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Defining the Ideality of the Protective Masks by the Mathematical Modeling Method

Technical contradiction occurs when the system improves one parameter, which automatically causes the deterioration of some of its other parameters. In such a situation, instead of usual acceptance of the optimization of the solution to the problem, in inventology - the process of idealization is carried out for finding the ideal final solution for the given problem. It is achieved if the physical contradictions that exist within the technical contradiction are solved. The paper deals with the procedure of mathematical modeling in determining the level of ideality as a criterion for the effectiveness of the Serbian military protective masks model M3 (mark ZM M3) in relation to the Serbian protective mask of the previous generation of the M2FV label (phonic with the drinking water subsystem). The presented mathematical model for the protective mask can be used as a standard for determining the idealness of any engineering system.

Key words: *idealization, mathematical modeling, protective mask.*

1. INTRODUCTION

Inventology as a science of innovative creativity starts from the fact that in every technical and technological problem it is necessary to seek its ideal final solution (IFS) [1]. Inventology is based on the Theory of Inventive Problem Solving (TRIZ, Rus. abr.) that essentially identifies, emphasizes and eliminates technical and physical contradictions in the system (S), and does not tend to create a compromise through optimization of the parameters. The term technical contradiction (TC) is the key to the TRIZ concept. One TC represents two contradictory features of the system. Improving one part or one feature of a system (for example, increasing the protective power of respiratory protection) automatically aggravates some of their other characteristics (for example, it increases resistance to breathing, which reduces the comfort of wearing it). In accordance with TRIZ, the problem is solved only if TC is identified and eliminated. The so-called common blindness, psychological inertia and a well-known tendency towards compromised (optimization) - all this can be overcome in a logical way through the use of inventology. Demonstration of the application of the TRIZ's 40 principles, as its most popular tools, is explained through numerous examples of technically and technologically [2,3] and ecologically appropriate products [4].

In 76 innovation standards, as the following essential TRIZ tools, each class of standards is divided into subclasses and subgroups [2-5]. In order to solve technical-technological problems using TRIZ standards, it is first necessary to determine which class the given problem belongs to, and then into which subclass and the group it can be classified. Special attention should be given to the fifth class of standards. It is applied when there are complications in the search for substances or fields that are missing. This class increases the degree of ideality of the system on which it is working, because it is focused on the maximum use of resources, both substances and fields that exist in the given system [1].

Once the ideal system is reached, then its mass (m), dimensions (d) and energy capacity (E) tend towards zero, and the ability to execute the main useful function (MUF) is not reduced. Idealism is always reflected in the maximum use of the existing system resources, both external and internal. The less costly the resources and the more they are prone to be used, the system will be more ideal. The ideal formula was first suggested by Altshuler [5], and it implied that the degree of ideality was inversely proportional to the sum of the useful functions of the system, on one hand, as well as the collection of the harmful system functions and the cost of its functioning, on the other hand. Mathematically, this can be expressed by the expression:

$$I = \sum F / \left(\sum C + \sum D\right) \qquad (1)$$

where is: I - ideality or the ideal final solution (IFS) of the system, ΣF - total functional possibilities (uses) of the system, ΣC - total harmfulness of the system, ΣD - total costs of the system maintenance.

From the expression (1) it can be seen that the ideality of the system can be increased in one of the three possible ways: by increasing the useful functions in the upper value of the fraction, by reducing the harmful functions and costs (prices) in the bottom value of the fracture and by combining the previous two modes. However, due to the increased demands for objectivity and validity of the methodology of estimating the achieved degree of ideality in some engineering system, there are efforts to show the expression (1) with the

Received: September 2018, Accepted: February 2019
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doi: 10.5937/fmet1903496R

most precise quantitative meaning [6]. In doing so, it has to be taken into account that the real system is asymptotically approaching the ideal system by resolving contradictions, using all available resources, minimizing components, using new physical, chemical and geometric phenomena and effects without increasing the harmful functions [1].

In this paper, Serbian military protective masks were used as concrete examples of one system engineering in the process of determining the ideality using the mathematical modeling method. The military protective mask is a filtering device for protection of the respiratory organs, eyes and faces from radiological, chemical and biological (RCB) contamination in a form of gas, vapor, solid and liquid aerosols [7]. It is also intended to protect users from industrial toxic substances, if the appropriate filter is applied to it.

