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CONWIP based control of a lamp assembly production line

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Abstract Efficient and effective production control systems are very important for manufacturing plants. CONWIP, one of these production control systems, has a high potential of becoming the best one available because it suits a variety of production environments and is easy to implement. In the following paper, we compare the single-loop and multi-loop CONWIP production control systems for an actual lamp assembly production line producing different kinds of products with discrete distribution processing time and demand. A model is formulated with respect to total cost and service level. A novel rule-based genetic algorithm (GA) approach is proposed for the multi-loop CONWIP system to find the optimum parameter setting. The results have shown that the single-loop CONWIP production control system is more efficient than the multi-loop system. It can greatly decrease the total cost and the WIP (Work-In-Process) with zero shortage probability.

Keywords Production control system · Single-loop CONWIP · Multi-loop CONWIP · Simulation · Genetic algorithm

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Introduction

Production control is so important in manufacturing that it attracts the attention of both researchers and practitioners. In these decades, production control systems are introduced to produce the right parts, at the right time and at a competitive price. They are usually divided into two types: the push and the pull systems (Spearman, Woodruff, & Hopp, 1990). The push systems, such as MRP and its successor MRP II, schedule releases based on the forecast value of lead time, while the pull systems, such as kanban (Sugimori, Kusunoki, Cho, & Uchikawa, 1977), generic kanban (Chang & Yih, 1994) and CONWIP (Spearman et al., 1990) authorize releases based on the rate at which the products have been consumed (Gstettner & Kuhn, 1996; Hopp & Roof, 1998; Kimura & Terada, 1981; Venkatesh, Zhou, Kaighobadi, & Caudill, 1996). The pull systems control the WIP (Work-In-Process) directly, and hence minimize it to facilitate quick responses to changes in demand and production fluctuations. The advantages of pull over push are observability, efficiency, variability, and robustness. All are discussed by researchers (Hopp & Spearman, 1996; Spearman & Zazanis, 1992; Spearman et al., 1990) and supported by firms that have successfully used the pull systems (Hopp & Roof, 1998).

Dr. Taichi Ohno, a manager of Toyota Motors, in order to limit the inventory level at each production stage, developed the kanban control mechanism utilizing a cards based system. The card number of each stage is predetermined so that the WIP is controlled effectively. Due to its efficiency, there is an immense literature about kanban, e.g. the survey papers from Berkley (1992), Price, Gravel, and Nsakanda (1994), Huang and Kusiak (1996) et al. There are many forms of kanban mechanism such as generic kanban (Chang & Yih, 1994) and extended kanban (Dallery & Liberopoulos, 1995). Some manufacturers, especially Japanese firms, have also successfully used Kanban. However, as it was pointed by Hall (1981), "Kanban is intrinsically a system for repetitive manufacturing." In order to take into consideration the characteristics of a more complex environment, CONWIP (Spearman et al., 1990) was proposed.

In the CONWIP control mechanism, cards assigned to the whole production line control the WIP. The product can be pulled into the production line when the WIP is smaller than the predetermined card number and then be pushed between machines till the end of the production line. The main difference between CONWIP and kanban system is: CONWIP pulls products into the initial machines of the production line and then pushes them between machines, while kanban pulls products at each machine. Therefore, CONWIP is applicable to a wider variety of production environments and is inherently simpler than kanban (Spearman et al., 1990). Furthermore, it has demonstrated an excellent performance when compared to other types of pull systems (Hopp & Spearman, 1996; Spearman & Zazanis, 1992; Spearman et al., 1990). Nowadays, CONWIP has become the focus of many researchers, including the comparison between CONWIP and other production control systems (Bonvik, Couch, & Gershwin, 1997; Huang, Wang, & Ip, 1998; Muckstadt & Tayur, 1995a, 1995b; Roderick, Toland, & Rodriguez, 1994; Spearman, 1992; Spearman et al., 1990; Spearman & Zazanis, 1992), performance analysis (Ayhan & Wortman, 1999; Duenyas, Hopp, & Spearman, 1993; Duri, Frein, & Lee, 2000; Hopp & Spearman, 1991), generation of the order of backlog list (Golany, Dar-El, & Zeev, 1999; Herer & Masin, 1997; Lee & Chen, 1997; Luh, Zhou, & Tomastik, 2000), and determination of the card number (Golany et al., 1999; Hopp & Roof, 1998).

