Objective Technology Selection Model: The Example of complex combat systems

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Abstract - Basic objective of designers and manufacturers is a technical system with better features than others, especially their competitors. On the other side, customers demand a product that enables maximum gains and minimum costs. In such a way, key issue in decision making process is selection of different options, and finding out the best one. This paper presents the objective selection model as an unbiased approach in selecting the technology to be implemented in a long-term period of time. The basic prerequisites imply the fact that a specific technical system and its characteristics are not considered as a single unit, but as a part of specific technological solution during a predetermined period of time. Temporal dimension includes the comparison of specific parameters (realized effects and generated costs) between successive generations for the same technological type and between different types of technologies. Manufacturers should recognize customers' demands and increase technical systems performances and decrease their costs. Presented model could be implemented in industry, economic, social, and other spheres in the development planning process.

Keywords: decision making process, costs estimation, multi-criteria analysis, technology.

0 NOMENCLATURES:

p_{kj} - Observed technical system performance of j technology generation;

p_{ji} - Individual technical system performance of j technology generation;

$\bar{p}_{kj}$ - Individual performance normalized value of generation j;

$p_{k\min}$ - Individual performance minimal value of generation j;

$p_{k\max}$ - Individual performance maximal value of generation j;

P - Average performance values matrix;

$\bar{P}$ - Normalized performance values matrix;

W - Performance relative importance matrix;

T - Technology effectiveness matrix;

C - Cost matrix;

w_{pi} - Individual performance weight;

σ_{pi} - Individual performance standard deviation;

c_j - Average unit costs of observed technology.

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j - *Observed technology generation (time interval) from 1 to the g*

g - *Number of technology generations (time intervals);*

k - *Observed performance designation of a specific technical system (e. g. V_{max}, h_{max}, etc.), from 1 to the r;*

r - *Number of observed performances;*

n - *Number of observed technical systems;*

t - *Number of observed technology*

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1. INTRODUCTION AND RELEVANCIES OF MODELING

Modern trends indicate the existence of exponential growth in real production costs between successive generations of complex combat systems and the decrease in defence expenditure [1] and [2]. This phenomenon is a consequence of changes in modern environment, new threats and challenges and constant competition between the rivals. It also results remarkable advances in technology and productivity in military industry, large investments in R&D and implementation of more sophisticated outcomes [3]. According to [4] the cost growth for Western technology fighter aircraft is on the average of 5-10% per annum. Other analyses claim that the increase in unit costs between successive generations of complex combat systems exists, but at a lower rate, 2.6-5.9% [5].

The growth of military equipment costs is often resulted by different procurement terms determined in the sales contract by nations in the sales process, as well as the specifics of bilateral relations existing between the two nations (the buyer and the seller). As this is the case of non-standardized patterns of behaviour, it should be excluded from the analysis to determine the real roots of cost growth.

Considering trend analysis, one may arrive at a conclusion that there is a progressive increase in both, production costs and performances among successive generations of the same type of combat aircraft [4]. Also, the production cost growth rate is significantly higher than the performance growth rate, and a slight increase in performance can lead to disproportionate increase in costs [16].

Maintaining existing and developing new capabilities to effectively respond to new challenges and threats requires higher investments in procurement of new and more sophisticated pieces of military equipment. Given the fact, that there is a decreasing trend in defence spending, the key issue for military management becomes the selection of the optimal option [1]. The optimal option is the one that provides maximum effects with minimum allocated costs.

The process of capability development in modern environment is very complex and contains different conflicts, moreover it imposes the need to recognize multiple requirements (criteria) that have an influence on the decision-making process, and this is a so-called multi-criteria decision-making process [7] and [8]. In theory and practice, there are several different approaches to multi-criteria decision making [9], and each of them has advantages and disadvantages. The application of a specific approach depends on the nature of the problem to be solved. The aim of multi-criteria decision-making is to determine criteria that provide influence on problem solution, their mutual interrelationships, and alternatives determination, impact of criteria on various alternatives and to rank the alternatives in accordance with the impact of the criteria [10].