The aim of this paper is to determine the level of its quality in comparison to the Serbian protective mask of the previous generation of the M2FV label (phonic with the drinking water subsystem) through an experimental comparative examination of the most important characteristics of the Serbian protective mask M3. After this, if the expected advantage in the ZM M3 characteristics in relation to the above-mentioned masks of the older generation is confirmed, the aim is to calculate the level of achieved ideality in its construction in relation to its main construction parameters. Based on the described methodology in this concrete case, the method of induction can be used for the analogous procedure for measuring the ideality of any engineering system.

2. THE FORMULA OF IDEALITY

If formula (1) is expanded, it is possible to obtain a ratio of so-called weighted sums [8]:

$$I = \left(k_1F_1 + k_2F_2 + \ldots + k_nF_n\right)/[(l_1C_1 + l_2C_2 + \ldots + l_nC_n) + (m_1D_1 + m_2D_2 + \ldots + m_nC_n)]. \quad (2)$$

where is: I - ideal final solution (IFS), k, l, m - coefficients that represent the importance of useful functions of the system, costs and harmful functions of the system.

In this expression, the formula is still dysfunctional, since the expressions have different units (e.g., the protective power i.e. the protection factor in the mask cannot be combined with its mass, nor the mass with the price, etc.). The problem can be solved by switching to normalized parameters, without units, but in this case the formula has at least two basic problems. These are the problems of mathematical and subjective linearity. Namely, if the system's functionality is doubled, it does not mean that there will be an increase in the ideality of the engineering system [8]:

$$I_1 = F/\left(C+D\right),\ I_2 = 2F/\left(C+D\right) \Rightarrow I_2 = 2I_1 \quad (3)$$

According to the expression (3) it can be seen that many of the small advantages of a system can compensate for one major (limiting) defect, such as, for example, mandatory minimum value of the protection factor prescribed by the standard. Accordingly, from the standpoint of the mathematical linearity, the expression (3) needs to be re-examined. The expression (3) should also be reconsidered from the point of view of subjective linearity, as technics and technology are developed to meet the needs of users. Therefore, the user is the one who needs to decide whether and how much the engineering system is sufficient. For example, if the cost of producing a protective mask is reduced by 5%, this is good, and in case they are reduced by more than 10%, this is extraordinary. However, in practice this is not realistic because the user's response to the same level of parameters in the same product can vary depending on external circumstances, which the formula completely ignores. For example, if a person by chance finds himself/herself in a very dangerous life situation in which, for example, there is an accidental release of industrial toxic gases, he/she will probably without much thought grab and use the first protective mask he/she finds on his/her hands, ignoring its ability to protect against the liberated agents. However, if the same person is in a normal life situation, which does not endanger him/her, then he/she will choose from more options the most adequate protective mask that is guaranteed to protect against a particular type of agent. It means that his/her answer is different in two different situations, in spite of what formula (3) claims. Therefore, this formula is not good.

2.1 Determination of user's responses to the parameter improvement of the engineering system

Improvement of any engineering system means improvement of one or more of its main parameters. Displaying the absolute value of parameter P cannot indicate whether this parameter choice is good or bad, whether it is too much or insufficient, etc. Therefore, parameter P should be normalized for an interval [8]:

$$P_n = \frac{P - P_{\min}}{P_{\max} - P_{\min}} \quad (4)$$

where is: P_n - normalized parameter for P_{min}, P_{max} intervals, P_{min}, P_{max} - minimum allowed and maximum necessary parameter values.

