Methods and algorithms of technological preparation for organizing automatic surface mount of printed circuit boards

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Abstract. The production of electronics is largely associated with the development, technological preparation and automatic surface mount of printed circuit boards. The concept of Industry 4.0 and the introduction of digital methods encompass already cover the basic processes of development and production. Technological preparation of production combines both automated operations and manual ones. The quality of manual operations depends on the qualifications and experience of the engineers. The article presents an analysis of technological preparation operations and a methodology for choosing software for design automation based on a multi-criteria model. Particular attention is paid to manual operations. The above algorithms for performing such operations are the basis for their subsequent automation.

1. Introduction

The processes of automation and intellectualization of the development and production of printed circuit boards are constantly evolving and errors due to the influence of the «human factor» are minimized. This is facilitated by the methods and tools of IoT, M2M and other tools presented in the concept of «Industry 4.0» \[1, 2\]. In the field of technological preparation, there are CAD-CAM tools, DFM analysis techniques, and others containing automation tools \[3, 4\], however, a significant part of the operations is performed by engineers manually.

The quality of manual operations depends on their qualifications and experience. The engineer’s actions include analyzing the PCB file received from the customer to adapt to production requirements. When a new project arrives, the PCB engineer must make adjustments to the file if necessary. Table 1 shows the composition of the automated actions of the engineer and performed manually at the stages of analysis of printed circuit boards.

Table 1. Composition of automated and manual operations at the stages of analysis of printed circuit boards and automation tasks.

| Automated Actions | Manual Actions | Necessity and ways of automation |
|-------------------|----------------|---------------------------------|
| Checking gaps between topology elements. | Checking Indentation from Non-Metalized Holes and Board Edges (stage 3) | The stage is not fully automated. Using the DRC, you can check the margins from the edges of the board, but not from non-metallic holes. In the future |

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Checking the minimum conductor width (stage 1)

Development of CAD and CAM systems, this stage can be fully automated.

Short circuit and open circuit test (stage 2)

Placement on the board of reference marks (RP) according to the requirements of production (stage 4)

The stage is completely manual. In the future development of CAD and CAM systems, it is possible to create a function that defines the area that meets the requirements, which will subsequently be allocated for RP placement by the engineer.

Adjusting the vias mask (Opening or closing the mask) (stage 6)

Correction of component pads in SO, TSOP, SOIC, etc. enclosures (stage 5)

The stage is performed manually. The engineer independently searches for components in the indicated cases on the board, checks and corrects if necessary. In the future, you can consider the option of creating a single library and function in design systems, which will determine and automatically correct these components.

Check vias in pads (stage 11)

Site adjustment (replacement to sites from the production library, correction according to datasheet (stage 9)

The stage is automated. However, the engineer needs to change the components in the library manually, and check the automatically replaced seats on the board to avoid errors.

Creating a blank: output of gerberas of a file, multiplication (stage 12)

Moving surface mount components from pin to pin soldering (stage 10)

The step is completely manual. In the future development of design systems, it is possible to create a function that will determine the components located close to the conclusions (set in advance) for selective soldering.

Creating Thermal Barriers (stage 7)

Markup contour processing (stage 13)

To determine the milling contours, there are utilities in the CAM350 program. Part of the contour for scribing is indicated manually. In the future development of CAM systems, it is possible to create a similar function for marking the contour under scribing.

Marking correction (removal from KP, etc.) (stage 8)

The results show that for further automation of the technological preparation of production, it is necessary to improve operations based on the choice of CAD-CAM tools, to analyze manual operations, their formalization and algorithmization. Automation problems can be sequentially solved based on the developed algorithms.

2. Choice of CAD-CAM software based on a multi-criteria model

In the process of analyzing a new project and making adjustments to it, it becomes necessary to determine the software for work. Since developers work in different CAD systems, the task of choice is complicated [5]. In the article, as an example, the software was selected from the PCAD, Altium, CAM350 based on the multi-criteria TOPSIS model. Presented programs are the most popular design environments. The following parameters were selected as criteria: performance, the possibility of inconsistencies, the convenience of the interface. When constructing a matrix of alternatives and criteria, the opinion of experts was used. They were asked to give scores from 1 to 4 according to the ordinal scale presented in table 2.

| Productivity (K) | 1 - significant time costs are allocated for the stage |
|------------------|-------------------------------------------------------|

Table 2. Scale for evaluating alternatives relative to the criteria.
2 - the average time costs are allocated for the stage
3 - small time costs are allocated for the stage
4 - insignificant time costs are allocated for the stage

