MATH6119

Case Study - Information Sheet

Printed Circuit Board Assembly

1 Background

Philips Electronics produces printed circuit boards (PCBs) for use in consumer electronics (audio and video equipment, personal computers) and in professional industries (telecommunication systems, aircraft navigation, medical equipment). Special machines are used to mount components onto the boards. The problem to be considered is one of production preparation: for each type of PCB, it is necessary to specify the way in which the components should be mounted.

This case study is based on work carried out for one of the major product divisions of Philips. Although some simplifications have been made to the original problem, this does not affect the main characteristics of the decisions that have to be taken.

2 Assembly of PCBs

PCBs are assembled by automated machines. A conveyor feeds each board into the first machine, and transports the boards between machines. Thus, a board passes into the first machine where a selected subset of components are mounted, then passes to the second machine where further component mountings are performed, and so on, until the last machine completes the PCB. The conveyor moves all partially assembled boards to the next machine simultaneously. Thus, the conveyor only moves when every machine has completed its work on a board. For example, if there are eleven components to be mounted by three machines, A, B and C, where machine A mounts components 1, 2, 3 and 4 and takes 8 seconds, machine B mounts components 5, 6 and 7 and takes 12 seconds, and machine C mounts components 8, 9, 10 and 11 and takes 9 seconds, then the conveyor moves the boards every 12 seconds. Consequently, the first PCB is completed after 36 seconds, and a further PCB is completed at the end of each subsequent 12-second interval.

The components to be mounted on the board are contained in feeders on one side of the conveyor. The components are classified into different types, and each feeder only contains components of a single type.

Each machine has a robot arm with three heads. The heads are each fitted with a piece of equipment which can pick components from the feeders and subsequently place them on the board. At most one component at a time can be carried by a head. Note that each component type can only be handled by a subset of the set of head equipments. In other words, a head with a given piece of equipment can only pick and place components of a limited set of component types.

The mounting process consists of a sequence of pick-and-place moves. In the picking phase, the heads pick a component from the relevant feeders in turn. The order is fixed: the first head picks first, then the second, and finally the third head. During the placing phase, the robot arm moves to appropriate points on the board so that the components can be sequentially mounted. In contrast to the picking, the order in which the components are mounted can be chosen. Note that it is possible to choose pick-and-place moves in which only one or two of the three heads are used.

To illustrate the process, consider the following example in which a single machine is used to mount five components on a board. There are two components of type α, one of type β, and two of type γ. The feeders for these component types have coordinates (5, 0), (10, 0), and (15, 0), respectively. Further, the two α components have to be mounted at locations with coordinates $a_1 = (10, 2)$ and $a_2 = (10, 12)$, the β component has to be mounted at a location with coordinates $b_1 = (6, 5)$, and the two γ components have to be mounted at locations with coordinates $c_1 = (15, 8)$ and $c_2 = (14, 16)$. Suppose that, on the first pick-and-place move, the second α component is assigned to head 1, the β component is assigned to head 2, and the first γ component is assigned to head 3, and that these components are mounted in the order γ, α and β. Then, the robot arm moves successively between locations (5, 0), (10, 0), (15, 0), (15, 8), (10, 12) and (6, 5): a total distance of $5 + 5 + 8 + \sqrt{41} + \sqrt{65} = 32.49$. Suppose that on the second pick-and-place move, the first α component is assigned to head 1, and the second γ component is assigned to head 2, and that these components are mounted in the order α and γ. Starting at the location (6, 5) where the last component was mounted on the previous move, the robot arm moves successively between locations (5, 0), (15, 0), (10, 2) and (14, 16): a total distance of $\sqrt{26} + 10 + \sqrt{29} + \sqrt{212} = 35.04$. These pick-and-place moves are illustrated in Figures 1a and 1b, respectively.