Little attention has yet been devoted to the assembly line. Duenyas (1994) started to study the problem of estimating the throughput of a cyclic assembly system with general processing time distributions. Closed queueing network approximation is used in this method. Ayhan and Wortman (1999) proposed an approximation for computing the throughput of a closed assembly-type queueing networks by using Markovian analysis. However, they only addressed single-loop CONWIP but not multi-loop CONWIP. Also, none of these researches considered different kinds of products as well as discrete distribution processing time and demands of products, which might be faced in actual production situations. The aim of this paper is to compare single-loop and multi-loop CONWIP with respect of service level and WIP for an actual lamp assembly line that produces different kinds of products with discrete distribution processing time and demands. A novel rule-based genetic algorithm (GA) approach is proposed for the multi-loop CONWIP system aimed at finding the optimum parameter setting where a rule is proposed in order to modify the card number of the loop in the evaluation process of genetic algorithm according to the throughput rate of corresponding loop and the demand rate. These characteristics reflect an actual production situation we met in a lamp company. This study was motivated by the request of a lamp producing company to improve the control on the cost of the assembly line while maintaining high service level performance.

In the following two sections, we describe the background of the lamp company and the control mechanism of both single-loop and multi-loop CONWIP of the production line. The model formulation and approaches for finding the optimum parameter configuration of both control systems are introduced in section "Parameters setting of the CONWIP systems." The comparison between the single-loop and multi-loop CONWIP system can be found in section "Comparison between the single-loop and multi-loop CONWIP system" while the final section contains the conclusions.

The background of the lamp company

The lamp company has manufactured miniature and subminiature lamps for about 40 years. The assembly line is a flexible one (Fig. 1). A glass tube is preheated and blown to form a glass bulb. A glass bead, a filament and a lead wire are joined to form a core. Then, an aluminum sheet is drawn out to form a cap-shaped base. Finally, the glass bulb, the core and the base are assembled to form a light bulb.

More than 100 kinds of products are produced by this assembly line. Some of them are: Bicycle Lamp, Energy Saving Lamp, Radio Panel Lamp, Toy Lamp, Pen Torch Lamp, Flashing Lamp, Pre-focusing Radio Panel Lamp, etc. The shape of the light bulb and the method employed classify these products. Three different shapes of bulbs—pear shaped, round or conical shaped, tube shaped—are produced by this manufacturer. Therefore, all products are grouped into three families. In the following part of this paper, we use the word "product" to substitute for the word "family." The processing times (Tables 1, 2, 3) and the demands per day (Fig. 2) of the products are taken directly from the statistical data of the company and assumed to be a discrete distribution. The basic raw materials used are

