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A Requirement-Dependent Inventory Allocation Model for Dynamic Allocation Process in LED Chip Manufacturing Plants

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Abstract *LED chip manufacturing (LED chip manufacturing, LED-CM) factory play an important role in the LED supply chain. Basically, product specifications (for LED-CM BIN plant) are expressed by BIN. Required specifications of an order are composed by several BINs. Because the processing of LED-CM production is unstable, LED chip factory could produce the products which are not fit required specifications and further, side-product could be generated. The side-product is not defective product, and it could also meet the inventory requirement for subsequent orders. For the reason, while LED-CM plant receives a new order, it must provide inventory to meet demand at first. Then, insufficient quantity would be produced by further orders. In order to response to different customer demands, there are two types of demand, dynamic allocation procedures and static allocation procedures. Dynamic allocation process means that factory receives the order and it should allocate inventory for immediate shipment to customers. Static allocation process can wait until the orders are accumulated to a certain volume, then the entire batch simultaneous is distributed and shipped to customers. Although the static allocation process can efficiently use factory inventory and get maximum output by optimizing distribution model, but it will lengthen the response time and shipping time. When a customer requires an immediate response, how to immediately allocate chip combination of each BIN in warehouse to have maximum shipments or to make maximum subsequence order shipped efficiently is a dynamic allocation decision-making problem for improving customer server level and profiting effectively. In practice, there are two most common used dynamic allocation process shipping method for LED-CM factory, the average method (Average, AVG) and inventory quantity ratio method (Inventory Proportion, IP). Although both two methods are simple and practical, but they ignore different level consumptions of orders to each BIN. In order to use inventory of factory efficiently and increase subsequent using probability for different BIN, this study proposes a dynamic allocation procedure which takes into account inventory and demand proportion. This study verifies the effectiveness of proposed method by simulation and experiment design. The results show that under different demand environments, performance of proposed method which could meet the demand of dealing more orders and the performance of proposed method is better than the performances of AVG and IP under the same inventory.*

Key words LED chip manufacturing, Unstable process, Inventory allocation, BIN allocation combination

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1. Introduction

Main manufacturing processes of LED industrial consist of four parts as follows: raw material substrates, upstream, midstream and downstream (Hop and Kawtummachai, 2005; Sahin *et al.*, 2008). Substrate is important raw material to produce Epitaxy wafer (EPI wafer). Two raw materials of substrates are sapphire and Si substrates. Midstream manufacturing process is to generate LED chip or Sapphire by Epitaxy wafer. Downstream manufacturing process would be LED chip package or module plant depending on different demand. LED chip manufacturing (LED-CM) process is not only complicated but also unstable, and product quality of this process will affect the merits of the subsequent application of LED. Therefore, LED-CM plants play the key role in LED supply chain and it is also the research topic in this paper. In general, LED-CM plants produce product by order to meet customer diversity demand. Manufacturing process is unstable and product specifications are composed by different BIN (segment). For the reasons, production management members face tremendous pressure for effective inventory control and delivery must be completed accurately in compliance. Therefore, Wu *et al.* (2013) proposed an order performance model, and this model also includes a product delivery process. Product specifications of order could be composed by chip quantity of different BIN (segment). The characteristic of LED manufacturing process is that the actual quantity of production may be lower than expected production quantity. The stock of BINs which have specifications used by different products would quickly reduce. This study proposed a BIN delivery model which delivers each BIN quantity of different product specification by different type. Then, we utilize simulation experiment to verify feasibility of proposed model and figure out the optimal BIN delivery combination.

2. Manufacturing process of LED-CM factory and product specification

In general, manufacturing process of LED-CM factory would input epitaxy wafer and product LED chip. The process includes two parts: frontend processes and backend processes. Frontend processes would grant electrical function to epitaxy wafer. The functions of backend processes are chip-point measurement, segmentation, classification and packaging. One epitaxy wafer could be segmented to a few or thousands LED chip depending on wafer size. There are many different types of LED chip product specifications according to lightness and wavelength of electrical function and we utilize the two functions to define product specifications in this study. Some symbols used in this paper are as follows:

b_{jk}: stock quantity of BINs, brightness degree is j, wave length is k, j = 1, 2,.., J; k=1, 2,.., K.

bp_{jk}: stock ratio of BINs, brightness degree is j, wave length is k, j=1,2,..,J; k=1, 2,.., K.

dq_{jk} : history average demand ratio of BIN_{jk}, brightness degree is j, wave length is k, j=1, 2,.., J; k=1, 2,.., K.

DBP_{jk}: partial demand ratio for product feasible BIN_{jk} , i =1, 2,.., I; $j = ll_i,…,lu_i$; $k = wl_i,…,wu_i$.

I: order number.

J: rang of maximum brightness degree.

K: rang of maximum wave band.

ll_i: brightness degree lowest limitation of order i, i =1, 2,…, I.

lu_i: brightness degree highest limitation of order i, i =1, 2,…, I.

