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RATIONAL SELECTION OF A MEDICAL DEVICE WITH THE HELP OF INFORMATION SYSTEMS IN HEALTH CARE

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Abstract: It is suggested to develop a decision support system that will optimize the process of medical device procurement. The system will be able to select an optimal model of a medical device according to the needs of a hospital and the announced price. Information models of medical devices have been developed in order to create such a system. Pareto principle and multi-objective optimization are used.

The diversity of the medical device arena and the rational choice of the required product

Information systems in health care that are based on service-oriented architecture should not only capture, present and evaluate the information about the person's health status, but also they should increase the efficiency of the hospital. For example, health care information systems should control rational selection of a medical device in a hospital.

Medical devices are used to enhance health care in general and to enhance the health of everyone. One of World Health Organization's strategic objectives is to ensure improved access, quality and the use of medical devices [1]. On the one hand, the use of medical devices brings health care to the next level and it has a lot of benefits to the patients. One the other hand, the process of selecting a medical device is intricate. World Health Organization understands the importance of medical devices' expansion. One of World Health Organization's strategic objectives is to ensure improved access, quality and use of medical devices [1]. Key issues affecting progress include the extreme diversity of the medical device arena – diverse in terms of types of devices, degrees of complexity, applications, usage, users and categories and issues like the context dependency of medical devices and research in medical devices often not based on public health needs [1]. The process of rational selection of a medical device is tedious and lengthy. In many cases the choice and use of medical devices is not based on the needs of a hospital. So, information systems, models and methods should be developed to optimize the process of selecting a medical device. Developing a decision support system is one of the ways to solve the current problem of lack of a medical device management system and to improve health care.

Current problems of selecting an optimal medical device

It is worth noting that medical devices market is growing. For example, in Germany alone there are more then 170 manufactures of medical devices. How do doctors decide which one to buy when there is such a diversity of medical devices? Medical devices are often chosen for their technical attributes. Marketing policy of the seller or physician preferences also influence the decision. But there are a lot of problems related to selecting and buying a medical device.

One of the major obstacles to rational selection of a medical device is innovation. The fact that this particular medical device is innovative can influence the decision. The specialist does not always consider whether this technology will be used in the hospital. The second important barrier to selecting a medical device is the lack of adequate information. Marketing and selling experts try to show the best options of the device. So, sometimes it can be difficult for decision-makers to compare the analogues medical devices reasonably. Moreover, the post-market surveillance systems, which are the way to follow-up on the safety and effectiveness of a device, do not function properly. The third problem that decision-makers face when they need to select the medical device rationally is high costs. Not only are the medical devices expensive, there are also hidden costs such as those of accessory options, years of warranty, installation, procedures and recurrent costs for maintenance, spare parts, consumables etc. These costs are usually not included in the price but they can amount up to 80 % of the total cost of a device [1]. In addition, the doctor often selects the medical device according to his preferences and previous experience. This choice may not be rational.

The major obstacles that decision-makers face while selecting a medical device (**MD**) are summed up in Figure. The possible solutions to these problems are also highlighted in Figure.

To overcome the mentioned barriers to selecting a medical device it is suggested to develop a decision support system that is able to meet the following requirements:

– Include the information on all medical device models;

– Compare medical devices according to the adjusted criteria regardless of the marketing policy of the seller;

– Evaluate the medical devices according to the adjusted criteria;