The possibility of inconsistencies
(N) 1 - the probability of inconsistencies is very small
2 - the probability of inconsistencies is small
3 - high probability of inconsistencies
4 - most likely inconsistencies

Interface convenience (I) 1 - performing actions in this software is very inconvenient
2 - performing actions in this software is not convenient
3 - perform actions in this software conveniently
4 - to perform actions in this software is most convenient

After normalization, the matrices filled by the expert were determined and presented in Table 3, the weights of the criteria by the method of analysis of Saati hierarchies [6].

| Stages | Criteria | Alternatives | PCAD | ALTIUM | CAM350 | PCAD & CAM350 | Altium & CAM350 | Weight of criterion |
|--------|----------|--------------|------|--------|--------|--------------|-----------------|-------------------|
| Stage 1 | K        | 0.00121      | 0.00121 | 0.00121 | 0.00121 | 0.00121     | 0.01254         |
|        |          | 0.00097      | 0.00097 | 0.00193 | 0.00097 | 0.00097     | 0.04027         |
|        | I        | 0.00057      | 0.00057 | 0.00043 | 0.00057 | 0.00057     | 0.00590         |
| Stage 2 | K        | 0.00094      | 0.00094 | 0.00094 | 0.00094 | 0.00094     | 0.00979         |
|        |          | 0.00381      | 0.00190 | 0.00381 | 0.00190 | 0.00190     | 0.07922         |
|        | I        | 0.00040      | 0.00040 | 0.00040 | 0.00040 | 0.00040     | 0.00420         |
| Stage 3 | K        | 0.00022      | 0.00067 | 0.00067 | 0.00067 | 0.00067     | 0.00927         |
|        |          | 0.00061      | 0.00061 | 0.00061 | 0.00061 | 0.00061     | 0.02551         |
|        | I        | 0.00017      | 0.00051 | 0.00034 | 0.00051 | 0.00051     | 0.00712         |
| Stage 4 | K        | 0.00093      | 0.00093 | 0.00062 | 0.00093 | 0.00093     | 0.01290         |
|        |          | 0.00319      | 0.00319 | 0.00319 | 0.00319 | 0.00319     | 0.06639         |
|        | I        | 0.00031      | 0.00031 | 0.00021 | 0.00031 | 0.00031     | 0.00429         |
| Stage 5 | K        | 0.00299      | 0.00299 | 0.00224 | 0.00299 | 0.00299     | 0.03108         |
|        |          | 0.00123      | 0.00123 | 0.00369 | 0.00123 | 0.00123     | 0.05121         |
|        | I        | 0.00040      | 0.00040 | 0.00020 | 0.00040 | 0.00040     | 0.00416         |
| Stage 6 | K        | 0.00161      | 0.00161 | 0.00121 | 0.00161 | 0.00161     | 0.01678         |
|        |          | 0.00065      | 0.00065 | 0.00195 | 0.00065 | 0.00065     | 0.02708         |
|        | I        | 0.00089      | 0.00089 | 0.00044 | 0.00089 | 0.00089     | 0.00926         |
| Stage 7 | K        | 0.00246      | 0.00246 | 0.00123 | 0.00246 | 0.00246     | 0.02556         |
|        |          | 0.00192      | 0.00192 | 0.00576 | 0.00192 | 0.00192     | 0.07986         |
|        | I        | 0.00042      | 0.00042 | 0.00021 | 0.00042 | 0.00042     | 0.00432         |
| Stage 8 | K        | 0.00042      | 0.00042 | 0.00166 | 0.00042 | 0.00166     | 0.01732         |
|        |          | 0.00260      | 0.00260 | 0.0130  | 0.00260 | 0.0130      | 0.02704         |
|        | I        | 0.00010      | 0.00010 | 0.00039 | 0.00010 | 0.00039     | 0.00409         |
|        | K        | 0.00252      | 0.00252 | 0.00063 | 0.00252 | 0.00252     | 0.02626         |

Table 3. Normalized, weighted matrix of parameters and alternatives.
Further, criteria for positive and negative impact were identified. The possibility of occurrence of defects was considered as a criterion of negative impact, the rest of the positive. It is necessary to determine the solution vectors using formulas 1, 2 to calculate the distance from ideal solutions.

\[
p_i^+ = \left\{ \left( \max p_{i j}, j \in J \right) \lor \left( \min p_{i j}, j \in J' \right) \right\}
\]

\[
p_i^- = \left\{ \left( \min p_{i j}, j \in J \right) \lor \left( \max p_{i j}, j \in J' \right) \right\}
\]

where \( P_i \) is the ideal positive and ideal negative decision vector for each criterion, \( p_{ij} \) is the weighted normalized estimate of the alternative with respect to the criterion, \( J \) represents the criteria for positive impact, and \( J' \) represents the criteria for negative impact. As a result of applying the multicriteria model, the data presented in table 4 were obtained.

