# Enhancement of Production Efficiency in the IC Packaging Industry via a Computerized WIP and Scheduling System

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***Abstract***

*Enhancing production efficiency in the IC packaging manufacturing heavily relies on acquiring shop floor information and then utilizing it, thereby necessitating the development of a computerized WIP and scheduling system (CWSS). Therefore, this work develops a production model to flexibly define shop floor information in the production flow. The proposed model comprises four modules: operation template setup, general process setup, enhanced bill of manufacturing (EBOMfr) setup, and work-order process setup. To timely handle manufacturing data, this work also proposes a WIP module to monitor and control production flow. Moreover, a scheduling module is constructed with a time-advanced scheme. The primary results of the integration of both modules for the IC packaging industry are discussed as well.*

**Keywords:** WIP, Scheduling, IC packaging, enhanced bill of manufacturing

## 1. Introduction

IC packaging is the downstream industry of IC supply chain. A standard process of IC packaging includes the following steps: wafer grinding, wafer saw, die bond, epoxy cure, wire bond, post-bonding inspection (PBI), molding, marking, dejunk/trimming, solder plating, forming/ singulation, O/S test, final inspection, packing, and outgoing QC. Since the product cycle time is short and the arrival of the product can not be planned, IC packaging industry managers heavily rely on shop floor information to timely handle dynamic shop floor environments and respond to customer requests. Therefore, improving the competitiveness of a company mostly depends on flexibly incorporating shop floor information into the production flow, handling manufacturing data quickly according to the production flow, generating good-enough decision support information according to feedback shop floor information and future manufacturing requests.

A shop floor information system (SFIS) generally includes functions such as scheduling, dispatching, monitoring, and equipment controls (Melnyk [1,2], Satori [3], Vollman [4]). Furthermore, information in a SFIS can be categorized into decision support information and shop floor information. Generally, a WIP (work-in-process) module that focuses on collecting the manufacturing status of lots and resources is the core of the shop floor information system. This module provides operation tracking, feeds information back to the planning system, and produces managerial reports to support decisions. In short, a WIP module bridges the scheduling and equipment control levels. However, the most important tool directly involved in enhancing manufacturing efficiency is a scheduling module. A scheduling module can play a role in assisting people making various plans with different plan horizon.

This work adopts a computerized system in developing a production model of the production flow, WIP module, scheduling module, and the integration of both modules for the IC packaging industry. Figure 1 illustrates the proposed integrated system and associated function modules required for constructing the CWSS. The production model replicates a real manufacturing plant. Various resources, including personnel, machines, and tools are included in this production model. The proposed model also contains required information, as the modeling information of a plant needs for the scheduling module. The production model is a global model referenced by all modules in Fig. 1. The order entry module first provides the information on customer orders. Then customer orders are changed into work orders based on the manufacturing viewpoint. Finally, a work order is divided into various lots that are the basic manufacturing and transportation units. The WIP module lets users define the production model and monitor the machine, mold, and lot status in real time. Additionally, a lot needs to be expanded into some manufacturing operations representing the operations required to manufacture the lot in various workstations according to its production flow. The scheduling module gathers the information of the lots that are currently running in the system or that will be released into the system to create a schedule. Such a decision-making mechanism must refer to the expert knowledge, special production experience, or manufacturing constraints to decode the sequence of lots in each workstation. Such information includes (1) the available resources for each lot, (2) the specific scheduling parameters for each work station, (3) the process time information for each lot, (4) the scheduling rules, and (5) the equipment maintenance and break down estimates. Scheduling results including dispatching list and Gantt Chart are then transformed into the dispatching module. The dispatching module displays the dispatching list on appropriate devices near the manufacturing locations as a reference for the operator or equipment controller in the manufacturing.

## 2. Developing a production 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 production model views the shop floor activities of IC packaging as an accumulation of sequential operations. Applying the four basic modules of the production model, that is, operation template setup, general process setup, enhanced bill of manufacture (EBOMfr) setup, and work-order process setup, as Figure 3 depicts, allows shop floor production flow to be designed in a configurable manner.

