Synergy of QFD and FMEA methods to improve workplaces in aircraft wire manufacturing

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Abstract. The integration of QFD and FMEA methods for improving workplaces is considered. The use of priority calculations in the QFD method in matrix form facilitates integration with the FMEA risk analysis method. An example is given of improving the workplaces of supporting operations in the manufacture of dual-use wire & cable products. It is proved that the direction of improving the activities and workplaces in the enterprise management system, determined on the basis of the proposed synergistic FMEA and QFD methods, is an innovative way of developing a wire & cable manufacturing.

1. Introduction
Aviation airborne wire is a product that has special requirements due to the specifics of operation. Designed for power and control circuits of instruments and electrical equipment installed on board an aircraft, such a wire must combine high reliability and the lowest possible weight and dimensions, as well as have properties that exclude the possibility of damage during installation and during operation (increased resistance to bending, abrasion and bursting). One of the innovative and promising developments in the aerospace and automotive industries is the Spec55 series wires. They have proven themselves well in many aviation programs around the world, from small businesses to such global giants as Boeing and Airbus.

The importance of using modern quality management tools, including the concept of "Lean Manufacturing" in the development of innovative products and technologies, is determined by the long-term practice of the best enterprises and international management standards in the automotive and aviation industries. However, in Russia, such tools as quality function deployment (QFD) and failure mode and effects analysis (FMEA) have so far found a superficial application and their role in the development of innovations and implementation of lean production is underestimated [1–3]. There has been unacceptably little emphasis on deploying and applying these tools to deliver the right quality right in the workplace.

In the generally accepted sense, innovation is an implemented innovation in the field of technology, technology, labor organization or management, based on the use of scientific achievements and best practices, providing a qualitative increase in the efficiency of a system or the quality of products and
services. The structure of innovations of Russian enterprises practically does not change from year to year — the greatest attention is paid to the acquisition of machinery and equipment (Figure 1).

Small improvements (kaizen) can be developed both on a planned basis and as a result of FMEA in the form of measures such as finalizing the equipment, introducing error protection elements (poka-yoke), introducing the "Sequencing" system (5S), etc. Innovations, including radical changes in the management and infrastructure of the organization (the introduction of technologies, automated control systems and world-class equipment), can be developed as a result of the implementation of the QFD method.

![Figure 1. Innovative directions at JSC "SCC".](image)

A methodology for the systematic and structured transformation of customer requirements into product requirements and the further deployment of requirements down to the workplace with the least risk is a modern instrumental way of developing innovations.

2. Examples of the implementation of modern approaches to quality assurance in the aerospace industry

2.1. Structuring and deploying customer requirements

The quality function deployment (QFD) method, along with planning experiments and other methods, is an element of the modern approach to quality management "Big Q" [1, 7]. Despite the fact that the QFD method has long been used by various companies in Japan and the USA, and is widely implemented in Europe, it can be noted that approximately 80% of publications on Russian devoted to its implementation contain descriptions of only Level I QFD.

The QFD method is implemented using a matrix diagram, the so-called House of Quality (HOQ). In its expanded form, QFD includes four phases, and for each of them its own HOQ is built. After converting consumer characteristics into technical ones (phase No. 1, QFD level I), the latter are converted into characteristics of components (phase No. 2, QFD level II), then into process parameters (phase No. 3, QFD level III), and then into requirements to the execution of operations (phase 4, QFD IV level).

The absolute values of the characteristics' priorities in matrix form are determined by the formula:

\[ \Theta = H^T \times P, \]

where \( H^T \) is the transposed matrix of relationships (for QFD I level — the transposed matrix of relationships between consumer and technical characteristics); \( P \) — vector of weights (for QFD I level — vector of weights of consumer characteristics).

2.2. Risk analysis method

Risk analysis using the failure mode and effects analysis (FMEA) method is carried out to analyze potential inconsistencies, their causes and consequences, assess the risks of their occurrence and take measures to eliminate or reduce the likelihood of damage from their occurrence [5, 6]. This is one of the most effective methods for finalizing the design of technical objects and their manufacturing
processes at such critical stages of the product life cycle as its development and preparation for production.

