Group Technology in Electronics Assembly

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Abstract

Group technology (GT) concepts can be applied in printed circuit board (PCB) assembly. GT provides flexibility to production planning and can increase the productivity in high-mix low-volume environments. Basic concepts of GT and a brief survey of the literature are presented. Four setup strategies—unique, minimum, group and partial—for PCB assembly are described, and the practical benefits of the group setup strategy are outlined. The groups can be either dynamic or static, depending on the product variety and diversity. The paper concludes with remarks of real-world production planning systems utilizing GT principles.

Keywords: printed circuit boards, group technology, production planning, setup strategy

1 Introduction

Machine grouping problem and *group technology* (GT) philosophy were first introduced in the late 1950s, and since then researchers have developed different techniques for these problems. However, most of the research so far has focused on more "traditional" forms of assembly, whereas, for the time being, applications in *flexible manufacturing systems* (FMS)—and especially in *electronics assembly*—have been quite rare. An FMS comprises a group of programmable production machines integrated with automated material handling equipment which are under the direction of a central controller to produce a variety of parts at non-uniform production rates, batch sizes and quantities. The flexibility of the FMS is characterized by how well it responds to changes in the product design and the production schedules, and these are key-factors in electronics assembly.

The approaches to reduce setup times in electronics manufacturing are usually divided into two categories: reducing the setup frequency by enlarging the lot sizes, and applying GT. In GT, efficiencies in manufacturing are realized by *grouping similar tasks* (e.g., according to shape, dimension or process route) and dedicating equipment for performing these tasks [11]. A significant advantage of applying GT principles in scheduling is that the setup time and, consequently, the setup costs are reduced. In general, production planning is divided into long-, medium- and short-range—or strategical, tactical and operational—level according to the timespan of the plan. GT is often considered to be a part of the medium range planning, but in electronics assembly the dynamic nature of the production environment sometimes enforces us to apply GT also in the short-range planning.

Kulkarni and Kiang [10] categorize the approaches to GT to conventional and artificial intelligence (AI) related approaches. Conventional approaches include *mathematical programming formulation*, which tries to minimize the total distance measures between parts within families and gives an optimal solution; *graph theoretic method*, which uses cliques of the machine-graph as means of classification; and *matrix formulation*, which represents part-part, part-machine or machine-machine relationships in a matrix form. AI related approaches include *syntactic pattern recognition*, which treats the machine sequences

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as strings which are then used to form part families; *expert systems*, which use a knowledge-base and clustering algorithms interacting closely with each other and make heuristic decisions according to 3–4 meta-constraints; *fuzzy mathematics*, which is used in quantifying imprecise and uncertain relationships (e.g., by using a matrix formulation with non-binary values); and *neural networks*, which involve pattern recognition and feature memorizing as well as learning in order to give a representation of the problem. An extensive review of different approaches to GT and cellular manufacturing in general is provided by Heragu in [6].

2 Grouping in PCB Assembly

Johnsson [8] classifies the literature on PCB assembly according to the number of different PCBs and machines present in the problem. Accordingly, the four main problem classes are:

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.

In this paper, we concentrate on the problem class (M–1). Leon and Peters [12] classify the different setup management strategies proposed in the literature into four categories:

- *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, which is a common strategy when dealing with a single product and a single machine in a high-volume production environment.
- *Group setups* form families of similar parts so that setups are incurred only between families.
- *Minimum setup* strategy attempts to sequence boards and determine component–feeder assignments to minimize the changeover time.
- *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.

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. 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.

Carmon *et al.* [2] describe a group setup (GSU) method for a high-mix low-volume production environment. In GSU, the products are divided into groups, each of which is produced in two stages: Set up common components and insert them to all the PCBs of the whole group, and then set up the residual components and insert them on each PCB separately. In [15], the same authors compare GSU to sequence dependent scheduling (SDS) on three performance measures—line throughput, average WIP level and implementation complexity—and conclude that in general SDS performs better on all areas. Maimon and Shtub [14] present a mixed-integer programming formulation and a heuristic method for grouping a set of PCBs to minimize the total setup time. A user-defined parameter is used to indicate whether multiple loading of PCBs and components is allowed. This approach is developed further in [4] by Daskin *et al.* Here the goal is to minimize the total component and PCB loading costs subject to a capacity constraint. Shtub and Maimon [16] establish that grouping PCBs is an extension of the set-covering problem and present a general heuristic approach based on cluster analysis and similarity measures, which are traditionally found in group technology literature.