N_i: feasible BIN_{jk} quantity of order i, i = 1, 2,…, I.

P: each fixed pick shipments.

r_i: demand quantity of order i, i =1, 2,…, I.

S_{ijk}: picking quantity of BIN_{jk} for order i, i =1, 2,…, I; $j = ll_i,…,lu_i$; $k = wl_i,…,wu_i$.

SBP_{ijk}: partial stock ratio of feasible BIN_{jk} for order i, i =1, 2,.., I; $j = ll_i,…,lu_i$; $k = wl_i,…,wu_i$.

T: total stock quantity.

Tbp_{ijk}: sum of feasible BIN stock ratio for order i, i =1, 2,…, I; j =1, 2,.., J; k =1, 2,.., K.

Tdq_{jk}: sum of history average demand ratio, where product's brightness degree is j and product's wave length is k.

v_i: sum of feasible BIN stock quantity for order i, i =1,2,…, I.

wl_i: lowest limitation of wave length for order i, i =1, 2,…, I.

wu_i: highest limitation of wave length for order i, i =1, 2,…, I.

2.1. Product specification

The product specifications of LED are defined by the composition of brightness degree and wavelength and the compositions of range for brightness degree and wavelength are infinite. Products produced from manufacturing process are unstable, therefore, products are required to be classified (BIN). Take yellow light LED as example, the wavelength is between 584nm and 594nm and lightness degree is from 100mcd to 300mcd. In addition, order specifications are further required to describe the range of lightness degree and wave length (Ho *et al*., 2012). If customers require LED chips which have more yellow color and brighter brightness, then the wave length specification of required chips is from 586nm to 588nm and lightness degree is from 200mcd to 250mcd (Lee *et al.*, 2011). LED-CM plants classify LED chip's brightness (*j* degree) and wavelength (*k* degree) to many different degrees depending on customer's requirement (listed in Table 1). The detail contents about BINs are shown in Wu *et al.* (2013).

Table 1. The inventory example for BIN of yellow LED chip (unit: K)

BIN (×K chip) b_{jk}			Wavelength *k* (nm)				
			1	2	3	4	5
			584~586	586~588	588~590	590~592	592~594
Brightness degree *j* (mcd)	1	50~100	462	220	277	325	295
	2	100~150	99	435	224	427	401
	3	150~200	432	420	181	169	182
	4	200~250	109	218	293	161	379
	5	250~300	417	405	396	237	312

LED-CM plants would transfer customer's required specifications into applicable BINs when plants receive order (Wu and Li, 2011). The applicable BINs of product specification*I*in order are as equation (1).

$$FB_i = \{b_{jk}, ll_i \leqq j \leqq lu_i, wl_i \leqq k \leqq wu_i\},\ i = 1, 2,..., I \tag{1}$$

Chip shipment for order is according to available chip of Bins. For example, specification of LED chip is yellow, wavelength is from 587nm to 593nm, and brightness is from 80mcd to 160mcd. Quality of BINs shipment must fit order's specification. Therefore, available wavelength of BINs for this order is 2~4 (i.e., wl_i=2 and wu_i=4) and brightness degree is 2~3 (i.e., ll_i=2 and lu_i=3). Available BINs fitting to this order are shown in Table 1 (gray area). Expressions for chip stock quantity are as equation (2).

$$v_i = \sum_{k=wl_i}^{wu_i} \sum_{j=ll_i}^{lu_i} b_{jk},\ i = 1,2,...,I \tag{2}$$

If available BINs for chip stock are enough for order, then the products of the order are shipped to reach compliance. On the contrary, production project or manufacturing order for product specification 1 would feed raw material and begin to produce product.

3. Picking BIN shipping model in LED-CM plants

The worth of producing manager in LED-CM comes from shipping on time and maintaining inventory level in order to reduce production costs. Order fulfillment model of LED-CM factory includes product shipment process (Boas, 2011). This study focuses on LED-CM factory how the LED-CM plant through efficient shipping model allow inventory to meet more orders and effectively reduce inventory levels, and reduce waste caused by excess production. When an order comes in, you must confirm whether there are enough inventories before shipping. And the quantity of each BIN must meet the minimum proportion of shipments. Each BIN which has same stock and has different shipping type would have different shipping quantity. Shipping quantity of different BIN combinations for the same product specification order will affect the likelihood of subsequent orders shipping. Therefore, how to effectively use inventories within the plant and increase the using probability of subsequent different BIN is the challenge of LED-CM plant managers.

For easy picking BIN shipments, average (Average, AVG) is a common shipping method used by LED-CM plant manager. This method will equally allocate the volume of orders to each BIN contained product specifications. In other words, BIN is the average number of orders according to order specifications requirement, and each BIN would ship the average quantity. AVG method is simple and easy to use. However, the method does not consider the consumption patterns in stock. In order to increase the likelihood of subsequent orders shipping and increase the opportunities for all BINs are selected. Stock quantity ratio method (Inventory Proportion, IP) is also an often used shipping method. Each order includes different BIN and different products contain common using BIN. According to the number of the existing inventory to allocate shipping BIN number, which can effectively control the inventory of each BIN, but you can always monitor BIN number reducing status.

