

# Development of an evaluation method for electromechanical systems unification

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**Abstract.** The paper examines problematic areas of electromechanical systems unification, formulates and presents formal writing of problem for systemic unification of electromechanical systems and its solution procedure, describes general evaluation scheme of technical-and-economic effect from implementation of different variants of electromechanical systems unification. Presents results of the calculation relations that allow to carry out full and thorough formulation of technical specifications with due consideration of possible unification variants that brings out maximum result at the designing and execution project stage, operation and servicing of the electromechanical systems. Method is designed to evaluate values of technical-and-economic outcome from work that is being conducted in the interests of the suggested unification variants implementation for electromechanical system specimens at the development stage. Presented method is the primary way to construct criterial function of system unification problem. Project's future outlook can be determined at any point of the designing stages with consideration to service life of the product that is being in development, product family, its components, which included in the electromechanical system, as a separate entity and also as a part of an entire system.

## 1. Introduction

As of now electromechanical systems consist of a big number of interdependent parts that are diverse by function-based tasks and structural design nature. Development of component parts (CP) for electromechanical systems should be done with unification of this systems in mind. This kind of work is critical for the electromechanical converters due to a variety of structural designs, that limits area of its application. Electromechanical systems converters assortment acknowledges insufficient unification in this industry. [1].

Electromechanical systems development and operation requires a lot of time, material and financial spending. Existing limitations on this kind of expenses makes unification work during the development of this systems very important. [2].

## 2. Materials and Methods

Conducted analysis of existing way and content of complicated technical systems unification work, which electromechanical systems part of, and also status analysis of this kind of work allows to make several very important conclusions that outlines directions for improvement of not just unification work itself but also methodological support for this kind of work.



In the first place, while unification work for complicated technical systems is conducted at the research and project justification stages, impact from its implementation should be evident and assessed for all stages of the life cycle. However, at present time, process of unification, continuous in terms of content, its results and subjects, practically «disintegrates» into several independent and consequent work efforts for unification at every stage of the life cycle. Those inconsistencies, in the first place, are connected to the different degree of detail consideration in these systems as a subject of unification [3]. In fact, if during research and project justification of electromechanical system subjects, within the context of strategic (program) planning, all interdependent advanced electromechanical system entirety at the related planning period considered as a subject of unification, then at the development stage of specific subject of energy system as a subject of unification, in general, considered specific subject excluding its place in the advanced entirety of such systems. Therefore, in fact, at present time, during unification work at this stage, results of the previous stage are not considered. In addition, when choosing ways of subject unification at this stage, influence of this choice on the whole advanced entirety is not considered. In other words, influence of the chosen way of unification of the subject in development on the degree of unification and other technical-and-economic and operation-and-maintenance characteristics of other system specimens, that are part of advanced entirety, is not being taken into consideration. In addition, influence of these specimens on the under development [4] is also not being taken into consideration. Disadvantage of the existing approach to organize implementation of the end-to-end unification process of electromechanical system specimens also determines disadvantages of the existing methodological support.

This allows to establish that existing methodological support is not sufficient to make well founded system-based decisions about electromechanical system unification problems, which are relevant to all levels of its disaggregation, interconnected with life cycle stages [5] and with all possible directions of unification.

In view of this, facts of research work duplication are present, especially at the CP elements level of electromechanical systems, also reduction tendency to borrow ready-made, previously developed CP, and, as a result, this creates increase in assortment of non-compatible but with similar characteristics CP, and increase of expenses for development and operation of electromechanical systems in general.

All of this suggests a necessity for improvement of methodological support for electromechanical systems unification work from the prospective of system approach. In other words, review unification work and outcome evaluation from it, in the context of all life cycle stages, and as a unification subject – all advanced entirety of one-type electromechanical systems on all levels of its disaggregation and in the context of all possible directions of unification.