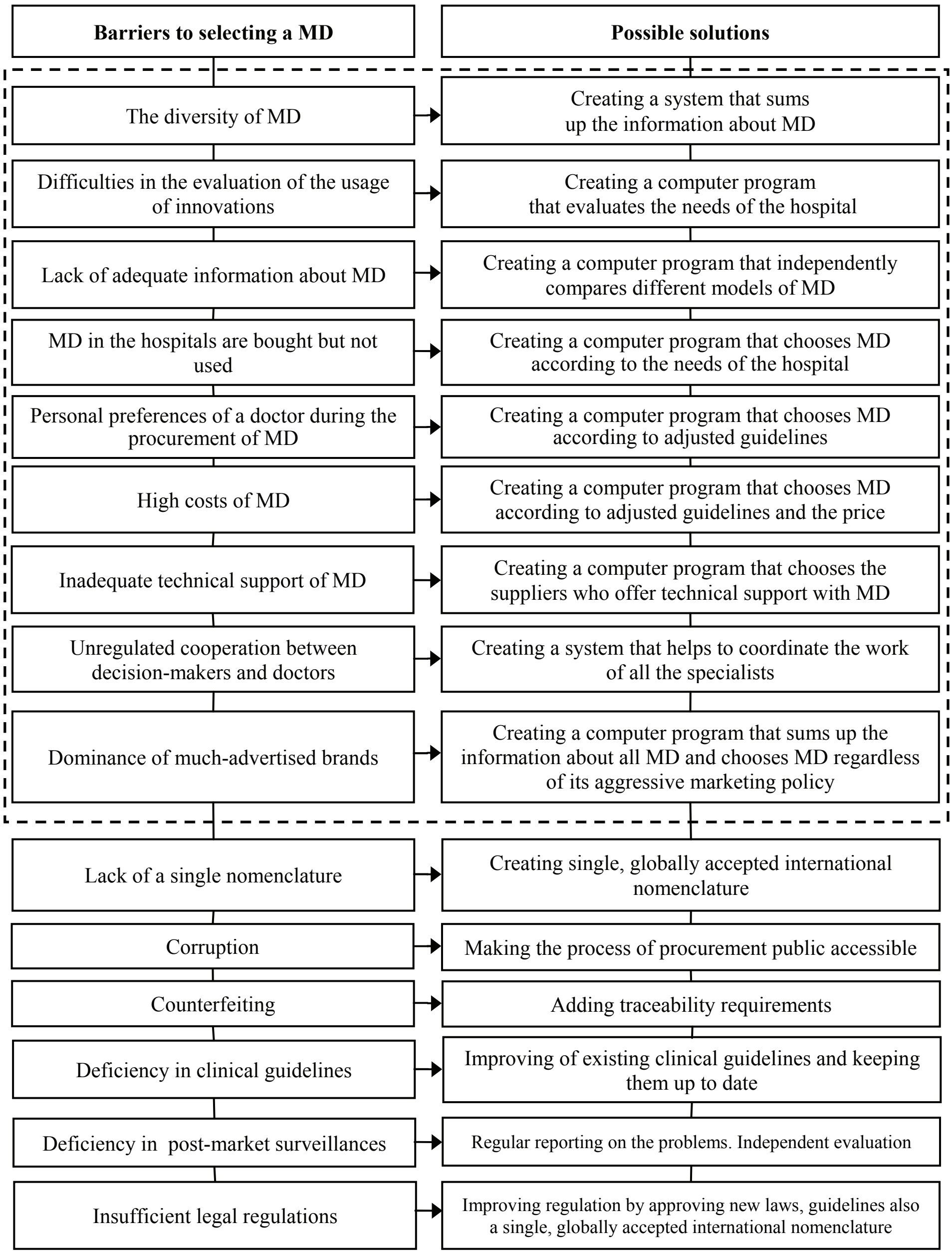
– Choose an optimal model of a medical device according to the needs of the hospital and the price;

– Choose a medical device offered by a supplier with technical support.

The use of this decision support system will help to coordinate the work of all decision-makers. As a result it will lead to an appropriate use of medical devices and save the financial resources of the hospital.

Information models as the basis of the decision support system

To reveal the most important factors in the procurement of medical devices all devices bought for the period of 01.11.2012–31.03.2013 in Russia have been analyzed. Invitations to tender and tender documentation have been found on the official site zakupki.gov.ru. The analysis has shown that the most significant factor during the procurement of a medical device is its specification. In the specifications all the options, configurations and integration are described. So in order to create a described decision support system and optimize the process of selecting a medical device the information models of medical devices and those of their specifications should be developed.



