

# Hybrid Model applied in the Semiconductor Production Planning

Pengfei Wang, Tomohiro Murata

**Abstract-** One of the most studied issues in production planning or inventory management is to get the lowest possible cost with the satisfied service rate (less waiting time). Analyzing and comparing two main stream methods which are used for solving complex system – System Dynamics Model(SDM) and Agent Based Model (ABM), studying the characteristics of these two methods, and attempting to transfer a common system dynamic model to a new hybrid model which is based on system dynamics model and agent based model in Anylogic. This article tries to obtain the optimal inventory policy for semiconductor production.

**Key word:** Production Planning, Hybrid Model

## I. INTRODUCTION

The semiconductor industry is the aggregate collection of companies engaged in the design and fabrication of semiconductor devices. It also needs to consider the excellent manufacture planning techniques for improving production management. These problems have several features that make them hard to be solved, such as: the bullwhip effect cost controlling, complex product flows, and rapidly changing products and technologies. The produce process of semiconductor can be divided into four basic steps: wafer fabrication, wafer probe, assembly or packing and final testing. The back-end process in the semiconductor production can be treated as a “pull” system. In the pull production system, the order policy plays very important role in the production planning.

It is neither a discrete event system nor a continuous dynamic system. Existing methods of production modeling and simulation usually reflect one aspect of production system, and cannot give consideration to both. In addition because of the existing of discrete event in this problem, the mathematic methods are not suitable for it. So the simulation methods are adopted, and through a hybrid model to solve it.

In this article, finding the optimal combination of inventory cost and reasonable service level, evaluating the impact of inventory policy can provide some significance guidance for some commercial activities. Therefore, a useful hybrid model methodology was proposed which reflects the discrete-continuous combined property of semiconductor production system for supporting the decision makers.

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## II. RELATED METHODS

### A. System Dynamic Model (SDM)

Jay Forrester introduced system dynamics as a modelling method. Then, SDM has developed to a valuable and powerful tool to represent, analyse and study the dynamic behaviour of complex systems for strategic and policy related decision problem.

In SDM, a Stock and flow model helps in studying and analyzing the system in a quantitative way. A stock can be described as an accumulation or integration of flows over time. It has a certain value at each moment. For example, stock variables are the accumulations like the inventory within the supply chain system. In general, the flow includes the inflows which can add the stock and outflows can decrease the stock. It is measured over a certain interval of time, for example the order is a outflow for the stock inventory. In complex systems such as a manufacturing system, objects interact through feedback loops, where a change in one variable affects other variables dynamically, which feedback the original objects, and so on.<sup>[1]</sup>

### B. Agent Based Model (ABM)

The first use of the word "agent" and a definition as it is currently used today is hard to track down. One candidate appears to be John Holland and John H. Miller's 1991 paper "Artificial Adaptive Agents in Economic Theory" which is based on an earlier conference presentation of theirs.

ABM is a mindset more than a technology. The ABM mindset consists of describing a system from the perspective of its constituent units. A number of researchers think that the alternative to ABM is traditional differential equation modelling; this is wrong, as a set of differential equations, each describing the dynamics of one of the system's constituent units, is an agent-based model.

Agent-based modelling is a useful and practical simulation modelling technique that has been used in a number of applications recently, including applications to kinds of real-world problems.<sup>[2]</sup>

In agent-based modelling, a system is modelled as a collection of autonomous entities called agents. Each agent individually assesses its situation and does action according to rules.<sup>[3]</sup>

Repetitive competitive interactions between agents are a character of agent-based modelling, which can explore dynamics problems. Complex behaviour patterns often can be described and solved by even a simple agent-based model.<sup>[4]</sup> And it also can offer information about the dynamics of the real-world system. In addition, agent based model has the

evolving capability, which allow it to deal with unanticipated behaviours.<sup>[5]</sup>

### III. PROPOSED HYBRID MODEL OF DYNAMICAL SYSTEM

This article discussed how to transform a common system dynamic model to a hybrid model based on system dynamic and agent-based model. As be shown in the Fig. 1 the system dynamic model is consisted of the stock, flow and decision policy part. The stock1 can affect stock2 through flow rate. And the time, speed and quantity of flow rate are decided by the decision policy.<sup>[6]</sup>