From the stated above follows that during development of the problem statement for systematic unification of electromechanical systems it is necessary, as a unification subject, consider all entirety of such systems, having in mind all its structural and functional complexity and inconsistency, and also dynamics of its evolution on all life cycle stages. Estimating potentially possible outcome from electromechanical systems unification work one should consider that this outcome is achieved by implementing specific directions of unification during development of isolated samples of such systems.

In such case, during development of the problem statement for systematic unification of the advanced electromechanical systems we should consider the following model of unification.

For any direction of unification, according to the P 50-54-102-88 «Operating procedures for intersectoral, sectoral and factory unification», which included into possible variant of electromechanical system specimens unification [6], as a result of implementing one of the unification variant, some elements (subjects of unification) of the initial homogeneous elements set remain unchanged, and some, that form subsets, replaced by the others, as a rule, more advanced elements. Therefore, set of elements split up into several subsets, to be exact, subset where elements are not being replaced (not unified) and several subsets, where elements being replaced with one more advanced element. As a result of this, set (manifold) with a smaller number of elements is obtained [7]. From this kind of unification model follows that all ways of getting technical-and-economic outcome from different variants of uni-

fication implementation are connected with reduction of elements manifold – subjects of unification. Mainly, in the context of different life cycle stages of specimen, these are gains obtained by means of:

- cutback in a number of engineering designs (newly designed specimens and their CP);
- cutback in number of types, mass-produced and purchased specimens of electromechanical systems and its CP;
- cutback in an assortment of electromechanical system specimens and their CP which are on supply and in operation.

In addition, it is necessary to consider fact that for the accepted model of unification, some elements of initial manifold (set) are being substituted for more advanced elements, this creates excessive quality, and, therefore, creation of extra expenses for «servicing» this excessiveness [8].

Keeping in mind the suggested model of unification, problem of systematic unification of electro-mechanical systems can be formulated in the following way.

For given initial set of required specimens, and also for initial set of required CP, included in it, one should chose variant of advanced entirety unification of electromechanical systems, that provides maximum technical-and-economic outcome from its implementation for given efficiency level of electromechanical system specimens, technical level of its CP and given amount of financing for development and operation of electromechanical systems advanced entirety.

When selecting measure for technical-and-economic effect, one should consider [9] fundamental matching principle: «to what extent one state or process is better (worth) that the other state (process)». From this perspective, using accepted model of unification, as a basis for criterial function construction of formulated problem of systemic unification is appropriate to take full impending expenses for engineering and operation of electromechanical system specimens, that has been developed using one or another variant of unification and included into the advanced entirety of electromechanical systems.

In the interests of formal writing development of formulated systemic unification problem, let us introduce the following notations.

Let us denote by:

$m = 1, 2, \dots, M$  – work stage number, and  $M$  - its total number;

$i = 1, 2, \dots, I$  – electromechanical systems disaggregation level number, and  $I$  - its total number;

$k = 1, 2, \dots, K$  – homogeneous specimens group number, and  $K$  - its total number;

$n = 1, 2, \dots, N$  – electromechanical system specimens and its CP numbers for the initial group sets of homogeneous specimen (CP) sets, respectively, and  $N$  - its total number;

$n^* = 1, 2, \dots, N^*$  – electromechanical system specimens and its CP numbers for the resultant (unified) group sets of homogeneous specimens (CP), and  $N^*$  - its total number;

$\{O_n\}$  and  $\{O_{n^*}^*\}$  – sets of homogeneous specimens (CP) of electromechanical systems before conducting unification work (initial) and after it (resultant);

$H_j$  –  $j$  - th direction of unification, where  $j = 1, 2, \dots, 5$ ;

$\{B_j\}$  – sets of unification variants of electromechanical system specimens (CP), in addition, unification variant  $B_j$  described by mapping  $\{O_n\} \xRightarrow{\hat{H}_j} \{O_{n^*}^*\}$ ;

$H_j$  – operator, which transfers the initial set into the resultant on  $j$  - th direction of unification.

