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ORIGINAL ARTICLE

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A service level model for the control wafers safety inventory problem

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Abstract This paper considers the control wafers safety inventory problem (CWSIP) in the wafer fabrication photolithography area. The objective is to minimize the total cost of control wafers, where the cost includes new wafers cost, re-entrant cost and holding cost while maintaining the same level of production throughput. For the problem under pulling control production environment, a nonlinear programming model is presented to set safety inventory levels so as to minimize total cost of control wafers. A numerical example is given to illustrate the practicality of the model. The results demonstrate that the proposed model is an effective tool for determining the service level of safety inventory of control wafers for each grade.

Keywords Control wafers · Nonlinear programming model · Pull control · Safety inventory · Service level

1 Introduction

In the wafer fab photolithography area, control wafers are utilized for monitoring and measuring the particle content, measuring photo-resist coat thickness and uniformity, examining focus and de-focus, checking critical dimension, and inspecting overlaps [1]. The purpose of using control wafers is to assure that manufacturing process in a wafer fab can satisfy the required specification. Control wafers are repeatedly used until their immaculacy and thickness no longer conform to the process requirement. For control wafers that do not conform to the process requirements, they are either downgraded or discarded. To avoid pollution to factory machines due to the misuse of control wafers, managers often apply grade concepts of control wafers for diverse machine types according to the requests of processing circumstances, such as immaculacy degree. Any shortage of control wafers may result in a halt of machine operations and as a consequence, may seriously affect the process yield and production planning. To avoid such situations, a large number of control wafers are usually prepared and stored for use. This, however, unnecessarily increases the inventory of control wafers.

As for control wafers, deterioration of goods is realistic in many inventory systems. In determining the optimal inventory policy of product, the loss due to deterioration should be taken into consideration. Ghare and Schrader [2] began the analysis of deteriorating inventory by establishing a classical no-shortage inventory model with a constant rate of decay. Covert and Philip [3] extended Ghare and Schrader's model by building an economic order quantity (EOQ) model for a variable rate of deterioration with a two-parameter Weibull distribution.

Many later researches developed EOQ models that focused on deteriorating items. Chang and Dye [4], with the concern of finding the optimal total cost savings for deteriorating items during the special replenishment period, developed an EOQ model for a varying rate of deterioration, by assuming a two-parameter Weibull distribution to extend the applications of developing mathematical inventory models and fit a more general inventory feature. Chung and Tsai [5] developed an inventory model for deteriorating items with the demand of linear trend and shortages during a finite planning horizon. With the consideration of time value of money, a line search was applied in a simple solution algorithm to determine the optimal interval that would not encounter stock-outs. Chang et al. [6] proposed a finite time horizon EOQ model with the consideration of a time-varying deterioration rate, time value of money, shortages and permissible delay in payments.

Inventory models have been continually modified to accommodate more practical issues of the real inventory systems. Platt et al. [7] declared that for a large family of lead time demand distributions, the optimal policy depends on two parameters: the fill rate (the proportion of demand that is satisfied from stock) and the EOQ scaled by the standard deviation of demand over the constant lead time. By assuming that the lead time demand is normally distributed, the asymptotic results can be used as the EOQ from zero to positive infinity to fit a theoretic curves for the order quantity Q and the reorder point R. For the semi-

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conductor industry, Popovich et al. [8] designed a reuse matrix that takes into account the contamination level of the used test wafers as well as other characteristics of wafers. This is useful in determining possible usage for the used wafers. Although the reuse process requires manual operation, it provides a less expensive alternative to buying new wafers. Kar et al. [9] develops a deterministic inventory model for a single product, which is stored in two storage facilities while the demand is linearly increasing, time-dependent over a fixed finite time horizon, the rate of replenishment is assumed to be infinite, and the successive replenishment cycle lengths are assumed in arithmetic progression.

Although many mathematical models have been developed for controlling inventory, a nonlinear programming model of production inventory policies for setting safety inventory level has received relatively little attention. Pal et al. [10] constructed a deterministic inventory model by assuming that the demand rate is stock-dependent and the items deteriorate at a constant rate, and two highly nonlinear equations are generated and solved. Furthermore, Bhunia and Maiti [11] assumed that the production rate is a variable. They also presented inventory models in which the production rate depends on either on-hand inventory or demand. In practice, demand and service level may influence safety inventory. Das et al. [12] constructed a multi-item inventory model with quantity-dependent inventory costs and demand-dependent unit cost under imprecise objective and restrictions. The problem is solved by both geometric programming (GP) and gradient-based nonlinear programming (NLP) methods. In addition, a fuzzy geometric programming (FGP) method is used.