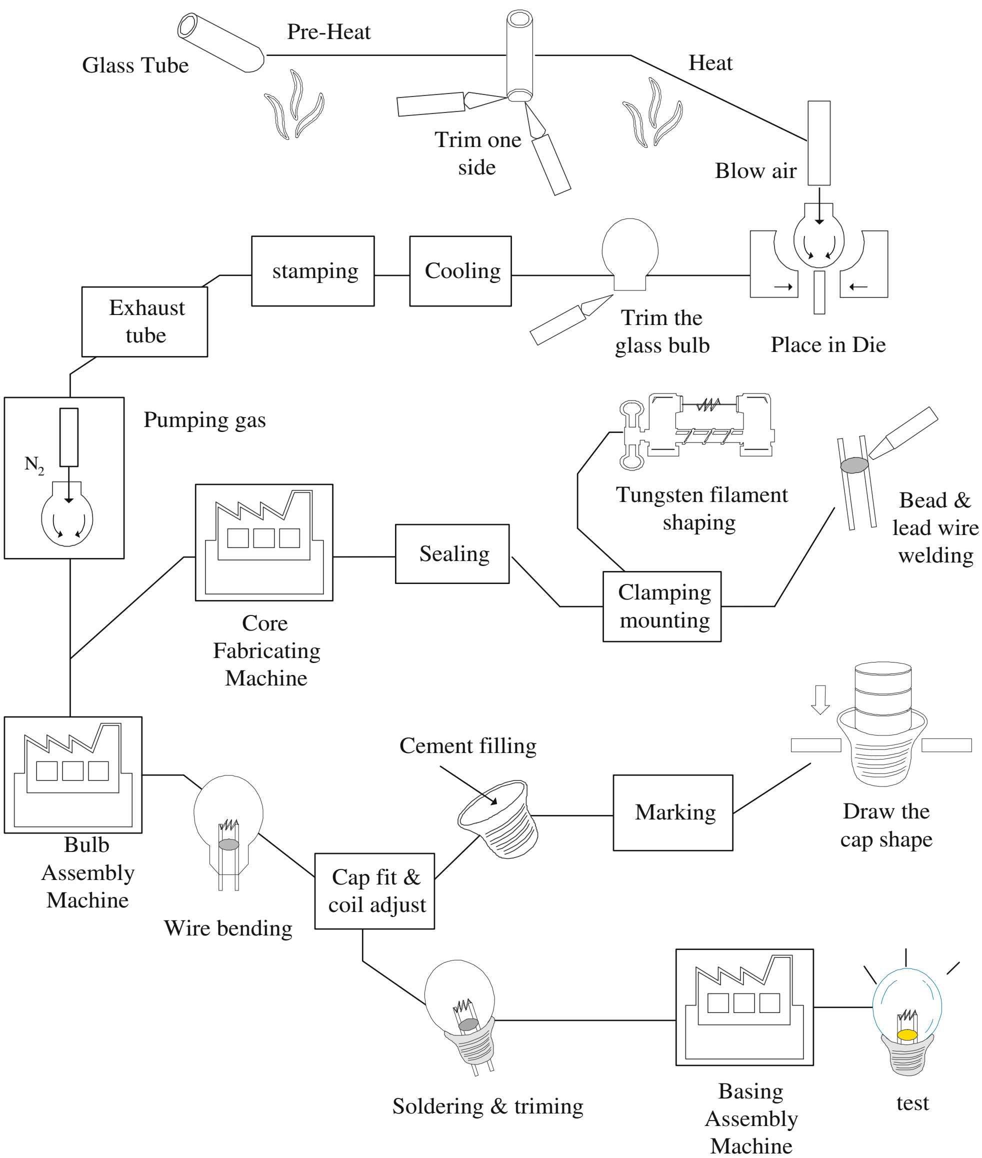


Fig. 1 The lamp assembly line

Boron lead wire, glass rods, glass tubing, electrical wiring and aluminum sheet. The assembly line works 24 h a day. The holding cost of the different products in the assembly line buffer is shown in Table 4, while the shortage cost of the products is shown in Table 5. The relationship between the machines number and the production machines is shown in Table 6.

The lamp company in an effort to improve the control on the cost of the assembly line while maintaining high service level performance considered employing the single-loop and multi-loop CONWIP systems.

The single-loop and multi-loop CONWIP systems

The single-loop and multi-loop CONWIP can be distinguished according to the time at which information about demand at the final buffer is forwarded, and the path that the information takes. In both systems, information about demand at the final buffer is forwarded by means of a card immediately after the demand has occurred. However, the path that the information will take differs from one system to another.

The single-loop CONWIP contains only a single loop. When a product in the final buffer of the production line is consumed, the card is detached from the product. The free card then returns to the initial machine of the system where it joins a queue of cards waiting for subsequent parts to be processed. The single-loop CONWIP for the lamp production line is shown in Fig. 3.

The multi-loop CONWIP contains several loops, each one corresponding to a production or assembly line. When a product in the final buffer of a loop is consumed

Table 1 Processing time and its probability of product 1

Probability (%)		Processing time (seconds)									
		31	32	33	34	35	36	37	38	39	40
Machine	1	20	25	30	25						
	2		30	15	30		25				
	3		10	25	25	15			25		
	4			30	30	15	25				
	5					10	25	25	15	25	
	6			20	25	30		25			
	7		30	15	30		25				
	8		10	25	25	15			25		
	9			30	30	15	25				
	10					10	25	25	15	25	
	11		25	30		25		20			
	12		30	15	30		25				
	13		10	25	25	15			25		
	14			30	30	15	25				
	15					10	25	25	15	25	
	16	20		30		27		23			
	17		34	15	26		25				
	18		10	25	29	15			21		
	19			30	30	22	18				
	20					10	26	30	15		19
	21		28	25	30		17				