In this paper a new multi-criteria analysis model is formed and it includes consideration of basic characteristics (performances) that largely represent the real combat systems. The model considers the improvement tendency of these performances within certain time limits, the ability to forecast them in the future and to identify their specific weights [11]. For more comprehensive analysis it is necessary to select the optimal technology, and then within the framework of selected technology, to make a decision about procurement of a specific combat system. This process becomes very important since the relevant decision includes large financial spending and requires many additional costs during the unit life span. Sometimes, it is more rational to operate within the framework of the existing technology, because changing the technology is very costly and would not provide greater benefits than the overall costs in the long-term perspective [12] and [13].

The results of this analysis greatly depend on data availability and data accuracy related to complex combat systems. They are considered as sophisticated products that have characteristics of strategic hardware. However, the aim of this research is not emphasizing the most cost-efficient technology, but finding the most objective method of selection based on available data.

2. PRESENTATION OF THE OBJECTIVE TECHNOLOGY SELECTION MODEL

In selecting the optimal technology it is necessary as much as possible to exclude the subjective stakeholders' influence. The multi-criteria model of objective technology selection is used to make the selection process simpler and to make an objective decision. This model is based on the use of different criteria with their predetermined relative importance/weights [14]. Objective technology selection model is a mathematical model that enables an objective selection between different types of technology in four steps: identifying the most significant performances to be valued; determining the effects that specific technology provides; determining the cost trends, and measuring the rationality of technology implementation within the organization [16]. Finally decision makers can make the optimal decision in the selecting process (Fig. 1).

The selection process starts with determining major performances (criteria) and their weightings based on overwhelming tendencies in real value of their parameters. In the first step initial matrix is formed - the mean of the performance values of a specific technology generation. The elements of the initial matrix are determined using Eq. (1).

$$p_{kj} = \frac{1}{n}\sum_{i=1}^{n} p_{ji} \quad (1)$$

According to these determined elements starting matrix P is formed – Eq. (2) and (3).

$$P = [p_{kj}]_{r\times j} \quad (2)$$

Or,

$$P = \begin{bmatrix} p_{v1} & p_{v2} & \cdots \\ p_{h1} & p_{h2} & \cdots \\ \cdots & \cdots & \cdots \end{bmatrix} \quad (3)$$

For further use and performances comparability the normalized performance values are calculated comparing each individual performance value of technology generation – *j* to its extreme values, the lowest value of each individual performance of a technology generation – *j* (the lowest element value of initial P matrix) and the highest value of each individual performance of a technology generation – *j* (the highest element value of initial P matrix) of Eq. (4).

$$\bar{p}_{kj} = \frac{p_{kj} - p_{k\min}}{p_{k\max} - p_{k\min}} \quad (4)$$

After the calculation of normalized performance values, the normalized matrix $\bar{P}$ is formed of Eq. (5).

$$\bar{P} = [\bar{p}_{kj}]_{r\times j}, \quad (5)$$

Deviation of each individual performance normalized values of technology generation – *j* is used to determine the weight of each performance w_p and to form a matrix *T* that represents specific type of technology. The weight of each performance represents normalized value of standard deviation for all performances of Eq. (6).