The purpose of this paper is to obtain the minimum total cost of control wafers. Under the production control of a pulling system, a nonlinear programming model, which considers the safety inventory level to set the control wafers supply rates (i.e., new wafer and re-entrant wafer)for each grade, is proposed. The remainder of this paper is organized as follows. Section 2 describes the problem and assumptions. Section 3 introduces the construction of the nonlinear programming model. In Sect. 4, a numerical example is investigated using the proposed nonlinear programming model. The results are analyzed to show the effectiveness of the proposed model. In Sect. 5, some concluding remarks are made.

2 Problem description and assumptions

Control wafers are employed for monitoring the machine parameters in the production process and for maintaining manufacturing conditions of semiconductor wafer fabs. Control wafers are not only used to control the machine manufacturing capability, but also to increase the process yield. An increase of control wafers WIP and safety inventory level would result in an increase of the holding cost but a decrease in the shortage cost. Therefore, a trade-off decision must be made. The most common decisions in current industrial practice often result in maintaining each grade of control wafers at its maximum service level. This paper attempts to determine appropriate service level of control wafers for each grade in the system. How to determine the optimal safety inventory of control wafers for each grade is important to the performance of the inventory management system. In order to simplify the complexity of the environment, we shall restrict our investigation of control wafers to the photolithography area in a wafer fab.

In general, the reuse status of control wafers can be divided into (1) pre-disposition, (2) in-use, and (3) re-entrant, termed the PUR process [13]. With the addition of the fourth status, inventory, the entire process is termed the PURI process. The in-use control wafers in the photolithography area provide functions for product monitoring, equipment monitoring, breakdown and recovery monitoring, and preventive maintenance [1]. In this paper, a loop system concept is applied to explain the downgrade and PURI process.

Figure 1 displays the relationship of PURI and downgrading in the jth loop system of control wafers. In Fig. 1, the loop consists of four stages, and each stage consists of one machine for processing. X_{j0} represents the inventory stage,X_{j1} represents the pre-disposition stage, X_{j2} represents the in-use stage, and X_{j3} represents the re-entrant stage. At inventory stage, control wafers in stock are to be used, and an appropriate safety inventory level is set for this purpose. At the pre-disposition stage, operations must be completed to make the control wafers comply with the manufacturing condition so that they can be used. At the in-use stage, control wafers are employed in wafer fab to monitor and control some machine functions. After control wafers pass through the pre-disposition and in-use stages,

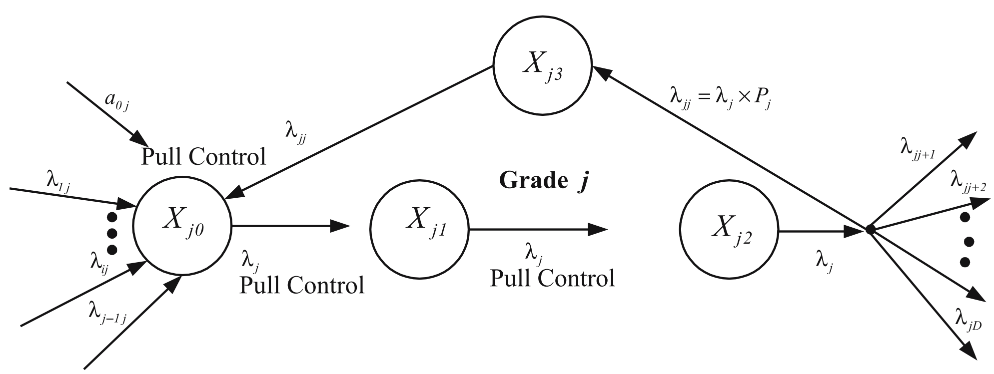

Fig. 1. The relationship of downgrade, pull control and PURI process in the jth loop system

they either enter the re-entrant state, are downgraded or are discarded. For the jth loop of control wafers, the new wafer arrival rate is a_{0j}, the re-entrant arrival rate is λ_{ij} (for $i = j$ and $\lambda_{jj} = \lambda_j \times P_j$, where P_j is both the re-entrant ratio and the service level), the downgrade arrival rate is λ_{ij} (for $i < j$), the discard rate is λ_{jD}, and the downgrade leaving rate is λ_{jk} (for $j < k$). The arrival rate is λ_j, which is the sum of a_{0j}, λ_{jj} and λ_{ij} (for $i < j$). If these control wafers enter the re-entrant state, they will be repeatedly used and remain in the PURI process. Therefore, a sufficient amount of control wafers must be maintained in the jth loop to achieve the smoothness of the PURI process.