P_{min} i P_{max} have a real physical meaning. Their values are usually prescribed by appropriate standards and in this case they are binding by law. P_{min} is the minimum allowed value of the parameter, below which the user will not accept the engineering system under any circumstances. For example, if users who are continuously exposed to poisonous vapors, offer a respiratory disposable half-life mask, which can protect the user for several hours, and only from biological agents, most probably nobody will buy it regardless of its advantages (low price, comfort, availability, etc.). If the protective half-life mask was good enough for all-day protection, it would have most likely to been purchased. Therefore, there is a minimum protection time between these two values, under which no one will consider purchasing such a mask. Similarly, P_{max} is the maximum necessary parameter value so that its further overrun will not be essential to the user, so this increase will not necessarily be considered an improvement. For example, if the standard stipulates a protection factor of 100,000 [9], which guarantees absolute respiratory protection to the user, and the measurement found that it is actually only 110,000 in reality, it is unlikely that the user will be delighted by it. Therefore, there is always a certain limit beyond which further improvements are meaningless. Since the quality of the engineering system is determined by several parameters of different meanings for the user, it is necessary to introduce weight coefficients. Then the more important parameter will look like this [8]:

$$P_n = \frac{P - P_{\min}}{P_{\max} - P_{\min}}^{K} \quad (5)$$

where is K -weight coefficient (ponder), $0 < K < 1$.

As it has been already mentioned, when evaluating the ideality of a system, the value of the parameters that have been achieved is not what is being taken into account so much as the user's response to its improvement. This answer also depends on another factor called the degree of saturation of the market or the degree of availability of this parameter on the market. In the small-scale market, even small improvements will be of interest, while the user in a highly saturated market may be uninterested even when he/she is offered a significant improvement in the engineering system parameter. So, for one parameter the formula should look like the following [8]:

$$S = \left(\frac{P - P_{\min}}{P_{\max} - P_{\min}} \right)^{KL/1-L} \quad (6)$$

where is: S - the user's satisfaction with the parameter's value P, L - coefficient of the market saturation, $0 < L < 1$.

If the measuring units are such that improvement of the system implies a decrease of the parameter value (e.g. in a protective mask, an increase of the total resistence at inhalation is an undesired property) the formula changes slightly [8]:

$$S = \left(\frac{P_{\max} - P}{P_{\max} - P_{\min}} \right)^{KL/1-L} \quad (7)$$

where is: P_{min} and P_{max} - minimum and maximum allowed parameter values (i.e., improvement limit is P_{min}, and not P_{max}).

2.2 Defining the overall characteristics of the engineering system

Now the overall system characteristics, which can be called practical IFS, can be calculated in order to avoid confusion with ideality and its value as a geometric means of satisfaction for separate parameters [8]:

$$IFS = \left(\prod_{i=1}^{n} S_i \right)^{1/n} = \left(S_1 S_2 ... S_n \right)^{1/n} \quad (8)$$

where is: IFS – a practical value of the ideal final solution, S_i - user's satisfaction with the parameter value P_i, n – the number of parameters.

Also, a relative harmful Ri regime can be calculated as a "negative contribution" of each parameter to the practical value of the engineering system [8]:

$$R_i = \left(1 - s_i\right) / \sum_{i=1}^{n} \left(1 - S_i\right) \quad (9)$$

Formula (9) is a limiting case where all $Si = 1 \Rightarrow IFS = 1$. This means that all functional parameters have reached their best values, and the costs are reduced to insignificant levels. Such a system is perfectly suited to the "approximating ideal" system. It functions only where it is needed, when necessary and in the way it is needed. Indeed, why do we need an ideal system with zero costs when it is enough to reduce them to the level at which, for the user, it does not differ from zero? In this way, the system does not have to completely disappear as long as it retains the ability to perform its function.

3. MATERIAL AND METHODS

3.1 Determining the inner permeability level of the protective mask

One of the key parameters for testing the efficacy of the protection which the protective mask gives is monitoring the RBC contaminant aerosol's penetration, i.e. determining the inner permeability level of the protective mask. The mean value of face piece's inner permeability, tested on 10 face pieces and 10 examinee according to a defined matrix, using sodium chloride aerosol, must not be more than 4×10^{-2} % [9, 10]. During the comparative quality testing of different protective masks, the protective factor has been measured on: Serbian protective mask M2FV, size M (middle) and - Serbian protective mask M3, size M. The protection factor of protective masks has been measured by a standard test [11].

