Single Machine Scheduling with Fuzzy Multiple Criteria Optimization in Electronic Assembly

Tommi Johtela, Jouni Smed, Mika Johnsson, Olli Nevalainen

Department of Mathematical Sciences and Turku Center for Computer Science (TUCS), University of Turku, FIN-20014 Turku, Finland

Abstract

The scheduling problem of a surface mounting machine for printed circuit boards (PCB) is studied. The scheduling requires the forming of product groups. All PCBs in a group use the same component set-up and can be printed sequentially without a delay. Fuzzy multiple criteria optimization is used to model the various, partly conflicting aspects of the grouping problem.

1 Introduction

In this paper we describe an actual production environment for printed circuit board assembly (Teleste Corporation, Nousiainen, Finland). Our focus is on one of the various work phases of the production line, namely surface mounting. In our previous work [1] we have applied heuristic methods for solving the problem. However, it is hard for these methods to account for the existence of several conflicting criteria present in the actual problem.

We have applied fuzzy techniques to the problem. This has enabled us to analyze the production environment and its properties more closely and to build a more complex but still manageable model of the production process. In addition, the fuzzified criteria correspond more accurately to the requirements of the user.

This paper is organized as follows. We start in section 2 by describing the production plant and the properties of the surface mounting device. Section 3 concentrates on the theoretical foundations of the fuzzy model which is incorporated in the actual environment in section 4. Concluding remarks appear in section 5.

2 Production Environment

A typical assembly line for automatic component printing on printed circuit boards (PCBs) comprises several successive work phases. In this paper we suppose that each PCB goes through a glue dispenser, two surface mounting machines, an oven and a manual insertion

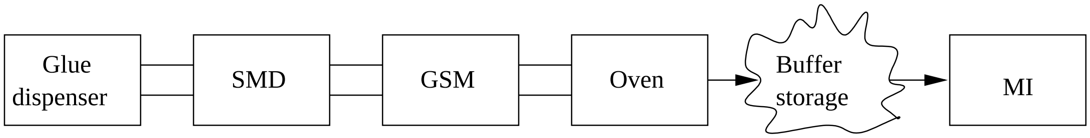

Figure 1: The production line of the surface mounted onsertion. Legend: SMD = surface mounting device, GSM = general surface mounting device, MI = manual insertion, '=' stands for a conveyor belt

