

PRODUCT CONFIGURATION DESIGN VIA GROUP  
DECISION MAKING AND COMBINATORIAL  
OPTIMIZATION

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(Submitted by Academician V. Sgurev on July 10, 2019)

**Abstract**

Due to the importance of quality, different human aspects are used to meet the customer expectations. In this respect, the article deals with group decision making for evaluation and selection of compatible modules for product design configuration to comply with customer expectations. The proposed approach relies on estimations from group of decision makers regarding the given evaluation criteria. A new utility function is formulated to aggregate the estimations of individual decision-makers, weights for relative importance between evaluation criteria, and weights on decision makers in forming the final group decision. This utility function is used as objective function in formulated optimization model with binary decision variables. The described approach is applied in a medium-sized enterprise to propose a new product platform configuration for personal computers. It is shown that usage of different weights for decision maker leads to various modules combinations for the designed product. The applicability of group decision making in modular design is proved by obtained different configurations as a result of using of different weights for the group experts.

**Key words:** group decision making, combinatorial optimization, product configuration, modular design, product platform

**1. Introduction.** The modern development of science and technology imposes new challenges for enterprises due to mass personalization and globalization. Nowadays, the manufacturing companies are pressured to develop production that

is not only low-cost and high-quality but also has to respond to rapid market and customer needs changes. This is due to the frequent market changes caused by global competition. Thus, the modularity in the design systems becomes a promising research direction, able quickly to reflect market changes [1]. The product platforms design and product family design are based on the concept of modular design that relies on some kind of modules or standardization components [2]. Therefore, the modular design has been employed in different areas such as buildings industry [3], night vision devices [4], etc.

The modular design proposes an alternative to satisfy consumers' customization needs without sacrificing the scale of economy in production procedures. These new methods are required to support the production system design activity satisfying requirements of modularity, connectivity and intelligence [2]. On the other hand, the modularity of products is considered a suitable approach in innovative design development, because it contributes to improvement of quality, cost and schedule performance, and allows flexibility in building.

The modular design is widely used and different approaches have been proposed. A new GA-based method is proposed for searching a proper balance between the commonality of baseline-product and the performance of product family derived from the baseline-product [5]. In addition, a decision making framework for multi-criteria product modularization in cooperative environments could also be useful [6]. These product modularization approaches are focused on the prediction of either internal or external consequences. Another direction to modular design is based on multi-objective and mixed-model assembly systems optimization formulation [7,8]. It is also possible to use quantitative approach to identify relations between the usages of spare parts [9]. To realize the design of modular product multiple criteria for evaluating a modular product design can be used together with fuzzy group genetic algorithm for grouping components of a design [10,11]. In some cases, it could be better the bi-level optimization to be applied as it allows determination of additional characteristics by using of maximal/minimal values [12]. Product configuration provides an effective tool to satisfy the customer requirements making the product development in a cost-efficient way [13].

The design for complex products requires involving of different participants that are not equally qualified. This requires using weights for opinions of DMs when aggregating the individual preferences [14], or by using some business intelligence [15]. It is shown that the generalized network flows renders good results and may be used in the decision making systems [16]. The most commonly used structures to express the preferences of experts in group decision making can be categorized as: 1) utility function; 2) orders of preferences; and 3) preference relations. The advantage of utility function using is the possibility to apply the compensatory strategy. In contrast to the order of preferences and preference relations, using of utility function allows determining the best alternative as a result of the best value of the obtained aggregated function.

One of the representative examples for modular design is the configuration design of personal computers (PC), server machines, workstations and laptops. This sector is developing extremely fast and different configurations are offered on the market. Due to the importance of modularity in manufacturing, the goal of this article is to propose a group decision making model for better conceptualization of designed system. The focus is not to create universal and sustainable modules, but to use available ones for building of such configuration that market is expecting. For this purpose, a group of decision makers (DMs) are involved to evaluate different sets of modules to configure common platform to comply with market changes and customer needs.