The test comprises seven activities which have simulated the action from real life conditions: a) Normal breathing without head movement at the beginning of the testing b) Energetic head movements to the left c) Energetic head movements to the right d) Energetic head movements upward e) Energetic head movements downward (towards the chest) f) Opening and closing the mouth with a deep inhale when the mouth is open to the maximum (hereinafter deep breathing) g) Normal breathing without head movement at the end of testing. For each test activity the measurement of protective mask factors has been carried out separately and the mean value has been calculated for all examinees.

3.2 Total resistance of the protective mask

Total resistance of the protective mask during inhalation has been measured according to the method described in [11]. For measuring total resistance of the protective mask during inhalation, a standard method has been applied, the method which uses a vacuum pump (provides sub pressure at the flow of 120 dm^3/min), flow meter (Rotameter) 0-120 dm^3/min, resistance meter 0-1500Pa and artificial head with anthropometric dimensions which correspond to the size of the tested protective mask. Before testing the resistance of each protective mask, it is necessary to carefully seal the mask along the fitting line onto the artificial head.

The exhaust valve resistance has been measured according to the method described in the literature [11]. For measuring the dynamic resistance of the exhaust valve a standard method has been applied, the method which uses the source of the airflow, flow meter, tray subassembly of the exhaust valve and instruments for measuring the resistance. The method of static permeability of the subassembly of the exhaust valve is described in the literature [11-13].

4. RESULTS AND DISCUSSION

One of the most important protective features of the protective mask is the internal leakage of ambient atmospheric air below the face along the face line of the user's head. The measured value of the internal leakage (protection factor) of the protective mask includes the leakage of the exhaust valve. Through the value of the protection factor, the quality of the protective masks design, the hermetic nature of the faces and the quality of its constituent elements are checked, and this feature is considered one of the most important ones.

Inner leakage (*P*) is calculated from aerosol concentration average values in the last 100 seconds of every test session. Inner leakage (*P*) expressed in percentage is calculated with the formula (10):

$$P(\%) = \frac{C_m}{C_0} \times \left[\frac{t_{in} + t_{ex}}{t_{in}} \right] \times 100 \quad (10)$$

where is: C_m - NaCl aerosol concentration under the mask, determined in the inhalation phase (mg/m^3), C_o - average NaCl aerosol value in the testing chamber (mg/m^3), t_{in} - overall inhalation time (s), t_{ex}- overall exhalation (s).

Review of the calculated mean values of the protection factor for all tested protective masks is shown in Table 1, where: *PF (1)* - protection factor mean value for normal breathing at the beginning of the testing, *PF (2)* - protection factor mean value for head movements to the left, *PF (3)* - protection factor mean value for head movements to the right, *PF (4)* - protection factor mean value for the upward head movements, *PF (5)* - protection factor mean value for the downward head movements, *PF (6)* - protection factor mean value for deep breathing, *PF (7)* - protection factor mean value for normal breathing at the end of testing, *PFm* - protection factor mean value for all test activities of all the examinees.

Table 1. Protection factor mean values of the tested protective masks

Protection factor	*PF (1)*	*PF (2)*	*PF (3)*	*PF (4)*	*PF (5)*	*PF (6)*	*PF (7)*	*PF m*
M2FV (M)	43228	59832	53004	52643	53613	44564	50852	51105
M3 (M)	109213	250318	92590	101349	109645	109325	89650	123156

During the testing of masks' resistance, mostly 4 different airflows have been applied: 30, 60, 90 and 120 dm^3/min, and given results are shown in Fig. 1. By analyzing given results of the total resistance of protective masks during inhaling, it can be concluded that the lowest resistance during inhaling, in complete applied flow range of 30 to dm^3/min, give Serbian protective mask M3, then the highest level of resistance has been measured in Serbian mask M2FV.