Then formulated problem can be written in the following way:

$$B^{m+1} = \arg \max_{j_{ki}} \sum_{k_i, j_k=1}^{K_i, J_k} E_{k_i} \left[ B^m, B_{j_{ki}}^{m+1}(H_{j_{ki}}, O_{j_{ki}}, O_{j_{ki}}^*), W(O_{j_{ki}}^*) \right] \quad (1)$$

$$F(H_{j_{ki}}, O_{j_{ki}}^*) \geq F_{j_{ki}}^0 \quad (2)$$

$$TY(H_{j_{ki}}, O_{j_{ki}}^*) \geq TY_{j_{ki}}^0 \quad (3)$$

$$C(H_{jk_i}, O_{jk_i}^*) \geq C^0 \quad (4)$$

where:  $W(\text{On})$  – electromechanical system specimens (CP) demand function;

$E$  – function that characterizes difference of full impending expenses for development and operation of electromechanical system specimens, which are being developed without unification and with implementation of unification variant which is under consideration;

$F$  – function that characterizes the electromechanical system specimens effectiveness;

$F^0$  – required levels of the electromechanical system specimens effectiveness;

$TY$  – function that characterizes technical excellence of electromechanical systems CP;

$TY^0$  – required levels of technical excellence of the electromechanical system specimens CP;

$C$  – function that characterizes full impending expenses for the development and operation of the advanced entirety of electromechanical system specimens;

$C^0$  – given financing volume for the development and operation of advanced entirety of electromechanical system specimens;

$k_i$  – group numbers of the electromechanical system homogeneous specimens (CP) on  $i$ -th level of disaggregation;

$j_{k_i}$  – unification direction number for  $k_i$  - th group of homogeneous electromechanical system specimens (CP).

General scheme of the presented procedure which solves systemic unification problem for electromechanical systems (1)-(4), based on suggested approach, chosen principles and corresponds to its content and specific, described earlier, is presented on figure 1.

Figure 1 also presents the assortment of methods, which are necessary to solve systemic unification problem (1)-(4).

For evaluation of technical-and-economic effectiveness of work, which is being conducted in the context of the suggested unification variants [10] of electromechanical system specimens implementation as part of systemic unification of electromechanical systems and its development, procedure is presented, which is the basis for construction of criterial function of systemic unification problem.

In accordance with this and with systemic unification of electromechanical systems problem statement, value of technical-and-economic effectiveness of work to unify electromechanical systems is taken as a difference in full impending expenses for development and operation of electromechanical system specimens, which is being developed in accordance with chosen variant of unification and being developed without its unification, therefore:

$$E = C - C^u \quad (5)$$

where  $E$  – technical-and-economic effect value;

$C^u, C$  – full impending expenses for specimens considering expenses for its unification work and without such work, respectively.

Therefore, in general case:

$$C = C_{dd} + C_n W + C_{op} WT \quad (6)$$

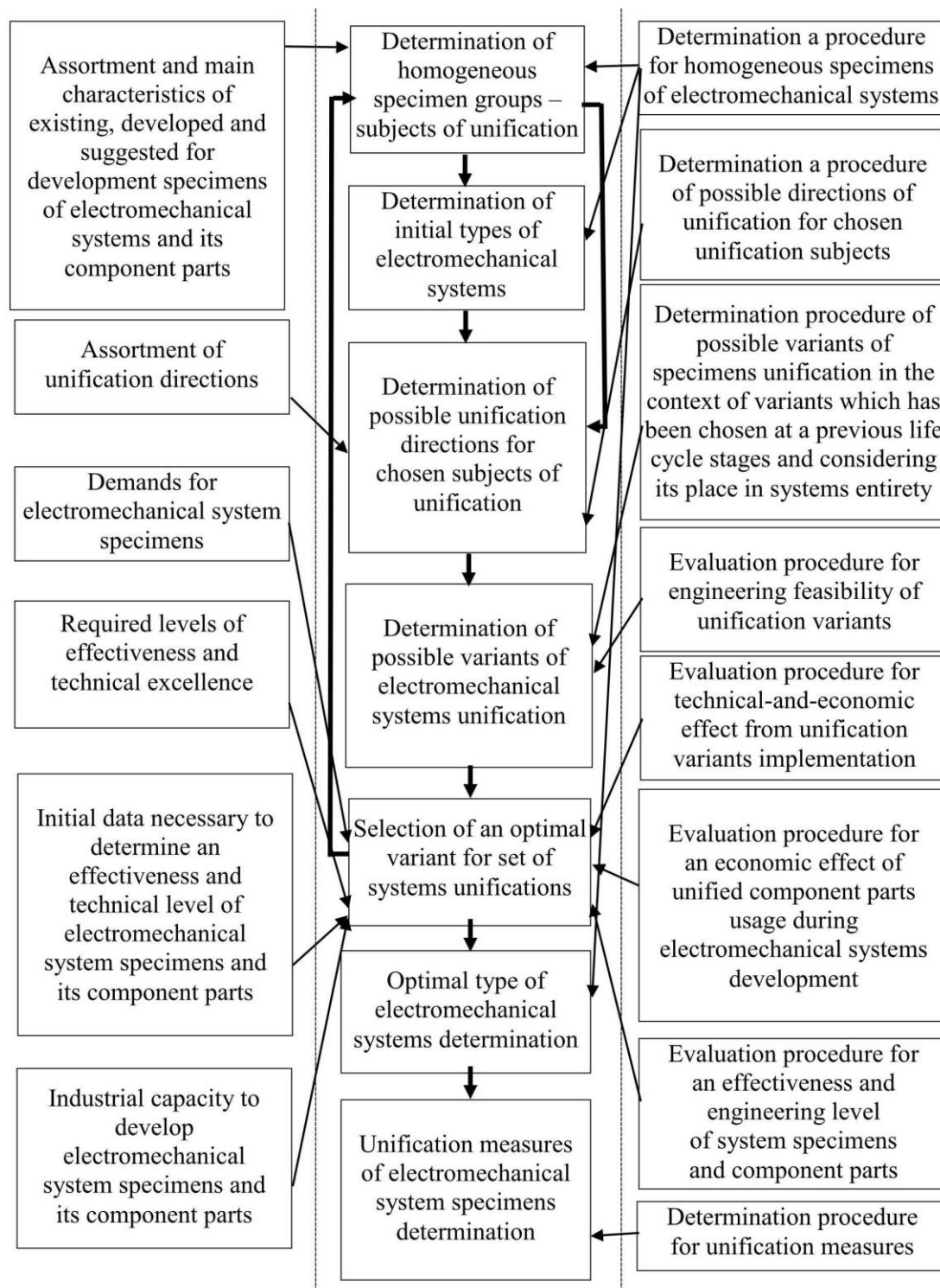
$$C^u = C_{dd}^u + C_n^u W^u + C_{op}^u W^u T^u, \quad (7)$$

where  $C_{dd}^u, C_{dd}, C_n^u, C_n, C_{op}^u, C_{op}$  – costs of development, production and average cost of specimen operation over the year period in accordance with its unification and without it, respectively;

$W^u, W$  – demand (requirement) for a specimen in accordance with its unification and without it, respectively;

$T^u$ ,  $T$  – useful lifetime of specimen in years in accordance with its unification and without it, respectively. Then:

$$E = (C_{dd} - C_{dd}^u) + (C_n W - C_n^u W^u) + (C_{op} WT - C_{op}^u W^u T^u) \quad (8)$$



**Figure 1.** Problem solving procedure general scheme.

To receive calculation relations to estimate value of technical-and-economic effect of electromechanical systems unification work, on the basis of routine unification problem formulation [6], and without constrains for generality of received results, let us be guided by the following unification model [11] of advanced electromechanical systems.