The management system of control wafers is constructed by the safety inventory and PURI process. In Fig. 1, when the jth loop declares a need of control wafers, control wafers can be supplied from the inventory stage (X_{j0}) to meet the demand. In this paper, we assume that the system will only pull new control wafers for use and the downgrade arrival rate is therefore set to zero when the inventory control wafers are not sufficient to meet the demand.

The model developed here is based on the following assumptions:

- The downgrade arrival rate λ_{ij} (for $i < j$) is set to zero
- Daily demand rate (d) follows approximately normal distribution
- The standard error (σ_d) is equal to α times of demand rate
- Lead time follows approximately Beta distribution
- The optimistic lead time is equal to X times the process time
- The most likely lead time is equal to Y times the process time
- The pessimistic lead time is equal to Z times the process time
- The new control wafers unit cost is C_0, the safety inventory control wafers unit cost is $C_0 \times e^{-\beta \times j}$, and the safety inventory control wafers unit holding cost is $C_0 \times e^{-\beta \times j} \times h$
- Control wafers are classified into four grades. Control wafers with a particle number of less than 1 in 1 m^3 is classed grade one, less than 10 in 1 m^3 is grade two, less than 100 in 1 m^3 is grade three, and less than 1000 in 1 m^3 is grade four
- The demand rate and lead time are independent

3 Control wafers service level based on safety inventory

This paper develops a CWSIP algorithm to decide on an appropriate service level of control wafers for each grade. The proposed algorithm can be divided into two phases: (1) estimating control wafers demand distribution and re-entrant lead time distribution, and (2) calculating control wafers service level and cost for each grade.

The management system presented here can supply new control wafers to each grade. When demand is greater than supply, we can use safety inventory to meet the demand. If the safety inventory is not sufficient to meet the demand, the system can pull new control wafers for use. We can estimate the expected demand and its variance, and the expected re-entrant lead time and its variance. The cost for each grade of control wafers is calculated by adding up the new wafer cost, the re-entrant cost and the holding cost of the grade. The optimal service level for each grade of control wafers is obtained by differentiating the cost function. The algorithm procedures for the two phases are depicted in Fig. 2 and described in the next section. Before describing the model, all required notations are defined as below.

Notation

Q_n	The actual process quantity of product n
$\Re$	The system throughput quantity in a planning period
π_n	The product mix ratio for product n among all products
γ	The average rework rate in the system
S	The set of product types
NU_{nj}	The number of times the jth grade control wafers are used in the process of product type n
EA_{nj}	The expected amount of the jth grade control wafers needed in the process of product type n
LP	The length of planning period
j	The sequencing grade numbering for control wafers
C_0	The new cost per unit of control wafers
$C_0 e^{-\beta \times j}$	The cost per unit of re-entrant control wafers for grade j
β	The parameter of re-entrant cost of control wafers
$C_0 e^{-\beta \times j} h$	The holding cost per unit of safety inventory control wafers for grade j
h	The holding cost rate of control wafers
P_j	The probability of service level (also the re-entrant ratio)
$1 - P_j$	The risk of a shortage
Z_{Pj}	The lower $100 \times P_j$ percentile point for the standard normal distribution
$\overline{d}_j$	The expected value of demand for the jth grade control wafers
σ^2_{dj}	The variance of demand for the jth grade control wafers
$\overline{LT}_j$	The expected value of re-entrant lead time for the jth grade control wafers
σ^2_{LTj}	The variance of re-entrant lead time for the jth grade control wafers
C_j	The cost of the control wafers for grade j
TC	The total cost of the control wafers.