Although, two shipping method mentioned above are all simple and practical, and consider the inventory can be equally picking to ship. However, the two methods ignore the different level consumptions of order to each BIN. The ability of the methods is not enough to deal more order requirement. Therefore, this study proposed a dynamically allocating method considering stock quantity and demand ratio. Proposed method could efficiently use of inventories within the plant and increase the using probability of subsequent different BIN.

4. A Requirement-Dependent Inventory Allocation Model

The orders of LED-CM plant have different specifications to meet customer requirement. Some BINs are shared by different specifications. Inventories of the BINs which shared frequencies are higher are rapidly consumed when it is continuously used. The BIN cannot be shipped when inventory of the BIN is not enough. In order to obtain subsequence high opportunity of shipping for different specifications, dynamic allocation method should take into account both of inventory quantity and demand ratio. In other words, the shipping method considers demand proportion of demand differences. Figure 1 is the logic procedure of Demand Proportion. First, the method should set minimum picking quantity (*P*), and the purpose of this step is to pick products in batches to achieve optimal allocation ratio. This study set minimum pick quantity as one tenth of experiment average order quantity. Then we should calculate inventory ratio of BIN for order specification (SBP_{ijk}) and actual requiring ratio of the BIN (DBP_{ijk}). Comparing the two ratio size of required BIN by order; if inventory ratio is greater than demand ratio, then minimum picking quantity (*P*) is deducted from inventory to assign to the order to ship. According to the step we continue to compare each required BIN. The process will stop until shipping quantity meet all order quantity. Distribution will stop while inventory of any BIN is less than or equal to 0 during the distribution process. The detail procedure of the method is shown as follows:

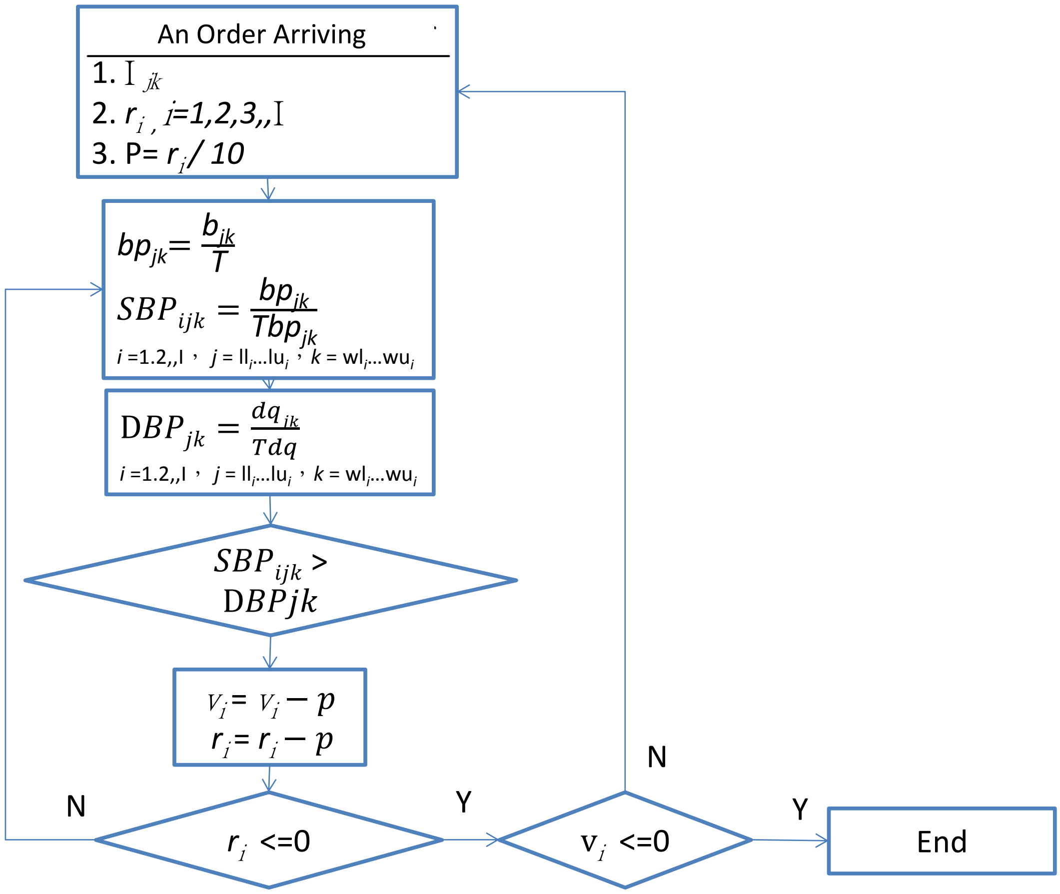

Figure 1. DP logic procedure

Step 1: Calculate inventory ratio of BINs, where brightness degree of BINs is *j* and wavelength of BINs is *k*. The purpose of this step is to calculate the ratio (inventory quantity of each BIN relative to total inventory).