**2. Group decision making with combinatorial optimization for product configuration design.** The design of module-based product family shares common platform that could be upgraded with different additional modules. The design of common platform relies on compatibility between components that can be assembled and conforming to some predefined requirements and restrictions. In group decision making the experts play an essential role. The differences between the experts' knowledge and experiences should be taken into account to express more correctly the group decision. All of these considerations are involved in the proposed generalized model for group decision making in design of modular product configuration as follows:

$$(1) \quad \max \left( \sum_m M_m x_a^m \sum_k \sum_a \lambda^k E_{m,a}^k \right)$$

subject to

$$(2) \quad \forall m : \sum_a x_a^m = \alpha^m, x_a^m \in \{0, 1\}$$

$$(3) \quad \sum_k \lambda^k = 1, \lambda^k \in [0, 1]$$

$$(4) \quad \forall m, \forall k : E_{m,a}^k = \sum_g (w_{m,a}^k)^g (e_{m,a}^k)^g$$

$$(5) \quad \sum_g (w_{m,a}^k)^g = 1,$$

where  $M$  is the number of module;  $x_a^m$  are binary integer variables for selection of alternative/s (element/s) from each module;  $\lambda^k$  is the weight for opinion importance of  $k$ -th DM;  $E_{m,a}^k$  is the overall performance of each alternative (element) from the modules sets according to point of view of  $k$ -th DM;  $(w_{m,a}^k)^g$

expresses the relative weight for  $g$ -th evaluation criterion (modules' parameters) of  $a$ -th alternative for  $m$ -th module accordingly  $k$ -th DM; and  $(e_{m,a}^k)^g$  is the particular evaluation of  $a$ -th alternative for  $m$ -th module from  $k$ -th DM toward  $g$ -th evaluation criterion.

The evaluations  $(e_{m,a}^k)^g$  expressed by score are limited within the range of  $(0, 1)$  where the bigger value means the better performance. Another evaluation scale could be to use also for example the range between 0 and 10 or 0 and 100, but using of different scale requires normalization to obtain the comparable measure between coefficients  $(w_{m,a}^k)^g$ , evaluation score  $(e_{m,a}^k)^g$  and weight  $\lambda^k$  for DMs.

The equation (2) provides the required number of elements from each module to be selected. For particular design the number of elements from different modules could vary and using of (2) allows selecting the needed number of elements. The feasible interval for coefficients  $\lambda^k$  in relation (3) makes possible to transform the group decision making into individual decision making if  $\lambda^k$  takes value equal to 1.

### 2.1. Group decision making model for PC configuration design.

The proposed generalized model (1)–(5) is applied in PC configuration design using the basic components as CPU, MB, RAM and PSU that determine the common platform responsible for overall PC functionality and which could be upgraded with additional modules. The design of PC configuration by group decision making is expressed by the following combinatorial optimization model:

$$(6) \quad \max \left( \sum_{i=1}^I x_i \sum_{k=1}^K \lambda^k A_i^k \right) + \left( \sum_{p=1}^P y_p \sum_{k=1}^K \lambda^k B_p^k \right) + \left( \sum_{q=1}^Q z_q \sum_{k=1}^K \lambda^k C_q^k \right) + \left( \sum_{t=1}^T u_t \sum_{k=1}^K \lambda^k D_t^k \right)$$

$$(7) \quad \sum_{i=1}^I x_i = 1, \quad x_i \in \{0, 1\}$$

$$(8) \quad \sum_{p=1}^P y_p = 1, \quad y_p \in \{0, 1\}$$

$$(9) \quad \sum_{q=1}^Q z_q = r, \quad z_q \in \{0, 1\}$$

$$(10) \quad \sum_{t=1}^T u_t = 1, \quad u_t \in \{0, 1\}$$

$$(11) \quad \sum_{j=1}^J w_j^k = 1, \quad \forall k = 1, 2, \dots, K$$

$$(12) \quad \sum_{n=1}^N w_n^k = 1, \quad \forall k = 1, 2, \dots, K$$

$$(13) \quad \sum_{m=1}^M w_m^k = 1, \quad \forall k = 1, 2, \dots, K$$

$$(14) \quad \sum_{s=1}^S w_s^k = 1, \quad \forall k = 1, 2, \dots, K$$

$$(15) \quad \forall i = 1, 2, \dots, I : \left( \forall k = 1, 2, \dots, K : A_i^k = \sum_{j=1}^J w_j^k e_{i,j}^k \right)$$

$$(16) \quad \forall p = 1, 2, \dots, P : \left( \forall k = 1, 2, \dots, K : B_p^k = \sum_{n=1}^N w_n^k e_{p,n}^k \right)$$

$$(17) \quad \forall q = 1, 2, \dots, Q : \left( \forall k = 1, 2, \dots, K : C_q^k = \sum_{m=1}^M w_m^k e_{q,m}^k \right)$$