Set of homogeneous electromechanical systems is given, which are part of the advanced electromechanical system specimens entirety  $\{O_i\}$ , where  $i = 1, 2, \dots, I$ , basic characteristics of these specimens and demand for it are given  $W^i$ , respectively. At a later stage, during problem solving of technical-and-economic effect evaluation to determine value of demand for component parts (CP) it is necessary to consider demand, caused by inclusion of component parts into the SPTA and further use of CP during specimen operation. Also, initial set  $\{C_{Pi}\}$  of required homogeneous CP is given, which are part of the electromechanical system specimens, and its main characteristics, full impending expenses for it are given as well, in other words  $C_{dd}^i$ ,  $C_n^i$ ,  $C_{op}^i$ ,  $T^i$  are given. It is supposed that CP, which are parts of different specimens, also different. It is assumed that CP aligned in increasing order of its quality and technical level (values of its main characteristics), and therefore, its development cost.

### 3. Results and Discussion

Variant of electromechanical system specimen unification has been developed (generated), which means that truncated resultant is determined after work completion for unification of CP set, which are part of electromechanical system specimens, meaning that also given a scheme to divide initial set  $\{C_{Pi}\}$  into subsets  $\{C_{Pi}\}_j$ , which are being replaced, on the basis of the unification work results, for one of the component part of truncated (resultant) CP set  $\{C_{Pj}^*\}$ , where  $j = 1, 2, \dots, J$ . Basic characteristics are also given  $C_{Pj}^*$ .

Let us introduce notation for the scheme to replace CP of initial set for  $CP^*$  of truncated (resultant) set:

$$\begin{aligned} \{C_{Pi}: i=1, \dots, I\} &= \{C_{Pi}: i=1, \dots, i_1\}_1 \cup \\ &\{C_{Pi}: i=i_1+1, \dots, i_2\}_2 \cup \{C_{Pi}: i=i_2+1, \dots, i_3\}_3 \cup \dots \\ &\{C_{Pi}: i=i_{j-1}+1, \dots, i_j\}_j \cup \dots \{C_{Pi}: i=i_{J-1}+1, \dots, I\}_J, \end{aligned} \quad (9)$$

where  $i_j$  can take a value from 1 to  $I-1$  if conditions are met:

$$\sum_{j=1}^J i_j = I \quad (10)$$

$$J \leq I-1 \quad (11)$$

In addition, every subset  $\{C_{Pi}\}_j$  of the initial set is replaced for single element (component part) of the truncated (resultant) set  $\{C_{Pj}^*\}$ . Let us denote full impending expenses, development, production, annual operating costs and time in service of  $j$ -th CP of truncated (resultant) set by  $C^{*j}$ ,  $C_{dd}^{*j}$ ,  $C_n^{*j}$ ,  $C_{op}^{*j}$  and  $T^{*j}$  respectively, and by  $W^{*j}$  – demand for it.

In this case, value of technical-and-economic effect from implementation of considered unification variant of considered electromechanical system specimens can be written as follows:

$$E = \left( \sum_{i=1}^I C_{dd}^i - \sum_{j=1}^J C_{dd}^{*j} \right) + \left( \sum_{i=1}^I C_n^i W^i - \sum_{j=1}^J C_n^{*j} W^{*j} \right) + \left( \sum_{i=1}^I C_{op}^i W^i T^i - \sum_{j=1}^J C_{op}^{*j} W^{*j} T^{*j} \right). \quad (12)$$

Having in mind the accepted replacement scheme we can write that:

$$W^{*j} = \sum_{i=i_{j-1}+1}^{i_j} W^i. \quad (13)$$

It is obvious, that summarized for the whole group of homogeneous electromechanical system specimens demand for CP stays unchanged, which means that:

$$\sum_{j=1}^J W^{*j} = \sum_{i=1}^I W^i = \sum_{j=1}^J \sum_{i=i_{j-1}+1}^{i_j} W^i. \quad (14)$$

Let's describe, in addition to that, the following limitations for determining calculated relations which are perfectly acceptable for the considered problem statement and accepted scheme of advanced electromechanical systems unification, meaning that  $C_{op}^i = C_{op}^{*j}$  and  $T^i = T^{*j}$  for all values  $i$  and  $j$ .

