The Optimal Crane Scheduling for Chemical Polishing Process Based on Expert System

Chi-Yen Shen, Shuming T. Wang, Kaiqi Zhou, Hanlin Shen, and Rey-Chue Hwang

***Abstract*—It is well known that the manufacturing process of many industrial products requires the crane lifting and delivering. The use of crane can not only reduce the cost of manual handling, but also increase the production's capacity. Thus, how to design an accurate, efficient and optimal crane scheduling becomes a very important issue in the industrial manufacturing process, especially to the electronic industry. This paper presents an optimal crane scheduling and control for the multiple manufacturing processes of electronic surface treatment based on the entire plant design. The expert system with "time-axis" method is used to find the minimum number of cranes needed for the entire plant design. The surface treatment of electronic industry is used as the example for the whole design process. The result shows that the optimal crane scheduling developed can not only have the optimal cranes' control, but also fit the requirement of minimum cycling time of each manufacturing process.**

***Index Terms*—Crane, optimal scheduling and control, expert system, time-axis.**

I. Introduction

Due to the rapid evolution of science and technology, time control of the manufacture has become an important work for the competitiveness of industrial companies. Through the precise manufacturing time control, the daily production of the product could be easily estimated and controlled. In addition, the company could also make an accurate planning for the productive capacity expansion in the future and have the maintenance scheduling for the productive equipment. Thus, the automation of production is becoming more and more important to the industry. It is not only related to the cost of company's business running, but also related to the competitiveness of company's product. In many industries, the product's delivering mainly relies on the automatic crane. The auto-crane indeed could reduce the labor cost and increase the production of the product.

In past two decades, the scheduling and control of automatic crane had been studied in many articles. However, due to the requirements and the crane operating conditions for various industries are different, it is quite difficult to have a regular rule for the setting and planning of crane's operation. For instance, Armstrong, etc. had investigated the research about the crane's number needed for an electroplating process [1]. Occena and Lei, etc. did the research about the minimum cycling time of crane operation needed [2]-[15]. Since the number of crane and crane's operation are also related to the deployment of the crane and its working area, the research about the overlapping and non-overlapping of working area were also investigated in the literatures. [16]-[20]. In fact, in many applications, most of the crane's deployments and schedules are based on the expert's experience. Thus, the knowledge based intelligent technique had been employed into the study of crane's operation and scheduling [21]-[28].

Currently, the electronic industry plays a very important role to the economic growth for many countries. In the manufacturing process of many electronic products, the surface treatment is an indispensable and necessary step. Generally, the surface treatment consists of several steps including oxidation, etching, pickling, plating, staining and polishing. In the steps of etching and pickling, the part of circuit board must be handled by the chemical treatments of acid and alkali. However, the whole working environment of chemical treatment is bad and it is not suitable for the working people to have the prolonged exposure and contact. The gas in the air will also harm the health of human's body. Thus, the unmanned and automatic crane becomes a necessary and indispensable equipment of the industry.

In general, the number of chemical tank setting and the crane control in the process of surface treatment are impossible to be designed for one product only. The type of surface treatment must depend on the product's characters. Different types of product have the different surface treatments. The treatment time and the number of crane needed are different for each product. The control procedure for each crane is different either. Thus, for many different products, how to use the minimum number of crane to do the most efficient manufacturing control is the most important demand and expectation of the company and it is the aim of this research. Under an optimal crane scheduling and control, the company could accurately estimate the possible total amount of daily products and then make a good business management.

II. Surface Treatment

The surface treatment process has been used in many metal and electronic industries. In which, there are many various surface treatments. Table I lists the example of the chemical polishing, which has five different processes, including

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oxidation, coloring, staining-1, staining-2 and staining-3. In this table, P stands "pass". It means the necessary step in the polishing process. The illustrative diagram for the surface treatment process is shown in Fig. 1.

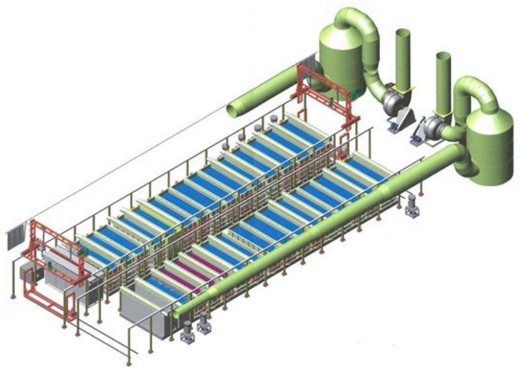

Fig. 1. The illustrative diagram for the surface treatment process. (Provided by Kamar Tech.)