$$(18) \quad \forall s = 1, 2, \dots, S : \left( \forall k = 1, 2, \dots, K : D_s^k = \sum_{t=1}^T w_s^k e_{s,t}^k \right)$$

$$(19) \quad \sum_{k=1}^K \lambda^k = 1, \quad \lambda^k \in [0, 1],$$

where decision variables used to perform the selection of a single element are  $x_i$  ( $i = 1, 2, \dots, I$ ) for CPU,  $y_p$  ( $p = 1, 2, \dots, P$ ) for MB,  $z_q$  ( $q = 1, 2, \dots, Q$ ) for RAM,  $u_t$  ( $t = 1, 2, \dots, T$ ) for PS. The single selection of elements for modules CPU, MB and PS are realized by the relations (7), (8) and (10). The choice of element for RAM module can be more than one and this is expressed by the relation (9), where  $r$  determines the number of elements that should be selected

and used in the PC configuration design. The relative importance between criteria from all DMs are expressed by relevant weighted coefficients that represent the relative importance between evaluation criteria for each of the modules. The weighted coefficients for the importance of  $j$ -th evaluation criterion of elements for CPU module from  $k$ -th DM point of view is denoted by  $w_j^k$  and relation (11). The coefficients  $w_n^k$  are used to express the relative importance of evaluation criteria (parameters) for module of MB using (12). The importance of evaluation criteria for the modules for RAM and PSU from  $k$ -th DM point of view are denoted as  $w_m^k$  and  $w_s^k$ , respectively, according to (13) and (14). An essential characteristic of these coefficients for criteria importance is that their total sum must be equal to 1 separately for each of the modules. The corresponding evaluations for  $i$ -th element toward  $j$ -th criterion and  $k$ -th DM is denoted as  $e_{i,j}^k$  in case of evaluation of elements for CPU module. The rest of the evaluations for MB, RAM and PSU modules are denoted as  $e_{p,n}^k$ ,  $e_{q,m}^k$  and  $e_{s,t}^k$ , respectively. The overall assessment of the  $i$ -th element (alternative) against all criteria for CPU module, according to the point of view of the  $k$ -th DM is expressed by  $A_i^k$  and relation (15). The aggregate assessment of the  $p$ -th element against all criteria of MB module according to the  $k$ -th DM is denoted by  $B_p^k$  and relation (16). Analogically for the rest of modules, the aggregate assessments are denoted by  $C_q^k$  and  $D_s^k$ , respectively, for RAM and PSU modules using (17) and (18). Thus, the selected elements of each module could be used as basis to add additional necessary modules for fully functional PC configuration, like HDD, graphics cards, keyboard, etc.

The proposed model (6)–(19) could be used when the predefined modules are compatible with each other. This is the case when a company makes a decision to realize on the market particular configuration about desktop computer, server or workstation.

**3. Numerical application.** The proposed group decision making approach in PC configuration design is considered representative example in modular design. For numerical testing a real data for CPUs, MBs, RAMs and PSUs modules are used as they essentially influence the PC performance as a whole. Each module is evaluated toward 3 criteria (parameters). The given PC modules are evaluated from a group of 3 DMs composed of product manager (DM-1), sales manager (DM-2) and marketing manager (DM-3) as shown in Table 1.

Numerical testing is realized by using the input data from Table 1 and formulation of corresponding optimization tasks based on the proposed model (1)–(14). Three different cases that represent three different scenarios about the opinions importance of DMs are investigated:

Case-1:  $\lambda_1 = 0.33$  (DM-1),  $\lambda_2 = 0.33$  (DM-2),  $\lambda_3 = 0.34$  (DM-3)

Case-2:  $\lambda_1 = 0.54$  (DM-1);  $\lambda_2 = 0.23$  (DM-2);  $\lambda_3 = 0.23$  (DM-3)

Case-3:  $\lambda_1 = 0.13$  (DM-1);  $\lambda_2 = 0.31$  (DM-2);  $\lambda_3 = 0.56$  (DM-3)

The selected modules for PC design configuration are shown in Fig. 1.

