Dynamic and Static Grouping in PCB Assembly

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Abstract
Group technology (GT) concepts can be applied in printed circuit board (PCB) assembly when determining a setup strategy for a single machine. In the group setup strategy, PCBs, which have similar component setups, are grouped together so that all the components required by a group can be loaded to the machine at one time. Thus, any board in the group can be produced without changing the component setup, which is only required when switching from one group to another. The benefits of the group setup strategy are fully realized in high-mix, low-volume production environments.

Introduction

Modern consumer goods include an ever-increasing number of electronic parts, which, in turn, must be assembled more cost-effectively to ensure the competitiveness of a manufacturer. However, the average product lifespan has shortened radically, and close competition forces companies to design, manufacture and market the products on a tight schedule. In addition to cost-efficiency and high-precision, flexibility is nowadays a key factor, since the same machinery is used for manufacturing slightly differing variants of the same product as well as a range of different product types. These *high-mix low-volume* environments have become common in printed circuit board (PCB) assembly.

The problems encountered in PCB assembly can be divided into four major classes according to the number of different PCBs and machines present in the problem:[2,3]

- One PCB type and one machine (1–1) class comprises *single machine optimization* problems, which amasses feeder arrangement, placement sequencing, nozzle assignment, and component retrieval problems.
- Multiple PCB types and one machine (M–1) class comprises *setup strategies for a single machine*.
- One PCB type and multiple machines (1–M) class concentrates on *component allocation to similar machines*, where the usual objective is balancing the workload of the machines in the same production line.
- Multiple PCB types and multiple machines (M–M) class or *scheduling problems* concentrates on allocating jobs to lines (including routing, lot sizing and workload balancing between lines) and line sequencing.

The research has traditionally concentrated on the problem class (1–1). However, the class (M–1) or *setup strategy* (i.e., the management of setups concerning multiple PCB types in a single placement machine) has also a significant impact on the efficiency. Here we can discern two kinds of setups: A *component setup* comprises the required operations to *replace one component feeder with another*. A *machine setup* comprises the required operations (component setups, conveyor belt adjustments, tooling plate changeovers, printing program updates etc.) which are required when the *manufacturing changes from one PCB type to another*. Nowadays, a common trend is to reduce the setup time by introducing new feeder types and auxiliary techniques (e.g., barcodes for locating the feeders) which aim at speeding up the changeover process. However, significant improvements can be attained by selecting carefully a proper setup strategy.

The different setup management strategies proposed in the literature fall into four categories:[4]

1. *Unique setups* consider one board at a time and specify the component–feeder assignment and the placement sequence so that the placement time for the board is minimized.
2. *Group setups* form families of similar parts so that setups are incurred only between families.
3. *Minimum setups* attempt to sequence boards and determine component–feeder assignments to minimize the changeover time.

4. *Partial setups* are characterized by the partial, rather than complete, removal of components from the machine when changing over from a product type to the next.

Table 1 collects the differences of the strategies. We have omitted partial setup, since it resembles minimum setup. Instead, we have included a *standard setup* strategy where the most common components remain in designated feeders throughout the production, while the rest are treated as in the unique setup strategy.

In this paper, we concentrate on the group set strategy. We discern two types of grouping: *static* and *dynamic*. Both types suit to certain production environments, and we discuss their applicability and benefits.

Group Setup Strategy

In the *group setup strategy* the feeder assignment is determined for a group or a family of similar PCBs. Any board in this group can be produced without changing the component setup, which is only required when switching from one group to another. Because the placement time for a specific board is, in general, larger than in unique setup strategy, some efficiency can be potentially lost. In the group setup strategy the feeder assignment is determined for a group or a family of similar PCBs (see Figure 1). Any board in this group can be produced without changing the component setup, which is only required when switching from one group to another. The placement time for a specific board is, in general, somewhat larger than in the unique setup strategy, and, consequently, some efficiency can be potentially lost. There are variations of the group setup strategy, where a certain set of common or standard components are left on the machine, while the rest of the components (which are called *residual* or *custom*) are added or removed as required for a particular board.

