

Observations on PCB Assembly Optimization

MIKA JOHANSSON

Valor Computerized Systems (Finland)

Tykistökatu 4 B, 20520 Turku, Finland

Email: mika@valor.com

JOUNI SMED

Turku Centre for Computer Science (TUUS), University of Turku

Lemminkäisenkatu 14 A, 20520 Turku, Finland

Email: jouni.smed@cs.utu.fi

Abstract

We present a hierarchical classification scheme for the optimization problems encountered in printed circuit board (PCB) assembly. The classification is based on the number of machines (one or many) and number of boards (one or many) present in the problem. The scheme also incorporates lower level classifications presented in the literature.

1. Introduction

The problems in PCB assembly vary from deciding the component insertion sequence to problems of how to run the whole production plant efficiently. Because of the wide variety of planning and control problems, hierarchical decomposition is a widely used approach to solve these problems. At the top of operational and tactical levels is the *scheduling problem*. Here we have to decide how to operate the machinery to produce a set of different PCBs (usually how to execute the weekly production plan). The next hierarchy level includes *grouping* and *line balancing* problems. In the *line balancing problem* we try to balance the workload of different machines when producing a single PCB. In the *grouping problem* the aim is to reduce the set-up times by constructing a common feeder set-up for several products. The lowest level on the operational level is called the *single machine optimization problem*.

These problems are connected to each other so that the solving of the complex problems requires the solutions of the simpler ones. For example, when solving grouping, we must be able to optimize the feeder set-up for the whole group and optimize the insertion order for every board. Similarly, we need to solve the grouping of the products in order to schedule them efficiently. Since the single machine optimization problem is at the lowest level, it has to be solved each time when solving any of the higher hierarchy level problems.

The most prevalent analytical approach to production planning problems of flexible manufacturing systems (FMSs) attempts to hierarchically decompose the problem into a number of more easily manageable subproblems. One of the main reasons for this kind of approach is that the original problem is usually too complex to be solved globally, whereas it is easier to solve each subproblem one at a time. The solution to the global problem can then be obtained by solving the subproblems successively. Naturally, this solution is not likely to be globally optimal, even if all subproblems are solved to optimality. Nonetheless, this approach is a productive and popular way to tackle hard problems, and the majority of production planning software systems utilize, in some way or another, hierarchical decomposition technique.

Traditionally, a hierarchical classification scheme for assembly problems discerns (1) *strategic level* or *long-range planning* which concerns the initial deployment and subsequent expansion of the production environments, (2) *tactical level* or *medium-range planning* which

determines the allocation patterns of the system production capacity to various products so that external demands are satisfied, and (3) *operational level* or *short-range planning* which coordinates the shop floor production activities so that the higher level tactical decisions are taken into consideration [COS94].

This paper concentrates on tactical and operational level problems in printed circuit board (PCB) assembly. We present in the next section a novel hierarchical classification scheme for PCB assembly problems (for further details and a review of the relevant literature, see [SJJN99]).

2. Hierarchical Classification

Generally speaking, we can classify the PCB assembly problems according to the number of different board types (one or many) and machines (one or many) present in the problem (see Figure 1). Accordingly, the four main problem classes are [Joh99, SJJN99]:

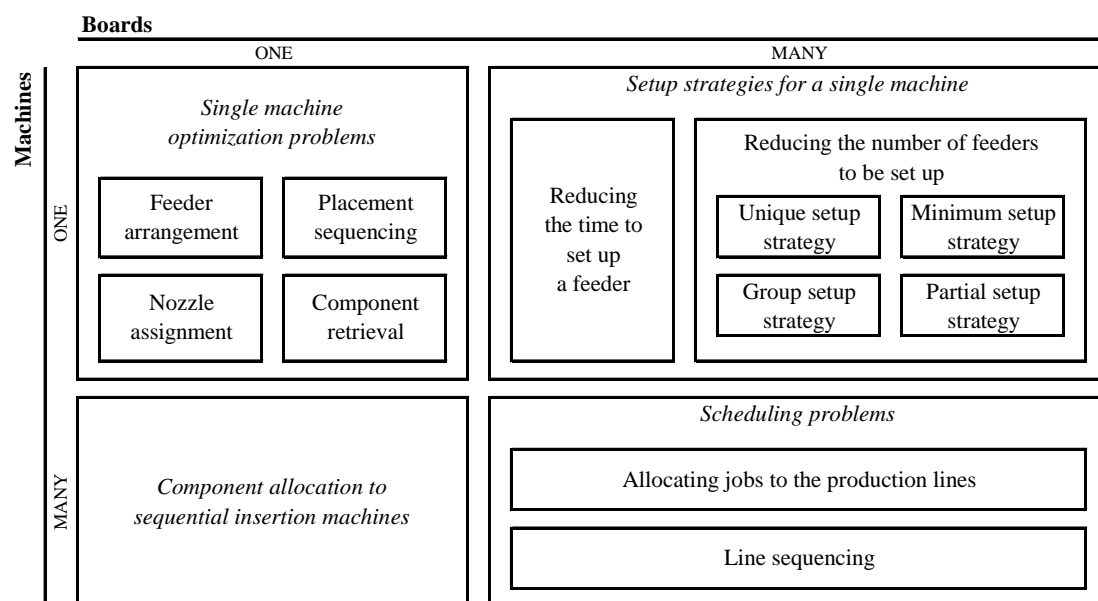


Figure 1: Hierarchy of the problems in PCB assembly

ONE PCB TYPE AND ONE MACHINE (1–1) class comprises *single machine optimization* problems, where the goal is to minimize the printing time of the machine. The class can be further divided into four subclasses [BDG⁺97, CFKS97]:

- *feeder arrangement* problem concerns assigning components to the feeder slots,
- *placement sequencing* (or insertion order) problem concerns determining the sequence in which the components are printed on the board,
- *nozzle assignment* problem concerns the tool changes for the placement head, and
- *component retrieval* problem concerns determining from which feeder slot the component is retrieved if it has been assigned to more than one slot.

MULTIPLE PCB TYPES AND ONE MACHINE (M–1) class comprises *setup strategies for single machine*. There are two approaches to reduce setup times [CB97]: (1) reduce the time to set up a feeder, and (2) reduce the number of feeders to be set up. In the latter case, the setup strategies can be classified as follows [LP98]:

- *unique setup strategy*: Consider one board at a time and specify the component–feeder assignment and the placement sequence so that the placement time is minimized. This is a common strategy when dealing with a single product and a single machine in a high-volume production environment.
- *minimum setup strategy*: Sequence the boards and determine feeder assignments to minimize the total component setup time. The idea is to change only the feeders required to assemble the next board. In general, similar product types are produced in sequence so that little changeover time incurs.
- *group setup strategy*: Form families of similar parts so that setups are incurred only between the families. Therefore, any board within a group can be produced without changing the component setup. Because the placement time for a specific board is, in general, larger than in unique setup strategy, some efficiency can be potentially lost. However, this is compensated by less frequent setup operations, which compensates the losses in machine speed especially in high-mix, low-volume production.
- *partial setup strategy*: Sequence the boards and determine a subset of the feeders on a machine that are changed when switching from one product to the next. Because the goal is to minimize makespan, the partial setup strategy resides between the unique setup strategy (where only the placement time for each individual PCB is minimized) and the minimum setup strategy (where only the changeover time of each PCB is minimized).

ONE PCB TYPE AND MULTIPLE MACHINES (1–M) class concentrates on *component allocation to sequential insertion machines*, where the usual objective is balancing the workload of the machines in the same line (usually by eliminating bottlenecks) [MAC⁺92].

MULTIPLE PCB TYPES AND MULTIPLE MACHINES (M–M) class or *scheduling problems* usually concentrate on

- allocating jobs to lines which includes routing, lot sizing and workload balancing between lines, and
- line sequencing.

The main advantage of the hierarchical classification scheme is that it makes easier to recognize the problems and to find suitable and efficient approaches for solving them. In addition to theoretical interest, the scheme also provides support for practical issues. It is a natural basis for a production planning system, where optimization is done separately for each subproblem. It has provided us with good results in both designing and implementing software systems for electronics manufacturers (e.g., see [SJP⁺99, SJJ⁺00]).

2.1. Single Machine Optimization

Although we can recognize four distinct subproblems (feeder arrangement, placement sequencing, nozzle assignment and component retrieval) in single machine optimization, they are strongly intertwined and, therefore, usually not solved altogether independently. For example, an optimal placement sequence does not guarantee optimal printing time if the feeder assignment is neglected (and vice versa). Another aspect of the problem is the wide variety of different machine environments considered in the literature. Most of the work have been based on (variants of) pick-and-place machines and rotary turret machines. Also, manual and semi-automated operations are considered by some authors.