Table 1

Evaluations and weights for the basic PC modules

CPU	DM-1			DM-2			DM-3		
	Price	Cores	CPU	Price	Cores	CPU	Price	Cores	CPU
	<b>0.41</b>	<b>0.26</b>	<b>0.33</b>	<b>0.22</b>	<b>0.42</b>	<b>0.36</b>	<b>0.33</b>	<b>0.34</b>	<b>0.33</b>
CPU-1	0.8	0.77	0.82	0.84	0.82	0.81	0.79	0.88	0.86
CPU-2	0.75	0.72	0.88	0.83	0.79	0.84	0.86	0.82	0.79
CPU-3	0.71	0.74	0.86	0.91	0.89	0.79	0.83	0.77	0.83
CPU-4	0.78	0.79	0.83	0.88	0.84	0.68	0.95	0.83	0.86
CPU-5	0.82	0.75	0.81	0.87	0.86	0.83	0.8	0.79	0.76
CPU-6	0.84	0.81	0.78	0.85	0.8	0.72	0.86	0.85	0.79
CPU-7	0.8	0.79	0.82	0.8	0.81	0.78	0.89	0.86	0.84
CPU-8	0.82	0.72	0.81	0.75	0.79	0.8	0.81	0.81	0.82
CPU-9	0.79	0.83	0.77	0.76	0.78	0.76	0.82	0.88	0.83
CPU-10	0.74	0.78	0.85	0.8	0.82	0.86	0.81	0.78	0.86
CPU-11	0.76	0.75	0.74	0.86	0.8	0.81	0.75	0.81	0.87
CPU-12	0.84	0.83	0.79	0.93	0.79	0.82	0.81	0.78	0.85
MB	Price	RAM slots	Max RAM	Price	RAM slots	Max RAM	Price	RAM slots	Max RAM
	<b>0.4</b>	<b>0.35</b>	<b>0.25</b>	<b>0.3</b>	<b>0.35</b>	<b>0.35</b>	<b>0.2</b>	<b>0.35</b>	<b>0.45</b>
MB-1	0.85	0.84	0.68	0.95	0.93	0.88	0.84	0.68	0.82
MB-2	0.86	0.86	0.83	0.8	0.84	0.68	0.95	0.81	0.86
MB-3	0.84	0.8	0.72	0.9	0.86	0.83	0.8	0.79	0.76
MB-4	0.8	0.81	0.78	0.89	0.8	0.72	0.88	0.85	0.79
MB-5	0.81	0.81	0.78	0.89	0.8	0.76	0.82	0.84	0.78
MB-6	0.82	0.79	0.8	0.81	0.73	0.72	0.87	0.83	0.82
MB-7	0.84	0.78	0.76	0.82	0.71	0.74	0.86	0.93	0.81
MB-8	0.78	0.84	0.86	0.82	0.78	0.79	0.89	0.88	0.87
MB-9	0.88	0.84	0.68	0.82	0.82	0.79	0.8	0.81	0.72
MB-10	0.82	0.83	0.8	0.78	0.78	0.84	0.68	0.75	0.78
RAM	Price	Clock	Size	Price	Clock	Size	Price	Clock	Size
	<b>0.38</b>	<b>0.27</b>	<b>0.35</b>	<b>0.25</b>	<b>0.35</b>	<b>0.4</b>	<b>0.35</b>	<b>0.4</b>	<b>0.25</b>
RAM-1	0.81	0.9	0.85	0.79	0.72	0.88	0.81	0.9	0.85
RAM-2	0.79	0.89	0.9	0.84	0.76	0.9	0.79	0.82	0.9
RAM-3	0.83	0.81	0.81	0.82	0.7	0.77	0.83	0.89	0.81
RAM-4	0.86	0.82	0.88	0.83	0.72	0.81	0.86	0.82	0.88
RAM-5	0.76	0.78	0.79	0.89	0.69	0.79	0.76	0.78	0.79
RAM-6	0.83	0.72	0.81	0.82	0.79	0.89	0.88	0.79	0.82
RAM-7	0.79	0.83	0.77	0.77	0.83	0.81	0.83	0.72	0.81
RAM-8	0.87	0.85	0.89	0.81	0.86	0.82	0.79	0.83	0.77
RAM-9	0.72	0.81	0.86	0.82	0.86	0.79	0.89	0.9	0.84
RAM-10	0.69	0.79	0.76	0.78	0.79	0.83	0.81	0.81	0.82
PSU	Price	Connectors	Capacity	Price	Connectors	Capacity	Price	Connectors	Capacity
	<b>0.36</b>	<b>0.24</b>	<b>0.4</b>	<b>0.28</b>	<b>0.33</b>	<b>0.39</b>	<b>0.34</b>	<b>0.4</b>	<b>0.26</b>
PSU-1	0.82	0.7	0.77	0.78	0.79	0.76	0.78	0.79	0.81
PSU-2	0.8	0.72	0.81	0.79	0.82	0.82	0.75	0.8	0.88
PSU-3	0.79	0.69	0.79	0.72	0.88	0.88	0.72	0.81	0.79
PSU-4	0.81	0.82	0.79	0.74	0.86	0.89	0.69	0.79	0.77
PSU-5	0.76	0.77	0.83	0.79	0.83	0.8	0.76	0.82	0.83

