Functional product map design in lifting and transportation machine building digitalization conditions

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Abstract. In the Industry 4.0, mechanical engineering is undergoing major changes. Combining industry and digital technologies for the flexible and efficient production creating is a main idea of the Fourth Industrial Revolution. The article proposes a high-tech product functional map designing approach based on the author's functions classification, taking into account the specifics of products designed within the Industry 4.0 framework. Based on the warehouse floor transport market trends study, as well as the forklifts consumers survey results, a functional map of a product designed at the Russian lifting and transport engineering enterprise was proposed.

1. Introduction
The transition to Industry 4.0, as a means of the manufacturing industry competitiveness increasing, has been started in many countries all over the world. The Fourth Industrial Revolution aims to combine industry and digital technologies to create flexible and efficient goods production and high-quality services with the lowest cost [1]. This transition will make the market more personalized through the development and production of products individually for each customer.

Certainly, according to the Industry 4.0, not only mechanical engineering as a whole becomes a subject for a huge transformation, but also its subindustries are involved in this process (for example, the lifting and transport engineering). Consumers of this industry are increasingly in need of automated technology that can carry out logistics operations with the least human participation. So, automated storage and retrieval systems (AS/RS) of industrial, and then trading enterprises became a development trend since 1970s and continue their transformation until now [2]. A huge variety of equipment and its models are used for charging and discharging operations: trolleys, forklifts, trucks, reach trucks, etc. Consumer’s requirements for equipment used in such warehouse complexes are the possibility of integration into warehouse system, the long-term battery life, complex operations automation functions (necessary to prevent the emergencies), etc. The increasingly complicated functionality of lifting and transportation equipment requires manufacturers of new flexible design methods, taking into account the customer’s individual requirements.

This article proposes high-tech product functional map designing approach based on the author's functions classification. This classification takes into account the specifics of products designed within the Industry 4.0 framework. As an object of investigation, the electric forklift is considered.

2. Research method
One of the main approaches for forming the greatest products value with the lowest costs at the designing stage is value engineering [3]. Value engineering determines the product’s functional structure, which
is necessary for the formation of the product’s consumer value [4]. This analysis involves functional map designing (including external and internal product functions), relationships and links between functions based on a functional approach.

Functional map designing is one of the most difficult tasks, because on the one hand, it should ensure the product competitiveness in terms of “price-quality” ratio, on the other hand, a rationally designed functional map will gives opportunities for the further product improvement with the lowest modernization cost.

To design a functional product map, it is necessary:
1. Product operating conditions have to be determined. For lifting and transportation equipment, this is the general organization characteristic (activity scope, cargo turnover, average weight and dimensions of the transported cargo, etc.); warehouse parameters; used equipment and its technical characteristics; operation simplicity evaluation of lifting equipment.
2. A list of the main technical characteristics have to be determined. These characteristics are important for consumers, according to this list consumers make a decisions about the brand and model of lifting equipment.
3. Technical characteristics of competitor products have to be analyzed.
4. The lifting equipment basic model characteristics have to be established as well as the optional parameters that increasing consumer properties and the product price.

Once all the necessary parameters for the designed product have been set and the function carriers have been defined - product design elements (parts, assemblies, aggregates, etc.), it is necessary to formulate functions that indirectly or directly will create the product’s consumer value. All functions performed by the object and its components are formulated based on the definition that "function" is the content of the action or process for which the product is intended, as well as from the position of execution and providing them with the required consumer properties [5].

![Figure 1. Product function classification.](image)

After the product functions complete list is ready functions have to be divided into the main classification groups, which allow to describe the product and its component elements purpose and functioning, as well as their interaction with the external environment - the lifting equipment operator and the warehouse complex as a whole. The authors propose the following functions hierarchy (figure 1), which allows to describe a complex product and to realize the effective modernize it the functional or process areas.
All functions of a complex product can be divided into 2 groups, which in turn are also divided into their constituent subfunctions.

The chief function is a function that reflects the purpose of an object (the purpose of its creation). It answers the question what the object is doing or what the object is for [6].

Secondary function is a function that provides the consumer properties of an object together with the chief function. It answers the question how an object interacts with the external environment, performing the chief function.

All secondary functions can be divided into:

- ergonomic - functions that create convenient conditions for operator;
- aesthetic - functions that create a person's perception of an object (appearance);
- ecological - functions preventing environmental damage;
- safety - functions that create conditions for the object’s (and its components) safe operation during its interaction with the external environment;
- external system integration - functions that allow to integrate the product into the warehouse complex information system.

The core functions are functions that contribute the chief function implementation through the work execution.

Ensuring functions - functions that allow to ensure the object serviceability, creating the necessary conditions for the chief function implementation.

Subsidiary functions - functions that allow to perform a top-level function. Functions that reflect actions and relationships within an object, due to the construction principle, execution peculiarities. Answer the question how (technologically, structurally) the main function is implemented [6].