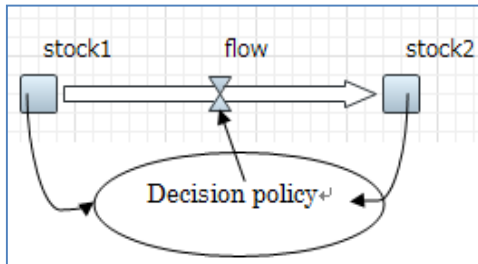


Fig 1 System Dynamic Model

Then using the conceptual framework of agent based model to analyze this model, there are one agent should exist in this model, and own the unique behaviour.<sup>[7]</sup> Each stock is a state of this agent and flow is the transition between the states in the hybrid model. The transition can be divided into synchronous and asynchronous. If in each time step it do decision, it is synchronous. On the other hand, if it does not make decisions in each time step, because of the time delay or only accumulated amount can drive the transition in system, it asynchronous.<sup>[8]</sup>

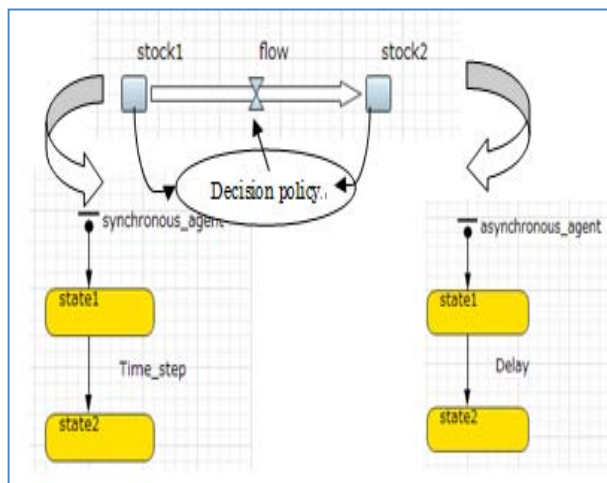


Fig 2 System dynamic model transfer to agent based model

The steps showed below are procedures to simulate proposed hybrid dynamical system model.

Step1. For the two stocks we create two states in one agent.

Step2. For each flow, new transitions are created from one state to others in agent.

Step3. In one agent, it receive message by ports in each

agent from system dynamic model. There are different states in each agent, and the transition is triggered by time delay or events.

Step4. Making the agent based model which is responsible for the controlling part, it can receive the information from the continuous part, judge the states and do action based on the rule policy.

### IV. HYBRID MODEL FOR PRODUCTION PLANNING

The purpose of applying hybrid Model for production planning is to support decision maker to do policy making. The maximum and minimum policy (s, S) will be used in this model. The decision-maker sets policy and the hybrid model affords some index, including inventory fluctuation, waiting time, service level and inventory cost, to help them realize the potential problems or strengths and weaknesses for each policy.

In the Semiconductor industry, the back-end emphasizes the daily demand and plan. The model needs to consider the inventory, the time cycle, the daily demand, the production capability, wip, defective percentage. It can calculate the daily release policy according to the order, inventory, and daily situation. In this part, daily production capability is rate and inventory is stock.

wip is influenced by the release and production.

$$N_{wip,t} = N_{wip,t-\Delta t} + R \Delta t - P \Delta t \quad (1)$$

$N_{wip,t}$  is the wip in the time t.  $\Delta t$  is the time interval between two decision. R is the daily release quantity. P is the daily production quantity in plan. For keeping wip as a constant, so the release quantity can equal to the production quantity.

Because of the defective percentage, the material release quantity R will bigger than the production quantity.

$$R = \frac{P}{1-Y} \quad (2)$$

Y is the defective percentage. P is the daily production quantity which are needed.

$$P = \min(D, C) \quad (3)$$

D is the amount of demand and C means the actual daily production capability.