3.1 Estimation of demand rate and re-entrant lead time

Note that in a stabilized manufacturing system, the expected arrival rate equals the expected throughput rate. In addition, in the planning period, the throughput level equals to the release quantity. Therefore, with a throughput target, the product mix ratio and rework rate for normal products, we can calculate the actual process quantity in the planning period as follows:

$$Q_n = \Re \times \pi_n \times (1 + \gamma)\,, \text{ for each } n\,. \tag{1}$$

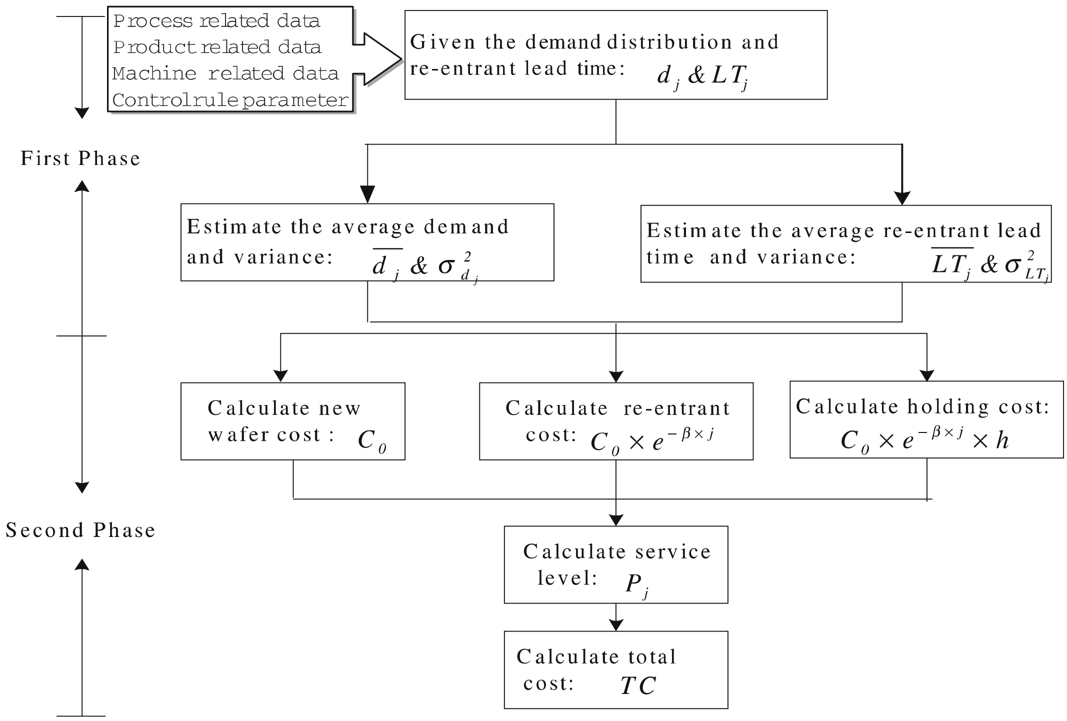

Fig. 2. Flow process of the CWSIP algorithm

Control wafers can be categorized into several grades depending on their quality, that is, the amount of particle content on them. For every grade of control wafers, no matter what product type it is producing or what layer it is on, the PURI process is the same. In the wafer fab, the demand rate has approximately normal distribution. Based on the historical experience data, the standard error of expected demand rate, denoted by $\sigma_{d\,j}$, is set to be 0.05 times ($\alpha = 0.05$) the demand rate. The approximate expected value and variance of demand rate for grade j control wafers are as in Eqs. 2 and 3.

$$\overline{d}_j = \sum_{n \in S} Q_n \times NU_{nj} \times EA_{nj} \times \frac{1}{LP},\ j = 1, 2, \ldots c \tag{2}$$

$$\sigma^2_{d\,j} = \left(0.05 \times \overline{d_j}\right)^2,\ j = 1, 2, \ldots c \tag{3}$$

Re-entrant lead time of control wafers is defined to be the time interval from control wafers leaving to re-enter the inventory stage, and it consists of re-entrant waiting time and PURI process time. In wafer fab, the re-entrant lead time is approximately beta distribution. The most likely estimated re-entrant time, denoted by m, is three times ($Y = 3$) the PURI process time. The optimistic estimated time, denoted by a, is two times ($X = 2$) the PURI process time. The pessimistic estimated time, denoted by b, is five times ($Z = 5$) the PURI process time. The expected value and variance of re-entrant lead time for grade j control wafers are approximately as in Eqs. 4 and 5.

$$\overline{LT}_j = \left(\frac{a_j + 4m_j + b_j}{6}\right),\ j = 1, 2, \ldots c \tag{4}$$

$$\sigma^2_{LT\,j} = \left(\frac{b_j - a_j}{6}\right)^2,\ j = 1, 2, \ldots c \tag{5}$$