### 2.1 EBOMfr

Basically, a product, semi-product or product family can own multiple sets of EBOMfr. Meanwhile, 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, equipment assignments and override attributes, based on customer requirements before the review and release of a work order. Each EBOMfr is linked to a general process. Meanwhile, a general process, consisting of a group of sequenced operations, is used to control production flow. An operation is the basic tracking unit on a shop floor. The contents of an operation are copied and modified from the corresponding contents of an operation template. Meanwhile, the contents of an operation template can be defined freely by the user. For example, a user can establish attributes of operation templates, such as yield rate, input quantity, or define exceptional rules, such as low-yield-rate rule and unmatched-input-quantity rule. The template contents are summarized according to shop floor activities. The concept of EBOMfr closely resembles that of BOMfr (Bill of Manufacturing, Hastings [5]). However, the EBOMfr described herein is made after the general process and operation template. A user can easily alter the production conditions of a production flow either by (1) adding, modifying or deleting an operation in the general process or (2) adding, modifying or deleting the contents of an operation to effectively respond to changing product requirements and floor situations. This production model is characterized by its ability to provide users with the following functions: (1) flexible definition of production 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 establish related attributes, equipment and materials according to customer requirements at the time of work order review and release through late customization of the work-order process.

### 2.2 Operation template

The contents of an operation template include attribute setup (including preset value setup, check-in value setup, check-out value setup and calculated value setup), formula setup, check-in rule setup, check-out rule setup, and global parameter setup. These setups are also the basic components of the EBOMfr and general process.

### 2.3 General process

A general process controls production flow and handles shop floor exceptions. This process includes 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 an operation template. According to the predefined operation template, a user can easily add, modify, or delete an attribute, rule, or formula of operation contents to create the production 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.

## 2.4 Work-order process

The work-order process can associate the product attribute with EBOMfr. Therefore, the production planner can specify an appropriate EBOMfr for the product according to the special product requirement, and then reassign the product related factors, which include (1) Factors related to the product and operation of the process; and (2) Factors related only to the product. The information used by the work-order process is modified from the information of EBOMfr. The work-order process can then be carried by a lot, i.e. a basic tracking quantity on the floor, and the production flow is guided all the way on the floor.

# 3. Developing the WIP module

To ensure good customer service, the WIP module should allow the user to perform the following tasks: (1) Flexibly define shop floor information in the production flow before production; (2) Timely handle the lot activities of customer orders according to predefined production flow during production; and (3) Easily modify production flow information to allow fulfilling of changing product requirements and floor situations.

Through its early standardization of operation template, general process and EBOMfr, and late customization of work-order process, the proposed production model of production flow gives the user a flexible descriptive mechanism to define the relevant production information and action control rules of shop floor activities. However, to timely handle manufacturing data in IC packaging industry, the production model incorporates a WIP module to monitor and control the production flow on the shop floor as Figure 4 illustrates.

The WIP module normally monitors any transferred quantity from the first to the final operation according to the predefined work-order process, and controls the following events in each operation. (1) During check-in, the module can assess whether or not an operation can be executed based on user check-in attributes and predefined check-in rules. (2) During check-out, the module can assess what the next operation is based on the user check-out attributes and the predefined check-out rules. If exceptional production problems occur in a certain operation, the WIP module initiates the predefined handling procedure. To accumulate information on shop-floor production lots for every operation in the packaging industry, including associated material, equipment, people, quality, and time, an additional data scheme is required, called lot-based tracking process, to record lot status and course.

Take the post-bonding inspection (PBI) operation (which can originate from the PBI operation template established previously) for example. Figure 5 depicts the production flow of a certain product in the packaging industry. The lower portion of this figure depicts the setup of the operation. 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 operation also defines the check-in, check-out rules and the global parameters like transfer quantity. The upper half of the picture represents the processing of a WIP module. The module is executed according to the operation defined in the lower half of the figure. Thus, performing a check-in at PBI operation requires inputting the key-in quantity while performing check-out, and needs to input good, scrape and lost quantities. When the input number satisfies the defined check-in and check-out rules, the module issues actions (such as displaying warning messages) according to the handling procedure. Otherwise, if the input scrape quantity does not equal zero, which 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 production model for the product.

## 4. Developing the scheduling module

In the proposed scheduling module, the emulation time is driven by events that occur at resource status change or lot movement. The emulation time is different from the simulation time in that the event time of the former is not totally dependent on the simulation event time of assigned scheduling horizon while the later is. The scheduling algorithm of such event-driven is named the time advance scheme.