Table 2 Processing time and its probability of product 2

Probability (%)		Processing time (seconds)									
		31	32	33	34	35	36	37	38	39	40
Machine	1		10	24	26	15			25		
	2			30	24	21	25				
	3					10	25	25	22	18	
	4		25	29		25		21			
	5		30	21	24		25				
	6		10	25	25	14			26		
	7			30	22	23	25				
	8					10	25	27	15	23	
	9	20	25	30		25					
	10		26	17	28		29				
	11		25	30		25		20			
	12		25	30	23		22				
	13		22	23	30		25				
	14		10	25	25	14			26		
	15			20	30	29	21				
	16					10	25	19	21	25	
	17	21	25			25		29			
	18		30	19	26		25				
	19		10	27	23	15			25		
	20			30	28	17	25				
	21					10	23	21	17	29	

by its downstream machine or demand, the card is detached from the product. The free card then returns to the initial machine of the loop where it joins a queue of cards waiting for subsequent parts to be processed. The multi-loop CONWIP for the lamp production line is shown in Fig. 4.

As the comparison of the two CONWIP systems must take place while the two systems are running on optimal parameters setting, next section presents the methods employed in setting those parameters.

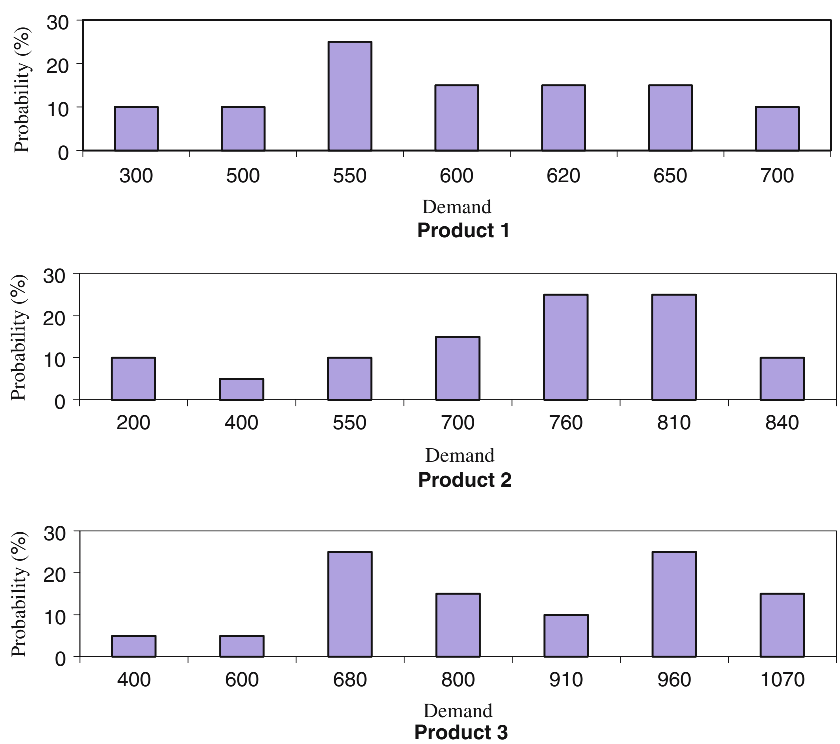
Parameters setting of the CONWIP systems

The main parameters for the single-loop and the multi-loop CONWIP systems are the cards. For a

Table 3 Processing time and its probability of product 3

Probability (%)		Processing time (seconds)									
		31	32	33	34	35	36	37	38	39	40
Machine	1					10	27	28	12	23	
	2	22	25	28		25					
	3		26	19	29		26				
	4		10	23	28	17			22		
	5			30	22	23	25				
	6					10	28	22	18	22	
	7		25	23		25	27				
	8		27	18	27		28				
	9			28		25		22			25
	10		25	27	25		23				
	11		22	26		28		24			
	12		23	22	27		28				
	13		10	25	28	15			27		
	14			30	30	15	25				
	15		16	25	25	15			19		
	16			27	29	18	26				
	17	28	23	22		27					
	18		27	18	30		25				
	19		16	25	19	15			25		
	20			23	29	22	26				
	21					17	25	18	15	25	

Fig. 2 The probability distribution of the different products



quantitative comparison between them, approaches that enable the parameters setting of the systems with respect to the goal of the lamp company are needed. An optimization model and methods are proposed in this section.