3.2 Costs of control wafers for each grade

The total cost of control wafers consists of the purchase cost of new control wafers, re-entrant process cost and holding cost. New control wafers have the highest clarity and are suitable for all classes of production. As a result, the cost of new control wafers is the highest. Re-entrant control wafers are produced by the single loop of the same grade, and the grades must be considered in determining the cost. Holding costs consider the control wafers in the PURI process for the grade, and the relationship between the grade and holding must be studied to set the cost. Control wafers of a higher grade have higher re-entrant and holding costs, and control wafers of the same grade have the same re-entrant/holding costs. The costs of new, re-entrant and holding control wafers are defined as follows and will be discussed in detail in the next section. (1) The new cost per unit of control wafers: C_0. The new control wafers cost is the purchase price from the supplier. New control wafers have the highest clarity and are suitable for all classes of production. As a result, the cost of new control wafers is the highest. (2) The re-entrant cost per unit of control wafers: $C_0 \times e^{-\beta \times j}$. The re-entrant control wafers cost is caused by the operations in the re-entrant stage of the PURI process of grade j. The new control wafers cost is multiplied by the $e^{-\beta \times j}$ to estimate the re-entrant control wafers cost. (3) The holding cost per unit of control wafer: $C_0 \times e^{-\beta \times j} \times h$. The holding control wafers cost is caused by holding control wafers in the PURI process of grade j. Holding cost is obtained by multiplying re-entrant cost by the holding rate(h). These costs for each grade j, C_j, equals the sum of new wafer cost, re-entrant cost and holding cost. The total cost, TC, of control wafers in the entire system is as follows:

$$TC = \sum_{j=1}^{c} C_j \, . \tag{6}$$

3.3 Formulation of the control wafers safety inventory problem

In this paper, a production planner's objective is to minimize the total cost of control wafers in the system and to determine the optimal service level of control wafers in the jth grade. A grade system must supply enough control wafers for use in time, and shortage is not allowed. The operative constraints are as follows. First, the service level of control wafers equals the probability of integrating the standard normal distribution from negative infinite to Z_{Pj}. Second, the service level is between zero and one. The relationship of the two constraints is depicted in Fig. 3. The objective and constraints are as follows:

$$\begin{aligned}\text{Minimize } TC = &\sum_{j=1}^{c} C_0 \times \left(1 - P_j\right) \times \overline{d_j} \\ &+ \sum_{j=1}^{c} C_0 \times \mathrm{e}^{-\beta \times j} \times P_j \times \overline{d_j} \\ &+ \sum_{j=1}^{c} C_0 e^{-\beta \times j} \times h \times P_j \\ &\times \left(\overline{d} \times \overline{LT} + Z_{P_j} \sqrt{\overline{d_j^2} \sigma_{LT\ j}^2 + \overline{LT_j} \sigma_{d_j}^2}\right)\end{aligned} \tag{7}$$

$$\text{subject to } P_j = \int_{-\infty}^{Z_{P_j}} \frac{1}{\sqrt{2\pi}} \mathrm{e}^{-\frac{Z^2}{2}} \, \mathrm{d}Z, \; -\infty < Z_{P_j} < +\infty \tag{8}$$

$$0 \leqslant P_j \leqslant 1 \, . \tag{9}$$

3.4 Algorithm procedures

The above cost function TC contains two variables P_j and Z_{P_j}. However, they are not independent. To determine the optimal value of P_j that minimize the total cost TC, we take the first and second derivative of TC with respect to P_j as follows:

$$\begin{aligned}\frac{dTC}{dP_j} = &\, C_0 \times (-1) \times \overline{d_j} + C_0 \times e^{-\beta \times j} \times \overline{d_j} \\ &+ C_0 e^{-\beta \times j} \times h \times \left(\overline{d} \times \overline{LT} + Z_{P_j} \sqrt{\overline{d_j^2} \sigma_{LT\ j}^2 + \overline{LT_j} \sigma_{d_j}^2}\right) \\ &+ C_0 e^{-\beta \times j} \times h \times P_j \times \sqrt{\overline{d_j^2} \sigma_{LT\ j}^2 + \overline{LT_j} \sigma_{d_j}^2} \times \frac{dZ_{P_j}}{dP_j}, \\ &j = 1, 2, \ldots c\end{aligned} \tag{10}$$