In the automotive industry, the most common FMEA for design, process and equipment. In this case, the risk is assessed according to the value of the Risk Priority Number (RPN), which is a generalized quantitative characteristic of the nonconformity, taking into account its significance and the likelihood of occurrence and detection of the cause of the nonconformity. A significant drawback of the FMEA process in practical application is that often the production and support operations are not clearly separated or the support operations FMEA is not carried out, since they are often considered not adding value and not requiring attention.

2.3. Integration of QFD and FMEA methods
When implementing the QFD method in the development of new or modernization of existing products, it is proposed to use the results of FMEA analyzes of similar products and processes, expertise of experience and knowledge.

Thus, when the QFD and FMEA methods are used together, a synergistic effect is achieved and the development of innovative products and technological processes is carried out taking into account the risks. The absolute value of the priority of the characteristic using the results of the FMEA methods in the QFD I level (transformation of requirements and expectations of consumers into technical characteristics of products) is calculated in matrix form, taking into account the risk assessment:

$$\Theta = H^T (P \times R^T),$$

where $H^T$ is the transposed matrix of the relationship between characteristics and requirements; $P$ — vector of requirements weights; $R$ is the vector of risk assessments.

This approach is extended to the rest of the QFD phases (levels II, III, and IV). This paper presents the results of the implementation of QFD and FMEA methods at level IV (transformation of process parameters into requirements for the execution of operations) - in order to ensure quality directly at the workplace, taking into account measures for the introduction of lean manufacturing technologies.

3. Application of integration of QFD and FMEA methods to improve the efficiency of workspaces of supporting operations in Aircraft Wire Manufacturing
The workplace can be considered as a sub-process of the organization's production process with the application of management functions to it and, therefore, the implementation of the process approach is the basis for the implementation of methods for improving the workplace, in particular, lean manufacturing methods. The workplace is a link in production, the organization and equipment of which determines the efficiency of the use of material and labor resources. Opportunities to reduce waste in the workplace can be found in avoiding overuse of resources. Proceeding from this, the reserves of increasing the efficiency of the use of jobs should be understood as the possibility of using jobs with the use of more economical methods, which, in fact, are the methods of lean production.

In the modern sense in the framework of the process approach, the term "workplace" means: an organizationally indivisible element of an enterprise, in which the forces of one or more employees perform the specified operations of the business process in accordance with the requirements of the consumer. Workplace activities can be viewed as a process model with the allocation of three groups of processes: production, support and management. Manufacturing processes form the foundation for the formation of product value and determine the outputs of the organization. These processes are strategically important to the organization's successful business and directly affect customer satisfaction. In contrast to manufacturing, supporting processes and management processes only indirectly add value to products.

The standard lean approach is to reduce the time for operations that do not add value to the customer. We have analyzed the workplaces of the process of "Production of automotive cable" and "Production of aerospace wire&cable" from the point of view of actions that add and do not add value for the consumer. As a result, it was revealed that only individual actions create value that is important.
for the consumer. A number of other actions are also needed, although they do not create value. For example, a crimper must change the output and take-up drums and clean the forming head.

From the point of view of the new approach, the task is to spend as little time as possible on actions that do not add value to the product, but without losing the accuracy of meeting requirements and without risk. This is achieved by integrating the QFD and FMEA methods for the workplace.

The most critical stage that determines the quality and performance of the wire is the process of applying insulation to the copper conductor - extrusion. Insulation is carried out on a complex machine called an extrusion line. The most important part of the extrusion line is the die. It is designed to apply insulation consisting of the following elements: inner layer, outer layer, one or more strips of auxiliary color, or surface painting of the outer layer of insulation. A sketch of the extrusion unit is shown in Figure 2a. The appearance of the main element (mandrel) is shown in Figure 2b.