Optimization model

The aim of the production control of the lamp company is to ensure the service level while minimizing the total

Table 4 The holding cost of different workcenters

Workcenter	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Holding cost	5	5	6	6	6	7	8	8	3	3	4	4	15	15	4	4	4	20	20	20	20

Table 5 The shortage cost of different products

Product	1	2	3
Shortage cost	10	16	8

Table 6 The workcenters and their numbers

Number	Workcenter
1	Pre-heat
2	Trim one side
3	Heat
4	Blow air and place in Die
5	Trim the glass bulb
6	Cooling
7	Stamping & exhaust tube
8	Pumping gas
9	Bead & lead wire welding
10	Clamping mounting
11	Sealing
12	Core fabricating machine
13	Bulb assembly machine
14	Wire bending
15	Draw the cap shape
16	Marking
17	Cement filling
18	Cap fit & coil adjust
19	Soldering & trimming
20	Basing assembly machine
21	Test

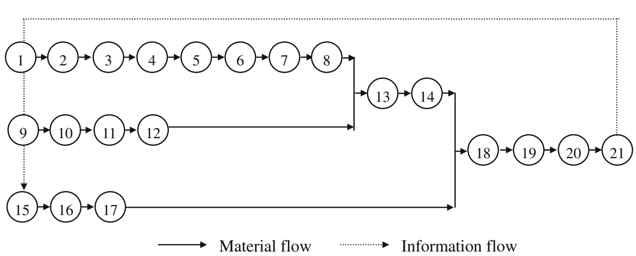


Fig. 3 The single-loop CONWIP for the lamp assembly line

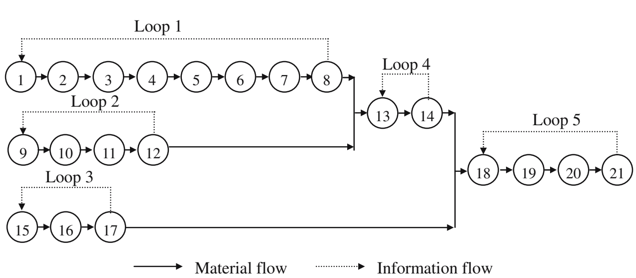


Fig. 4 The multi-loop CONWIP for the lamp assembly line

cost of the production process. This is formulated as follows:

$$\min \mathrm{TC}(K) \quad (1)$$

$$\text{s.t.} \quad \mathrm{SP}(K) \leq b \quad (2)$$

$$k_l \geq 1 \quad \text{with } l \text{ an integer} \quad l = 1, 2, \ldots, L \quad (3)$$

where $K = (k_1, k_2, \ldots, k_L)$ is the cards distribution, $k_l(l = 1, 2, \ldots, L)$ is the card number in the lth loop of the CONWIP system. L is the number of loop, TC(K) is the total cost of the production process, SP(K) is the shortage probability of the production process, b is the up bound of the shortage probability.

It can be observed that TC(K) and SP(K) are the performance measures of the production line under the setting of cards in the control systems. Therefore, approaches, which enable the modeling of the assembly line with respect to the different control systems and parameter setting, are needed. Although there are some analytical methods proposed for the CONWIP (Bonvik et al., 1997; Bonvik, Dallery, & Gershwin, 2000; Di Mascolo, Frein, & Dalley, 1996; Duenyas 1994; Duenyas & Hopp, 1992a, 1992b), they mainly focus on the single-loop or the multi-loop CONWIP in serial. Therefore, simulation is used here. By simulation, the two performance measures are calculated as follows:

(1) The total cost, TC(K), is composed of the inventory holding cost and the shortage cost of final machine n. That is:

$$\mathrm{TC} = \frac{1}{T}\sum_{t=1}^{T}\left[\sum_{j=1}^{n}\left(\mathrm{IC}_j * \sum_{i=1}^{m}\max\left\{0, I_{ij}(t)\right\}\right) + \sum_{i=1}^{m}\left(\mathrm{SC}_i * \max\left\{0, -I_{in}(t)\right\}\right)\right] \quad (4)$$

where n is the number of machines, m is the number of products, IC_j denotes the unit holding cost of machine j, SC_i denotes the shortage cost of product i, T is the statistic time, $I_{ij}(t)$ is the inventory of product i at machine j in period t. As the cost of production is independent of the strategy, it is not considered here. The inventory of finished product $I_{in}(t)$ can be negative which means that product i is in short supply.