and

$$\begin{aligned}\frac{d^2 TC}{dP_j^2} = &\, 2 \times C_0 \mathrm{e}^{-\beta \times j} \times h \times \sqrt{\overline{d_j^2} \sigma_{LT\ j}^2 + \overline{LT_j} \sigma_{d_j}^2} \times \frac{dZ_{P\ j}}{dP_j} + \\ &C_0 \mathrm{e}^{-\beta \times j} \times h \times P_j \times \sqrt{\overline{d_j^2} \sigma_{LT\ j}^2 + \overline{LT_j} \sigma_{d_j}^2} \times \frac{d^2 Z_{P_j}}{dP_j^2} > 0, \\ &j = 1, 2, \ldots c \, .\end{aligned} \tag{11}$$

Let $h(\alpha_j) = \frac{dTC}{dP_j}$. Then, h increases as P_j increases, and thus P_j^* is the optimal value if and only if $h(P_j^*) = 0$. Since TC is convex with respect to P_j, the one-dimensional search method can be used to find the optimal value of P_j^* by nonlinear programming. In this section, we shall present a simple algorithm to compute the optimal value of P_j. Before describing the CWSIP algorithm, an important theorem is presented here.

Intermediate value theorem: Let h be a continuous function on $[L, U]$, and let $h(L)h(U) < 0$. Then, there exits a number $d \in [L, U]$ such that $h(d) = 0$.

Since $h(P_j)$ is strictly increasing, the following algorithm is based on the above theorem and the uniqueness of the root of Eq. 10. Notice that $h(0.01) < 0$ and $h(P_U) > 0$. The CWSIP algorithm can be described as follows.

Step 1. Select $\varepsilon > 0$.
Step 2. Find an initial $P_L = 0.001$ and $P_U = 0.999$ by inspection.
Step 3. Let $P_j = \frac{P_L + P_U}{2}$.
Step 4. If $\left|h(P_j)\right| < \varepsilon$, go to Step 6. Otherwise, go to Step 5.
Step 5. If $h(P_j) > 0$, set $P_U = P_j$. If $h(P_j) < 0$, set $P_L = P_j$. Then, go to Step 3.
Step 6. $P_j = P_j^*$, and the optimal value is obtained.

The optimal value of P_j^* is calculated using the intermediate value theorem. The optimal values of Z_{P_j} and the minimum total cost TC can be obtained from Eqs. 7 and 8.

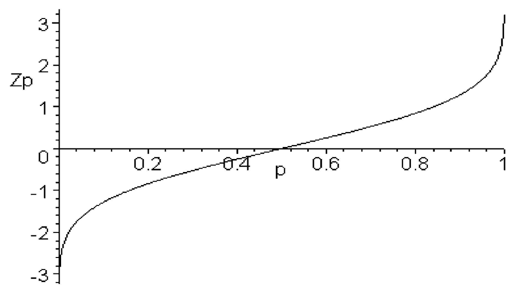

Fig. 3. The relationship between Z_{P_j} and P_j for grade j

4 Numerical example and results analysis

The nonlinear programming model is implemented by using the computer software to solve the CWSIP. The example aims to determine the minimum total cost of control wafers including new control wafers cost, re-entrant process cost and holding cost for each grade.

4.1 Basic information input

To investigate the effects of the planning on the management system, actual data is taken from a wafer fab factory located in the Science-Based Industrial Park in Hsinchu, Taiwan. The basic information is as follows:

1. Production information. In our production system, we have five products, A, B, C, D, and E. Product A and B are logic, while product C, D and E are memory products. The process of each product is different and unique.
2. Workstation information. There are 83 workstations in our production system.
3. Master production scheduling (MPS) information. The product mix for product A, B, C, D, E is 4, 6, 5, 3, 2, respectively. Monthly output target ($\mathfrak{R}$) is 1890 lots. In order to achieve the throughput target and the mix, the CONWIP rule is adopted and WIP level of normal wafers for the system is set to be 270 lots. The length of planning period (LP) is 28 days, and the rework rate (γ) is set to be zero.
4. Machine data for control wafers. In the photolithography area, process engineers disaggregate control wafers into four grades in the process. The depletion of control wafers is related to the amount of products processed. In addition, the relationship between control wafers depletion and the corresponding workstation is known. The number of times the grade j control wafers is used for each lot of each product type, NU_{nj}, is shown in Table 1, and the expected amount per lot (EA_{nj}) is a constant (i.e., one piece). One lot is equal to 24 pieces.
5. PURI process. In each grade j, the PURI process consists of four stages of operation, and each stage is represented by a workstation. These service rates are shown in Table 2. For the inventory stage, control wafers are ready and waiting for use; therefore, its service time is set to be zero.
6. The cost (C_0) of new control wafers is set to be US $100, the parameter ($\beta$) of re-entrant cost is set to be 0.2 and the holding cost rate (h) is set to be 0.06.