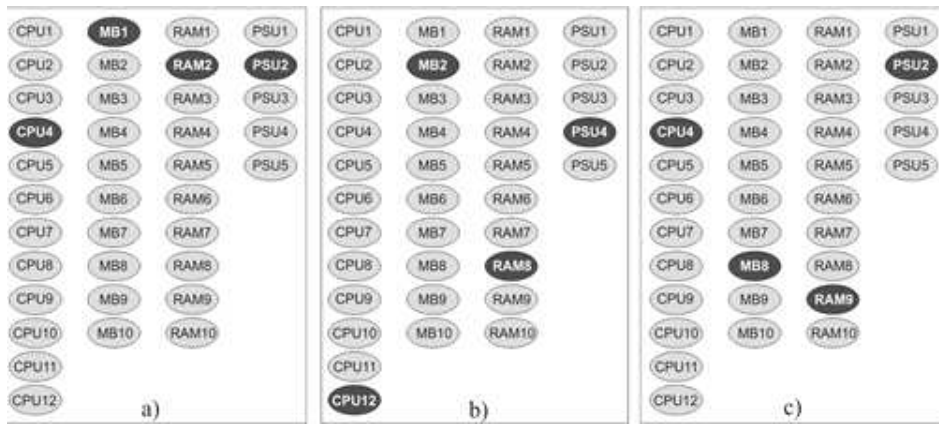


Fig. 1. PC design configurations based on single selection of elements for the modules CPU, MB, RAM and PSU: a) case-1; b) case-2; c) case-3

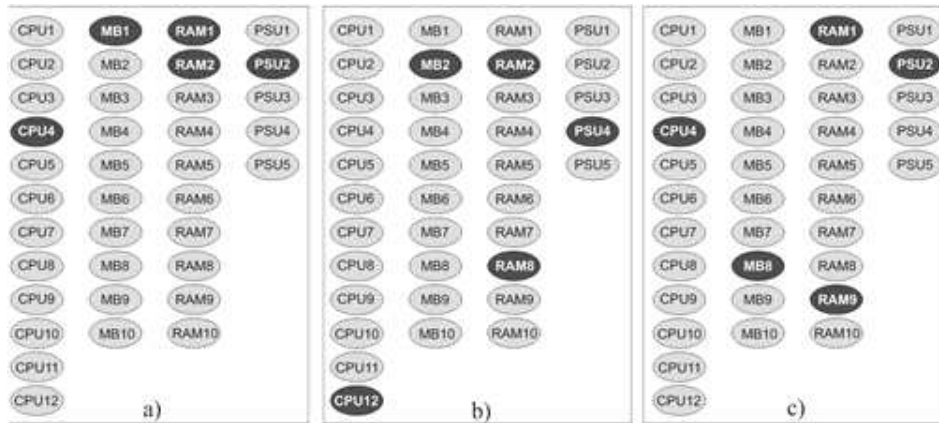


Fig. 2. PC design configurations with two RAM modules: a) case-1; b) case-2; c) case-3

It should be noted that Fig. 1 shows the results in the case of single selection of elements of each module (CPU, MB, RAM and PSU) for different design of PC configurations. Due to the specifics of the designed system, namely PC, the RAM module could be participating with more than one element. This depends on the parameter “RAM slots” of the module MB and is expressed by the restriction (4) of the proposed model. To demonstrate this applicability for selection of 2 elements for module RAM for PC configurations the corresponding optimization tasks are solved. The obtained results for same cases of the weights of DMs are shown in Fig. 2.

**4. Results and discussion.** All conducted calculations are based on the proposed optimization model (1)–(14) for two different scenarios: 1) selection of a single element for each of the modules about the CPU, MB, RAM and PSU; 2) selection of 2 elements for module RAM and one element for the other modules.



