Applying Fuzzy Multiple Criteria Optimization to PCB Scheduling

Tommi Johtela, Jouni Smed, Mika Johnsson, and Olli Nevalainen

In this paper we describe an actual production environment for *printed circuit board* (PCB) assembly. Our focus is on one of the various work phases of the production line, namely *surface mounting*. In our previous work we have applied heuristic and exact methods for solving the problem. However, it is hard for these methods to account for the existence of several conflicting criteria present in the problem. Therefore, in the present study we apply fuzzy techniques. This approach enables us to analyze the production environment and its properties more closely and to build a more complete but still manageable model of the production process. In addition, the fuzzified criteria correspond more accurately to the requirements of the user.

A typical assembly line for automatic component printing on PCBs comprises several successive work phases. Each PCB goes through a glue dispenser, two surface mounting machines, an oven and a manual insertion phase. 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. The meeting of the due-dates 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. The components are either glued or pasted to the circuit board, and therefore they may require different oven temperatures.

Because the sum of different component types on a PCB is significantly smaller than the capacity of the feeders in the machine, we can choose an appropriate input organization quite freely. 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, oven temperature and the size of the set-up were all ignored. Although the original heuristics improved the actual production radically, further refinements are still needed—and one easy way to include them to the model is to apply fuzzy techniques. The fuzzy approach allows us to build a model which considers all the criteria and, at the same time, remains understandable. As a benefit of this the user has now a much clearer notion of the software model and its operation.

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.

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.

We overcame this problem by using a solution computed by our earlier algorithm as a basis and then improving the solution with a heuristic guided by the 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.

The advantage of the fuzzy 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. The implementation of a flexible and easy-to-use GUI is critical, and 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.