(2) Shortage probability, SP(K), is measured by the average shortage probability of the demands per unit time.

$$\mathrm{SP} = \frac{1}{T}\sum_{t=1}^{T}\sum_{i=1}^{m}\frac{\max\{0, -I_{in}(t)\}}{D_i(t)} \tag{5}$$

where $D_i(t)$ is the demand of product i in period t.

Parameter setting of the single-loop CONWIP system

For the single-loop CONWIP, the optimum number of cards is determined by enumerating different card number and reading curves of card numbers versus work in process WIP(K) and SP(K). WIP(K) can also be obtained by simulation:

$$\mathrm{WIP} = \frac{1}{T}\sum_{t=1}^{T}\mathrm{WIP}_t \tag{6}$$

On the curve, at the point where SP(K) reaches the up bound of the short probability, the card number is the optimal one. As when the card number is over this point, the SP reaches the up bound of the short probability and any additional card only results in higher WIP(K).

Parameters setting of the multi-loop CONWIP system

For the multi-loop CONWIP, the problem is a combination one and has large search space. The heuristic GA approach is suitable for this kind of problems. Ettl and Schwehm (1994) have presented a GA for optimizing the network partition and kanban allocation. However, their method is for the sequence of workstation. So, a novel rule-based GA approach is brought forth specifically for our problem.

In designing a GA, it is necessary to specify the chromosome description, a fitness function, the initial generation generating method, some genetic operators, a selection strategy, and an ending criterion (Holland, 1975; Michalewicz, 1996; Ostermark, 1999). Considering the characteristics of our problem, a rule is proposed in order to modify the card number of the loops in the evaluation process of genetic algorithm based on the knowledge of production line and demand rate.

The chromosome description of the GA

For our GA, the natural number string is selected as the gene description. Let $K = [k_1, k_2, \ldots, k_L]$, where k_l is an integer between 1 and $k_l^u (l = 1, 2, \ldots, L)$. k_l^u is the up bound of the card number of the loop l. This stands for the card number of k_l used for loop l. Thus, $K = [k_1, k_2, \ldots, k_L]$ refers to a card distribution of the multi-loop CONWIP and represents a chromosome or an individual in the GA. For example, a natural number string of 5 bits:

$$\begin{bmatrix}5 & 2 & 6 & 5 & 3\end{bmatrix}$$

is a card distribution or a chromosome of a multi-loop CONWIP with 5 loops. This means 5 cards for loop 1, 2 cards for loop 2, and so on.

The up bound of the card number of loop l is determined by setting the card number of each loop as the same value and enumerating different values. For each value, SP(k) is recorded. When SP(k) reaches the predetermined short probability, the corresponding value is recorded. Then the up bound of the card number of each loop is set to two times this value.

Fitness function

For the previous problem, the objective is a minimum one. So it is transferred to the fitness function as follows:

$$F = \mathrm{TC}_{\max}(K) - \mathrm{TC}(K) + a \tag{7}$$

where $\mathrm{TC}_{\max}(K)$ is the maximum of TC(K) in the current generation; a is the adjustment coefficient

The initial population and ending criterion of the GA

In order to generate the initial generation, the following INI procedure is introduced for each chromosome:

Procedure INI:

Step 1: $l = 0$, go to Step 2;
Step 2: $l = l + 1$, if $l > L$, record the chromosome and stop; otherwise generate a random variable r within the interval of $[0, 1]$, let $k = 0$, go to Step 3;
Step 3: $k = k + 1$, go to Step 4;
Step 4: if $k/k_l^u \geq r$, then let $k_l = k$ go to Step 2; otherwise, go to step 3;

From the INI procedure, we can see that the initial generation is a legal one, as the partners are selected within the up bound of cards.

The maximum generation is used as an ending criterion.

The selection in the GA

Among many selection techniques, the "roulette wheel approach," one of the fitness-proportional selections, (Michalewicz, 1996) is adopted here.