We have demonstrated earlier that group setup has both theoretical and practical advantages over the other setup strategies. [5,6] To be precise, we have compared minimum and group setup strategies using a cost function

$$\text{cost}_{A,B} = A \times \text{setup\_occasions} + B \times \text{component\_setups}$$

where parameters A and B can be viewed as the time factors for starting to set up components and setting up an individual component, respectively. In PCB assembly, a single component feeder can be changed in 1–5 minutes but it may take, for example, 15 minutes to prepare the machine for the component setup operations and to take it back on line when the setup is complete. By setting $B = 0$ we can compare the algorithms by the number of machine setup occasions (i.e., a job grouping problem), and by setting $A = 0$ we can make a comparison on the basis of the total number of component changeovers (i.e., a tool switching problem).[1] Our computational experiments indicate that methods based on the group setup strategy turn out to yield better overall results. Also, a hybrid approach, which combines both group and minimum setup, gives promising results.

There are also other, production-oriented reasons why group setup strategy suits well in high-mix low-volume production environments. In-group setup strategy, smaller production batch sizes become economical, which enables to cut down the work-in-process (WIP) levels. Although the unique setup strategy enables one to construct better placement sequences for each PCB—and hence the printing time of each individual PCB can be shorter than in the group setup—the overall production time can be considerably longer, because setups occur whenever the produced PCB type changes. Also, modern placement machines can have multiple different feeders types (e.g., tray, stick), which further advocates the group setup approach, since the groups can observe also these limitations.

The possible theoretical advances of minimum and partial setup strategy are outweighed by the practical benefits of the group setup strategy: Because setups, albeit larger than in other setup strategies, occur less frequently, the human operator who carries out the component changeovers is less prone to make mistakes, and thus the economical risks involved in the setup operations diminish. The human operator usually prefers to change ten components once than to change one component ten times. Moreover, group setup strategy allows designing a production planning system, which provides the production planner with more freedom, since the production sequence among the groups as well as within an individual group can be easily altered[6].

Table 1 - Comparing the Attributes of Setup Strategies

Setup strategy	Printing time	Setup time	Flexibility	Risk for errors	Suitable batch size
Unique	Good	Poor	Good	Quite large	Large
Minimum	Medium	Quite poor	Poor	Large	Quite large
Standard	Poor	Medium	Medium	Quite small	Quite small
Group	Quite good	Good	Quite good	Quite small	Small

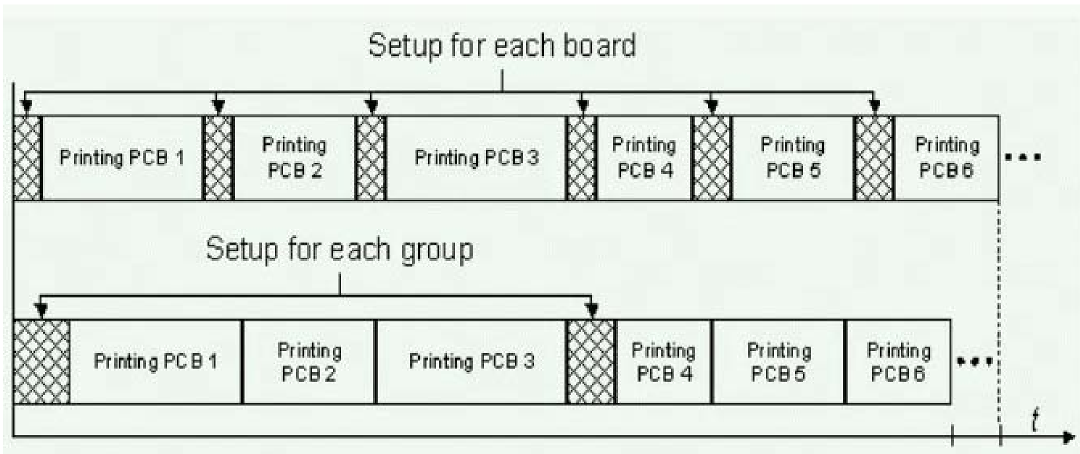

Figure 1 - Comparing Unique and Group Setup Strategies

Dynamic and Static Grouping

In the group setup, the PCBs are grouped according to their component requirements. After that, the components of each group are assigned to feeder slots (i.e., feeder optimization, and the printing time of each PCB is minimized separately on the basis of the feeder set-up of the group (i.e., printing order optimization).