Major obstacles to selecting medical devices and possible solutions to these problems

Medical devices that should be selected with the help of the decision support system

During technical and economical analysis the most complex and expensive medical devices have been chosen (Table). It is extremely important to make up correct specifications for them. Otherwise, a wrong model could be selected. As a result, financial resources would be wasted. When there is a problem of selecting an optimal model of one of these complex devices, decision support system should be used.

Medical devices which are supposed to be bought with the help of the decision support system

Field of application	Types of medical devices
Functional diagnostics	Daily monitoring systems; Diurnal blood pressure monitors; Stress-systems; Polysomnography systems; EEG systems; Rheotachygraphy systems; Spirometers; Fetal motinors; Electrocardiographs
Imaging systems	Ultrasound systems; CT scanners; Magnetic resonance imaging system; Angiographic system; Mammographs; Mobile surgical units C-arm; X-ray systems; PET/CT imaging systems; SPECT and SPECT/CT imaging systems; Endoscopes
Therapy and reanimation	Ventilators; Anesthesia and respiratory devices; Incubators; Radiotherapy systems, Defibrillators; Lithotriptors
Surgery	Laser systems; Laparoscopy systems; Coagulators
Laboratory	Biochemical analyzers; Immunochemistry analyzers; Hematology analyzers

Method to solve the problem of an optimal selection of a medical device

In order to optimize the procurement process of the devices mentioned in Table, it is suggested to elaborate a formalized procedure of selecting an optimal model of a medical device. The common information model of a certain medical device type should be worked out.

Information model of an object is a representation of information that defines essential for this case relationships, constraints, rules, and operations. Information models usually specify relations between these parameters to define the object. Information in each information model is processed with the help of languages [2], for example with the help of such artificial languages as symbolic algebraic language or graphical languages [2].

It is suggested to use set theory while creating the information model of a medical device. Set theory is universal. That is why information model created on the basis of set theory can be easily transferred into other information modelling language (for example, IDEF, EXPRESS, UML).

Information model can be presented as a multiplicity

$$MD_k = \{ L_k, A_k, B_k, c_k \}, \tag{1}$$

L_k – multiplicity of MD_k parameters with the logical value; A_k – multiplicity of MD_k parameters with the real value; B_k – multiplicity of MD_k parameters with the interval value; c_k – MD_k parameter that defines its price (the price of a medical device); k – number of a certain model of the concerned medical device's type, $k = \overline{1, K}$, K – quantily of the existing models of this medical device's type.

All the parameters of the medical device's model can be divided in 2 groups:

Group 1: parameters with the logical value. For example, there are two values for a logical variable: «Field of application. Ultrasound scanners: cardiology» – «true» – if the device supports this function, «false» – if the device does not support this function.

Group 2: parameters with the real value. For example, real value: «The number of channels» can be 1024.

Group 3: parameters with the interval value. For example, parameter «Frequency rate of an ultrasound scanner» can be [1.5, 18] mHz.

Group 4 is represented only by one parameter – the price of k model of the medical device.

The multiplicity L_k can be defined

$$L_k = \left\{ l_1^k, \dots l_i^k, \dots l_n^k \right\}, \tag{2}$$

l_i^k – the name of i parameter with the logical value of k model of the medical device.

The multiplicity A_k is defined as the sequence of tuples

$$A_k = \left\{ \left\langle a_1^k, x_1^k \right\rangle, \dots, \left\langle a_i^k, x_i^k \right\rangle, \dots, \left\langle a_m^k, x_m^k \right\rangle \right\}, \tag{3}$$

$\left\langle a_i^k, x_i^k \right\rangle$ – the tuple, where a_i^k is a logical variable that corresponds to k model of the medical device; a_i^k possesses the value «true», if k model of the medical device supports this parameter, «false» – if this parameter is not supported. When a_i^k =«true» x_1^k possesses the value the corresponds to the numerical value of i parameter of k model of medical device, 2 – groups (multiplicity A_k). When a_i^k =«false» $x_1^k = 0$.