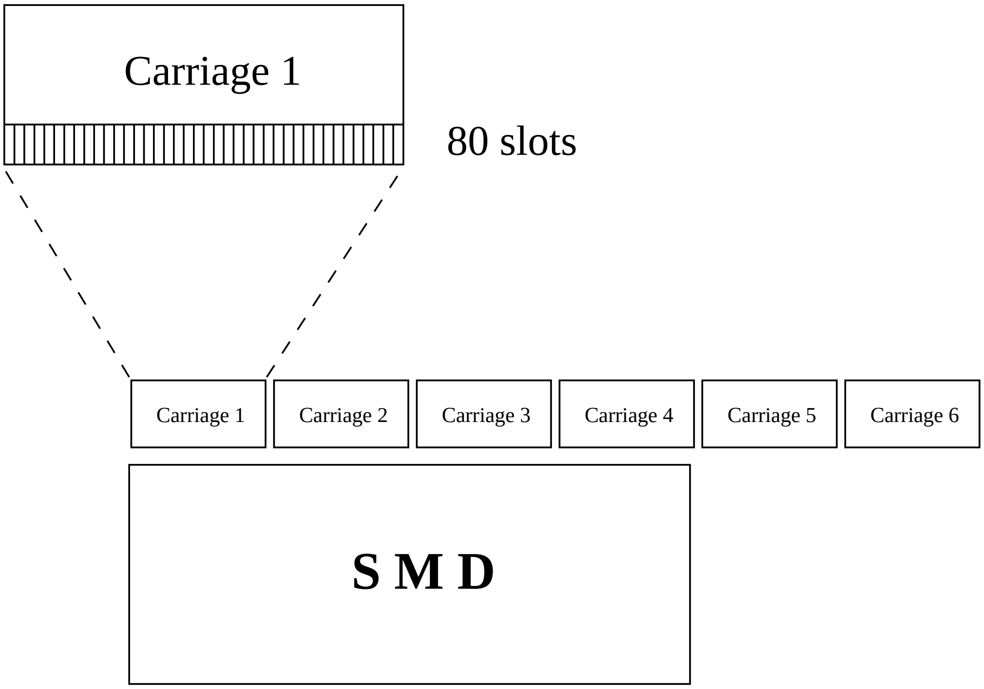

Figure 2: A schematic view of the SMD printing machine

phase (see figure 1). The first of the two surface mounting machines (SMD) is adapted to fast operation and used for the majority of the component onsertions, whereas the second machine, called general surface mounting (GSM) machine, is more flexible but its speed is much slower. In this work we consider optimizing the operation of the SMD machine because it has turned out to be the bottleneck of the production line. The reason for this is that its set-ups and component printing dominate the overall production time.

The difficult management of the SMD machine emanates from its flexibility. It gets the components from six carriage modules, each of which includes 80 linearly arranged feeder slots containing the components (see figure 2). A component occupies two or more slots. The two outermost carriages can be separated from the unit and their set-up can be changed while the machine is operating, whereas the set-up of the two midmost carriages cause an interruption to the printing process. Therefore, the two midmost carriers contain a seldomly changed fixed set-up of the most commonly used components.

The number of jobs processed on the line is very high and the amount of PCBs in a job is usually quite small. Therefore, the set-up times form a significant part of the total production time. In contrast to most scheduling problems, the meeting of the due-dates is not the most important restriction, but is, in this case, managed by a two-level priority classification (i.e., products are either urgent or non-urgent). The overall production time is affected by the fact that there are two different widths for the PCBs, and the change of the conveyor width causes an interrupt in the printing process. Also, some PCBs require component printing on both sides, and in order to avoid unnecessary storaging the other side should be printed as soon as possible after the first side.

Because the sum of different component types in a PCB is significantly smaller than the capacity of the feeders in the machine, we can quite freely choose an appropriate input organization. We have chosen a set-up which is identical for only a part of the products, and therefore the products to be manufactured must be divided into groups.

In our earlier work we have developed several methods (e.g., heuristic algorithms) for solving the grouping, but our solutions lacked a measure which takes into consideration the various aspects of the actual production environment. By using a "classical" objective function we were able to find a grouping with a minimal number of groups and after that affect somewhat the distribution between the groups. Urgencies, conveyor widths, the management of the double sided PCBs and the size of the set-up were all ignored. Although the original heuristics improved the actual production radically, further refinements were still needed—and one easy way to include them to the model was to apply fuzzy techniques.

3 Fuzzy Approach

All the criteria characterizing a good solution can be taken into account by representing each criterion as a fuzzy set. The intuitive idea behind this is: the greater the membership of the solution in the set, the better the solution. The objective function is obtained from the aggregation of the fuzzy sets representing different criteria. Thus, the objective function includes every criterion affecting the solution. It is also possible to specify conflicting goals where different criteria draw the solution to different directions. The final solution is essentially a *compromise* among all the criteria. Also, the priorities among the criteria have to be considered. The priorization can be done by *weighting* the fuzzy sets. The weights ensure that the more important criteria have a greater effect on the value of the objective function than the less important ones.

In many cases a criterion can be considered as a *fuzzy number*. For example, the fuzzy set which corresponds to the criterion "the group sizes should be as even as possible" can be formulated as a fuzzy number $\widetilde{N} = \frac{m}{n}$ where m is the total number of groups and n the total number of jobs. A fuzzy equality relation should hold between the number of jobs in each group G_i (denoted by $|G_i|$) and the fuzzy variable $\widetilde{N}$:

$$|G_i| \cong \widetilde{N}$$

Figure 3 shows the membership function μ of this fuzzy number; the value of the fuzzy criterion is obtained by evaluating μ with the input value $|G_i|$.