The type and design of the placement machine has a major importance when solving the above mentioned subproblems. One way to categorize the placement machines is to consider

their main components and the parallelism of the different operations. Most placement machines comprise one or more *feeder units*, a worktable holding the work piece (PCB), pick-and-placement head(s) capable of holding one or more nozzles (tools) for component handling, and a tool magazine for storing a (sub)set of nozzles.

The optimization of single machines is motivated for a number of reasons:

- *Increasing the effective operation rate.* Vendor supplied software systems for automated control program generation are commonly quick-and-dirty systems which put more strength to the total information flow of the assembly line and use rather simple heuristics to solve the four subproblems.
- *Improving the flexibility.* The changes in the design of the PCB or the component feeder assignment can be easily taken into consideration in the control code generation.
- *Consideration of higher levels of the production planning hierarchy.* Effective optimization of the higher levels of the planning hierarchy presupposes good knowledge of single machine problems. This property is essential in particular at the line balancing level which is important for the overall efficiency of the production.
- *Improvement of product design and pricing.* Design for manufacturing (DFM) and pricing of the products are applications that could benefit from more accurate data of the production time estimates. These data are provided by a simulator included in the control code generator.

2.2. Setup Strategy

Figure 2 illustrates how group setup strategy can be utilized in PCB assembly. In the example, there are six different component types and six different board types to be manufactured. If the feeder capacity is four, it is possible to divide the six boards into two groups which can share the same feeder setup.

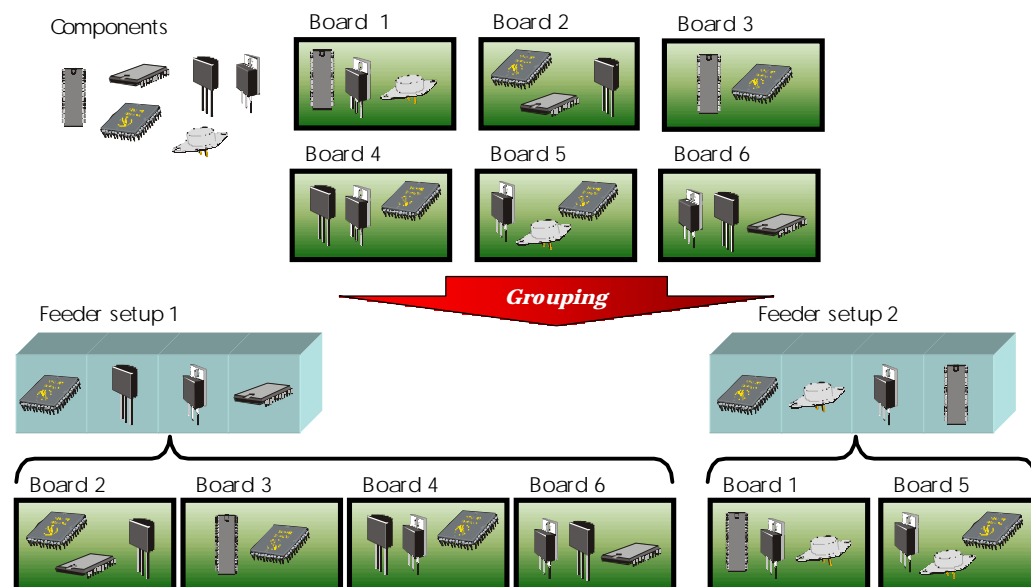


Figure 2: Component grouping

Figure 3 illustrates the benefits of group setup strategy over the “traditional” board-wise unique setup approach. In group setup, all the boards in a group are printed successively, and there is no need for setup operations between the boards residing in the same group. In

contrast, if each board requires a unique setup, the overall production time can be considerably longer.

