Models for formation and choice of variants for organizing digital electronics manufacturing

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Abstract. The directions of organizing digital electronics manufacturing are considered by the example of surface mount technology. The basic equipment choice has to include not only individual characteristics, but also mutual influence of individual machines and the results of design for manufacturing. Application of special cases of the Utility function which are complicated in the general representation of polynomial functions are proposed for estimation of product quality in a staged automation.

1. Introduction
Surface mount technology (SMT) is the main technology for electronics manufacturing. The production line for automatic SMT usually includes the following main equipment:

\begin{itemize}
  \item loader;
  \item conveyor;
  \item printer;
  \item solder paste inspection;
  \item automatic placement machine;
  \item identifier;
  \item oven;
  \item automatic optic inspection;
  \item board handling.
\end{itemize}

The necessity of constant quality improvement, the shortening of the development, development and serial production of electronics leads to the need to create a technology for digital product modeling, starting with the development of the electrical circuit. Such digital model will be consistently transformed at subsequent stages of the life cycle. The phased automation of all operations based on technological innovation and the minimization of the human factor will lead to the creation of an end-to-end digital cycle of development and production.

It should be noted that the selected type of contract production and development of electronics provides for the possibility of starting the end-to-end digital cycle not only from the schematic solution, but also from the finished circuit, GERBER file, PCB file, etc.
The formation of options and the choice of the optimal composition of equipment in terms of local
criteria and the criterion for the final choice depends on the goal. The goal corresponds to the level of
automation of all operations that must be achieved. Different levels of automation of the digital
development-production cycle are matched by models that take into account both the independent
influence of each piece of equipment on the product quality and the importance of simultaneous
presence of two or more criteria.
The line of automatic SMT mounting is a high-tech object of constant innovation improvement.

2. **Levels of automation for quality assurance**

A necessary condition for the functioning of the line is the compatibility of equipment at the
mechanical, electrical, software levels. The characteristics of accuracy, productivity determine the
applicability for the installation of printed circuit boards of various complexity and composition of
components.

At a low level of automation or in the initial assessment of the composition of equipment, the
mutual influence of individual components is not taken into account when constructing a quality
assessment model.

Currently, for most automatic SMT installation lines, SMEMA (IPC SMEMA 9851) requirements
are met [1]. The standard specifies the requirements for the mechanical interface of equipment for the
transition of the "machine-to-machine" board in surface-mounted PCB manufacturing systems. The
minimum requirement is that the equipment from the conveyor to the conveyor must meet the "input-
output" requirements. Compliance with the standard is achieved by the appropriate design of the
equipment or the provision of special adapters that allow the equipment to comply with the standard.
The electrical interface "from machine to machine" provides the correct sequence of printed circuit
boards. The interface implements local management. The account of mutual influence is achieved by
introducing the importance factors of the simultaneous presence of two criteria corresponding to the
neighboring equipment units in the conveyor.

The requirements of the SMEMA standard are not sufficient to improve product quality and SMT
line performance. Innovative development of the technology is implemented by introducing standards
that bring production closer to the digital structure of data exchange and management, and the
introduction of design for manufacturing methods (DFM).

The new standard "The Hermes Standard" [2] designed for vendor independent machine-to-
machine communication in SMT Assembly. This standard’s aim is to replace the electrical SMEMA
interface extending the interface to communicate:

- unique identifiers for the handled printed circuit boards (PCBs),
- equipment identifiers of the first machine noticing a PCB,
- barcodes,
- conveyor speed,
- product type specific information.

An important direction of innovative development of SMT technology is the mastering of DFM
methods as a component of the end-to-end process of digital development and production of
electronics and, in the long term, the whole process. For the Russian market, this is due to errors in
design documentation (DD) and discrepancies between DD and technology. The electrical circuit is
carried out with the help of circuit design tools in PCAD. The output of the end-to-end design process
is the PCB file. Design tools for production (DFM) provide the elimination of inconsistencies in
accordance with the requirements of IPC standards during this process. DFM tools are associated with
specially created databases or are represented by such powerful products as MENTOR, VayoPro-DFM
[3-5].

The evaluation of product quality, taking into account the set of factors for improving equipment,
the end-to-end digital design-production process, internal adaptation within the conveyor line and
other components inherent in the strategy "Industry 4.0" [6] leads to the need for a more complex
model.
3. The formation of optimal solutions and the final choice of equipment

Multicriteria tasks in which one has to choose the best option \( x \) from a set of feasible solutions \( X \), where the variants differ by several criteria \( \{ f_i(x) \} \), include an assessment of the significance of these criteria and the ranking of alternatives. There are various methods for solving similar problems, they are described in more detail in [7-11].

Formation and selection are carried out in 2 stages. At the first stage, the optimal options from all the alternatives provided are determined. In the second stage, the selected alternatives are evaluated according to the priority number of risk (PRN) criterion, and the best solution is chosen based on this. The proposed approach consists in combining methods for determining weight coefficients, this allows to minimize the subjective factor in the evaluation of alternatives. The method also allows for the importance of simultaneous presence of several criteria. This means that the simultaneous presence of two, three or more criteria will ultimately contribute significantly to the evaluation of the utility function, a synergistic effect will be taken into account.