There are many ways to weight the criteria. One must bear in mind that the poorly fulfilled criteria affect the aggregated result more than the criteria with higher membership

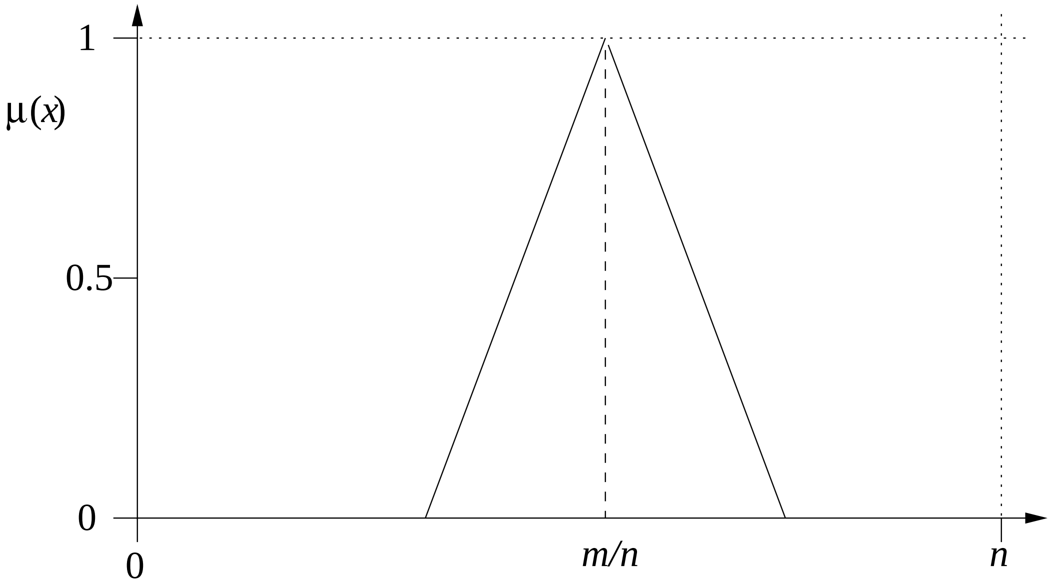

Figure 3: A fuzzy number representing the optimal group size

values. Therefore, weighting can be based on an interpretation of the *fuzzy implication* as a boundary which guarantees that a criterion has *at least* a certain fulfilment value. Let us assume that a fuzzy criterion $\widetilde{C}_i$ has a weight $w_i \in [0,1]$ where a greater value corresponds to a higher priority. Thus, the weighted value of a criterion is obtained from the implication $w_i \to \widetilde{C}_i$. This operation can be defined either classically as $A \to B \iff \neg A \vee B$ or with any other method proposed in the literature (for example, see [2] for an extensive list of possible implementations).

Any fuzzy conjunction operation can be used as an aggregator to combine the criteria. However, it would be preferable if the aggregator had also compensatory properties. Then the effect of one poorly satisfied criterion would not be so drastic on the result of the aggregation, as it is the case with fuzzy conjunction operators (i.e. t-norms). Mean-based or averaging operators possess this property and therefore we have used them in our work. The OWA operator (ordered weighted averaging), proposed by Yager [3], is particularly useful because the amount of compensation can be adjusted freely.

4 Implementation

The criteria representing a desirable solution in our single machine scheduling or job grouping problem are the following:

Similarity The amount of common components of PCBs in the same group should be maximal.

Urgency Jobs which belong to the same urgency class should be in the same group.

Track widths The conveyor track widths of the PCBs in a group should be equal.