Hashiba and Chang [5] study one machine when the objective is to minimize the number of setups. They apply heuristic decomposition and simulated annealing to solve the problem, and observe that the latter gives better results. Luzzatto and Perona [13] present a heuristic method for grouping the PCBs to minimize the setup size. Although the authors consider a production line consisting of several workphases, their model of the problem enables the solution for each workphase to be obtained separately from the others. Bhaskar and Narendran [1] apply graph theory for formulating the grouping problem. They model the PCBs as nodes and their similarities as the arcs between the nodes, and construct a maximum spanning tree to identify the PCB groups. Xu *et al.* [19] form PCB groups and divide the feeder slots into three “feeder bays”: fixed, semi-fixed, and configurable. The fixed feeder bay comprises the most frequently used components and it remains constant throughout the production, whereas the semi-fixed feeder bay is changed whenever the group changes and the configurable feeder bay whenever the board type changes.

Smed *et al.* [17] give an integer programming formulation of the job grouping problem (cf. [3]), and compare several heuristic algorithms based on greedy, clustering and repair-based local search methods. Johtela *et al.* [9] expand the problem to account multiple and possibly conflicting grouping criteria—such as different substrate widths, adhesive types, and production priorities—by modeling them as fuzzy sets.

3 Applying GT in PCB Assembly

Figure 1 illustrates the benefits of the group setup strategy over the unique setup strategy. 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. In the group setup strategy, all the jobs in a group are printed successively, and there is no need for setup operations between the jobs belonging to the same group. Also, 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 products can be classified into groups according to their similarity (i.e., the amount of mutual components), which can be done by calculating similarity measures for PCB pairs and then grouping them according to the measure [16]. Another GT formulation of a PCB assembly problem, namely the *job grouping problem*, can be stated as follows [17]: A set of *jobs* (i.e., PCBs) are processed on a machine. During the processing the machine performs a number of *operations* (i.e., component printing) on the jobs, and each operation requires one or more *tools* (i.e., components). Tools are stored in a *magazine* which can hold a limited number of different tools (i.e., it has a certain capacity). The task is to find a *loading strategy* (i.e., a specification of the contents of the tool magazine at the beginning of the processing of each job) with a minimum total setup time which depends linearly on the number of *tool switching instants* (i.e., feeder setup instants). As a result, the setup for the whole job group is done on one switching instant and after that all the jobs in the group are processed successively. Crama *et al.* [3] give a solid theoretical background for the tool management problems and prove that the job grouping problem is NP-hard.

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

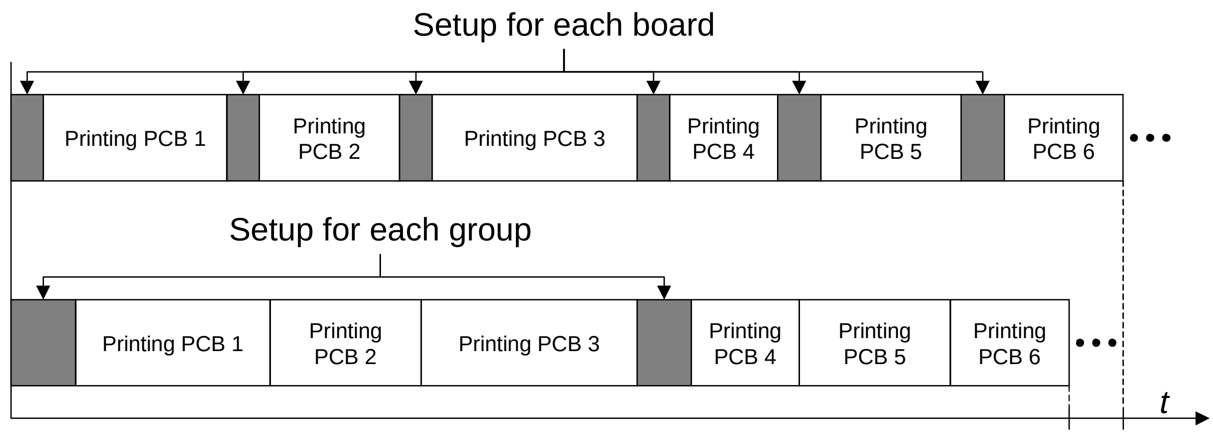

Figure 1: In unique setup strategy each board requires an individual setup. In group setup strategy boards are grouped so that no intervening setups occur.

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 six 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 an obsolete PCB removed from) a static group without having to form a new grouping. The static group setup strategy is recommended if 2–4 groups can be formed from the active product set; if the product diversity or the product variety is high, the dynamic group setup strategy offers a better alternative. In practice, however, the production plants can usually settle on the static group setup.

4 GT in a Production Planning System

In our research we have designed software systems which utilize the ideas of GT in PCB assembly. For solving static group setups, we have developed the SMD Optimizer system, which features printing sequence optimization, feeder optimization (also for multiple boards), setup minimization and job grouping [7]. Dynamic group setup strategy is engaged in the ControlBOARD system [18] (see Figure 2). It includes a graphical user interface, which provides the production planner with a clear visualization of the production plan, a set of possible operations for altering the grouping (e.g., moving jobs between groups), warning for exceptional situations (e.g., component starvation), numerical information (e.g., estimated printing times) and tight integration with other systems (e.g., printing order optimization).