### 4.1 Time Advance Scheme

Figure 6 depicts the architecture of the time advance scheme in an IC packaging factory. In Figure 6, the workstation is a logical collection of functionally identical machines to perform one kind of operation. The operation performed in a workstation is called job. Basically, each workstation has at least two data queues to identify the jobs that must be processed in the workstation at the current or in the future time. The AvailableQueue of a workstation collects the jobs that are currently waiting in the workstation for performing manufacturing at current emulation time (or named GlobalAdvanceTime). The UnavailbeQueue in a workstation collects the information of the jobs that currently allocates in another workstation but will arrive at the workstation at some time. The time advance scheme involves two decision-making at points of resource status change or lot movement: (1) performing sequencing in the AvailableQueue to select a new lot for processing and (2) conducting machine selection to pick up an appropriate machine for the operation.

Figure 7 depicts part of the events and their associated activities in triggering the present emulation time (GlobalAdvanceTime) to jump to a new GlobalAdvanceTime. In fact, a complete implementation of the time-advanced scheme is much more complicated than that represented in Figure 7. In Figure 7, the events merely include the status variations of available jobs and machines. As a matter of fact, secondary resources such as die sets and queues like ExceptionalQueue are also included in the scheduling module. The exceptional queue takes in exceptional jobs such as preventive-maintenance and downtime operations. A more complicated event to trigger system in order to capture a new GobalAdvanceTime will then be required under such condition.

### 4.2 Modeling Equipment

Machines are the basic elements in modeling the resources of a factory. The scheduling module should perform machine selection to arrange each job to an appropriate machine. Generally, all machines provide finite capacity. However, there are workstations such as marking, PBI and outgoing PC etc. in the IC packaging industry where capacity of machines may not be a matter of concern, or the capacity of these machines can accommodate any work load from its upstream work station. Then such workstation can be defined as infinite capacity, therefore, a period of time like transportation time is merely needed to be assigned to this kind of process to reduce complexity and enhance the scheduling performance.

### 4.3 Modeling Subcontractors

Cooperating with subcontractors can extend the capacity and decrease the investment venture. Factory may employ subcontracting in the operation like plating. The *s*ubcontractors are categorized into separate groups based on the products they can process, and the loading of each subcontractor is also being under careful watch. So the subcontractors are considered as infinite-capacity providers in this case. However, we cannot simply employ a period of transportation time to represent a subcontract processing. This is because the subcontract processing can merely be started and finished at some specific time. In addition, bringing back all the processed lots at once requires a better sequencing of WIP buffer in forming/singulation.

### 4.4 Sequencing

The module sequences the jobs according to a weighted combination of sequencing objectives that correspond to the manufacturing goal of the user. In this work, the concerned criteria include due date and priority. The contributed value of the due date criterion in the sequencing objectives addresses the objective of leaving enough time to meet the due date of lots, while priority criterion addresses the degree of emergency or importance of a lot. Weights are the extent of importance in considering among various criteria. To properly compare the criteria with different unit of measure, each contributed value of criterion should be normalized to a value ranging between 0 and 1. Through normalization, every criterion will be in the same unit-of-measure (the normal unit) and will be measured in the same magnitude (between 0 and 1). Two boundary values, Norm0 and Norm1, are specified for each criterion value sorting. Boundary of Norm0 implies that the system will take a normalized value as 0 if the criterion value of a lot is less than that of the boundary. Boundary of Norm1 implies that the module will take the normalized value as 1 if a criterion value of a lot is larger than that of the boundary. If the values of Norm0 and Norm1 are assigned by the user, the lots with criterion values equal or less than Norm0 will be recognized as equally important, and the other lots with criterion values larger than Norm1 as equally unimportant. In such case, these lots will bid the resources according to another criterion that can differentiate their important levels. However, the user generally needs expertise in determining the boundaries of the importance and unimportance.

All of the objectives are considered in determining the importance of a job. The normalized value is taken to multiply its respective weight of criterion, and the cost of scheduling is the summation adding these weighted values all together. The smaller the cost, the greater the important in sequencing the related job next.

### 4.5 Machine Selection

The scheduling module performs a machine selection algorithm to pick up an appropriate machine for a lot after its being sequenced. If there is more than one machine appropriate for the sequenced lot, the module will employ the load balancing consideration to select one. Of course, if the workstation is a mold station, the scheduling module should check all the needed resources such as appropriate die parts on an appropriate die base which must locate on an appropriate machine so an appropriate combination of resources can be picked up. In general, if the sequenced lot cannot find any appropriate resource to perform processing, the next available lot having higher cost in the available queue will try the same attempt to pick up an appropriate resource.