Then:

$$E = \left( \sum_{i=1}^I C_{dd}^i - \sum_{j=1}^J C_{dd}^{*j} \right) + \left( \sum_{i=1}^I C_n^i W^i - \sum_{j=1}^J \sum_{i=i_{j-1}+1}^{i_j} W^i C_n^{*j} \right) = \sum_{i=1}^I \left( C_{dd}^i + W^i C_n^i \right) - \sum_{j=1}^J \left( C_{dd}^{*j} + C_n^{*j} \sum_{i=i_{j-1}+1}^{i_j} W^i \right). \quad (15)$$

Obtained expression for  $E$  is the general expression for value evaluation of the technical-and-economic effect from unification variant implementation.

To obtain much more simple relations to calculate  $E$  et us assume that:

$$C_n^i = \alpha^i C_{dd}^i \quad (16)$$

Coefficients  $\alpha^i$ , which connect development cost with mass production cost [12], can be determined on the basis of available statistic support and equal to 0,1÷0,4.

In addition, let us take into account that production cost (manufacturing) is defined in the context of product cost decrease at the expense of series production increase [13], meaning increase of demand. With that the following relation is true:

$$C_n^{*j} = C_n^{i_j} \left( \frac{W^{i_j}}{\sum_{i=i_{j-1}+1}^{i_j} W^i} \right)^\gamma, \quad (17)$$

where  $\gamma$  - measure, which takes into consideration decrease of product cost at the expense of series production increase.

Value  $\gamma$  can also be determined on the basis of available statistic support and equals  $\gamma = 0,3$ .

Then:

$$E = \sum_{i=1}^I C_{dd}^i (1 + \alpha^i W^i) - \sum_{j=1}^J \left[ C_{dd}^{*j} + C_n^{i_j} \left( \frac{W^{i_j}}{\sum_{i=i_{j-1}+1}^{i_j} W^{i_j}} \right)^\gamma \right]. \quad (18)$$

At the same time, for  $C_n^{i_j}$  and  $W^{i_j}$  we take a value of mass production cost and demand for the last element of  $j$ -th subset of initial CP.

Let us assume that  $j$ -th CP of truncated (resultant) set, which can replace, based on its own capability, any CP from  $j$ -th initial subset of CP, will possess certain excessiveness, and, therefore, its development is going to be more expensive.

Having in mind, that dependence of CP development cost on its quality and technical level (its basic characteristics) is continuous and not decreasing, we can write  $C_{dd}^{*j} = \beta^j C_{dd}^{i_j}$ , where  $\beta^j$  – coefficient, which corrects for increase (cost increase) of the CP development at the expense of its excessiveness.

Then expression (18) can be written as follows:

$$E = \sum_{i=1}^I C_{dd}^i (1 + \alpha^i W^i) - \sum_{j=1}^J C_{dd}^{i_j} \left[ \beta^j + \alpha^j \left( \frac{W^{i_j}}{\sum_{i=i_{j-1}+1}^{i_j} W^{i_j}} \right)^\gamma \right]. \quad (19)$$

For  $C_{dd}^{i_j}$  we take development cost of the biggest by number CP in  $j$ -th subset of the electromechanical system specimen's life cycle.

#### 4. Conclusion

In summary, it is worth noting that obtained relation allows reasonably accurate prediction of the technical-and economic effect using sufficiently small volume of initial data, which allows to determine optimal values of unification measures for advanced electromechanical systems by way of problem solution of electromechanical systems systemic unification [14].

Solution of the formulated problem for electromechanical systems systemic unification, in accordance with suggested solution procedure, allows to preset, in the request for proposal for its development, optimal values of unification measures and, therefore, ensure obtaining optimal volume decrease for development and operation of advanced [15] electromechanical systems expenses.

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