For avoiding too much wip, the actual release quantity can be set as:

$$R = \min\left(P, \frac{P}{1-y}\right) \quad (4)$$

The inventory adjustment amount:

$$A = \frac{G - S_{t-\Delta t}}{T_{wip}} \quad (5)$$

G is the goal inventory,  $S_{t-\Delta t}$  means the actual inventory

amount in the last decision time.  $T_{wip}$  is inventory adjustment time. [9] Then the semiconductor production system is divided into 3 agents: Retailer Agent, Warehouse Agent, and Factory Agent. In each agent, the logic part controls the states and actions. The system dynamic model calculates the real-time situation, and sends the data to the agent-based model. The ABM has the ability to connect to the environment, and using event-driven method to control this system. The management rules are set in each agent part, ABM is responsible for the logic control in this model.

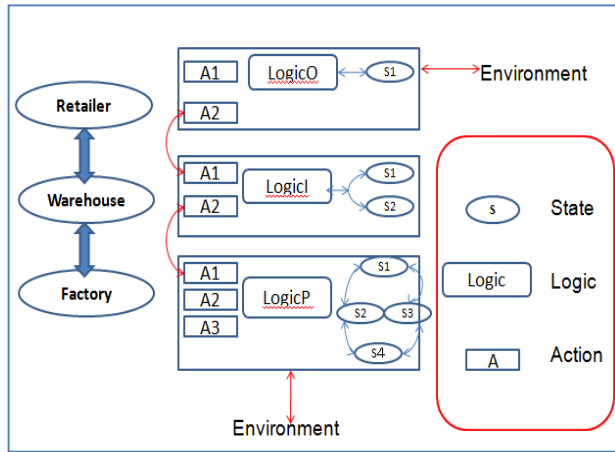


Fig 3 Framework of model

The agent can be dissected before making it.

In Factory agent, there are four states: satisfaction, dissatisfaction, produce, and standby. The factory can receive the information from the external environment (system dynamic model) and warehouse agent. When factory agent checks orders, firstly it will judge whether the current inventory can satisfy the order, if it can, factory agent will ship products to warehouse agent directly. If it cannot satisfy order, it will be in dissatisfaction state. Then it will calculate the backlog and judge whether to go to the Produce state basis of the order policy in factory agent. [10]

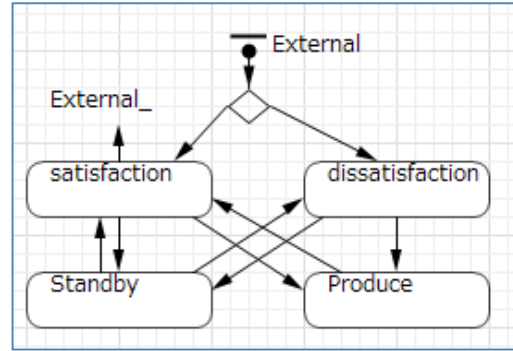


Fig 4 Discrete event in Factory Agent

The warehouse agent deals with the demand order every day, it provides the products to retailer directly. However, when the inventory of this agent is less than the floor level, it connects with factory agent; check the inventory in factory whether can satisfy its demand. If the factory has enough inventories can support it, it will feedback to the retailer agent. If the factory has not enough inventories, the warehouse agent makes a new demand to the factory agent and informs the retailer the waiting time. The input of warehouse agent is inventory management, orders, products; the output of the warehouse agent is shipping the products.

The retailer agent is responsible for sale products and marketing advertising, it also provides customer support. The retailer agent receives the orders from the customers. In this paper, the demand is based on the history data. When retailer agent gets the information from customers, it checks the inventory of it, and judged whether these orders can be satisfied. In retailer agent, the retailer do not have enough money to keep a high inventory, so it often choose a low inventory level and send orders frequency. Then it may connect with the inventory agent for getting more products. The input of retailer agent is inventory management, market demand; the output of it is sales products and market satisfaction.

The hybrid model can be made based on the system dynamic model and agent based model in Anylogic as Fig. 5.