$$bp_{jk} = \frac{b_{jk}}{T} \tag{3}$$

Step 2: Calculate partial inventory of available BIN_{jk} for order *i*, the inventory ratio of BIN is calculated in Step 1, then we use the results of step one to calculate relative ratio of partial order specification BIN inventory.

$$SBP_{ijk} = \frac{bp_{jk}}{Tbp_{jk}} \tag{4}$$

Step 3: Count partial actual demand ratio of viable BIN_{jk} for product. Count last actual demand of the products, and calculate partial demand ratio for each demand specification viable BIN. The purpose of this step is to calculate the actual demand ratio of each BIN.

$$DBP_{jk} = \frac{dq_{jk}}{Tdq_{jk}} \tag{5}$$

Step 4: Compare the partial inventory ratio of step 2 and the partial demand ratio of step 2. While partial specification BIN inventory ratio is greater than partial demand BIN ratio, and the results show that BIN inventory is greater than demand. Then, the BIN could be allocated to ship. In contrast, partial demand BIN ratio is greater than partial specification BIN inventory ratio, and the results show that the BIN inventory is smaller than the other's BIN inventory. Then, the BIN will be skipped and the other's BIN would be allocated to ship, and the deducting quantity of each allocating shipment is *P*.

Step 5: After allocation of the BIN is finish, we will compare the next BIN. This step would cycle to distribute inventory for order until a sufficient number of orders up to ship, or there are stocks of BIN less than zero.

The following will give examples to illustrate the picking inventory shipment method. Table 1 shows inventory status of each BIN at a point in time. Assuming customer give an order *i*, the demand specifications of the order are as following: wavelength is from 586 to 592, brightness is from 100 to 250, and demand quantity is 200K. Steps for picking stocks to ship are as follows:

Step 1: calculate the inventory ratio of BINs, where brightness degree is *j* and wavelength is *k,* We can calculate inventory ratio of BIN (1, 1) by equation (3) and the results are as follows: $bp_{j=1,k=1}$ = (462÷7476)=0.061798 (6.17%). We calculate the inventory ratio of each BIN by order, such as Table 2.

Table 2. Inventory ratio for each BIN

BIN (×K chip) b_{jk}			wavelength *k* (nm)				
			1	2	3	4	5
			584~586	586~588	588~590	590~592	592~594
Brightness degree *j* (mcd)	1	50~100	6.18%	2.94%	3.71%	4.35%	3.95%
	2	100~150	1.32%	5.82%	3.00%	5.71%	5.36%
	3	150~200	5.78%	5.62%	2.42%	2.26%	2.43%
	4	200~250	1.46%	2.92%	3.92%	2.15%	5.07%
	5	250~300	5.58%	5.42%	5.30%	3.17%	4.17%

Step 2: calculate partial inventory ratio of viable BIN_{jk} for order *i* by equation (4), the results are shown as follows:

$$SBP\,ij = 2, k = 2 = \frac{5.82\%}{33.81\%} = 17.21\%$$

We calculate partial inventory ratio of each viable BIN by order, and the results are listed in Table 3.

Table 3. Partial inventory ratio for each viable BIN

BIN (×K chip) b_{jk}			Wavelength *k* (nm)				
			1	2	3	4	5
			584~586	586~588	588~590	590~592	592~594
Brightness degree *j* (mcd)	1	50~100					
	2	100~150		17.21%	8.86%	16.89%	
	3	150~200		16.62%	7.16%	6.69%	
	4	200~250		8.62%	11.59%	6.37%	
	5	250~300					

Step 3: We calculate partial actual demand ratio of viable BIN_{jk} for product by equation (5), and the results are shown in Table 4.

Table 4. History demand ratio for the product

BIN (×K chip) b_{jk}			wavelength *k* (nm)				
			1	2	3	4	5
			584~586	586~588	588~590	590~592	592~594
Brightness degree *j* (mcd)	1	50~100	2.41%	3.37%	3.54%	3.30%	2.36%
	2	100~150	3.49%	5.28%	5.51%	5.16%	3.54%
	3	150~200	3.64%	5.06%	5.48%	5.06%	3.39%
	4	200~250	3.72%	5.33%	5.69%	5.33%	3.36%
	5	250~300	2.56%	3.58%	3.74%	3.65%	2.45%

$$DBP\ j=2,k=2=\frac{5.28\%}{47.9\%}=11.03\%$$

Table 5 shows the calculated partial demand ratio of viable BIN_{jk} for product.