TABLE I: THE PROCESS OF CHEMICAL POLISHING

Cycling time : 4.5 min./per tank Crane: 30 m/min. (Fastest pull-up/lay-down speed), 30 m/min. (Fastest moving speed), 2.5 m : Pull-up/lay-down distance, 1~1.5 m : The distance between front and rear tanks *The time of washing is adjustable. *The rectifier's voltage, current and time can be set.									
					Process of chemical polishing				
Steps	Process	Trough No.	Control Time	Operation Time	Oxidation	Coloring	Staining-1	Staining-2	Staining -3
	Adjust		Min.	Min.					
49.	Feeding crane	5			P	P	P	P	P
1.	Degreasing	1	2~3	3	P	P	P	P	P
2.	Washing	1			P	P	P	P	P
3.	Alkaline corrosion	1	3~4	3					
3-1.		1	3~4	3					
4.	Washing	1							
5.	Washing	1							
6.	Chemical polishing	1	2~4	4	P	P	P	P	P
7.	Washing	1			P	P	P	P	P
8.	Washing	1			P	P	P	P	P
9.	Neutralization	1	2~4	3	P	P	P	P	P
10.	Spray washing	1			P	P	P	P	P
11.	Washing	1			P	P	P	P	P
11-1.	Washing	1							
12.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P
13.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P
14.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P
15.	Washing	1			P	P	P	P	P
16.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P
17.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P

TABLE 1 CONTINUED

18.	Anodizing treatment (ON/OFF)	1	20~25	23	P	P	P	P	P
19.	Hard anodizing treatment (ON/OFF)	1	45~90	80					
20.	Washing	1			P	P	P	P	P
21.	Washing	3			P	P	P	P	P
21-1	Shifting crane (front)				P	P	P	P	P
21-2	Shifting Crane (back)								
22.	Washing	3			P	P	P	P	P
23.	Coloring (ON/OFF)	1	1~8	3		P			
24.	Washing	1				P			
25.	Surface adjustment	1	1~3	1			P	P	P
26.	Washing	1					P	P	P
27.	Washing	1					P	P	P
28.	Staining-1	1					P		
29.	Washing	1					P		
30.	Staining-2	1	1~4	4				P	
31.	Washing	1						P	
32.	Staining-3	1	1~4	4					P
33.	Washing	1							P
34.	Sealing	1	1~3	3	P	P	P	P	P
35.	Heat Sealing	1	4~6	5	P	P	P	P	P
35-1.		1	4~6	5					
36.	Hot watering	1	1	1	P	P	P	P	P
37.	Unloading	1			P	P	P	P	P
38.	Unloading	1			P	P	P	P	P
39.	Unloading	1			P	P	P	P	P
40.	Unloading	1			P	P	P	P	P

The purpose of this research is how to make an optimal scheduling of tanks number needed and crane control according to the different processes and products required. Thus, the following questions are what we have to focus on.

1. The arrangement of each crane for the product's delivery.
2. The order of each crane's movement.
3. The time interval between cranes' operation for avoiding the collision.
4. Two cranes are unable to cross with each other.
5. All cranes' operation must fit the cycling time set for the process.

III. Expert System with Time-axis Design

A. The Number of Tanks

In this research, the multiple manufacturing processes based on the entire plant design is mainly considered. The surface treatment plant must be suitable for many different processes according to the product's characters. Thus, the number of tanks needed should be considered firstly. It is known that the cycling time plays a key role in the whole manufacturing process. The cycling time could let company have an accurate estimation for the daily amount of product possibly manufactured.

Here, we use the chemical polishing process as an example to find the suitable number of tanks for each different process. In Table 1; there are five different treatment processes, including oxidation, coloring, staining-1, staining-2 and staining-3. In these five different treatments, staining-1, staining-2 and staining-3 have the most treatment steps. Therefore, the number of tanks designed must meet the cycling time for these three treatments.

We denote

T: The cycling time,

T_1 : The total moving time of each crane in the process,

T_2 : The total time needed for crane's pull-up and lay-down in the process,

T_{3j}: The operation time of j^{th} step in the treatment process,

N_j : The number of processing tanks needed for j^{th} treatment,

$j=1,2,\ldots$

The minimum number of j^{th} processing tanks needed can be inferred by the following rules.

Rule 1: IF $T_{3j}+T_1+T_2 < T$, THEN $N_j = 1$,

Rule 2: IF $T_{3j}+T_1+T_2 > mT$, THEN $N_j = m+1$, m is an integer,

Rule 3: The number of watering tanks between two consecutive processing depends on the waiting time of the rear treatment's processing time.