The multiplicity B_k is defined as the sequence of tuples

$$B_k = \left\{ \left\langle b_1^k, [y]_1^k \right\rangle, \dots, \left\langle b_i^k, [y]_i^k \right\rangle, \dots, \left\langle b_f^k, [y]_f^k \right\rangle \right\}, \tag{4}$$

$\left\langle b_i^k, [y]_i^k \right\rangle$ – tuple, where b_i^k is logical variable that corresponds to the name of i parameter of k model of medical device and possesses the value as variable a_i^k. Interval variable $[y]_i^k$ is defined by the values $\underline{y_i^k}$ and $\overline{y_i^k}$, which correspond to the real values of the lower bound of the parameter $[y]_i^k$ and to the real value of the upper bound of the parameter $[y]_i^k$. The real parameter c_k defines the price of k model of the medical device.

The multiplicity (1) can be made by binding the values to the variables of the model. When the multiplicity (1) is made, the specific information model of a medical device is formed (1) – (4).

The composition if the multiplicity (1) should be determined in order to create a common information model.

The information model of the medical device's specification should be createdin order to choose the optimal *k*-model. Certain type of medical device should be taken into consideration in this case.

It is a tedious and lengthy process to state the requirements to the medical device. The specialist who is creating the specifications is supposed to be very qualified. The united model of specification of medical device's certain type is suggested to be developed. The information models of a medical device should be used.

Information presented in the specification of medical device's certain type can be defined as a multiplicity

$$T = \left\{ L^T, A^T, B^T \right\}, \tag{5}$$

L^T – multiplicity of specification's parameters with the logical value; A^T – multiplicity of specification's parameters with the real value; B^T – multiplicity of specification's parameters with the interval value. It is worth noting, there is compliance between the multiplicity of the *k*-model of the medical device and the specification which means that the multiplicity L_k corresponds to L^T, $A_k - A^T$, $B_k - B^T$ for all $k = \overline{1, K}$.

The multiplicity L^T is defined as the sequence of tuples

$$L^T = \left\{ \left\langle l_1^T, \lambda_1 \right\rangle, \ldots, \left\langle l_i^T, \lambda_i \right\rangle, \ldots, \left\langle l_n^T, \lambda_n \right\rangle \right\}, \tag{6}$$

l_i^T – the name of *i*-parameter (logical value). The *i*-parameter possesses the logical value; $l_i^T =$ «true» if the decision-maker wants that the medical device supports this function; $l_i^T =$ «false» if the decision-maker does not want that the medical device supports this function; λ_i – real coefficient, describing to what extend the medical device should support this function.

Measure of significance is suggested to be described with the help of 5-scale. λ_i can possess the values $\lambda_i = 0, 1, 2, 3, 4, 5$. $\lambda_i = 0$ – the medical device must not support the *i*-function. $\lambda_i = 1$ – the measure of significance for *i*-function is low, $\lambda_i = 5$ – the measure of significance for *i*-function is high.

In the future to work out the solution to the multi-objective optimization number of possible values for λ_i should be increased. When there is *i*-parameter in the specification or the *k*-model of medical device does not support *i*-parameter, the penalty should be imposed. It is suggested ti use $\lambda_i = -10^6$ as a penalty.

The multiplicity A^T is defined as the sequence of tuples

$$A^T = \left\{ \left\langle a_1^T, x_1^T, \gamma_1, \alpha_1 \right\rangle, \ldots, \left\langle a_i^T, x_i^T, \gamma_i, \alpha_i \right\rangle, \ldots, \left\langle a_m^T, x_m^T, \gamma_m, \alpha_m \right\rangle \right\}, \tag{7}$$

a_i^T is a logical variable, that corresponds to the name of *i*-parameter in the specification of the medical device. $a_i^T =$ «true» if this medical device supports this parameter. $a_i^T =$ «false», if this medical device does not support this parameter. x_i^T is numerical value of *i*-parameter. The parameter of the medical device must not be higher or lower than x_i^T. Parameter γ_i concretizes the parameter «higher» or «lower». If $\gamma_i = -1$, then $x_i \le x_i^T$. That means that the parameters of the medical device should not be higher than x_i^T. If $\gamma_i = 1$ the parameters of the medical device should not be lower than x_i^T. That means $x_i \ge x_i^T$, $\gamma_i = 0$, if a_i^T =«false». α_i is the measure of significance of *i*-parameter ($\alpha_i = -10^6$, 0, 1, 2, 3, 4, 5).