Table 5. Partial demand ratio for viable BIN_{jk} of the product

BIN (×K chip) b_{jk}			wavelength *k* (nm)				
			1	2	3	4	5
			584~586	586~588	588~590	590~592	592~594
Brightness degree *j* (mcd)	1	50~100					
	2	100~150		11.03%	11.50%	10.77%	
	3	150~200		10.57%	11.44%	10.56%	
	4	200~250		11.12%	11.88%	11.13%	
	5	250~300					

Step 4: compare the partial inventory ratio of step 2 and the partial demand ratio of step 3.
$SBP_{ij=2,k=2}$ (17.21%) is greater $DBP_{j=2,k=2}$ (11.03%)
Therefore, we will allocate 1/10 demand quantity (P= r_i/ 10) from inventory $b_{j=2,k=2}$ for order to ship.

Step 5: After allocation of the BIN is finish, we will compare the next BIN. This step would cycle to distribute inventory for order until a sufficient number of orders up to ship, or there are stocks of BIN less than zero.

5. Simulation experiment

5.1. Experiment factor

In order to verify picking BIN shipping method can accomplish the amount of shipment under different combinations of order, the experiment sets two experimental factors: picking BIN shipping method and order specification range level.

5.1.1. Picking BIN shipping Method

AVG and IP are two commonly used picking BIN shipping method for LED-CM plant production manager. There are two advantages for two methods: easy to calculate and convenient to use. This experiment utilizes the two methods to be compared with DP method mentioned in section 4.

A. Average (AVG)

In order to increase the likelihood for subsequent order shipment and increase chance to be selected for each BIN, this study proposed 1-AVG method which equally allocates order quantity to each BIN contained the product specifications. BIN classes are used by each product specification, such as equation (3), and we can utilize equation (4) to generate the quantity of shipment for each BIN. If the value generated by AVG is aliquant then the value would be rounded. In order to increase opportunity of usage for BIN, the discarding value will be allocated one by one to each BIN, accordance with the highest number of current BIN inventory, up until the assignment is completed.

$$N_i = (lu_i - ll_i + 1) \times (wu_i - wl_i + 1) \quad (6)$$

$$S_{ijk} = (r_i / N_i),\ i = 1,2,\ldots,I;\ j = ll_i,\ldots,lu_i;\ k = wl_i,\ldots,wu_i \quad (7)$$

B. Inventory Proportion (IP)

Any order includes different BIN and different products would include common used BIN. Inventory quantity is allocated to ship in accordance with current inventory quantity, and this method can effectively control the inventory of each BIN. Further, this method can observe the status of BIN quantity reducing at any time. Therefore, this study proposed IP as method 2, and the logic procedure of IP is shown in Figure 2. We can observe the order specifications for order *i* as following: brightness is *j*, wavelength is *k*, order demand quantity is r_i, picking quantity of each demand BIN is S_{ijk} (the ratio for the order quantity (r_i) plus demand BIN percentage relative to inventory (b_{jk} / v_i)). The method would continue the procedure until there is a BIN which inventory of the BIN is less than or equal to 0.

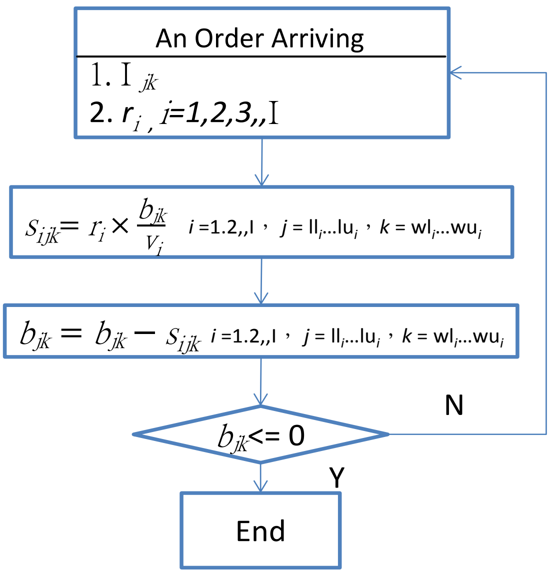

Figure 2. IP logic procedure

C. Demand Proportion (DP)

The logic of DP is described in section 4.

5.1.2. Demand proportion level of BIN

The purpose for setting factor is to compare the performances of different picking BIN shipping methods under different demand proportion level. The three methods are narrow BIN demand laying particular stress, normal BIN demand laying particular stress and wide BIN demand laying particular stress, respectively (Table 6).

D1.Narrow BIN demand laying particular stress

Demand range is 1 to 6 BIN: Demand range is 6 to 16 BIN: Demand range is 16 to 25 BIN = 80%: 10%: 10%.

D2.Normal BIN demand laying particular stress

Demand range is 1 to 6 BIN: Demand range is 6 to 16 BIN: Demand range is 16 to 25 BIN = 10%: 80%: 10%.

D3.Wide BIN demand laying particular stress

Demand range is 1 to 6 BIN: Demand range is 6 to 16 BIN: Demand range is 16 to 25 BIN = 10%: 80%: 10%.