B. The Number of Cranes

In Table I, it can be found that the whole process of various surface treatments is sequential. All steps of treatment must be operated in order. Thus, no path control for the crane's scheduling needs to be considered in this study. Only the minimum number of cranes needed will be scheduled and considered. In Fig. 1, the whole plant of treatment process is designed as "U" shape. Thus, two analyses will be scheduled and designed. The first analysis focuses on the left-hand side of plant, i.e., step 1 to step 21 in TABLE I. The second analysis focuses on the right-hand side of plant, i.e., step 22 to step 37. Due to the whole process is operated sequentially, the method of "time-axis" will be taken to find the minimum number of cranes.

Here, let ①,②,③, …denote the cargo's numbers, 1, 2, 3,… are tank's numbers, and A, B, C, …stand the crane's numbers. As previous description, the whole process of surface treatment is a kind of sequential control process, therefore, an analysis method called "time-axis" is developed in our study. In the analysis of crane scheduling and cargo shifting design, the time needed for cargo's pull-up and lay-down will be ignored temporarily. Only the scheduling of crane movement and cargo shifting are considered. Besides, the whole plant will be divided into two parts, i.e., left-hand side and right-hand side for planning the minimum number of cranes needed. The plant is designed to have the full function for doing multiple surface treatments, thus the staining process of chemical polishing treatment is used for the plant's design because it has more complicated processing steps. TABLE II lists the conditions of work and shift of cargos on the plant's left-hand side based on time-axis design. TABLE III lists the condition of work and shift of cargos on the plant's right-hand side.

TABLE II: THE ANALYSIS OF WORK AND SHIFT OF CARGOS ON THE PLANT'S LEFT-HAND SIDE

Chemical Polishing Process															
min.	Crane scheduling and cargo shifting (Left-hand side of plant)														
0-3	①-1 (A)														
3-6	①-6 (B)	②-1 (A)													
6-7	①-6	②-5 (B)	③-1 (A)												
7-9	①-9 (C)	②-6(B)	③-1												
9-10	①-9	②-6	③-5(B)	④-1(A)											
10-11	①-12(C)	②-6	③-5	④-1											
11-12	①-12	②-9 (C)	③-6 (B)	④-1											
12-14	①-12	②-9	③-6	④-5(B)	⑤-1(A)										
14-15	①-12	②-13(C)	③-6	④-5	⑤-1										
15-16	①-12	②-13	③-9(C)	④-6(B)	⑤-5(A)										
16-18	①-12	②-13	③-9	④-6	⑤-5	⑥-1(A)									
18-19	①-12	②-13	③-14(C)	④-6	⑤-5	⑥-1									
19-20	①-12	②-13	③-14	④-9(C)	⑤-6(B)	⑥-4(A)									
20-22	①-12	②-13	③-14	④-9	⑤-6	⑥-4	⑦-1(A)								
22-23	①-12	②-13	③-14	④-16(C)	⑤-6	⑥-4	⑦-1								
23-24	①-12	②-13	③-14	④-16	⑤-9(C)	⑥-6(B)	⑦-4(A)								
24-26	①-12	②-13	③-14	④-16	⑤-9	⑥-6	⑦-4	⑧-1(A)							
26-27	①-12	②-13	③-14	④-16	⑤-17(C)	⑥-6	⑦-4	⑧-1							
27-28	①-12	②-13	③-14	④-16	⑤-17	⑥-9(C)	⑦-6(B)	⑧-4(A)							
28-30	①-12	②-13	③-14	④-16	⑤-17	⑥-9	⑦-6	⑧-4	⑨-1(A)						
30-31	①-12	②-13	③-14	④-16	⑤-17	⑥-18(C)	⑦-6	⑧-4	⑨-1						
31-32	①-12	②-13	③-14	④-16	⑤-17	⑥-18	⑦-9(C)	⑧-6(B)	⑨-4(A)						
32-33	①-12	②-13	③-14	④-16	⑤-17	⑥-18	⑦-9	⑧-6	⑨-4	⑩-1(A)					
33-34	Car. Shift (C)	②-13	③-14	④-16	⑤-17	⑥-18	⑦-9	⑧-6	⑨-4	⑩-1					
34-35		②-13	③-14	④-16	⑤-17	⑥-18	⑦-12(C)	⑧-6	⑨-4	⑩-1					
35-36		②-13	③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-9(C)	⑨-6(B)	⑩-4(A)					
36-37		②-13	③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-9	⑨-6	⑩-4	⑪-1(A)				
37-38		Car. Shift (C)	③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-9	⑨-6	⑩-4	⑪-1				
38-39			③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-13(C)	⑨-6	⑩-4	⑪-1				
39-40			③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-9(C)	⑩-6(B)	⑪-4(A)				
40-41			③-14	④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-9	⑩-6	⑪-4	⑫-1(A)			
41-42			Car. Shift (C)	④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-9	⑩-6	⑪-4	⑫-1			
42-43				④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-14(C)	⑩-6	⑪-4	⑫-1			
43-44				④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-9(C)	⑪-6(B)	⑫-4(A)			
44-45				④-16	⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-9	⑪-6	⑫-4	⑬-1(A)		
45-46				Car. Shift (C)	⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-9	⑪-6	⑫-4	⑬-1		
46-47					⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-16(C)	⑪-6	⑫-4	⑬-1		
47-48					⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-9(C)	⑫-6(B)	⑬-4(A)		
48-49					⑤-17	⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-9	⑫-6	⑬-4	⑭-1(A)	
49-50					Car. Shift (C)	⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-17(C)	⑫-6	⑬-4	⑭-1	
50-51						⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-17	⑫-6	⑬-4	⑭-1	
51-52						⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-17	⑫-9(C)	⑬-6(B)	⑭-4(A)	
52-53						⑥-18	⑦-12	⑧-13	⑨-14	⑩-16	⑪-17	⑫-9	⑬-6	⑭-4	⑮-1(A)
53-54						Car. Shift (C)	⑦-12	⑧-13	⑨-14	⑩-16	⑪-17	⑫-9	⑬-6	⑭-4	⑮-1