These two scenarios are investigated for three cases that express different importance of DMs opinions in evaluations toward predefined sets of elements about the main modules for design of PC configuration. The results of single selection of elements for each module in Case-1, where the opinion of DMs are with equal importance, determine value of the objective function equal to 3.2961 and value for the decision variables as follows:  $x_4 = 1$ ,  $y_1 = 1$ ,  $z_2 = 1$  and  $u_2 = 1$ . That means that the design of configuration for PC should integrate the fourth element from the CPUs set namely CPU-4, the first element from set about MBs that is MB-1, the second element from set about RAMs that is RAM-2 and also the second element from set about PSUs that is PSU-2 (Fig. 1a).

Case-2 expresses the situation where the opinion of DM-1 is the most important, while the opinions of DM-2 and DM-3 are considered with equal importance. For this case, the results of optimization task determine objective function value is equal to 3.3033 and following values for binary decision variables:  $x_{12} = 1$ ,  $y_2 = 1$ ,  $z_8 = 1$  and  $u_4 = 1$ . Thus, the PC configuration should be composed of the following elements CPU-12, MB-2, RAM-8 and PSU-4 (Fig. 1b).

Case-3 illustrates the situation where the opinion of DM-3 is dominated and is considered the most important followed by opinion of DM-2 and the least important is the opinion of DM-1. The obtained results for the selected elements for each of modules determine the objective function value equal to 3.3417 and values for decision variables, respectively, for the modules of CPU, MB, RAM and PSU as follows:  $x_4 = 1$ ,  $y_8 = 1$ ,  $z_9 = 1$  and  $u_2 = 1$ . That means that the PC configuration should be composed of the following elements CPU-4, MB-8, RAM-9 and PSU-2 considering DMs point of view together with their importance (Fig. 1c).

The proposed model (1)–(14) allows also selecting more than one element for module RAM as expressed by relation (4). This is imposed by the nature of configured system that is considered, namely PC. The numerical calculations are done to obtain the corresponding configurations with two elements for RAM module (Fig. 2). The obtained decision variables for different cases are as follows: 1) for Case-1:  $x_4 = 1$ ,  $y_1 = 1$ ,  $z_1 = 1$  and  $z_2 = 1$ ,  $u_2 = 1$ ; 2) for Case-2:  $x_{12} = 1$ ,  $y_2 = 1$ ,  $z_2 = 1$  and  $z_8 = 1$ ,  $u_4 = 1$ ; 3) for Case-3:  $x_4 = 1$ ,  $y_8 = 1$ ,  $z_1 = 1$  and  $z_9 = 1$ ,  $u_2 = 1$ .

The described above results demonstrate the practical applicability of the proposed model for group decision making model in configuration design of PC. Beyond the basic functionality, further additional modules are needed to compose the PC as a whole, for example – HDD, Graphics Cards, keyboard, etc. These additional modules do not affect the PC performance, but contribute to build the product as a whole.

The optimization model could be easily extended with additional modules parameters if needed. Additional restrictions can be added to express the compatible relations when input sets of elements from different modules are not compatible with each other. The proposed model is useful to manage the design of product

platform configuration using group of experts with different knowledge area. In addition, the described model could be realized as a software application where experts can express their preferences.

**5. Conclusion.** In this article a group decision making approach for evaluation and selection of compatible modules for product platform design or product family design are proposed. The selected combination of modules defines basic configuration of product platform. The proposed approach relies on the modules' estimations by group of DMs in respect to the predefined evaluation criteria including also weights for qualification of each DM. The estimations about the product platform modules are used in an optimization 0-1 programming model to determine the combination of needed modules. The proposed group decision making model in design of product configuration is applied for PC configuration design in a medium-sized enterprise. As a result of optimization tasks solving, the basic elements for MB, CPU and RAM modules are determined taking into account the DM preferences. It is shown that the use of different weights for the opinions of DMs leads to various combinations for PC modules and, respectively, to different product platform.

It is of great importance to capture different DMs aspects of quality dimensions to meet the customer expectations. This could be done by using of the proposed group decision making model for design of product configuration. There is no limitation to use the proposed generalized model for group decision making in other product platforms that include variety of modules.

The proposed approach for group decision making could implement different utility functions depending on the requirements and this is a direction for future investigations.

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