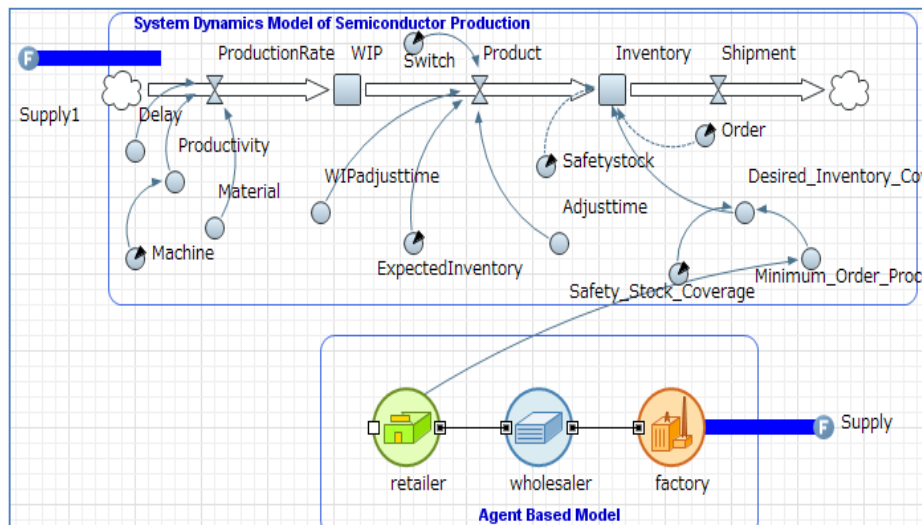


Fig 5 Hybrid Model

V. EXPERIMENTAL CASE STUDY

In this article, the simplification model from Hewlett Packard silicon wafer production research center lab is used in this article. It illustrated the production process in semiconductor industry. Although it is a simplification, the data are collected from the actual equipments. In this production process, there are 24 equipments and more than 130 steps.

After making model in Anylogic, which includes a graphical modeling language and can extend the simulation models with Java code, the decision maker can input the reasonable (s, S) value in UI, and get the result analysis by using the proposed hybrid model for production planning.

In this case, we use the optquest function to calculate the optimal order policy. The object of this case is to get a minimum total cost and a high service rate which must be higher than 98%. We run simulation 60 times, and because the random of order, in each time we get the different order policy and total cost.

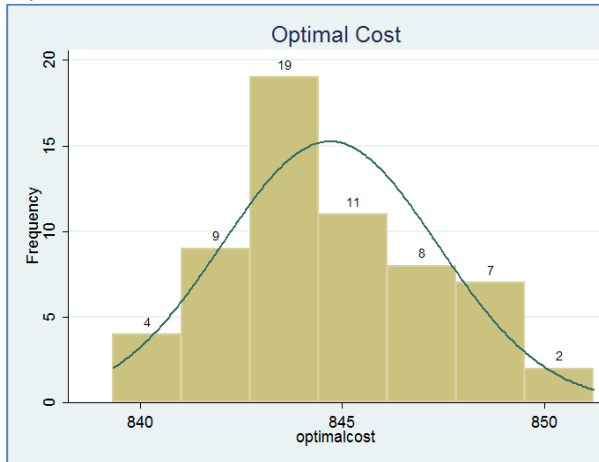


Fig 6 Possibility density of experiment results

From the analysis of 60 experiment results, we find the standard deviation of these results is 2.67. The 95% confidence interval of cost is from 843 to 846.

We can calculate the average optimal order policy which can be qualified with different market situations. The average order policy is: the retailer agent (47, 52), the warehouse agent (59, 87), and the factory agent (92, 99), the mean daily cost of this policy is 845 dollars.

The bullwhip effect is an observed phenomenon in forecast-driven distribution channels. It refers to a trend of larger and larger swings in inventory in response to changes in demand. It means the retailer do not order the same amount with their sales, in generally, the variance of order is much bigger than the variance of sales.

The bullwhip effect analysis can help user to analyze the bull-whip effect and the backlog situation. For this optimal policy, the coefficient of bullwhip effect in warehouse agent was 7.21 and in factory agent was 12.1. The decision maker can adjust the order level in the retailer, warehouse and factory according to the actual situation or company policy. For example some special company can set their floor inventory level s as 0.