The multiplicity B^T is defined as the sequence of tuples

$$B^T = \left\{ \left\langle b_1^T, \left[y_1^T\right], \beta_1 \right\rangle, \ldots, \left\langle b_i^T, \left[y_i^T\right], \beta_i \right\rangle, \ldots, \left\langle b_f^T, \left[y_f^T\right], \beta_f \right\rangle \right\}, \quad (8)$$

b_i^T is a logical variable that corresponds to the name of *i*-parameter of the specification and takes value as the variable a_i^T. The interval variable $\left[y_i^T\right]$ determines the variation interval of *i*-parameter in the specification. β_i is the measure of significance of *i*-parameter ($\beta_i = -10^6$, 0, 1, 2, 3, 4, 5).

The information model of the specification of medical device's certain model is determined in the equations (5) – (8).

The criterion of the medical device's optimal choice should be formulated. The criterion is supposed to have vectorial form. It consists of two criterions I_1 and I_2. The criterion I_1 determines the fulfilment of the terms of the specification.

The way that determines the criterion I_1 is:

$$I_1 = I^L + I^A + I^B; \quad (9)$$

$$I^L = \sum_{i=1}^{n} \lambda_i \delta_i^L;$$

$$D_i^L = \left(l_i^T \wedge l_i^k\right) \vee \left[\left(\lambda_i = 10^{-6}\right) \wedge \left(l_i^k = \text{«false»}\right)\right];$$

$$\tilde{D}_i^L = \overline{\left(\lambda_i = 10^{-6}\right) \wedge \left(l_i^k = \text{«true»}\right)};$$

$$\delta_i^L = 1, \text{ if } D_i^L \wedge \tilde{D}_i^L = \text{«true»}, \ \delta_i^L = 0, \text{ if } D_i^L \wedge \tilde{D}_i^L = \text{«false»};$$

$$I^A = \sum_{i=1}^{m} a_i \delta_i^A; \quad (10)$$

$$D_i^A = \left(a_i^T \wedge a_i^k\right) \wedge \left[\left[\left(x_i^k \le x_i^T\right) \wedge (\gamma_i = -1)\right] \vee \left[\left(x_i^k \ge x_i^T\right) \wedge (\gamma_i = 1)\right]\right] \vee$$
$$\vee \left[\left(\lambda_i = 10^{-6}\right) \wedge \left(a_i^k = \text{«false»}\right)\right];$$

$$\tilde{D}_i^A = \overline{\left(\lambda_i = 10^{-6}\right) \wedge \left(a_i^k = \text{«true»}\right)},$$

$$\delta_i^A = 1, \text{ if } D_i^A \wedge \tilde{D}_i^A = \text{«true»}, \ \delta_i^A = 0, \text{ if } D_i^A \wedge \tilde{D}_i^A = \text{«false»};$$

$$I^B = \sum_{i=1}^{f} \beta_i \delta_i^B; \quad (11)$$

$$D_L^B = \left(b_i^T \wedge b_i^k\right) \wedge \left(\left[y_i^k\right] \subset \left[y_i^T\right]\right) \vee \left[\left(\lambda_i = 10^{-6}\right) \wedge \left(b_i^k = \text{«false»}\right)\right];$$

$$\tilde{D}_i^B = \overline{\left(\lambda_i = 10^{-6}\right) \wedge \left(b_i^k = \text{«true»}\right)};$$

$$\delta_i^B = 1, \text{ if } D_i^B \wedge \tilde{D}_i^B = \text{«true»}, \ \delta_i^B = 0, \text{ if } D_i^B \wedge \tilde{D}_i^B = \text{«false»}.$$

The criterion I_2 determines the price of the *k*-model of the medical device

$$I_2 = c^k. \tag{12}$$

The vector criterion is (9) – (12)

$$\overline{I}(k) = (I_1(k), I_2(k)). \tag{13}$$

The problem of the choice of medical device's optimal model can be formulated as following. The *k*-model should be found for the specification $T = \{L^T, A^T, B^T\}$. The *k*-model is correct when the value of $\overline{I}$ criterion is optimal

$$\overline{I^*}\left(k^*\right) = \underset{k=\overline{1,K}}{\text{opt}}\,(I_1, I_2) \tag{14}$$

for all $MD_k = \{L_k, A_k, B_k, c_k\}$.