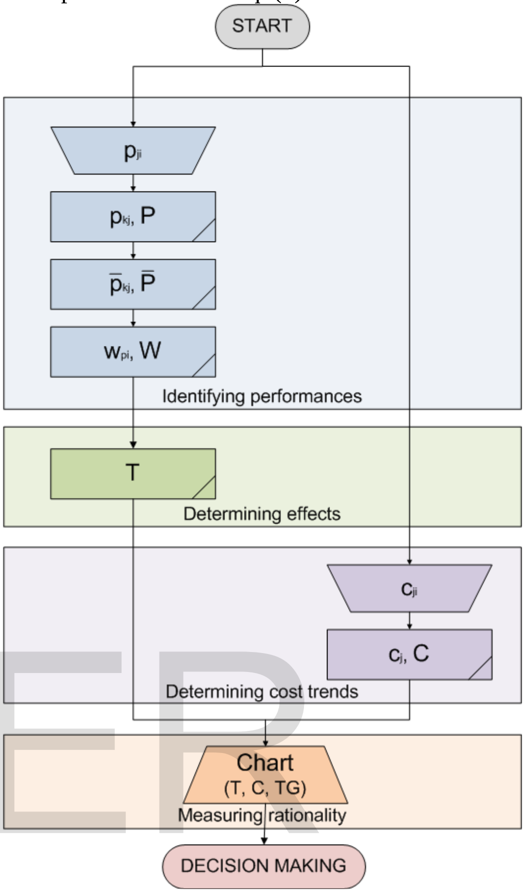

Fig. 1. *Objective technology selection model*

$$w_{pi} = \frac{\sigma_{pi}}{\sum_{i=1}^{n}\sigma_{pi}} \quad (6)$$

Taking weights into account, the matrix that represents relative importance of determined performances of technology is formed by Eq. (7).

$$W = [w_{pi}]_{1\times j} \quad (7)$$

The next phase is to determine the effects that the implementation of technology generates. The effects of the technology implementation are quantified as a sum of multiplication of performances and their weights, and they are presented as matrix *T* by Eq. (8). The more the sum of multiplied performances and their weights is the more is the effect that specific type of technology generates.

$$T = P \times W \quad (8)$$

After the effects determination and its presentation as a curve, the next step is to determine the function that represents cost trends that are generated by specific technology of Eq. (9), and that are observed through successive generations of the same technology.

$$c_j = \frac{1}{n}\sum_{i=1}^{n} c_{ji} \; , \quad (9)$$

According to these determined elements cost matrix *C* is formed – Eqn. (10).

$$C = [c_j]_{t \times j} \quad (10)$$

All this information is used as an input to determine rationality of specific technology application. This is presented by mapping and linking effects and costs in the same quadrant of coordinate system (Fig. 2). The coordinate system is given in Fig. 2 and it shows the average effects that specific technology provides (T), technology (C), generation (TG) and the average costs generated by specific type of technology (C).

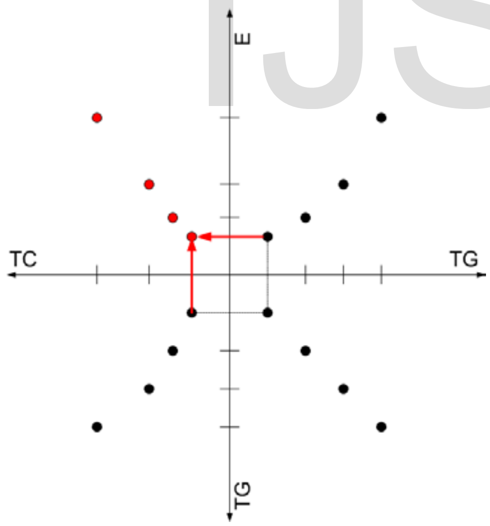

Fig. 2. The ratio of effects and costs of technology implementation

Effects are shown in the first quadrant (upper-right one), and costs in the third quadrant (down-left one). The curve that reflects the relation between effects and costs is shown in the fourth quadrant (upper-left one). This line is determined by bringing the bond between values from the first (effects) and the third (costs) quadrant for each technology generation.

The process of selecting a specific technology is performed by comparing the rationality of all the considered technologies and the most rational technology is the one whose rationality curve is closer to the axis that measure the effects.

3. SIMULATION OF THE MODEL AND RESULTS

To examine the model of objective technology selection, a simulation of two different aircrafts (A and B technological system) is conducted. To simulate the model, we determined flight performances: Maximum speed, Ferry range, Service ceiling, Rate of climb, Thrust-to-Weight Ratio and Wing specific load.

Data of the flight performances are collected from open sources from the first to the last aircrafts generation. Based on the historical value of the chosen flight performances and through Eqns. (1) and (2), the flight performances matrix for five successive generations of well-known fighters is formed (Table 1).

As it is shown in table 1, flight performances are increased during the past. For example, maximum speed of technological system A is increased from 1,040 (the first technological generation) to 2,410 (last technological generation).

For further data implementation and data comparability, the normalization of matrix values is performed by using Eq. (4) and (5).

The next phase is determination of relative importance (weight) of previously selected flight performances that is performed by using Eqn. (6).