![Figure 2a](image1)

**Figure 2.** Extrusion head: (a) sketch of the cross-section of the extrusion head; (b) mandrel.

During operation, the mass from the main extruder A flows along the splitter shaft (pos. 1) between the intermediate matrix (pos. 2) and the matrix (pos. 3), forming the outer layer (the main color of the insulation). The mass from the auxiliary extruder C is supplied to the main mass flow through the channels of the strip die (pos. 4) between the intermediate die and the die (pos. 2 and 3). The inner layer consists of the mass of extruders B and D. These two mass flows are combined in the channels of the splitter shaft (pos. 1) and are directed to the core between the mandrel (pos. 5) and the intermediate die (pos. 2). The inner layer has a mixed color B and D. The die screw (pos. 6) is used to adjust the die position (pos. 3) — the gap between the die and the intermediate die. The feed channels of the mass from a pair of extruders A, C and B, D run symmetrically along the splitter shaft, therefore the insulation layers (inner and outer) are changed by turning the camshaft by 180°. During the color change, pressure peaks are observed in the die. These peaks are absorbed by two discharge chutes on the splitter shaft, from where material exits the head through two discharge holes.

The mandrel hole diameter (Figure 2) is a geometric characteristic that affects the quality of the insulation application, ensures its concentricity. The diameter of the mandrel hole is measured using a Large Instrumental Microscope (BMI-1). The resolution of the measuring instrument is 0.005 mm.

A risk analysis was carried out using the FMEA method for both production and support operations carried out at the workplace of the pressure operator. The values of the RPN have been determined for each type of potential nonconformity. In accordance with the requirements of consumers with a RPN > 100, corrective actions have been developed to reduce this indicator.

Subsequently, when conducting a Level IV QFD for a pressure operator's workplace, the participation of adjusters, mechanics, power engineers and electronics in ensuring the effective functioning of the production process, as well as the results of FMEA of supporting operations, was also taken into account. The results of QFD (Figure 3) demonstrate that the greatest influence on the parameters of the technological process of applying insulation to a conductive conductor is exerted by: no temperature difference between mandrel and mandrel when cleaning the extruder head by an operator.
Figure 3. Application of the integrated method for the workstation of the pressure operator.

A study of the operating instructions of the operator and the adjuster was carried out, taking into account the risks, importance and influence of these supporting actions on the parameters of the technological process and, ultimately, on the quality of the finished product. Innovative transformations, including the revision of operations and the development of modern illustrated work instructions, allowed CJSC “SCC” to significantly reduce the level of external defectiveness and polyethylene waste (Figure 4).

Figure 4. Dynamics of improvements: (a) external defectiveness, ppm, (b) reduction of polyethylene waste.

As a result of improving workplaces, taking into account the risks identified for the supporting operations, the so-called “non-value-adding” in lean manufacturing, we received a reduction in the cost of performing actions that do not add value to the consumer:

- workplace of a pressure operator for wire — 17.4%.
- workstation of the operator: combined process of drawing copper wire and applying insulation — 18.7%.
- workstation of the twist: twisting of 5 (10) paired bundles — 8.6%.
The presented model is based on a new approach to the design and manufacture of products —
bionic design and on approaches to long-term planning of product quality adopted in the aerospace
industry. The model is aimed at reducing costs and non-production losses both at the early stages of
design and at the stages of production and testing, based on modern QFD and FMEA quality assurance
methods and additive production approaches.

4. Conclusions and discussion
The use of QFD and FMEA quality management methods in the development of innovative
wire&cable products has been substantiated. Structuring the requirements and expectations of
consumers to determine the key innovative characteristics of products, as well as the parameters of
technological processes to determine the key innovative technologies based on these methods, increase
the efficiency of choosing direction for improving workplaces.

It is proved that the direction of improving the activities and workplaces in the enterprise
management system, determined on the basis of the proposed synergistic FMEA and QFD method, is
an innovative way of developing a wire&cable manufacturing. This gives the enterprise great
opportunities in a competitive environment.

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