Moreover, "elitist strategy" (Goldberg, 1989), which preserves the best chromosome in the next generation and overcomes the stochastic errors of sampling, is used too. In the elitist selection, if the best individual in the previous generation is not reproduced in the new generation, it will remove one individual randomly from the new population and add the best one of the previous population onto the new population.

The genetic operators in the GA

The one-cut-point crossover and the altering mutation are used as the genetic operators in the GA. The first operator is used to exchange two different sections of the two selected parents to produce two children; and the second operator is used to randomly select a bit and alter its gene value within the up bound (Gen & Cheng, 1996). It is evident that all chromosomes can remain legal when the genetic operations of the above crossover and mutation are implemented. However, they may be infeasible. Hence, the adjusting rule for the infeasible chromosomes is proposed in section "The adjusting rule for the infeasible chromosomes."

The adjusting rule for the infeasible chromosomes

In the evaluation process of genetic algorithm, as the solution may not satisfy the constraint, an adjustment is needed for this kind of chromosome. The adjusting rule is

Rule: If $\mathrm{SP}(K) > b$, then

$$k'_l = k_l + \left(k_l^u - k_l\right) * \left(\frac{\mathrm{dd} - \theta_l}{\mathrm{dd}}\right) \tag{8}$$

where k'_l is the card number of loop l after adjusting, θ_l is the throughput rate of loop l, dd is the demand rate:

$$\mathrm{dd} = \sum_{i=1}^{m} \sum_{w \in D_i} w^* p_i\,(w) \tag{9}$$

where $D_i = \{D_{i1}, D_{i2}, \ldots, D_{ih}\}$ and is the set of possible demands of product i, $p_i\,(w)$ is the probability that the demand of product i is equal to w.

It can be seen that the card number of the loops is modified in the evaluation process of genetic algorithm based on the knowledge of production lines and demand rates in the rule.

The steps for the GA

The step-by-step procedure for the GA is:

Step 1: Specify the parameters: population sizes NP, the maximum number of generations NG, crossover probability p_c and mutation probability p_m.

Step 2: Generate an initial population with NP chromosomes by Procedure INI: $K(q) = (k_1(q), k_2(q), \ldots, k_L(q))$, $q = 1, 2, \ldots$, NP. Set the generation index $u = 0$, initial optimal solution $K^* = K_v$, where $K_v = [1, 1 \ldots 1]$ and the optimal fitness function value $F^* = 0$.

Step 3: Let $u = u+1$. If $u > \mathrm{NG}$, go to step 8, otherwise, implement Steps 4 to 7.

Step 4: For chromosome $K(q), q = 1, 2, \ldots$, NP, implement the following three sub steps:

- Substep 4.1: Call the simulation procedure for calculating the statistical values and return the values of $\mathrm{TC}(k_1\,(q), k_2\,(q)\,, \ldots, k_L\,(q))$ and $\mathrm{SP}(k_1\,(q), k_2\,(q)\,, \ldots, k_L\,(q))$.
- Substep 4.2: Call the rule to adjust the infeasible chromosome, calculate and return the fitness function value $F\,(q)$.
- Substep 4.3: Find $F_{\min} = \min\{F\,(q)\,, q = 1, 2, \ldots, \mathrm{NP}\}$ and $F_{\max} = \max\{F\,(q)\,, q = 1, 2, \ldots, \mathrm{NP}\}$. $q^* = \arg\{F\,(q) = F_{\max}\}$ are the indices of achieving $F_{\max}$ and the associate card distribution.

Step 5: If $F_{\max} > F^*$, let $F^* = F_{\max}$ and $K^* = K\,(q^*)$

Step 6: For $q = 1, 2, \cdots NP$, calculate the selection probability $pp_q = F\,(q)\,/q \sum_{q=1}^{\mathrm{NP}} F\,(q)$.

Step 7: To generate a new population, use the selection probabilities $pp_q, q = 1, 2, \ldots, \mathrm{NP}$, to select $\mathrm{NP}_c = p_c \times \mathrm{NP}$ chromosomes for one-point crossover, $\mathrm{NP}_m = p_m \times \mathrm{NP}$ chromosomes for altering mutation. Go to Step 3.

Step 8: Output F^* and K^* as the optimal solution.