Table 6. combination for experiment factor

Experiment number	Demand proportion level of BIN	Picking method
1	D1	AVG
2	D1	IP
3	D1	DP
4	D2	AVG
5	D2	IP
6	D2	DP
7	D3	AVG
8	D3	IP
9	D3	DP

5.2. Experiment design

The experiment will simulate each BIN inventory for one kind chip in LED-CM plant, and set an initial inventory of each BIN. Then, this experiment generates randomly order quantity and range for order specification. The experiment picks BIN to ship by four different picking BIN methods in three kinds order specification level. Delivery condition for each order is that each BIN must have inventory to ship. Therefore, the experiment will stop while any BIN inventory is less than zero. We would find which method can reach a maximum of orders at a fixed amount of inventory. As shown in Table 7, there are 25 BIN experiment settings. Order demand quantity generated randomly is at least one BIN and maximum quantity is 25 BIN. For example, required specifications are as follows: wavelength is from 588 to 592, brightness is from 400 to 600, and required BINs are BIN7, BIN8, BIN12, and BIN13.

Table 7. 25 BIN experiment settings

Brightness\wavelength	586~588	588~590	590~592	592~594	594~596
50~100	BIN1	BIN2	BIN3	BIN4	BIN5
100~150	BIN6	BIN7	BIN8	BIN9	BIN10
150~200	BIN11	BIN12	BIN13	BIN14	BIN15
200~250	BIN16	BIN17	BIN18	BIN19	BIN20
250~300	BIN21	BIN22	BIN23	BIN24	BIN25

5.3. Environment setting in experiment

5.3.1. Length setting in experiment

Experiment length depends the setting of in initial inventory. More inventories can meet more orders. Because the order quantity and specification range is generated randomly, experiment length must be able to effectively provide stability in random environment. Size of specification range is randomly generated depending on the ratio of experiment design. The order quantity is generated randomly by normal distribution mean 450k and standard deviation 100. Therefore, we estimate required sample size of experiment length depending on the two values. Three types of specification BIN range is composed by three proportion of 80%, 10%, 10%, respectively. We would estimate the required number of sample by 95% confidence level to meet the experimental error probability less than 5%. Sample estimating equation is as follow:

$$n = \frac{Z_{\alpha/2}^2 \cdot p(1-p)}{e^2}$$

For example, specification range ratio is 80%.

$$n = \frac{1.96^2 \cdot 0.8(1-0.8)}{0.05^2} = 245.86$$

From the example above, we should generate randomly over 246 samples to meet the condition (80% randomly generated specification range ratio under 95% confidence level and error does not exceed 5%). Random generated ratios for used experiment factor are shown in Table 8. The minimum required samples are 246, 139, 139 respectively and experiment sample should be over 246 to meet 5% error range.

Table 8. Random generated ratios for used experiment factor

P	0.8	0.1	0.1
1-P	0.2	0.9	0.9
Significance level	95%	95%	95%
$Z_{\alpha/2}$	1.96	1.96	1.96
Tolerable error	0.05	0.05	0.05
Minimum estimate sample	245.86	138.3	138.3

Order quantity is generated randomly 500 times by normal distribution (average is 450K, and standard deviation is 100K) .The average and standard deviation of generated order quantity are 505.45 and 100.39, respectively (Table 9). Sample estimating equation is shown as following:

$$n = \left(\frac{Z_{\alpha/2} \cdot S}{e} \right)^2$$

Table 9. Mean and standard deviation

Unit K	Number of samples
Sample mean	505.45
Sample standard deviation	100.39
Sample size	500
Significance level	95%
$Z_{\alpha/2}$ value	1.96
Tolerable error	20
Minimum estimating sample	96.76

From the results above, the required minimum example sample size is 97 to meet the condition (95% confidence level to meet the volume of orders generated randomly and the error does not exceed 20K). Therefore, the experimental factor error will not exceed 5% as long as the estimated number of experimental samples more than 246 times and the error of order quantity will not be higher than 20k. Table 10 assumes that the initial inventory of each BIN is all 12,000 K to do each experiment by using AVG under the environment which orders range ratio of arrow, middle and wide are 10%, 80%, and 10%, respectively. The results show that the average shipped order is 372 to meet the estimated minimum sample size (246). Then, the experiment will set initial inventory of each BIN as 12,000K.

Table 10. Assuming initial inventory of each BIN

Unit K	586~588	588~590	590~592	592~594	594~596
300~400	12,000	12,000	12,000	12,000	12,000
400~500	12,000	12,000	12,000	12,000	12,000
500~600	12,000	12,000	12,000	12,000	12,000
600~700	12,000	12,000	12,000	12,000	12,000
700~800	12,000	12,000	12,000	12,000	12,000

5.4. Number of times for experiment

From the setting in section 5.4, inventory of each BIN is 12,000K, and we do each 30 times experiment by AVG under the environment which orders range ratio of arrow, middle and wide are 10%, 80%, and 10%, respectively. The generated average shipped order is 376.3, and standard deviation is 26.79 orders (Table 11). The minimum sample size is 28 under the condition (the acceptable error range is 10 cases with 95% confidence level). Each set of experiments will be performed 30 times, and average available shipped order quantity is used as comparison.