**Table 4. Distance position of alternatives relative to ideal values.**

| Parameter                              | Software                                      |
|----------------------------------------|-----------------------------------------------|
|                                        | PCAD  | ALTIUM | CAM350 | PCAD & CAM350 | Altium and CAM350 |
| Measure of distance from a positive ideal solution (\( S^+ \)) | 7,903*10^6 | 4,144*10^6 | 11,551*10^6 | 0 | 0 |
| A measure of the distance from a negative ideal solution (\( S^- \)) | 23,625*10^6 | 18,334*10^6 | 38,482*10^6 | 1,670*10^6 | 0 |
| Proximity coefficient with the perfect solution (\( D_i \)) | 0,749 | 0,816 | 0,769 | 1 | 1 |

Table 4 shows that the proximity of the alternatives relative to the ideal values of the program combinations has a coefficient of 1. This means that within the framework of the multi-criteria model under consideration, these alternatives are ideal. However, when analyzing the distance from the negative ideal solution, you can see that the combination at number 4 is inferior to the combination at number 5. These values are explained by Altium’s more options when designing and making changes to the board file.

In addition, Altium’s DRC system is more reliable and can control more parameters than PCAD. It should be noted that the DFM analysis process is currently partially automated, as shown in table 1. There are still many labor-intensive steps that are performed manually by an engineer. To speed up the
process of adapting printed circuit board topology to production requirements, it is necessary to improve design systems and increase the level of automation at each stage.

3. Prospects for the development of CAD systems
The development of CAD systems is carried out in different directions, and their review and analysis is a separate task. The following are formalized manual operations and algorithms for subsequent automation are presented.

3.1. Checking indentation from non-metallic holes and board edges
At the moment, in the CAM350 program, it is possible to check the distance of topology elements from the edges of the board, however, the distance from non-metallized holes is checked manually. Figure 1 shows the automation algorithm for this stage.

![Automation Algorithm](image)

**Figure 1.** Automation algorithm for checking indentation from non-metallized holes.

3.2. Placing reference marks on the board
The time to install the RE varies depending on the density of the elements of the topology. Sometimes reference marks cannot be installed on the board. You can automate this process by creating an option to search for a place that matches the specified restrictions. The algorithm of actions of this option is shown in figure 2.
3.3. Correction of component pads in SO, TSOP, SOIC, etc.

In the process of manufacturing printed circuit boards, a distance (usually at least 0.15 mm.) is imposed on the distance between the terminals associated with the implementation of mask jumpers. The presence of the latter is necessary for automatic installation, so that the paste does not spread beyond the limits of the KP and does not form solder bridges. This process can be automated as shown in figure 3.

Figure 2. Algorithm for automating the installation of reference marks on a printed circuit board.
Beginning of component repair in SO, SOIC packages, etc.

Definition of components in packages of interest

pin spacing

Yes

Distance less than required

No

Reducing the pad by the required value is possible

Yes

pad reduction

No

Informing the user about the impossibility of reducing the pad

Verification Completion

Figure 3. Automation algorithm for correcting KP in SO, TSOP, SOIC, etc.

3.4. Adapting topology for selective soldering

This stage is one of the most time-consuming and requires significant time costs for large boards. Automation of these processes takes place at the stage of analysis, since when moving a component, it is necessary to take into account many random parameters. Some conductors can change their shape by creating multiple kinks.

The algorithm for the automated search for SMD components located too close to the terminals of selective soldering is shown in figure 4.

Start adapting topology for selective soldering

Through-hole authentication

Identification of SMD pads

Yes

The distance between the SMD pad and Through-hole 1 is > 2 mm.

Verification Complete

No

Select component

Figure 4. Algorithm for automating the process of adapting a board for selective soldering.
3.5. Marking the contour processing
The milling contour marking process is automated in CAM350 and is set using the GerbertoMill utility. However, scribing is done manually by the engineer.
This process can be automated by the example of milling designation by creating a utility (figure 5).

![Diagram of marking process]

Figure 5. Algorithm for automating the process of marking the contour.

4. Conclusion
The considered method for choosing automation tools for technological preparation of printed circuit board assembly is based on a multi-criteria model and can be extended to advanced CAD-CAM and DFM tools. The manual operations formalized as algorithms can be automated. This can be achieved by creating menu prompts and the corresponding DB and KB. Known, including those proposed by the authors [7] neural learning networks and fuzzy classifiers and regulators can be used to automate technological preparation and ensure the quality of production.

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