## 5. Integration and primary results

In order to make a scheduling module generate better planning and decision support, a full replication of real constraints, a good estimate of process time, and a correct feedback from WIP system are necessary.

Figure 8 (a) illustrates a WIP module performing check-in and check-out activities to collect input and output information from each station. However, to offer a flexibility to skip certain unimportant station to save tracking time, a WIP module allows users to record only the input of station 1 and the output of station 3 as in Figure 8(b). Naturally, whenever such event happens, a WIP module can only feed back the scheduling module that some job is in between station 1 and station 3 once a job enters station 1. It cannot tell exactly what station a job really stays until a job performs check-out in station 3. To solve this problem, the scheduling module will make comparison among the check-in time at station 1, the processing time of station 1, the current GlobalAdvanceTime, and the transportation time of station 2 and station 3 of such lot, to estimate lot check-out time from station 3. Nevertheless, such procedure is just to correct partial data distortion, it cannot reduce the degree of uncertainty by skipping required check-in and check-out activities. For the purpose of making CWSS integration more meaningful, the production control people must negotiate with WIP users to make a balance among reducing the checking actions in WIP tracking, eliminating the estimation in data refinement, and improving the scheduling accuracy.

The scheduling module also allows a planner to input different degree of information based on what he can collect. It means that the planner can refine his planning schedule gradually without being under too much data pressure. For example, the user, besides being able to obtain production flow and operation information from WIP module, he can just provide the basic information of lot, working calendar, the number of resources in each operation, and the average standard time of the operation to get system up and running. As the data is gathered in succession, the primary resource and secondary resources of each workstation can be added into the system. The operation standard hour can be further defined according to the influence factors being discovered, and such influence factors can be dynamically assigned to the system.

Presently, the integrated software is under parallel test in an experimental IC packaging Lab. The system takes around 30 minutes to schedule the production plan for a planning horizon of one week. The process workload contains about 20,000 lots and over 200 resources in the plant. The primary scheduled results obtained so far have been proved to be feasible and time-saving.

## 6. Conclusion

Although a WIP module can generally be a stand-alone module, a scheduling module cannot avoid successfully implementing the WIP module. This necessity is because a scheduling module has to know the current status of a manufacturing system to know the lots remaining in the manufacturing system at the beginning of scheduling horizon. Therefore, this work concentrates on developing a production model for the production flow, WIP module, scheduling module, and integration of both modules for the IC packaging industry.

From our experience, to provide good service, an IC packaging manufacturer must (1) flexibly define conditions for each lot, such as related material, equipment, and operation parameters, (2) master lot processing of customer orders in real time during production, (3) quickly adjust production flow to meet the variation of product requirements and floor situations, and (4) modify the schedule and dispatching lists to reflect the status variations of customer orders such as due-date changing or order cancellation. The above requirements lead to the incremental complication in designing a computerized WIP and scheduling system.

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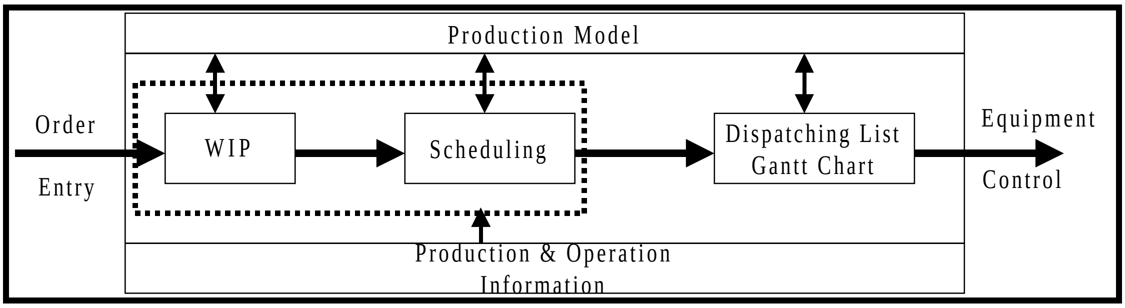



