quantity", and "target quantity". Meanwhile, three calculated formulae such as "output quantity = good quantity + scrape quantity + lost quantity", "move-in quantity = transfer quantity" and "transfer quantity = good quantity" are established. Moreover, the check-in, check-out rules and the global parameter like transfer quantity are also defined. The upper half picture represents the processing of a lot-based WIP execution module. It is executed according to the operation defined in the lower half of the figure. Thereby, performing check-in at PBI operation requires inputting the key-in quantity while performing check-out needs to input good, scrape and lost quantity. As the input number is satisfied the defined check-in and check-out rules, the module issues actions (e.g., display warning message) according handling procedure. Otherwise, if the input scrape quantity is not equal to zero that is the target quantity, the user is asked to input the cause of the scrape. As stated above, each product lot is executed according to the operation defined in the manufacturing flow for the product.

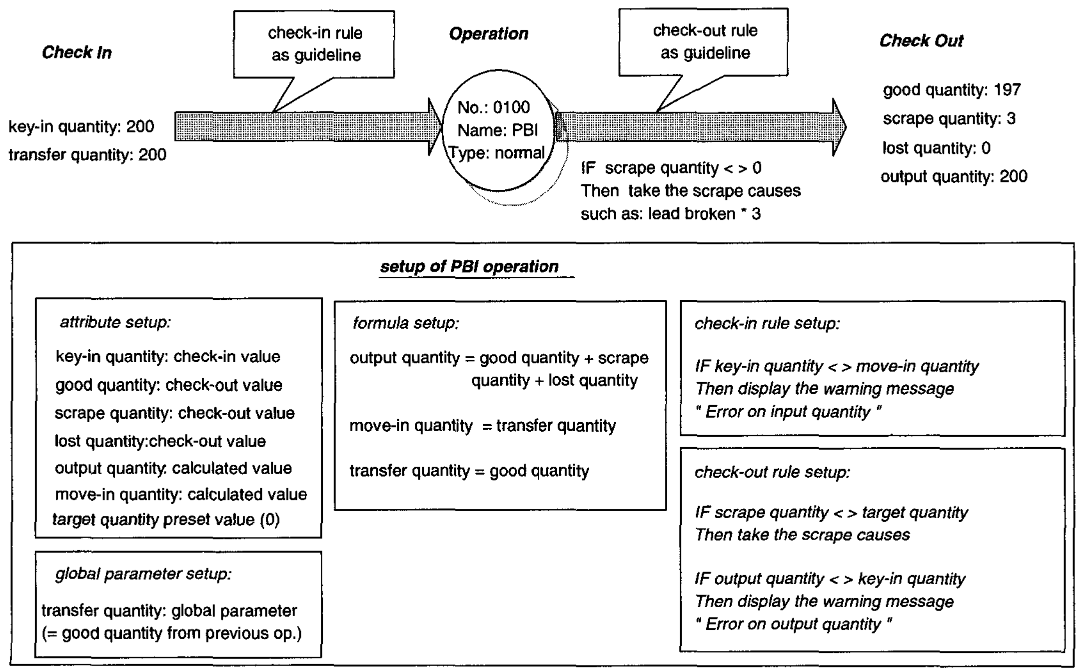

Figure 13. Setup of the post bonding inspection operation (PBI)

4. An Illustrative Example: The MIRL WIP System

The MIRL WIP system, developed by Mechanical Industry Research Laboratories of Industrial Technology Research Institute, comprises of a network, database, and personal windows environment. This system is based on the proposed data model of product manufacturing flow. The major functions of MIRL WIP Systems are as follows: Basic data setup, General process setup, EBOMfr setup, shop floor processing, inquiry/report, security setup. Basic data setup is the setup of all basic data, including material, material type, equipment, equipment type, employee, department, vendor and customer. General process setup is the setup of operation template and the general process. It includes the attribute setup, operation template setup, and general process setup. EBOMfr setup includes the setup of EBOMfr and the setup of product. Shop floor processing consists of lot processing, such as "release lot", "check-in lot", "lot check-out lot", rule processing, exceptional handling, "close lot", "finish lot". Inquiry/report consists of current status inquiry, production details inquiry, production report, yield rate report. Notably, current status inquiry displays the information of all the running lot according to the criteria selected. Production details inquiry provides the detailed course of every lot in each operation based on the criteria selected. Security setup bestows authority upon users and separates them into different access groups.