Comparing with traditional bullwhip effect analysis methods, the hybrid model has these merits:

1) The hybrid model uses system dynamic model to reflect the changing process of inventory and manufacture procedure, it also has the discrete characteristic, and the model is much closer to the realistic situation.

2) The hybrid model only needs to abstract the action rules and connect method, and then the computer can run the simulation and get results. It is much easier to set it.

3) We get simulation results according to describing the rules in each agent. So it is easy to modify the action rule based on realistic situation, the model has a good expansibility.

4) In anylogic, it is convenient to calculate the bullwhip effect under different policy, it avoid complex mathematic models.

The waiting time means the service rate in this case. Although higher service rate often leads higher inventory cost, High service rate are needed to be achieved for satisfying the customers. The total cost in each agent can be divided into 3 parts: ordering cost, holding cost and shortage cost. For getting an optimum cost, the decision maker need to balance the service rate and total cost.

Fixing floor level s or upper limit S, adding another one, it results in get less waiting time, but in the same time the daily cost does not always increase with it.

Table I Experiment Results

Retailer	Warehouse	Factory	Waiting time	Mean cost
20, 80	20, 80	20, 80	3.1	833
20, 85	20, 105	20, 110	3.4	880
20, 100	20, 110	20, 120	2.1	858
20, 120	20, 130	20, 130	1.6	875
40, 120	40, 130	30, 130	0.7	854
50, 120	50, 130	40, 130	0.5	903
50, 120	60, 130	50, 130	0.3	913

The Table I shows the cost (dollar) and waiting time (day) in different policy. In the case 2 and case 3, the waiting time decrease by nearly 1.3days and cost decrease by 22 dollars.

A higher S can promise a higher service rate is easy to understand. However, the decrease of cost is interesting to discuss. Because the conflict of holding cost and shortage cost exists in this problem, so even we have a high inventory holding cost, we can still have a optimistic total cost by decrease shortage cost, it need to be balanced by the decision maker and this experiment results can give them a ocular demonstration. But all these results don't have a better policy than the optimal policy which is provided by the model. They have a longer waiting time and higher total cost.

The production capability can be improved by purchasing more equipments and hiring more workers. Of course these policy will lead a higher additional production cost, include purchased cost, human cost, equipment depreciation, etc. Under a same inventory policy, we can observe the change of cost by adjust the production capability. Although production cost will be added, the shortage cost and holding cost can decrease, at the same time, it can improve the backlog situation, and therefore it is helpful to perfect service rate. We do this experiment as all the order policy as (20, 80)

Table II Production Capability and Cost

Production Capability	Waiting Time	Daily Cost
Current	2.423	1120.483
Increase Output	1.7	1216.437
Decrease Output	3.163	1300.37

From the table II, we can find that, in the current situation, the waiting time is 2.423 and daily cost is 1120. When we increase the output, as we image, it can improve service rate along with a higher cost. However, when we decrease the output, it is amazing to find we have a higher waiting time and a higher total cost. The manufacturing cost only occupy 8.1% in factory agent, the high holding cost and shortage cost lead a terrible total cost. So it may be a warning sign for the decision-maker if they want to reduce the cost by decreasing output.

## VI. CONCLUSION

Production planning is neither a discrete event system nor a continuous dynamic system; it is a complex system which is based on the discrete information flow and continuous material flow. This article discussed how to make a hybrid model based on the continuous model-system dynamic model and discrete model-agent based model. This hybrid model methodology can effectively reflect the important characteristics (continuous-discrete) of semiconductor production system. It can provide a natural description of a complex system and be flexible and easy to adjust.

This article proposed a hybrid model to find optimal order policy for semiconductor production planning maker to trade off the total cost and service rate. The friendly user interface can help user to analysis the inventory situation easily. The optimal order policy was proved reliable and bullwhip effect was provided. The investment of production capability was also discussed; the study of relationship between manufacturing cost and holding cost can help the decision maker when they want to change the scale of the enterprise.

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