Figure 1: Function modules in the CWSS

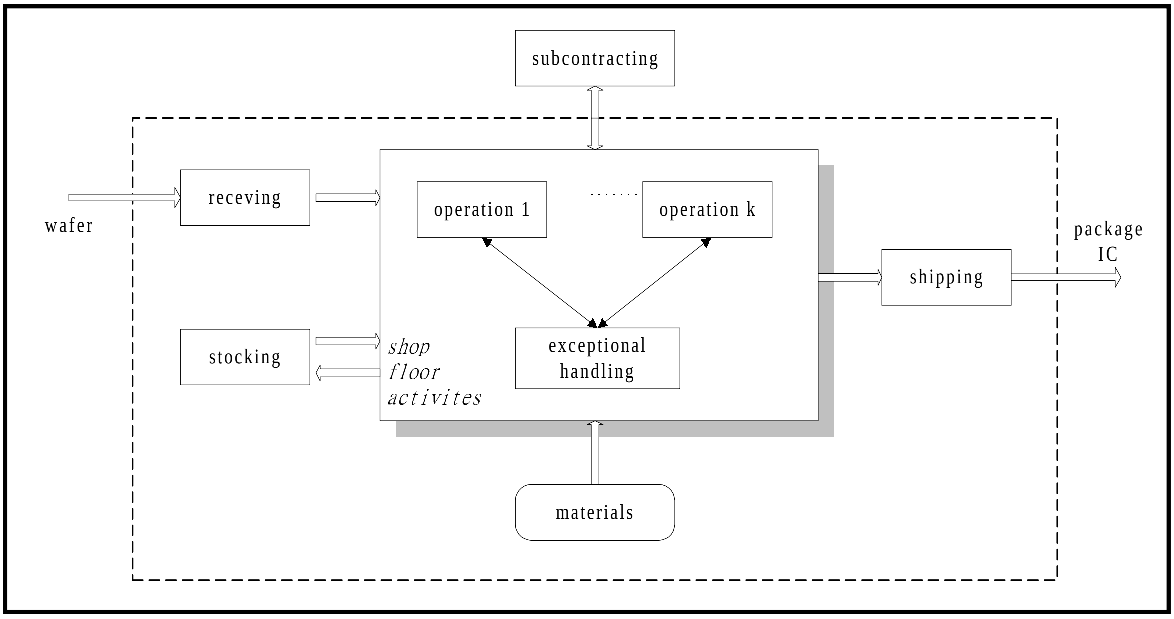



Figure 2: The shop floor activities of IC packaging industry

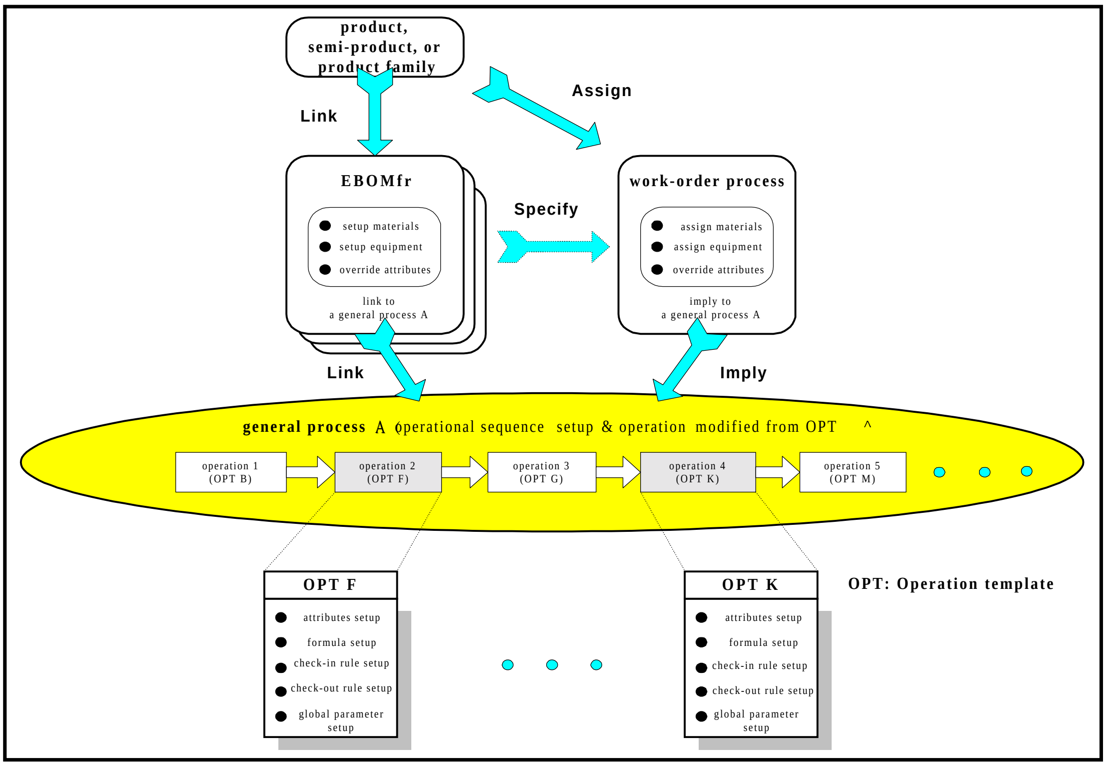