Industry 4.0 focuses on production digitalization associated with large data base that need to be read, collected, analyzed, systematized, processed, stored, transmitted, presented and much more [7]. Consequently, the authors singled out the secondary functions category: "external system integration," as well as a separate group of "managing functions".

Managing functions - functions that allow to control the functions interaction both on the same level and on different levels (upper and lower).

Basic and supporting functions description will allow to detail the functional model up to the second level, description of subsidiary and managing functions- up to the third level. Therefore, proposed functions' classification for the high-tech product a will allow to design both the basic and optional product concept, taking into account both internal and external working conditions.

3. Results

The respondents’ questionnaire survey (the structure of the companies participating in the survey is presented in figure 2) showed that recently there has been a to warehouse complexes automation level increasing tendency.

![Figure 2. Target focus group structure.](image-url)
The intra-warehouse floor-type transport market increasingly requires unmanned vehicles that are able to partially or completely replace the operator’s work, that reduces costs, while increasing the speed and accuracy of order processing. Many foreign manufacturers offer automated analogues for the existing models of lifting equipment on the market, for example, Linde and Jungheinrich. So, 90% of the organizations participating in the survey have the warehouse information system installed. The examples of such systems are: Warehouse Management System, Logistic MANAGER 8, Axapta, 1C Warehouse Management and others. 50% of respondents have fully or partially integrated forklifts into this system. The result confirmed the necessity and relevance of applying the more complex hierarchy for the functions proposed by the authors.

![Figure 3. Functions’ classification widely used in the value engineering.](image)

In the existing function classification system (figure 3), which is usually used in value engineering and functional cost engineering [8], there are no functions responsible for the automation and management of the object. However, today the equipment is controlled not only by the operator and internal software, but also by an external warehouse system into which this object is integrated, that inevitably leads to a product functional map complication during its designing and requires functions’ new classification.

![Figure 4. Electrical forklift main function diagram.](image)
Based on the investigation the functional purpose of the product was determined - ensure transportation and placement on racks up to 6 m high of cargo weighing up to 2 tons. Based on the proposed classification of complex product functions, all electric forklift functions were divided into main classification groups. Figure 4 shows the diagram of the product’s main function. The designed forklift has three main functions that facilitate the destination function implementation. The main functions of the upper level can also be divided into the lower level main functions, which, in turn, will consist of subsidiary and managing functions.

In addition to the trend of warehouse integration into a single information system for their remote control and management, a warehouse equipment consumers survey revealed another development trend - safety. More and more manufacturers are beginning to offer various solutions to increase the safety of work in the warehouses. As noted by many respondents, forklifts today are equipped with various sensors and systems that avoid collisions with racks and other obstacles, prevent the warehouse workers injury (for example, the RFID tag reading system on the clothes of employees). Therefore, ergonomics, safety and the forklifts integration into the warehouse complex information system became the main areas in the secondary functions map designing. Developed forklift secondary functions diagram is presented in figure 5.

Figure 5. Electrical forklift secondary functions diagram.

Secondary functions associated with the object interaction with the external environment determine the product appearance, the convenience and safety of its operation, environmental friendliness, and the possibility of integration in the warehouse complex information system. The composition of functions is determined by the particular market segment consumers requirements and preferences and can vary significantly from simpler requirements to the most specific ones. Operating conditions (the warehouse parameters) will also determine the variety and composition of these functions. Therefore, secondary functions affect the object design, but do not affect the product destination and actions it must perform, and work quality.

Note that the basic model of the designed product can include both functions related to the main and secondary functions, which allows to design an individual functional map of the product for each customer. The personal product concept creation takes into account the individual consumer requirements and the product operation peculiarities that will help to increase the manufacturer's competitiveness in the market, as well as contribute the transition for Industry 4.0.
4. Discussion
The proposed approach to the functional product map development can be used not only in the lifting
and transport engineering, but also in other high-tech mechanical engineering industries. To describe
the full composition and classification of the functional characteristics of the forklift, a survey of
potential customers was conducted, which made it possible to determine:

- basic operating and maintenance conditions for forklifts;
- compile a list of the most significant technical characteristics with the greatest value for the
  consumers;
- categorize product parameters into "base parameter" and "optional parameter".

The author's functions classification developed for the complex products functional map designing
allows to take into account the specifics of Industry 4.0, where new industries are created on the basis
of digital technologies, the objects of which interact with each other on the basis of the large data base
exchange. Multi-level management of such objects requires the corresponding functions of the products
being designed, and therefore new approaches to such products development. It should be noted that the
complication of products and their interactions does not allow creating a universal functions
classification value engineering method, which could be unified for all products and industries. The
proposed classification can be supplemented by other types of functions depending on the complexity
of the designed product and its control structure during operation.

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