The Pareto Principle is used to solve the problem of multi-objective optimization (13), (14). According to Pareto, if k^* solution is optimal, there are no other solution $k', k' = \overline{1, K}$,

$$I_1(k') \ge I_1\left(k^*\right),\ \ I_2(k') < I_2\left(k^*\right)$$

or

$$I_1(k') > I_1\left(k^*\right),\ \ I_2(k') \le I_2\left(k^*\right).$$

The equations formalize the Pareto Principle. There is no other k' model of the medical device, when there is an optimal solution – k^* model. There is no model, except for the optimal one, which price will be lower $I_2(k') < I_2\left(k^*\right)$, and which supports the same options $I_1(k') = I_1\left(k^*\right)$ or more options $I_1(k') \ge I_1\left(k^*\right)$.

There is just one optimal model, that has the same price $I_2(k') = I_2\left(k^*\right)$ or lower price $I_2(k') \le I_2\left(k^*\right)$ and that supports the same options $I_1(k') > I_1\left(k^*\right)$.

The result of solving the problem of multi-objective optimization is the multiplicity of values. This multiplicity is the Pareto field. All the optimal values on the Pareto field support the Pareto Principle. When one criterion is better, the other one is worse.

The algorithm of the working out a solution to the problem of selecting medical device's optimal model consists of the following steps.

1. The specification is created. The multiplicity *T* is determined (the information model of the specification).

2. The criterion I_2^Z is set (the price of the medical device). Only those *k*-models are chosen, which price equals to I_2^Z. k^* are chosen among them. The criterion of this model is $I_1 = \max$. This model defines the point in the Pareto field.

3. The new high price for the medical device is chosen. The price is increasing on ΔI_2. The new optimal Pareto model is determined.

4. The Pareto field is finished, when the highest possible price of the medical device is reached.

As a result there are models that are optimal according to Pareto. This procedure can be also called «price – quality».

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Оптимальный выбор изделия медицинской техники с использованием информационных систем в здравоохранении

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Аннотация: Предложено разработать систему поддержки принятия решений, позволяющую оптимизировать процесс закупки медицинской техники. Система будет иметь возможность выбирать оптимальную модель медицинского оборудования в соответствии с потребностями больницы и указанной цены. Для того чтобы создать такую систему, разработаны информационные модели медицинской техники, применены принцип Парето и многоцелевая оптимизация.

Optimale Auswahl des Erzeugnisses der medizinischen Technik unter Ausnutzung der informativen Systeme im Gesundheitswesen

Zusammenfassung: Es wird vorgeschlagen, das System der Unterstützung der Annahme der Entscheidungen, das zulässt, den Prozess des Einkaufes der medizinischen Technik zu optimieren, ausarbeiten. Das System wird die Möglichkeit haben, das optimale Modell der medizinischen Ausrüstung entsprechend den Bedürfnissen des Krankenhauses und den angegebene Preis zu wählen. Um solches System zu schaffen, waren es die informativen Modelle der medizinischen Technik entwickelt. Es waren das Prinzip von Pareto und die Mehrzweckoptimierung verwendet.

Choix optimal d'un produit de la technique médicale avec l'emploi des systèmes informatiques dans la santé publique

Résumé: Est proposé d'élaborer un système du maintient de la prise des solutions permettant d'optimiser le processus de l'achat de la technique médicale. Le système aura la possibilité de choisir le modèle optimal de l'équipement médical conformément aux besoins de l'hopital et au prix indiqué. Pour créer un tel système l'on a élaboré les modèles informatiques de la technique médicale. Ont été appliqués le principe Pareto et l'optimisation polyvalente.

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