Table 11. Mean and standard deviation

Sample mean	376.30
Sample standard deviation	26.79
Sample size	30
Significance level	95%
$Z_{\alpha/2}$ value	1.96
Tolerable error	9.59
Expectation tolerable error	10
Minimum estimating sample	27.57

5.5. DP initial test

DP method aim to compare the stock proportion of each BIN and demand proportion of each BIN. The greater difference between supply and demand means that supply and demand are more unequal, while demand proportion is greater than inventory proportion, then DP pick this BIN to ship as priority one. DP will constantly adjust shipment until proportion of inventory and proportion of demand can be equal for each BIN. Therefore, the accuracy of the demand percentage of each BIN is very important for the performance of the method. Demand proportion of this experiment based on average (450K) and standard deviation (100K), customer requiring order is simulated randomly by normal distribution. We generate the proportion by counting the required quantity of each available shipped BIN. The proportion of demand will be more accurate while more required order samples. We will use experiment 3 as initial experiment according to normal distribution (450) and standard deviation (100K). We would figure out how many sample we need in this environment to calculate appropriate demand proportion. Figure 3 shows the changes of demand differences for each BIN. In figure 3, horizontal axis is order quantity and vertical axis is the cumulative demand proportion at each time points minus final cumulative demand. From Figure 3, we can see that differences of each BIN gradually converge after generating 76 to 100 difference of order demand proportion. Therefore, we revise the first 75 order by AVG method, and continue to count demand proportion of each BIN. After order number is 75, subsequence orders are revised by DP method.

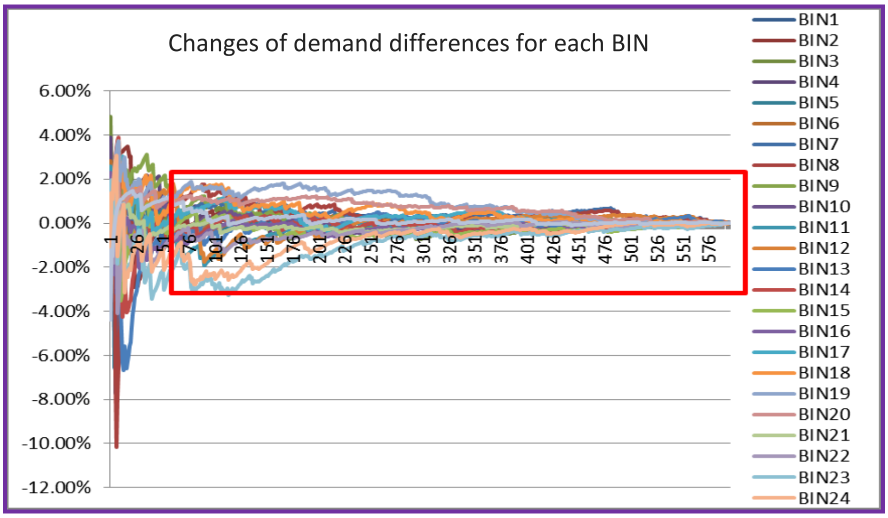

Figure 3. Changes of demand differences for each BIN

5.6. Performance Factor

The performances of different methods are evaluated under maximum shipped order quantity in range ratio of different order BIN.

Table 12. Experimental statistics (KK) for 1 to 9 of the experiment

Experiment number	BIN demand proportion level	picking method	AVG	SD
1	D1	AVG	172.90	10.29
2	D1	IP	242.02	10.56
3	D1	DP	291.22	5.06
4	D2	AVG	158.21	7.21
5	D2	IP	262.47	9.62
6	D2	DP	296.26	3.08
7	D3	AVG	214.97	5.24
8	D3	IP	292.39	5.98
9	D3	DP	297.22	2.02

Some statistical results of experiment 1 to experiment 9 are listed as follows (Table 12): Table 13 is the two-way ANOVA analysis table for two factors (the proportion of demand level and picking BIN shipping method) under 95% confidence level. P-value of the factor for order BIN range ratio is 1.53E-95 of much less than 0.05, which means that there are significant differences in the influence between the environmental factors for the range proportion of different orders BIN and maximum available shipping quantity. P-value of picking method is 9.3E-219 of much less than 0.05, which means that there are significant differences in the influence between different picking method and maximum available shipping quantity. Further, P-value of the interaction for two experiment factors is 8.01E-69 of much less than 0.05, which means that there are significant differences in interaction between two factors.

Table 13. Two-factor ANOVA analysis table under the 95% confidence level

ANOVA						
Variable source	SS	Degree of freedom	MS	F	P-value	Thresholds
Range proportion of order BIN	58,290.85	2	29,145.43	564.79	1.53E-95	3.03
Picking method	617,565.76	2	308,782.88	5,983.66	9.3E-219	3.03
Interaction	32,901.94	4	8,225.49	159.40	8.01E-69	2.41
Within the group	13,468.74	261	51.60			
Sum	722,227.29	269				

First, we utilize Tukey HSD method to compare the degree of difference between the average shipping numbers for three level of order BIN range ratio factor.