This is the matrix of normalized flight performance values for A and B technology (Table 2).

Later, the matrix of flight performance is formed (Table 3).

Transformation of flight performance values enables the determination of relative importance as well as the determination of effectiveness of the specific technology generation.

Applying Eqn. (8) we determined the effect of each technology generation for A and B case (Table 4).

Table 1. Average values of flight performances

Flight performances	Technological generation									
	I		II		III		IV		V	
	A	B	A	B	A	B	A	B	A	B
Maximum speed	1,040	1,102	1,702	1,927	2,035	2,447	2,296	2,387	2,410	2,440
Ferry range	2,476	1,650	2,701	1,417	3,150	2,239	4,003	3,476	3,220	5,500
Service ceiling	14,530	16,050	16,000	17,633	17,050	18,100	16,420	17,771	20,000	20,000
Rate of climb	35.78	58.10	146.58	188.33	192.50	237.20	247.75	265.67	350.00	350.00
Thrust-to-Weight Ratio	0.38	0.58	0.65	0.79	0.78	0.71	0.98	0.88	1.06	1.14
Wing specific load	307.26	239.58	353.28	349.00	390.82	478.54	434.42	490.89	376.86	371.45

Table 2. Transformation values of flight performances

Flight performances	Technological generation									
	I		II		III		IV		V	
	A	B	A	B	A	B	A	B	A	B
Maximum speed	0.000	0.000	0.483	0.613	0.726	1.000	0.917	0.955	1.000	0.995
Ferry range	0.000	0.057	0.147	0.000	0.442	0.201	1.000	0.504	0.487	1.000
Service ceiling	0.000	0.000	0.269	0.401	0.461	0.519	0.346	0.436	1.000	1.000
Rate of climb	0.000	0.000	0.353	0.446	0.499	0.614	0.675	0.711	1.000	1.000
Thrust-to-Weight Ratio	0.000	0.000	0.393	0.375	0.588	0.232	0.882	0.536	1.000	1.000
Wing specific load	0.000	0.000	0.362	0.435	0.657	0.951	1.000	1.000	0.547	0.525

Table 3. Flight performance weights

A technology – weights flight performances		B technology – weights flight performances	
Maximum speed	0.175	Maximum speed	0.183
Ferry range	0.168	Ferry range	0.175
Service ceiling	0.160	Service ceiling	0.152
Rate of climb	0.162	Rate of climb	0.157
Thrust-to-Weight Ratio	0.174	Thrust-to-Weight Ratio	0.159
Wing specific load	0.161	Wing specific load	0.174

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Table 4. Effectiveness of technology generations

Technology	Technological generation				
	I	**II**	**III**	**IV**	**V**
A technological	0.000	2.007	3.373	4.819	5.035
B technological	0.057	2.271	3.517	4.142	5.520

The effects of specific technology generation are linked with the effects of different technology generations of the same technology, forming the effectiveness curve and then comparing to the effects of other technologies for the same generation (Fig. 3. Effectiveness of A and B technologies.

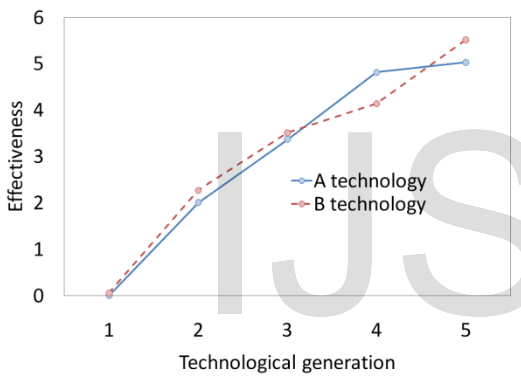

Fig. 3. Effectiveness of A and B technologies.

To select the optimal technology, it is necessary to include costs that its implementation generates as a second parameter. Decision makers are faced with different constraints in this case. The first constraint is the budget with the decreasing tendency. The second constraint is the trend of constantly increasing investment costs of military equipment and armament to satisfy consumer needs. In modern environment, the consumer factor is becoming increasingly dominant factor [6]. The consequence is high technological intensity of complex combat systems caused by the growth of research and development costs, designing and testing costs as well as costs of implementing complex software solutions in total amount of costs. All of these costs are fixed costs and they have a huge influence on a unit cost and final price of specific combat system. In this way buyer nations could buy less for their limited budget, and at a global level this leads to total decrease in produced and purchased complex combat systems. Also, the advantages of economic of scale become limited.