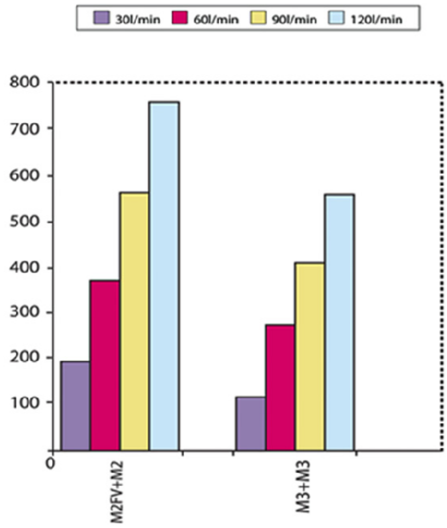

Figure 1. Total resistance (Pa) during inhalation in tested protective masks M2FV and M3 in combination with different filters (M2 and M3) - at different airflows

The Serbian protective mask M3 has significant improvements compared to the Serbian mask of the previous generation M2FV, both in the field of protection against RCB agents, and in terms of comfort for its user. In the M3 protective mask, material quality was improved with the choice of bromobutyl rubber instead of the natural rubber in the manufacture of the body of the face and nasal inserts, then the choice of the natural rubber in the manufacture of the inhalation and venting valve and transparent single-layer polycarbonate in the manufacture of eyepieces. By installing new subfolders, its functions are expanded. For example, the new construction of the venting valve subassembly and its carrier provide more reliable work and better hermeticity, as can be seen from the obtained results of the measurement of the protection factor. The new system of elastic strips of protective mask M3 contributes to the hermeticity, which ensures evenly fitting to the top of the user's head.

The field of vision with the Serbian protective mask M3 is 84% and it is at the level of the modern protection masks of the IV generation [12-15], and it is significantly higher compared to the Serbian protective masks of the older generation M2FV, in which this value is at the level of 70%.

The increase in the overall comfort of the M3 protective mask was achieved by a new structure of the body of the face, nasal insert and a new construction and the choice of the eyepiece position on the face.

On the basis of the obtained results of the examination of the protection factor, as well as the overall resistance of the respiratory masks when breathing, it can be concluded that the Serbian protective mask M3 in all cases met the set tactical and technical requirements [11].

The functions of the M3 protective mask have been extended by adding a new filter holder subassembly to the right, which makes it possible to efficiently use the mask for left-handed users when shooting, adding a correction glass bracket for visually impaired users and adding an auxiliary speech membrane for better speech transfer when using the means of communication.

The protective mask M3 meets all the set tactical-technical requirements of quality and in that sense represents a significant improvement in relation to the Serbian military protective masks of the previous generations of the M2FV labels. The obtained results show that it is according to its total tested characteristics at the level of modern means of personal respiratory protection of the IV generation [12]. However, from the point of view of practical value, it is necessary to determine the value of IFS protective masks M2FV and M3 (Tab. 2 and 3). To this end, the main parameters of the protective masks are essential for evaluating the ideality: the protection factor, the overall resistance (OR), the field of vision (FOV), the comfort of wear (CW) and the prices on the market.

Table 2. The achieved degree of ideality in the construction of the ZM M2FV

		PF, x 100.000	OR, dm^3/ min	FV (%)	CW, points	Price, x100 ($)	IFS (%)
Raw data	P_{min}-P_{max}	0.5-2.0	100-1000	50-100	1-10	2-10	34
	P	0.51	180	70	6	2	
	K	0.9	0.8	0.8	0.8	0.9	
	L	0.8	0.8	0.8	0.7	0.4	
Normal.	S/%	1.4x 10^{-8}	74	5.3	34	100	
Values	R/%	35	9	33	23	0	

Table 3. Achieved degree of ideality in the construction of ZM M3

		PF, x 100.000	OR, dm^3/ min	FV (%)	CW, points	Price, x100 ($)	IFS (%)
Raw data	P_{min}-P_{max}	0.5-2.0	100-1000	50-100	1-10	2-10	39
	P	1.2	100	84	7	2	
	K	0.9	0.8	0.8	0.8	0.9	
	L	0.8	0.8	0.8	0.7	0.4	
Nor-	S/%	6.6	100	29.1	47	100	
mal.		43	0	33	24	0	
Values	R/%						