Figure 3: The proposed production model of production flow

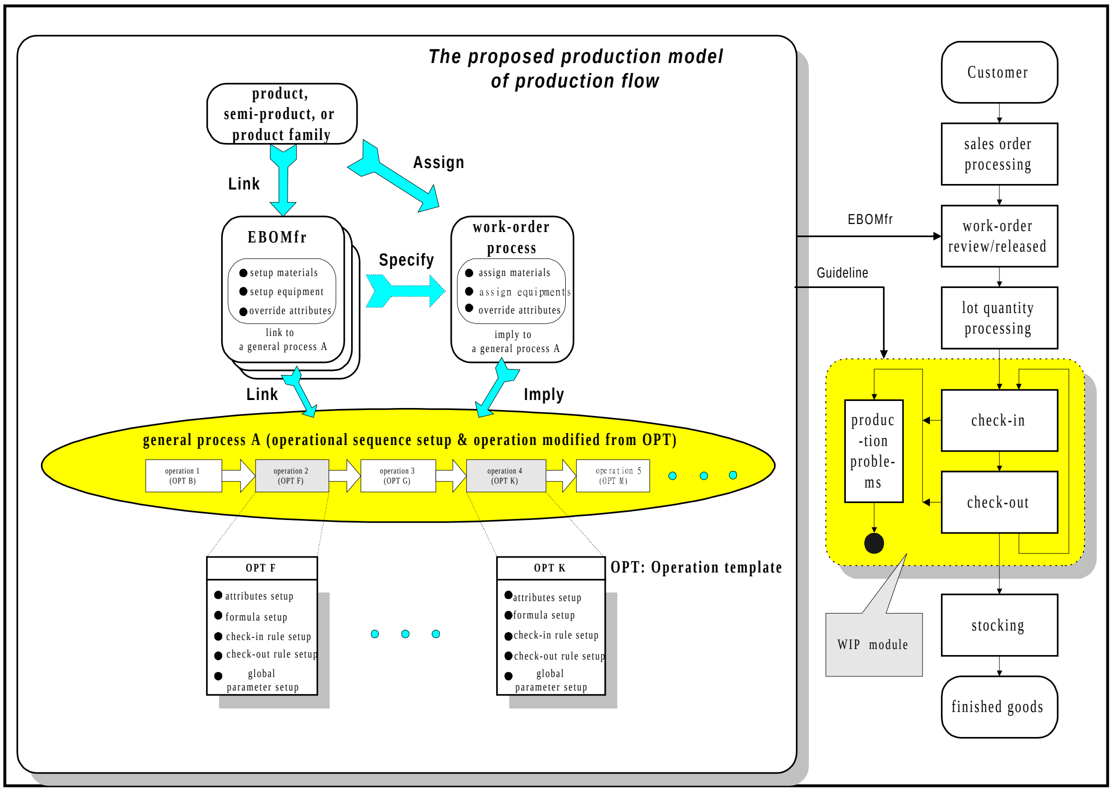



Figure 4: The proposed production model and the WIP module