The type of production determines whether the group setup strategy is *dynamic* or *static*. For example, if the whole production comprises fifteen PCBs that can be divided into two groups, it is probably preferable to form two static groups and alter the machine setup between them. Here, the grouping is static in the sense that it remains constant for a long period of time (e.g., for several months), whereas the dynamic groups are (re)formed on a much shorter timespan (e.g., daily or weekly). Nevertheless, the static group setup strategy requires that a new PCB can be inserted to (or obsolete PCBs removed from) a static group without having to form a new grouping.

The static group setup strategy is recommended if few groups can be formed from the active product set; if the product diversity or the product variety is high, the dynamic group setup strategy often offer a better alternative. Especially contract manufacturers can have different lines with different policies:

1. unique setup strategy for a line with single mass product,
2. static group setup strategy for manufacturing slightly varying products, and
3. dynamic group setup strategy for a line of new product introduction.

As a rule of thumb, static grouping is used

- when the boards remain in the same group,
- the amount of different product types is 20–40, and
- the amount of different groups is 2–4.

Conversely, dynamic grouping fits best when

- the boards are quite dissimilar and do not form large groups,
- the number of product types is greater than 100, and
- there are more 10 groups in the active production.

Table 2 lists observed improvements from adopting the group set strategy in a real-world production.[6] The table includes one week's production, and the production schedule is created by using both an old system using standard setup and a new system using group setup strategy. The benefits of the new system are obvious (see Table 3). In the old system we have to do 21 setups, one for each product, while in the new system products are divided into three groups, each requiring a single setup. Also, the printing time is vastly reduced; in this case the reduction is about 18 percent.

Table 2 - An Analysis of a Sample Schedule for a Period of One Week

PCB	pcs.	Old	New	Improvement	%	Group
D2284A1	200	48.61	32.64	15.97	32.9	1
CRT212	30	96.62	70.90	25.71	26.6	1
D5250A	100	55.06	40.73	14.34	26.0	1
D5450B1	210	42.87	34.13	8.75	20.4	2
CRR212C	35	103.16	83.70	19.47	18.9	1
D2187B1	31	33.15	27.05	6.09	18.4	1
D2161A1	79	31.77	26.21	5.56	17.5	1
D2481A	100	37.42	30.92	6.50	17.4	1
D2281A	200	38.95	32.45	6.50	16.7	1
DXA821RE	52	37.52	31.78	5.74	15.3	1
S2203	30	47.46	41.20	6.26	13.2	1
M3151EC2	30	105.90	93.49	12.41	11.7	3
AXP2011	50	39.19	35.10	4.09	10.4	2
MHE6107	47	78.28	70.47	7.80	10.0	2
DXO802	200	37.10	33.48	3.62	9.8	1
A80430B1	30	62.06	57.42	4.64	7.5	2
DTU082B1	31	30.78	28.73	2.06	6.7	1
AXF246D	30	22.52	21.96	0.56	2.5	1
AXA860	56	36.73	36.73	0.00	0.0	1
M3153CC2	10	104.30	104.53	-0.24	-0.2	1
DTU121B1	31	27.63	29.70	-2.07	-7.5	1
Total		1,117.07	963.31	153.76	13.8	

Legend: Old = production time in the old system (min), New = production time in the revised system, Improvement = difference between Old and New, % = difference in percents, Group = group to which the product belongs.

Table 3 - Comparing the Old and New System

	Number of setup occasions	Number of feeder changes	Total setup time	Total onsertion time	Total production time
Old	21	294	30,240 s	72,868 s	103,108 s
New	3	246	16,560 s	60,067 s	76,627 s
Improvement	18	48	13,680 s	12,801 s	26,481 s
%	85.7	16.3	45.2	17.6	25.7

Both the static and dynamic grouping are included in our system (see Figure 2). Moreover, the system includes methods for placement sequence optimization and workload balancing.