Note that Step 1 initializes the algorithm. Step 2 is used to generate the initial population of the GA. Steps 3–7 are the backbone of the GA. Step 3 checks the stop criterion. Step 4 is the nuclear step of the algorithm. It firstly calls the simulation procedure to calculate the statistical values for a given chromosome in Substep 4.1 and then calls the rule to adjust the infeasible chromosome and calculate the fitness function values in Substep 4.2.

Finally, it obtains the minimum and maximum values of this generation. Step 5 updates the optimum. Step 6 calculates the selection probability. Step 7 is used to calculate the genetic operations. The final step, Step 8, is used to determine the solution.

Comparison between the single-loop and multi-loop CONWIP system

In this section, the comparison between the single-loop and multi-loop CONWIP production control systems for the lamp assembly line is summarized. The up bound of the shortage probability b is set to be 0.

To optimize the number of cards in the single-loop CONWIP system, various card numbers are enumerated in order to obtain the resultant WIP and SP for corresponding card number. The curves of card numbers versus WIP and SP were plotted as shown in Fig. 5. It is obviously shown that when the card number increases, the WIP also increases while the SP decreases. However, when the card number is over 37, the SP reaches zero and any additional card only results in higher WIP. Thus, 37 is used as the rational number of cards for the CONWIP control system.

The optimum card numbers and allocation in the multi-loop CONWIP system are obtained by using the rule-based GA approach introduced in section "Parameters setting of the multi-loop CONWIP system." The parameters for the rule-based GA are set as follows: population size NP = 50; crossover probability $p_c = 0.5$; mutation probability $p_m = 0.04$; maximum number of generation NG = 100. Under these parameters for rule-based GA, the "Best Rate" of the algorithm is 100% and the rational card numbers and allocations are obtained (see Table 7). Here, the "Best" stand for the best one of the objective values achieved in 100 runs. The "Best Rate" is the rate that reaches the best value.

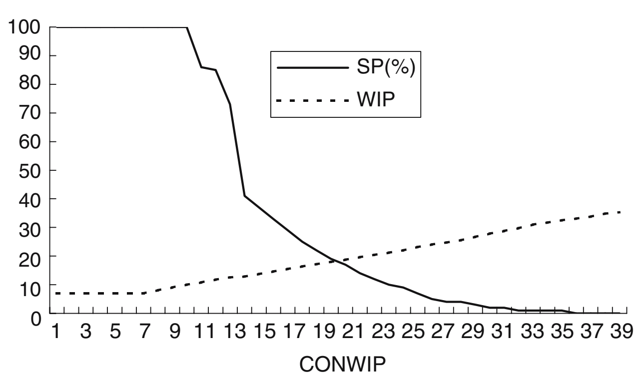


Fig. 5 Determine the card numbers in single-loop CONWIP

Table 7 Card numbers for the multi-loop CONWIP system

Loop	1	2	3	4	5
Card number	5	2	9	1	5

Table 8 The comparison of the single-loop and multi-loop CONWIP system for the lamp assembly line

Control system	TC	SP (%)	WIP
Single-loop CONWIP	135.29	0	33.07
Multi-loop CONWIP	152.15	0	34.71

Then we compare different control strategies under the rational card number by simulation. The three performance measures TC, SP, and WIP are recorded for each system. Table 8 demonstrates that the single-loop CONWIP system has a lower TC and WIP, when both systems reach the zero SP. Also, the single-loop CONWIP system is inherently simpler to implement and control. It is an effective system for the lamp assembly production line.

Conclusion

In this paper we compared the single and multi-loop CONWIP production control systems for an actual lamp assembly production line that produces a series of products with discrete distribution processing time and demand, a situation that differs from that of other current researches. In order to accomplish this, a model was formulated with respect to total cost and service level. A novel rule-based GA approach was proposed for the multi-loop CONWIP system in order to find the optimum parameter setting.

The model presented here can be easily extended to other production lines with the same control objectives and the rule-based GA approach is potential for this kind of problem. The only thing that needs to change is the analysis model of the production line by which the parameters in the objectives and constraints are obtained.

In conclusion, the results have clearly illustrated that the single-loop CONWIP offers better performances than the multi-loop CONWIP for the lamp assembly production line with respect to total cost and service level. The total cost is lower and the demand service level is guaranteed in the single-loop CONWIP. Therefore, the single-loop CONWIP is a more effective production control system for the lamp assembly production line.

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