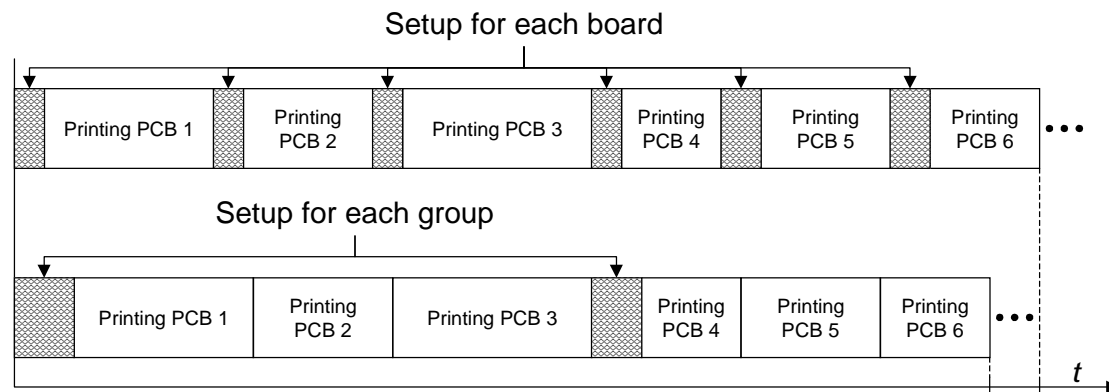


Figure 3: Comparing unique and group setup strategies

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 benefits of applying group setup strategy can be summarized as follows:

- The throughput is improved since setups are done less frequently.
- Less frequent setups also lead to that the human operator carrying out the component changeovers is less prone to make mistakes.
- Smaller production batch sizes become economical, which enables to cut down the buffer sizes.
- The production sequence within a group can be easily altered without affecting the predetermined feeder setup.

2.3. Workload Balancing

Only few papers considering the case of similar (sequential) machines in the same production line have been put forth. Here, the most eminent criterion is workload balancing so that the bottlenecks of the line are eliminated.

It should be noted that we must differentiate two kinds of balancing: We can balance the workload either among several *parallel lines* (i.e., “interline” balancing) or among machines within the *same single line* (i.e., “intraline” balancing), see Figure 4. The former clearly belongs to the problem class (M–M), whereas the latter is an instance of the problem class (1–M). Nevertheless, this only demonstrates the usefulness of the scheme, since the approaches for achieving interline or intraline balancing are somewhat different from each other and therefore cannot be lumped together.

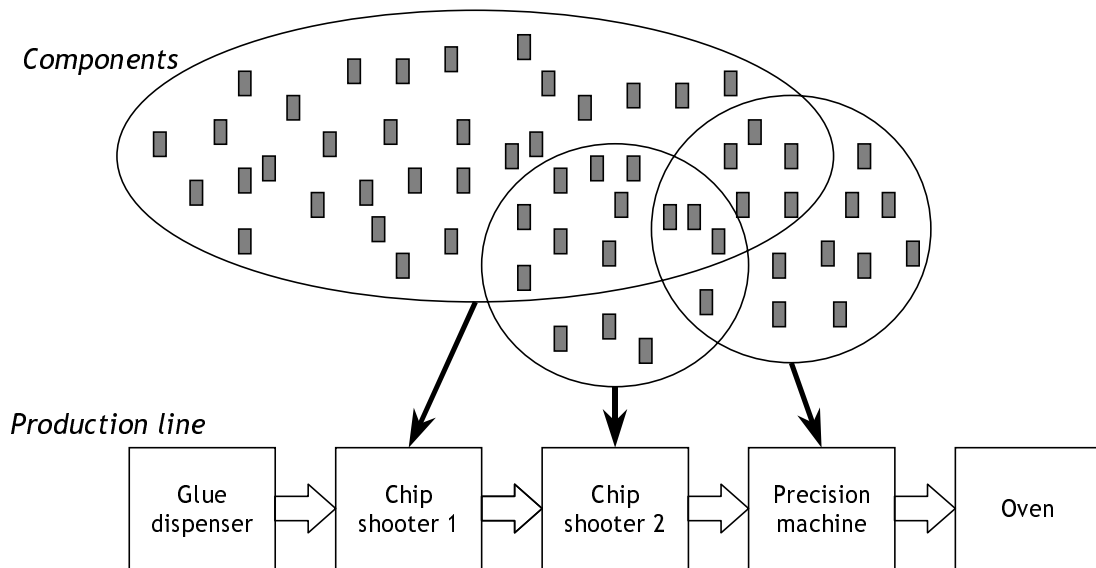


Figure 4: Intraline balancing

In intraline balancing, the optimization criterion is minimizing workload of the machine with the maximum workload (i.e., the eliminating the bottleneck), see Figure 5.