Table 14. Using Tukey HSD method to compare order BIN range ratio factor

(KK)	D1	D2	D3
AVG	235.38	238.98	268.19
MS	219,035.16	315,124.57	129,776.71
MSE	2,486.65		
HSD(α=0.05)	17.40		
	D2	D3	
D1	3.60	32.81	
D2		29.21	

From Table 14, the results show that the shipping quantity of difference for environment D1 and environment D2 is 3.6KK which is lower than the HSD value (17.4) of confidence level 95%. Therefore, there are no significant differences with higher ratio of narrow BIN and higher ration of normal BIN. There is a significant difference in improving the shipping quantity with higher proportion of wide BIN.

Table 15. Using Tukey HSD method to compare picking factor

(KK)	AVG	IP	DP
AVG	182.03	265.62	294.90
MS	57,437.97	45,463.81	1,759.76
MSE	391.99		
HSD(α=0.05)	6.91		
	IP	DP	
AVG	83.60	112.87	
IP		29.27	

From Table 15, we can see that the differences for each other by the three methods are all greater than HSD value (6.91) of confidence level 95%. Therefore, there are significant differences in the impact of each environment for three methods to maximum shipping quantity. IP method is superior to AVG method and the DP outperforms to the listing methods, from Figure 4 (The actual shipping quantity of high inventory level).

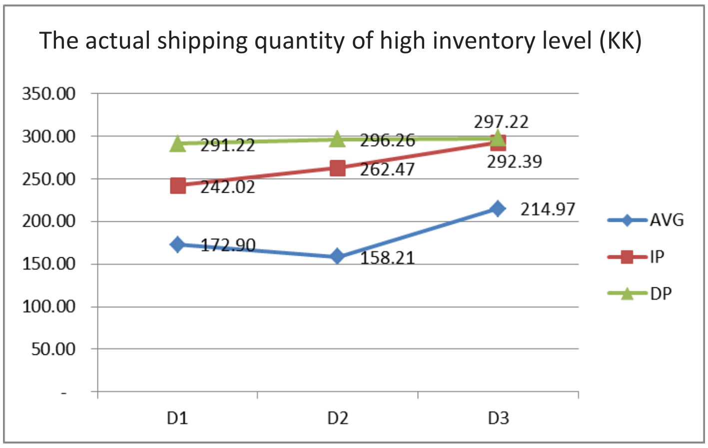

Figure 4. The actual shipping quantity of high inventory level

From experiment results mentioned above, some discussions of this paper are as follows: DP method takes proportion of inventory and proportion of demand into account. Under different demand conditions, DP method really utilizes same inventory to complete more orders. Although AVG and IP methods are simple computing and are easy to use, but the two methods ignore the different requirement proportion of each BIN. Therefore, the reason would easily result that stocks are not equally allocated. Although there are benefits of using the DP method, but there is a premise that there must be sufficient actual demand information to establish demand proportion information. If the demand information is insufficient than DP method would lapse.

6. Conclusions

LED-CM plants play an important role in LED supply chain. Basically, the product specification of LED-CM plant is described by BIN. The required product specifications of an order are composed by many BINs. Processing of LED-CM production is unstable. Therefore, not only the products for order requiring specification would be generated, but also the side-product would be produced. The side-product is not defective product, and it could also meet the inventory requirement for subsequent orders. For the reason, while LED-CM plant receives a new order, it must provide inventory to meet demand at first. Then, insufficient quantity would be produced by further orders. LED-CM plants are response to different customer needs, and there are two types of demand, dynamic allocation procedures and static allocation procedures. Dynamic allocation process means that factory receives the order and it should allocate inventory for immediate shipment to customers. Static allocation process can wait until the orders are accumulated to a certain volume, then the entire batch simultaneous is distributed and shipped to customers. Although the static allocation process can efficient use of factory inventory and get the maximum output by optimizing distribution model, but it will lengthen the response time and shipping time. When a customer requires an immediate response, how to immediately allocate chip combination of each BIN in warehouse to have maximum shipments or to make maximum subsequence order shipped efficiently is a dynamic allocation decision-making problem for improving customer server level and profiting effectively. In practice, there are two most commonly used dynamic allocation shipping method for LED-CM factory, the average method (Average, AVG) and inventory quantity ratio method (Inventory Proportion, IP). Although the two methods are both simple and practical, but they ignore the different level consumptions of order to each BIN. In order to use inventory of factory efficiently and increase subsequent using probability for different BIN, this study proposes a dynamic allocation procedure which takes into account inventory and demand proportion. This study verifies the effectiveness of proposed method by simulation and experiment design. The results show that under different demand environments, performance of proposed method which could meet the demand of dealing more orders and the performance of proposed method is better than the performances of AVG and IP under the same inventory.

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