It was found that in ZM M2FV the value of IFS = 34%, and the main problems are the protection factor, the wearing comfort and the visual field. In ZM M3 the value of IFS = 39%. So ZM M3 is about 5% more ideal than the previous generation ZM M2FV mask. Since the protection factor of 100,000 meets the requirements of the standard, ZM M3 does not need to further improve this parameter. This means that ZM M3 in the future only needs to improve its visual field and total comfort while wearing, which means improving its compatibility [16], with respect to other armaments and military equipment that is being carried by the user at the same time. Based on the above considerations, the limitations of the existing mode of calculating idealism (lack of quantitative calculations and low validity) are presented, which suggests an alternative formula (8) that has stronger arguments. This is quantitative calculation, which allows realistic calculations. This is important because all the necessary values are approximately known: the choice of Pi parameters, their current value, the relative importance of Ki, and the possible values of the interval (Pmin, Pmax) reflect the knowledge of user needs and saturation coefficients in the market while Li - the market offer of the product. This information is essential to carry out consultancy projects in every possible case. This analysis takes into account mathematical nonlinearity.

The practical value of the IFS is a non-dimensional value in the range of 0 to 1 and can also be expressed as a percentage and used to compare all the engineering systems, including those with different set of parameters.

4. CONCLUSION

The development of the engineering systems and other systems as a whole is a result of the improvement of their subsystems at all hierarchical levels. Since every subsystem under the law of unavailability of their development is at a different stage, it can primarily be concluded that the system is developing chaoticly because of the expansion, reduction and effect of one group of laws on the other. However, considering the development of each subsystem as part of a given system, it is strictly subordinated to the general scheme of evolution of a technical or engineering system. Determining the position of a particular system or subsystem on the line of its evolutionary development, it is possible to:

- objectively evaluate the obtained technical solution of the specific engineering problem and also immediately make several modifications of this solution in the direction of the effect of the law of technical evolution;
- progress the further development of engineering systems and more precisely formulate technical contradictions that prevent this development.

Knowing the law of evolution of technical systems is based on the method of solving specific inventive and innovative problems, and the standards for solving these problems are for the most part a direct consequence of them.

The formula for calculating the degree of ideality of an engineering system as a measure of their efficiency can be recommended for wider use in the following situations:

- to plan and evaluate the outcome of innovation from the standpoint of its efficiency,
- to select and evaluate business strategies,
- comparison of Competitive Heterogeneous Engineering Systems,
- for the evaluation of concepts and identification of secondary problems,
- for constructing and analyzing the S-curve type IFS = f (t) and Si = f (t).

When studying all the features of the engineering system, the IFS can be used to study the S-curve position in it. Thanks to its unique nature and scale, the use of Si allows analysis of several parameters on a single graph.

Based on the results obtained from the protection factor and the total resistance of air, it can be concluded that the Serbian protective mask M3 fulfilled all the tactical and technical requirements set out in the standards in question. The functions of the M3 protective mask have been extended to M2FV by adding a new sub-frame of the filter holder to the right, making it possible for the left handed users to use the mask more efficiently when aiming to shoot, adding correction glasses for the users with impaired vision, and adding auxiliary speech membrane for better speech transmission when using the communication devices.

The M3 protective mask meets all the established tactical-technical requirements of quality and in this respect represents a significant improvement of the Serbian military protective mask compared to the previous generation of the M2FV mask. Further construction enhancements should be aimed at increasing the visual field and improving the comfort of the user during its operational use.

ACKNOWLEDGMENT

This work is supported by the Ministry of Education, Science and Technological Development of the Government of the Republic of Serbia within the framework of the TR34034 project.

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ОДРЕЂИВАЊЕ ИДЕАЛНОСТИ ЗАШТИТНИХ МАСКИ МЕТОДОМ МАТЕМАТИЧКОГ МОДЕЛОВАЊА

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Техничка контрадикција се јавља кад се код система побољша један параметар, који аутоматски узрокује погоршање неког његовог другог параметра. У таквој ситуацији, уместо оптимизације решења насталог проблема, у инвентологији се спроводи процес идеализације, тј. проналажења идеалног коначног решења за дати проблем. Он се постиже уколико се реше физичке контрадикције које постоје унутар техничке контрадикције. У раду је дат поступак математичког моделовања при одређивању нивоа идеалности као критеријума ефикасности српске војне заштитне маске модел М3 (ЗМ М3) у односу на српску заштитну маску претходне генерације ознаке М2ФВ (фонична са подсистемом за пијење воде). Презентовани математички модел за заштитну маску може да се користи као еталон за одређивање идеалности било ког инжењеринг система.