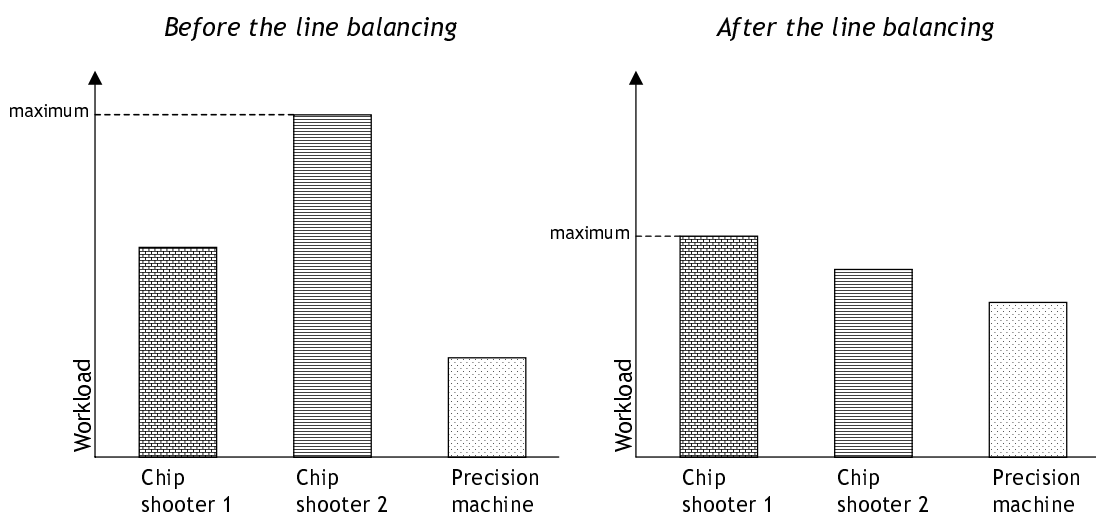


Figure 5: The goal of balancing is minimizing the maximum workload

3. Concluding Remarks

To conclude, we would like to point out six key topics for the future research on production planning in PCB assembly [SJJN99]:

- **ROLLING HORIZON.** Although the production plan is made for a given period of time, the production rarely begins with an empty line, nor does the line remain empty, when the due date of the last job of the current plan expires. Yet, this rolling horizon framework is scarcely considered in the problem formulations of the PCB assembly literature.
- **APPLICABILITY.** Many of the solution procedures overlook the problems associated with the machine operation and the human workers. For example, partial setup strategy may, in some cases, provide the best theoretical solution for a given setup problem—but it may also result that the human operator, who is required to change few feeders whenever the board type changes, is prone to make more mistakes than if he performs larger feeder

changeovers less often. Likewise, the technical considerations (e.g., machine code generation), in the main, are brushed aside in the literature, and thus the suggested solution procedures may have little applicability in actual production environments.

- **DYNAMIC PRODUCTION.** Reality rarely follows a plan; there are machine breakdowns, component shortages and maintenance delays, urgent prototype series surpass normal production, and the production plan itself can be subject to sudden alterations during the production period. Therefore, a practical production planning system must be able to cope with this kind of dynamic production and to give new or refined solutions whenever the integrity of the plan is challenged.
- **MULTIPLE CRITERIA.** The bulk of research done in PCB assembly contemplates optimizing one—or rarely a few—criterion (e.g., component setup or due dates). In reality, there are usually several more or less important practical aspects which affect the use of the solution. These aspects either define the space of admissible solutions (e.g., release dates, operation durations, setup times and resource availability) or characterize the quality of scheduling decisions (e.g., due dates, productivity, frequency of tool changes and WIP levels). Some of these multiple criteria must be satisfied for a schedule to be valid, while others may not always be satisfied and might need to be relaxed.
- **USER INTERACTION.** We discussed the importance of involving the human production planner in the decision making process earlier in this paper. To summarize, as long as the production planning systems are designed for not completely automated manufacturing processes (such as PCB assembly), the production planner must retain the final word on the production plan to be carried out. This means that the planner must be able to override the algorithmic solutions and effectively take the control if an exceptional situation requires it.
- **INTEGRATION.** The lack of cooperation with other systems (such as CAD/CAM and inventory management) is a common reason why a new production planning system can be reluctantly accepted by the shop floor personnel. Production data should be interchanged automatically via a network—it must not depend on routinely done manual input. Here the key issue is the seamless integration of the production planning system to the other existing systems.

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