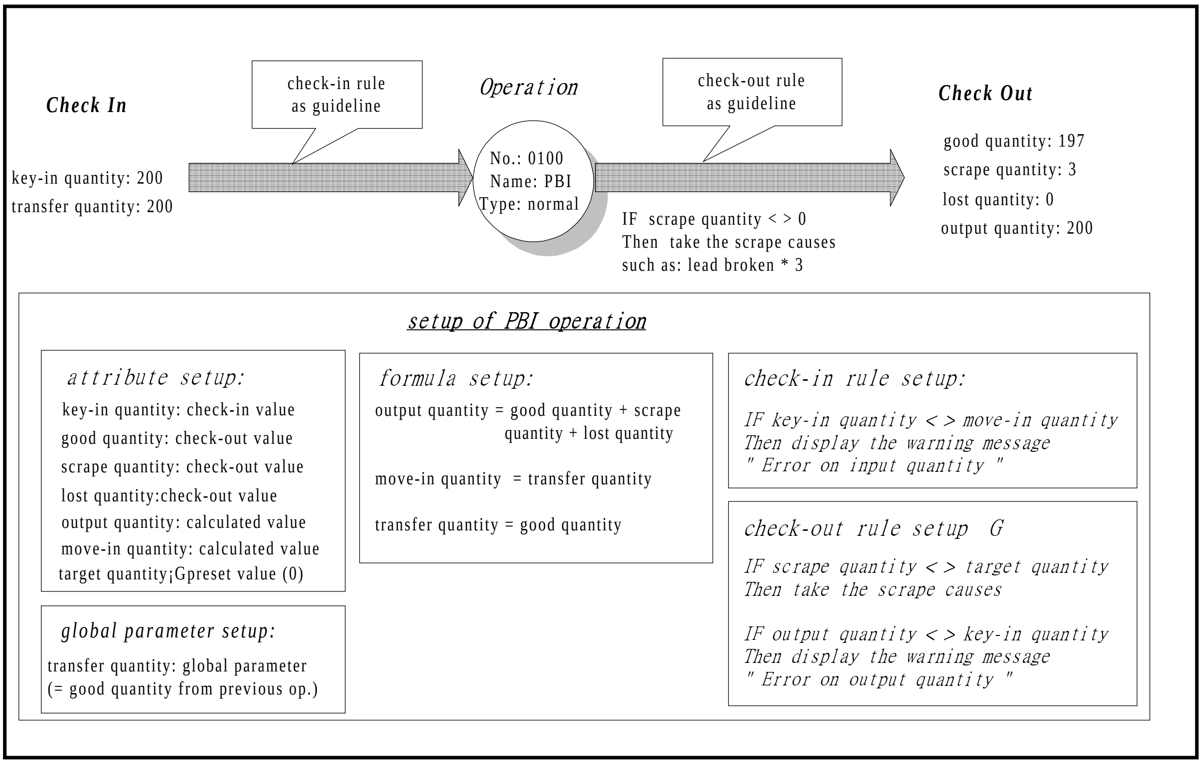



Figure 5: Setup of the post bonding inspection operation (PBI)

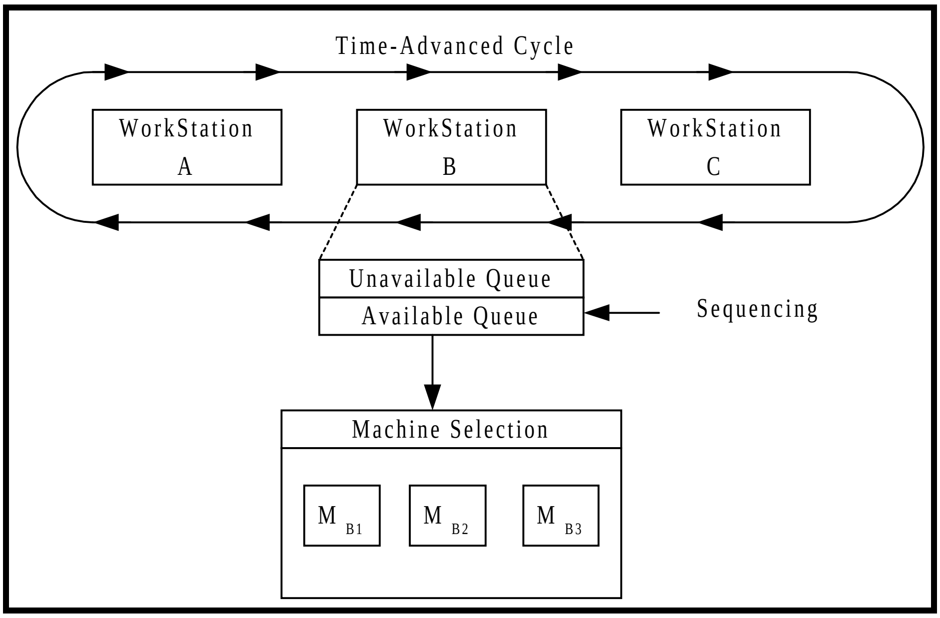
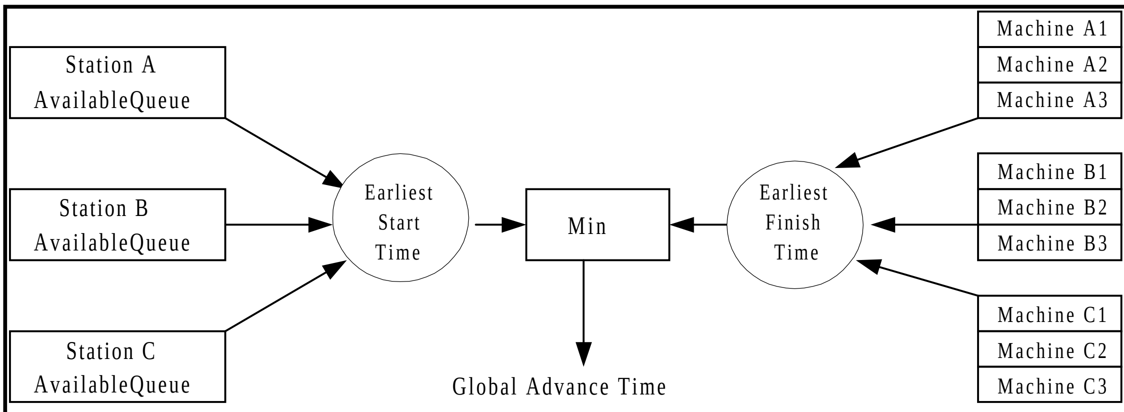