Table 1. The number of times control wafers demand for each lot of normal product and each grade

Grade j	A	B	C	D	E
$j=1$	6	4	6	7	5
$j=2$	5	6	5	6	9
$j=3$	9	7	8	6	5
$j=4$	3	4	6	5	3

Table 2. The service time per lot for each process (days)

Grade j	u_{j1}	u_{j2}	u_{j3}
$j=1$	0.07	0.56	0.42
$j=2$	0.03	0.63	0.50
$j=3$	0.04	0.50	0.45
$j=4$	0.05	0.42	0.42

4.2 Experimental result and analysis

The performance of the CWSIP algorithm is summarized in Tables 3 and 4. Based on Table 3, demand rate and variance of demand rate are positively related. Lead time and variance of lead time are positively related. An increase in service level also leads to an increase in percentile point of standard normal distribution.

Based on Tables 3 and 4, as service level (P_j) increases, re-entrant cost to total cost ratio and holding cost to total cost ratio also increase, while the new wafer cost to total cost ratio decreases. Re-entrant cost ratio and holding cost ratio are positively related, however, the re-entrant cost ratio and new wafer cost ratio are negatively related.

The relationship of cost and service level for each grade 1 is depicted in Figs. 4–7.

The service level of safety inventory for control wafers in CWSIP algorithm is 0.391 in grade 1, 0.923 in grade 2, 0.978 in grade 3, and 0.991 in grade 4. The higher the grade of control wafers, that is, the grade with a smaller j, the higher are their re-entrant control wafers costs and their holding costs. As a consequence, its safety service level is lower. The opposite is also true for the lower grades of control wafers. The total cost of the system is the sum of the cost for each grade, and the cost for

Table 3. The parameters for example

Grade j	$\overline{d}_j$	σ^2_{dj}	$\overline{LT}_j$	$\sigma^2_{LT\,j}$	P_j	Z_{P_j}
$j=1$	864	1866.24	3.30	0.27	0.391	−0.277
$j=2$	395	389.82	3.67	0.34	0.923	1.426
$j=3$	493	607.01	3.15	0.25	0.978	2.014
$j=4$	294	215.54	2.80	0.20	0.991	2.326

Table 4. Costs of control wafers

Grade j	New wafer cost	Re-entrant cost	Holding cost	Total cost
$j=1$	52618	27659	5233	85510
$j=2$	3042	24438	6606	34086
$j=3$	1085	26461	6610	34156
$j=4$	294	13077	3023	16394