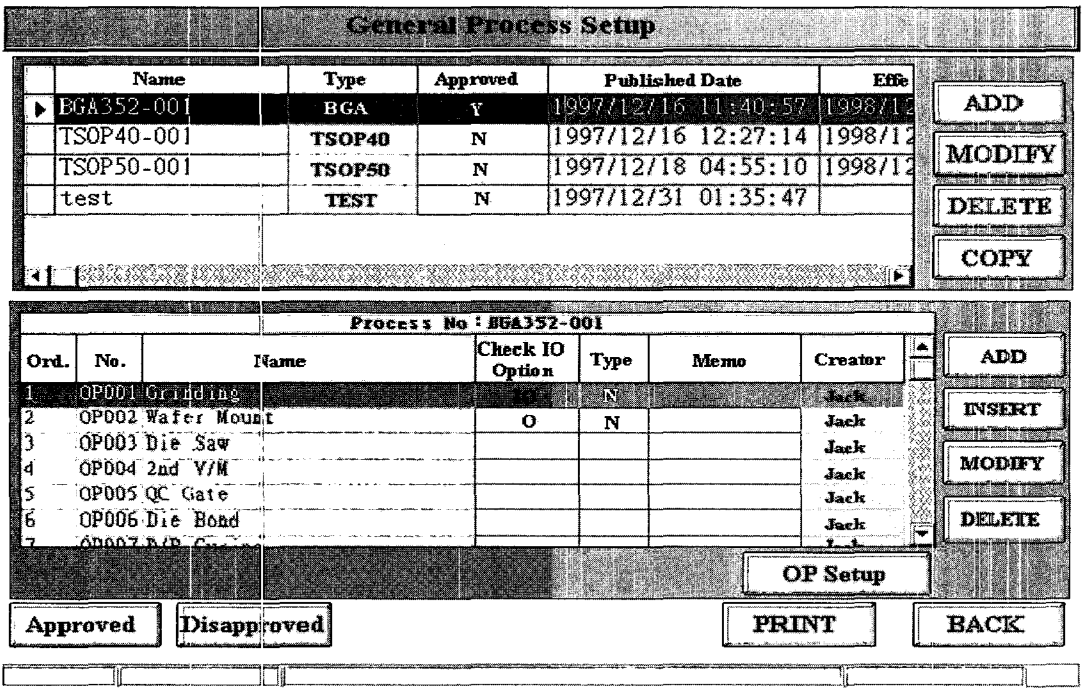

Figure 14. The example screen of general process setup

To allow users to easily modify parameters to fulfill varied floor dynamics without changing the source codes, the WIP system provides generic user interfaces in each operation. The interfaces include check-in interface, check-out interface, exceptional handling interface, close lot interface. The user can also develop its own specific interfaces. Figure 14 presents the example screen of general process setup. The upper portion of the screen presents the name, type and valid date of the general process. Meanwhile, the lower portion of the screen presents the operational sequence setup of the corresponding general process. The button of operation setup provides an entry to the attribute setup, formula setup, check-in rule setup, check-out rule setup, global parameter setup as illustrated in Figure 15. When the operator keys or barcodes in employee identity and lot number during login, the system can inform the user of the lot status and make the corresponding actions immediately. For example, Figure 16 displays the check-out screen. This figure also contains the required information for viewing and checking out entries. The upper portion of the screen is the operation name and move-in quantity. The left portion of the screen is the preset attributes, material description and material used. The right portion of the screen is the selected equipment and operator entries. The check-in screen displays the information of selected material, equipment and check-in values which is the same as in the check-out screen.