As a utility function, in the general case, a multilinear function of form (1) is used. This function is applicable for several criteria and is a generalization of the additive and multiplicative functions [12]:

\[
F(x) = \lambda_1 f_1(x) + \sum_{j=2}^{n} \sum_{k_{1,j}} \lambda_{jk} f_{jk}(x) + \sum_{j=2}^{n} \sum_{k_{1,j}} \sum_{l_{j}} \lambda_{jkl} f_{jkl}(x) f_{j}(x) f_{k}(x) f_{l}(x) + \lambda_{n+1} f_{n}(x) f_{n+1}(x) \ldots f_{n}(x),
\]

(1)

where \( f_j(x) \) - particular criterion; \( \lambda_j \) - coefficient of relative importance (significance) of criterion \( f_j(x) \); \( \lambda_{jk} \) - coefficient of joint importance of criteria \( f_j(x), f_k(x), f_l(x) \) for \( \sum \lambda_j = 1 \); \( F(x) \) - utility function or quality criterion of the chosen alternative.

Let us consider the case when each criterion considered independently affects the value of the utility function and does not take into account the coupled influence of particular criteria. This case corresponds to the additive form of the linear convolution of the vector criterion. It consists in the fact that utility function \( F(x) \) is formed in the form of a sum of particular criteria, taking into account weight (the coefficient of relative importance of the criterion) \( \lambda_j \) of each of them (2):

\[
F(x) = \sum_{j=1}^{n} \lambda_j f_j(x),
\]

(2)

where \( F(x) \) - utility function; \( \lambda_j \) - coefficient of relative importance criteria, such that \( \sum \lambda_j = 1 \); \( f_j(x) \) is a particular criterion.

Weight coefficients \( \{\lambda_j\} \) in formulas (1, 2) will be determined by statistical methods and \( \{\lambda_{jk}\} \) by expert ones. Statistical methods allow one to determine the values of weight coefficients without the participation of experts. As a statistical method, it is proposed using the method of partial statistics [7]. This method allows us to determine weight coefficients \( \lambda_{j} \) from the variance of particular criteria \( \{f_j(x)\} \):

\[
\lambda_j = \frac{\sigma_j}{\sum \sigma_j}, \quad \sigma_j = \left(\frac{1}{N-1} \sum_{i=1}^{N} \left(f_j(x_i) - \overline{f_j_{\text{cent}}}(x_i)\right)^2\right)^{1/2},
\]

(3)

where \( f_j(x_i) \) is the value of the normalized \( j \)-th partial criterion for the \( i \)-th object; \( f_{j\text{\text{cent}}} \) - mathematical expectation for the \( i \)-th criterion; \( N \) - the number of objects; \( \sigma_j \) - the standard deviation of the \( j \)-th criterion.
In the case when each criterion is considered independently affects the value of the utility function and does not take into account the joint effect of the particular criteria, function (2) is used. Weight coefficients \( \{ \lambda_k \} \) will be determined by the expert method because only an expert can assess the importance of simultaneous presence of several criteria. To do this, the expert compiles matrix \( A = (b_{ij}) \), where \( b_{ij} \in [0;10] \), the importance of simultaneous presence of several criteria is compared in pairs. Value "0" indicates that the criteria are not important in the aggregate; "10" - in the aggregate criteria are very important. Matrix \( A \) is normalized by condition \( \lambda_k = b_{ij} / \sum b_{ij} \).

For the final choice of the optimal solution, it is suggested to use the method of Failure Mode and Effects Analysis (FMEA) [14], FMEA allows one to analyze potential inconsistencies and take actions to eliminate or reduce the probability and damage from their appearance by making changes to the process plan for technological operations.

For the quantitative assessment of risks, the priority number of risk (PRN) is used based on an expert assessment of the severity of the consequences, the probability of occurrence and the level of detection of non-compliance:

\[
PRN = S \cdot O \cdot D,
\]

where \( S \) is the severity of consequences, i.e. the extent to which the inconsistency affects the process; \( O \) - the probability of inconsistency for a given or established period of time; \( D \) is the value characterizing the detection of non-compliance.

The expert group compiles a list of inconsistencies / reasons for which the value of the PRN exceeds a preset threshold. For them it is necessary to improve the process.

The main stages in carrying out FMEA analysis can be identified as the following [14]:

- Identification and compilation of a list of potential types of defects / errors / inconsistencies;
- Identification and compilation of a list of causes and consequences of potential defects / errors / inconsistencies;
- Calculation of the priority number of risks for this potential type of defects / errors / inconsistencies.

The lower the value of PRN compared to the assigned threshold, the more reliable and less risky the alternative is.

4. Conclusion

The methods and tools currently used in the organization of digital electronics manufacture do not form an end-to-end digital process. The SMEMA standard provides only mechanical and electrical interfaces, the HERMES standard describes more opportunities. The proposed models for estimating and selecting options can be applied as the electronics production, which becomes more complex with digital components for both internal adaptation and automation, and for direct communication with the results of the DFM methods. The complication of the organization of production must be accompanied, when applying the proposed approach by evaluating the joint influence of factors. This will allow one to assess more accurately the quality of products based on a more complete use of a polynomial function that represents quality in terms of the utility function.

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