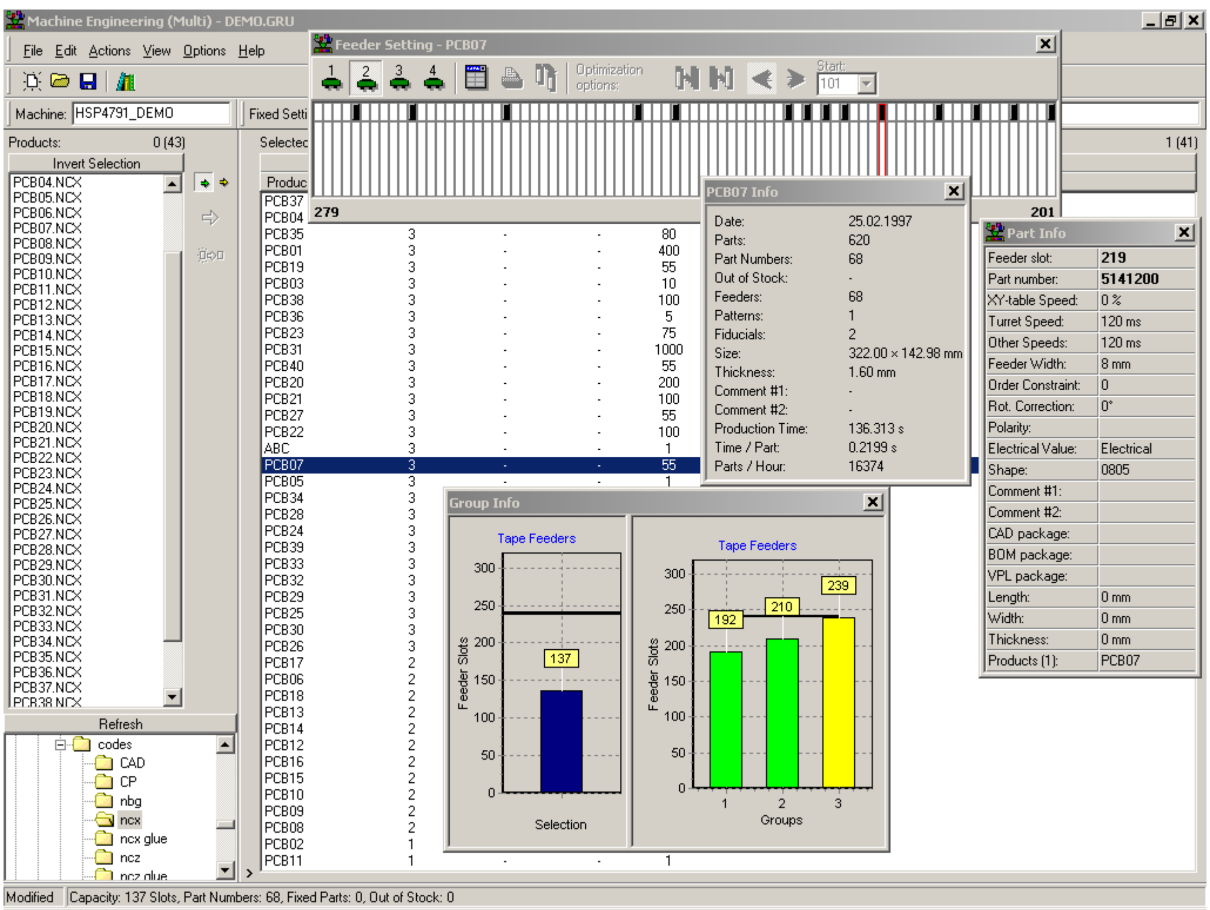

Figure 2 - A Snapshot of the Grouping System

Concluding Remarks

We presented dynamic and static grouping in PCB assembly. Generally, group setup strategy offers flexibility for the production as well as allows optimizing the production programs. The timespan and product variety of the manufacturer determines which grouping type suits better for the production.

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