Figure 6: Architecture of the time-advanced scheme in an IC packaging factory




| Event | | Activity |
|---|---|---|
| IF | And | Then |
| Some jobs exist in some AvailableQueues | Exist idle machines | Perform Machine-Selection to select an appropriate machine for the lot that has the earliest start time; GlobalAdvanceTime keeps unchanged. |
| | Without idle machine | GlobalAdvanceTime = EarliestFinishTime of all machines |
| No job exists in any AvailableQueue. Firstly, we should check the EarliestAvailableTime among the future jobs that will become available from other queues of all stations. | Exist busy machines | GlobalAdvanceTime= min(EarliestFinishTime,EarliestAvailableTime) |
| | Without busy machine | GlobalAdvanceTime=EarliestAvailableTime |

Figure 7: Events and activities in performing time-advance scheme

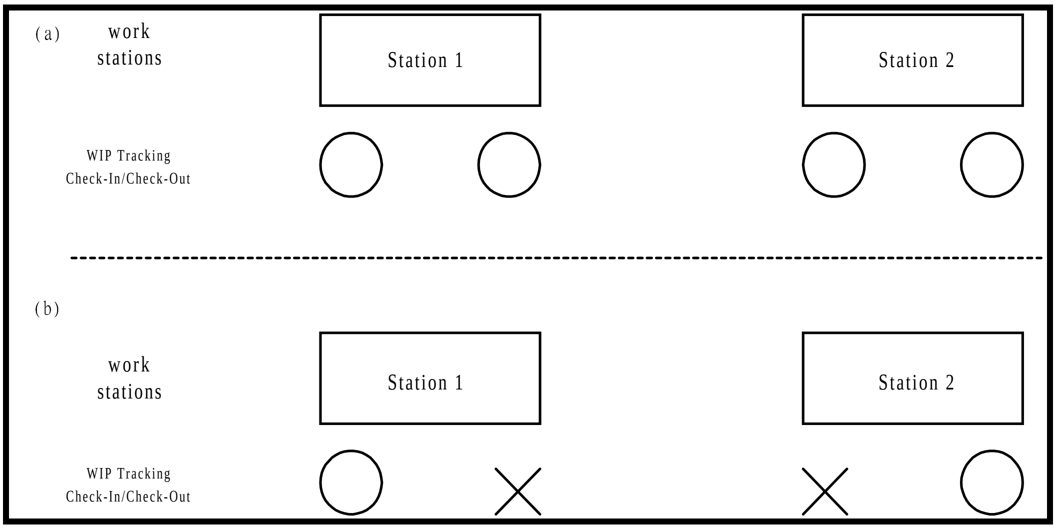



Figure 8: Simplification of checking actions in a WIP module