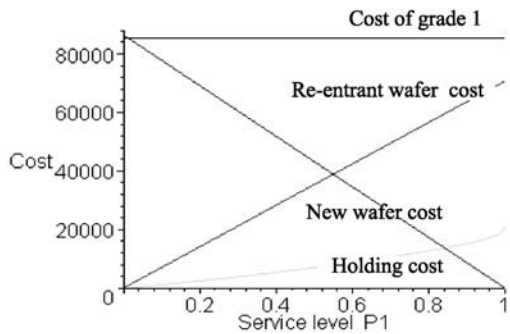

Fig. 4. The relationship of cost and service level for grade 1

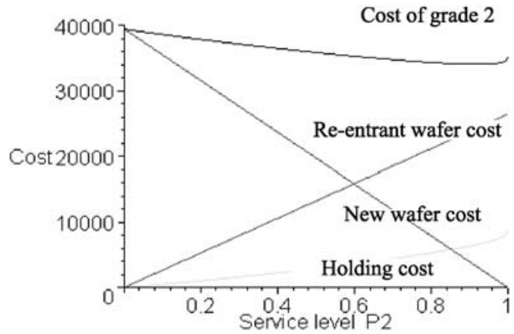

Fig. 5. The relationship of cost and service level for grade 2

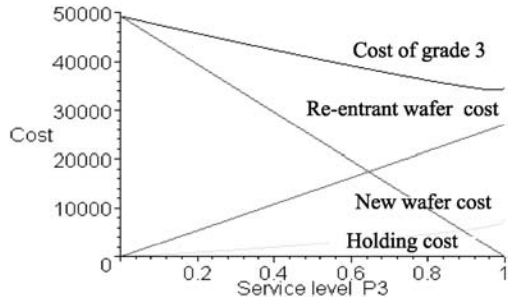

Fig. 6. The relationship of cost and service level for grade 3

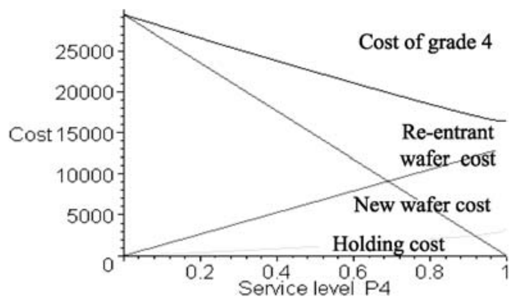

Fig. 7. The relationship of cost and service level for grade 4

a grade can be obtained with the determined service level and percentile point of the standard normal distribution. The minimal total cost of control wafers in the example is $170,146. Based on the above analysis, we can see that the proposed CWSIP algorithm performs quite well in setting service level and calculating cost for each grade of control wafers.

5 Conclusions

Control wafers inventory management is a challenge in wafer fab and setting optimal service level of safety inventory for each grade becomes a very important task. The service level of control wafers is closely related to many factors such as throughput target, work-in-process and cycle time. In this paper, the CWSIP algorithm is proposed to determine the service level of safety inventory of control wafers for each grade. By estimating new wafer cost, re-entrant cost and holding cost for each PURI process, service level and cost for each grade can be determined. From the results obtained in the example, the CWSIP algorithm performed quite outstanding on setting safety inventory level and minimizing total cost of control wafers with a nonlinear programming model. The results provided in this study can be very useful for managers in deciding the service level of safety inventory. Future research is suggested to work on the downgrading rate and cost for each grade of control wafers and a model for different parameters of control wafers may be established.

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References

1. Lin YL (2000) The design of inventory control model for dummy/control wafers at the furnace area in the wafer fab. Dissertation, National Chiao Tung University, Hsin-Chu, Taiwan
2. Ghare PM, Scharader GH (1963) A model for exponentially decaying inventory system. Int J Prod Res 21:449–460
3. Covert TB, Philip GS (1973) An EOQ model with Weibull distribution deterioration. AIIE Trans 5:323–326
4. Chang HJ, Dye CY (2000) An EOQ model with deteriorating items in response to a temporary sale price. Prod Plann Control 11(5):464–473
5. Chung KJ, Tsai SF (2001) Inventory systems for deteriorating items with shortages and a linear trend in demand-taking account of time value. Comput Oper Res 28(9):915–934
6. Chang HJ, Hung CH, Dye CY (2002) A finite time horizon inventory model with deterioration and time-value of money under the conditions of permissible delay in payments. Int J Syst Sci 33(2):141–151
7. Platt DE, Robinson LW, Freund RB (1997) Tractable (Q, R) heuristic models for constrained service levels. Manage Sci 43(7):951–965
8. Popovich SB, Chilton SR, Kilgore B (1997) Implementation of a test wafer inventory tracking system to increase efficiency in monitor wafer usage. 1997 IEEE/SEMI Advanced Semiconductor Manufacturing Conference, pp 440–443
9. Kar S, Bhunia AK, Maiti M (2001) Deterministic inventory model with two levels of storage, a linear trend in demand and a fixed time horizon. Comput Oper Res 28(13):1315–1331
10. Pal S, Goswami A, Chaudhuri KS (1993) A deterministic inventory model for deteriorating items with stock-dependent demand rate. Int J Prod Econ 32(3):291–299
11. Bhunia AK, Maiti M (1997) Deterministic inventory models for variable production. J Oper Res Soc 48(2):221–224
12. Das K, Roy TK, Maiti M (2000) Multi-item inventory model with quantity-dependent inventory costs and demand-dependent unit cost under imprecise objective and restrictions: a geometric programming approach. Prod Plann Control 11(8):781–788
13. Chen HC, Lee CE (2000) Control and dummy wafers management. J Chin Inst Ind Eng 17(4):437–449