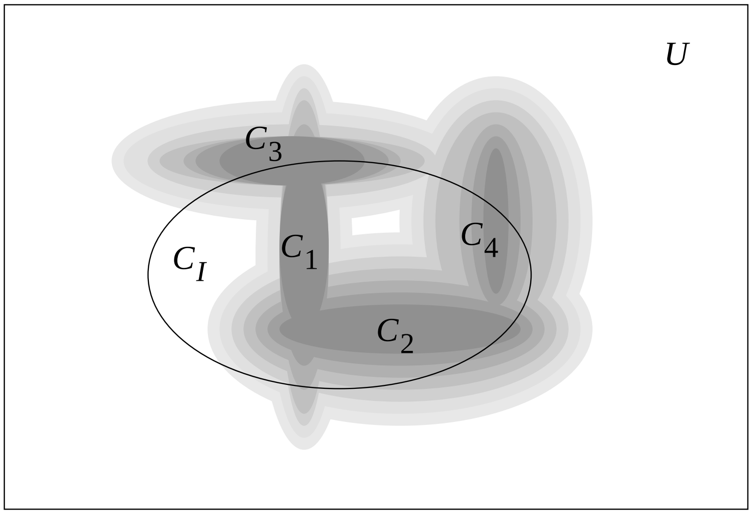

Figure 4: The solution space as fuzzy sets

Double-sided PCBs Opposite sides of a double-sided PCB should be processed in the same group.

Set-up size The amount of components needed for the group set-up should be minimal.

Number of groups The number of groups should be minimal.

Evenness of groups Group sizes should be as even as possible.

Oven temperature Group should comprise only glued or pasted boards.

The primary objective is clearly minimizing the number of groups since the set-up times are the bottleneck of the production. Our first approach was to model also this goal as a fuzzy criterion. The problem, as it turned out, was that the relative importance of the criterion had to be set so high that its weight dominated all the other weights. That in turn narrowed the effective range of the other criteria and their contribution to the solution diminished.

Because we already had efficient heuristics to find a solution which try to minimize the number of groups, we decided to use them to compute an initial solution. We then improve the solution with fuzzy criteria. We could thus fix the number of groups, which made our task much easier. Also, the distribution of weights became more even and the effect of the less important criteria became notable when evaluating our solutions.

In figure 4 the solution space is illustrated as a universe U. The crisp set C_I represents all the possible solutions for which the number of groups is minimal. Inside the universe resides also a group of fuzzy sets which represent the areas in the solution space where the fulfilment of some fuzzy criterion $C_1, C_2, \ldots$ grows. The areas covered by criteria with higher priorities are smaller than the areas of less important criteria. The crisp set C_I overlaps partially the fuzzy sets $C_1, C_2, \ldots$ and thus gives strict boundaries inside which the solution must be found. Therefore, the algorithm which looks for a good compromise has a smaller set of possible solutions to explore since some fuzzy areas are unreachable from the initial solution.

The algorithm can be summarized as follows:

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Solve (heuristically) the grouping with minimal number of groups for
  a given production plan
While solution not desired do
        Improve the solution by considering fuzzy criteria
        Adjust the weights of the fuzzy criteria
Output the grouping
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Because there are aspects in the actual production that even our refined model does not take into account (such as starvation of components), the user can decide the sequence of jobs inside a group him- or herself. Our intention is to extend our system to produce also the sequence of the groups, although the number of groups formed is usually quite small (3–5), and finding an optimal sequence becomes a trivial task.

5 Conclusion

We described in this paper a model which considers single machine scheduling in an actual production plant. Fuzzy theory provides us with a solid framework for modeling, weighting and aggregating multiple and conflicting criteria. The advantage of this model is that it is easy to develop and to update (e.g., to add a new criterion). It also provides us with a simple basis for the design of a graphical user interface: the user can decide the importance of the criteria and therefore influence the forming of the groups. This kind of interactivity was hard to accomplish in the original approach. Also, the user has now a better and more intuitive grasp of the solutions provided by the fuzzy system.

References

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