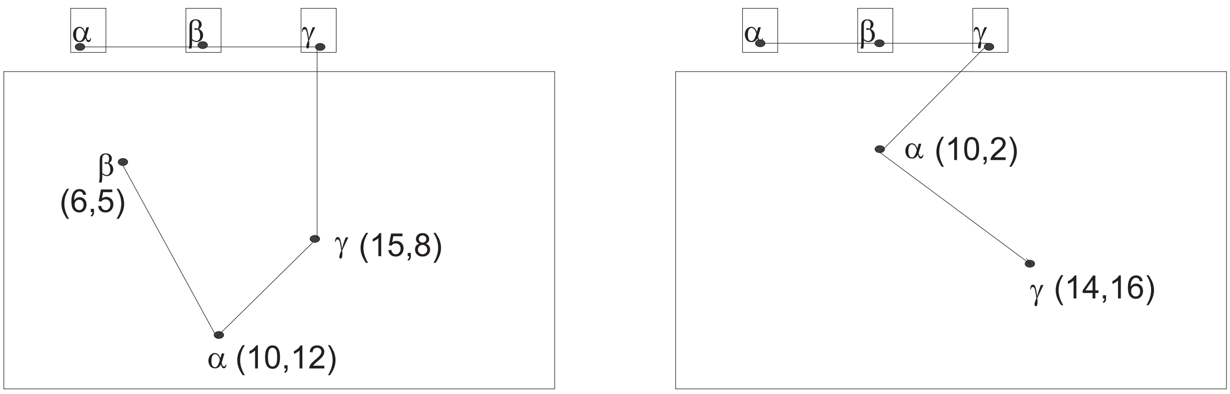

Figure 1: (a) First pick and place move; (b) Second pick and place move (the solid line denotes the route travelled by the arm during this move)

3 Throughput

It is required to maximize the throughput of the assembly line, which is determined by the machine with the heaviest workload. The workload of a machine is proportional to the total distance travelled by the robot arm. In computing this distance, you should assume that, when the conveyor moves, the robot arm remains at the position where the last component was placed until the new board arrives. Increased throughput is achieved by:

- avoiding large movements of the robot arm;
- balancing the workload between machines.

The scheme that is selected should minimize the time required for the busiest machine to complete all of its mounting operations.

4 Data

Relevant data for the problem are as follows. There are three machines, and 102 components to be mounted on the board. The components are of 10 different types, which are labelled as type A, type B, etc., up to type J. There are nine pieces of equipment which are to be fitted on the heads, and no piece of equipment is duplicated. The following table lists the equipment, giving the component types that each piece of equipment can handle.

Piece of equipment	Types of components that can be mounted
E1	C, F,G
E2	C, F,G
E3	B, G,H
E4	C,H
E5	E, I
E6	A,E
E7	E, J
E8	B,C, I
E9	D

Figure 2 displays the feeder positions, and shows the positions of the component types on the board. The feeders for components of types A, . . . , J have coordinates (2, 0), . . ., (11, 0), respectively. The board is depicted below the feeders. The components to be mounted at the top of the board have coordinates (1, 2), . . . , (12, 2), and the components to be mounted at the bottom of the board have coordinates (1, 13), . . . , (12, 13). There are some locations on the board where no component is to be fitted. For example, no component is required at the position with coordinated (9, 5), while a component of type J is to be mounted at the position with coordinates (10, 5).

Note that the times required to pick a component from a feeder, to mount a component on a board, and to move the board on the conveyor are neglibible.

	1	2	3	4	5	6	7	8	9	10	11	12	
0		A	B	C	D	E	F	G	H	I	J		Feeders
1													
2	E	F	D	F	D	F	D	F	D	F	D	E	
3	E	G		H	B	H		H		H	I	E	
4	E		B	A		G	C		C	G		E	
5	E	C	D		H		I	D		J	G	E	
6	E	A		I		A	B		G	H		E	
7	E	F	C		I			F			J	E	
8	E	B		D		C	B		J	J		E	
9	E	H	C		G		H	A	C		H	E	
10	E	C		A		G			I	D		E	
11	E		G	F	B		I		G		G	E	
12	E	B		C		H		J		I		E	
13	E	C	D		F	C	D		B	F	G	E	

Figure 2: Layout of the PCB board