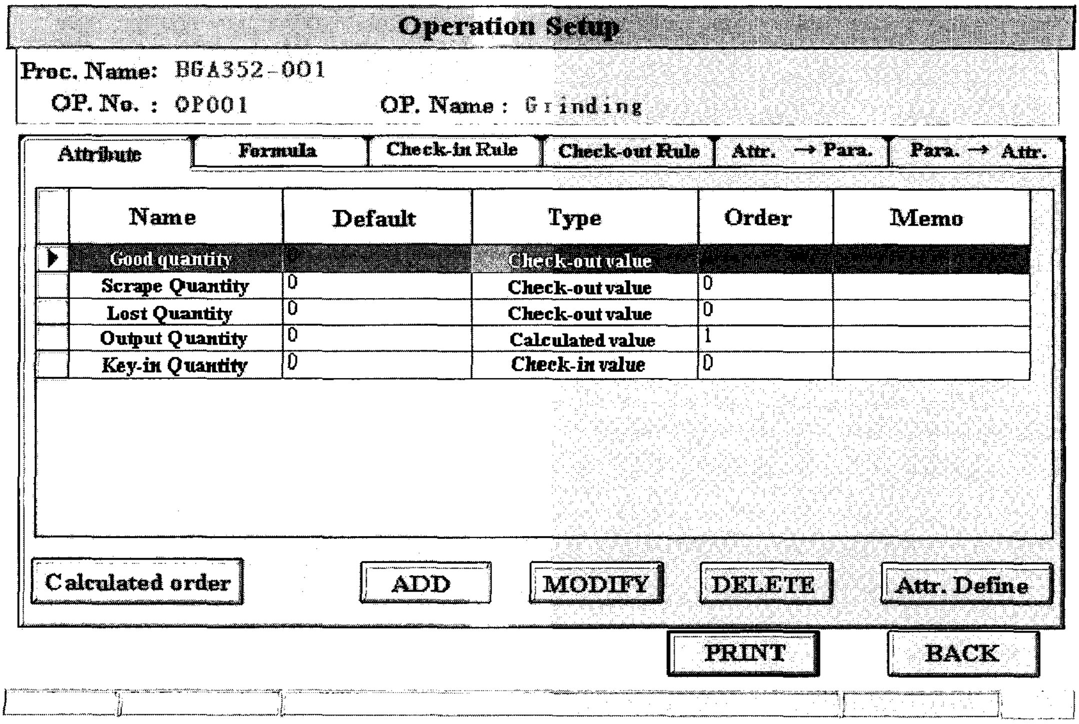

Figure 15. The example screen of operation setup

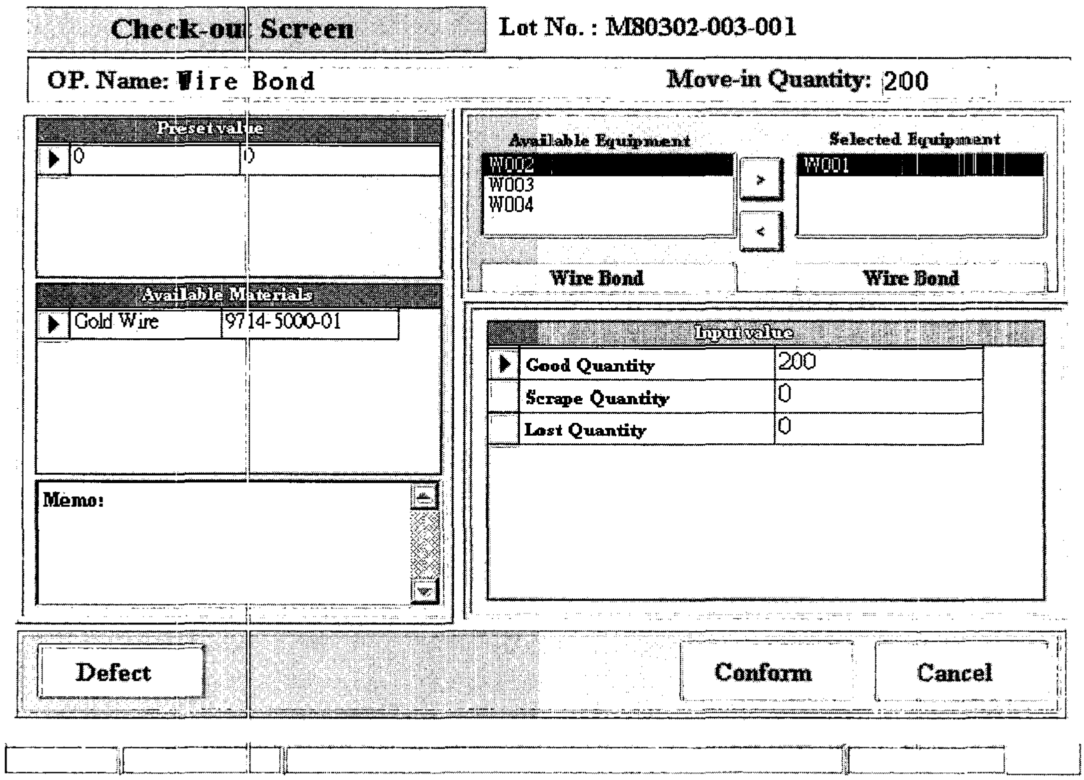

Figure 16. The example screen of check-out procedure

5. Conclusions

This study presents a data model of product manufacturing flow which has four modules: operation template setup, general process setup, enhanced bill of manufacture (EBOMfr) setup, and work-order process setup. The proposed data scheme provides users with a descriptive scheme in the shop floor execution level: (1) to define the information and decision rules required for manufacturing flow flexibly, and allow the user to easily adjust the system to fulfill the floor dynamics. (2) to monitor the execution of the manufacturing flow through lot-based WIP execution module in the IC packaging WIP system to facilitate reliable and speedy managerial decisions. In the future, the manufacturing flow data scheme can be applied to different industrial sectors by using different WIP execution modules. WIP systems of different industrial sectors can thus be constructed gradually to expand its areas of usage. On the other hand, the industry can also use the WIP system as the core and combine the corresponding function module that adapted such a data scheme to construct the shop floor information system to yield a higher productivity.

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