The system is used to support production planning in a high-mix low-volume production plant. The total number of different jobs (or PCB batches) processed on the line is high but the amount of PCBs in a job is usually small, and thus the setup times form a significant part of the total production time. Therefore, the main objective is to minimize the setup times by grouping the products efficiently. The system tries to minimize the number of groups by using a repair-based local search heuristic. Repair-based in this case means that capacity constraints can be violated occasionally to broaden the scope of the search after which the repair operations are used to bring the search back to the set of feasible solutions. The algorithm can be stopped at any time and the currently best solution is available to the user.

Additionally, the user can improve the grouping by considering also other criteria (e.g., the group should contain PCBs with the same substrate size, adhesive type and urgency class). These objectives can be taken into account by representing each of them as a fuzzy set and aggregating them together to give an overall optimality measure of the solution. The task is to search for a grouping which has the maximum degree of satisfaction of the specified goals and constraints, both of which may be subject to imprecision. This fuzzy multiple criteria model is discussed and analyzed in detail in [9].

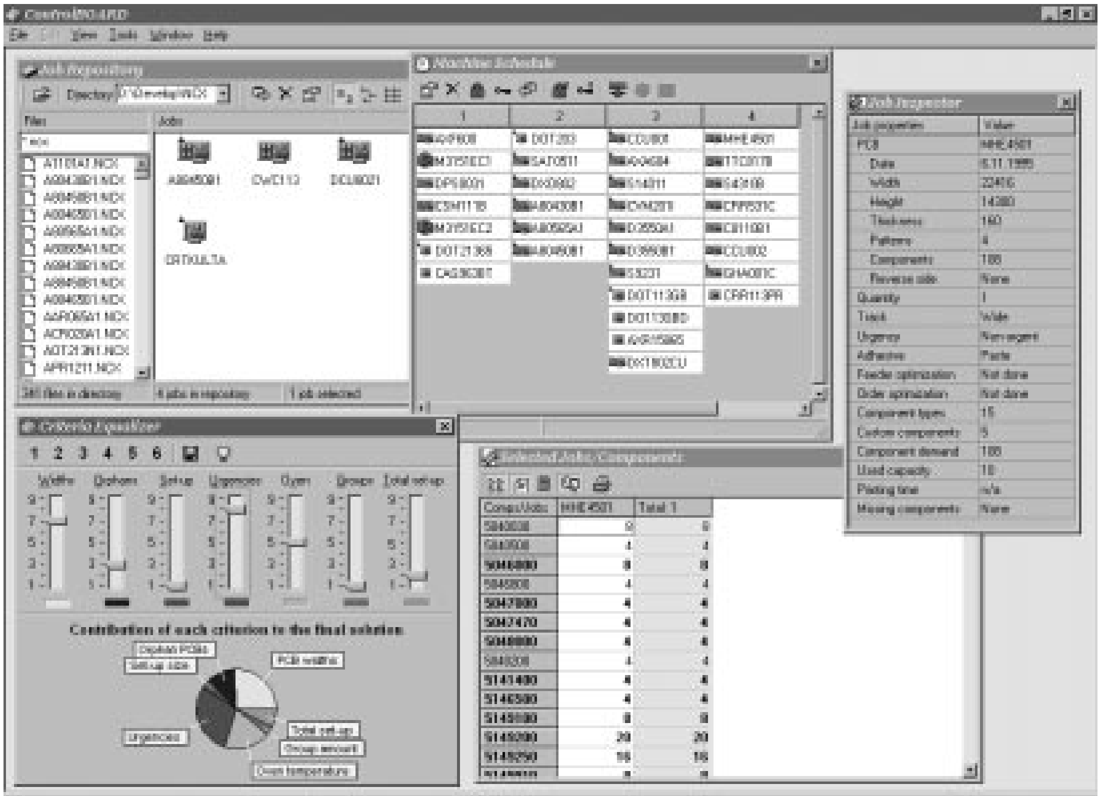

Figure 2: The main window of the ControlBOARD system

5 Concluding Remarks

The benefits of applying GT in PCB assembly are fully realized in high-mix low-volume environments. These benefits include:

- The production time can improve because of less frequent setups.
- The risk of misplaced components is reduced.
- Smaller production batch sizes become economical, which enables to cut down the WIP levels.
- The planning system provides the production planner with more freedom, since the production sequence within a group can be easily altered.
- Multiple criteria present in the production process can be accounted easily and intuitively.

To conclude, GT has provided good results in everyday use—in some cases the productivity of the electronics manufacturer has increased more than fifty percent [17].

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