TABLE III: THE ANALYSIS OF WORK AND SHIFT OF CARGOS ON THE PLANT'S RIGHT-HAND SIDE

Chemical Polishing Process									
min.	**Crane scheduling and cargo shifting (Right-hand side of plant)**								
33-34	①-25(D)								
34-37	①-28(D)								
37-38	①-28	②-25(D)							
38-41	①-34(E)	②-28(D)							
41-42	①-35(E)	②-28	③-25(D)						
42-45	①-35	②-34 (E)	③-28(D)						
45-46	①-35	②-35-1(E)	③-28	④-25(D)					
46-47	①-36(F)	②-35-1	③-34(F)	④-28(D)					
47-49	Unload car. (F)	②-35-1	③-34	④-28					
49-50		②-35-1	③-35(F)	④-28	⑤-25(D)				
50-51		②-36 (F)	③-35	④-34 (D)	⑤-28(D)				
51-53		Unload car. (F)	③-35	④-34	⑤-28				
53-54			③-35	④-35-1(E)	⑤-28	⑥-25(D)			
54-55			③-36(F)	④-35-1	⑤-34(E)	⑥-28(D)			
55-57			Unload car. (F)	④-35-1	⑤-34	⑥-28			
57-58				④-35-1	⑤-35(E)	⑥-28	⑦-25(D)		
58-59				④-36(F)	⑤-35	⑥-34(E)	⑦-28(D)		
59-61				Unload car. (F)	⑤-35	⑥-34	⑦-28		
61-62					⑤-35	⑥-35-1(E)	⑦-28	⑧-25(D)	
62-63					⑤-36(F)	⑥-35-1	⑦-34(E)	⑧-28(D)	
63-65					Unload car. (F)	⑥-35-1	⑦-34	⑧-28	
65-66						⑥-35-1	⑦-35(E)	⑧-28	⑨ -25(D)
66-67						⑥-36(F)	⑦-35	⑧-34(E)	⑨ -28(D)
67-69						Unload car. (F)	⑦-35	⑧-34	⑨-28

From TABLE II and TABLE III results shown, under the request of cycling time, at least three cranes are needed if the whole process of treatment on the left-hand side could be operated smoothly. Similarly, at least three cranes are also needed if the whole process of treatment on the right-hand side could be operated smoothly either. According to the analyses, it can be found that the minimum number of cranes needed for doing the whole process of chemical polishing shown in TABLE I is six.

IV. CONCLUSION

In this research, an optimal crane scheduling and control for the multiple manufacturing processes of electronic surface treatment based on the entire plant design is developed. Such an optimal crane scheduling not only could have the optimal design of the crane control, but also could fit the requirement of minimum cycling time of each manufacturing process. The number of tanks needed for various processes could also be studied and identified. In our study, the method of "time-axis" is proposed for the design of minimum number of cranes and the expert inference rules are used to decide the number of tanks needed. From the research results, the method proposed indeed could have the optimal solution for the crane scheduling and control based on the entire plant design. It is concluded that the method we developed do have the potential for the commercial using.

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