In Table 5 average costs of combat aircraft for five successive generations for A and B technology are given. To make this data comparable between generations and to neutralize the influence of inflation and price changes through the time, nominal values are converted to values in real terms by using the prices in USD of the base year [15]. Observing the values in the Table, it can be noted that there are large differences between successive generations in the average cost of combat aircraft for both the B as well as the A technology.

Fig. 4 shows the rising trend in the costs of combat aircraft for both, A and B technology. According to Fig. 4 it can be noticed that it is about exponential rise in both cases, with the remark that the slope of the curve which refers to B technology is milder in comparison with A.

Table 5. Average costs of aircrafts

Technology	Technological generation				
	I	**II**	**III**	**IV**	**V**
Average unit costs A technology (USD)	2,700,000	6,200,000	13,000,000	42,000,000	150,000,000
Average unit costs B technology (USD)	2,200,000	5,000,000	10,000,000	39,000,000	100,000,000

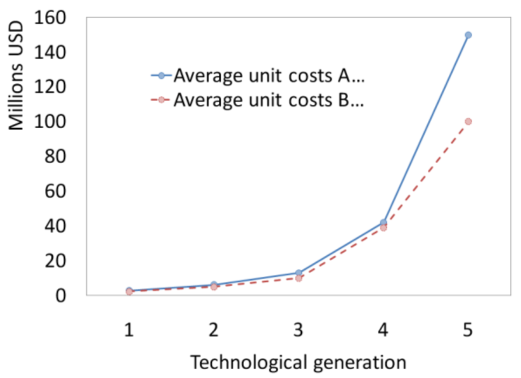

Fig. 4. Cost of A and B technologies.

While selecting an optimal technology it is necessary to relate effects with limitations. Considering this, optimal selection will be reached when there are maximal effects of technology implementation for a given budget.

In this step, the effects gained by implementation of specific technology generation are being related with its average generated costs comparing its curves. Obtained curves represent the correlation between the effects and costs that are generated by specific technology implementation. The technology curve with the flatter slope indicates greater costs increase than performances increase. In the long term, technology with the steeper slope would be an optimal selection. This means that it gains greater increase in performances comparing to the cost increase.

The effects-to-costs ratio is determined by bringing the effects and costs generated by technologies into connection (mapping data from the first and the third quadrant). In this way, it is enabled to compare rationality of specific technology implementation (Fig 5). As it is shown on Fig 4. besides different performance values used in this case, it is possible to compare different technologies as well as to determine trends.

Comparison of different technologies enables objective overview of advantages and disadvantages, and also selection of optimal technology among different ones.

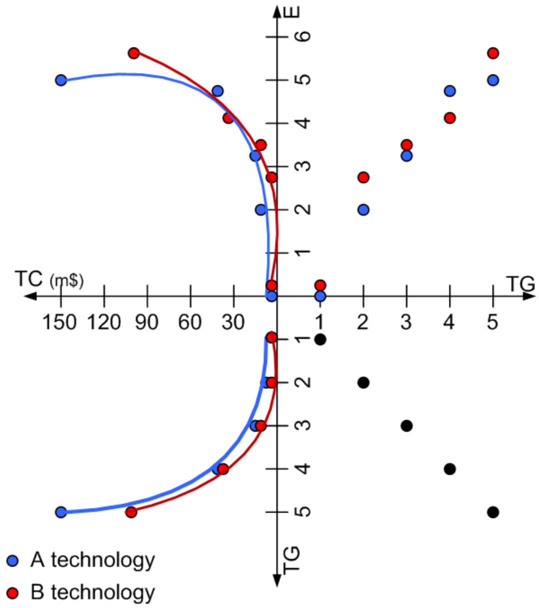

Fig. 5. Rationality of A and B technology

4. CONCLUSIONS AND DISCUSSION

The aim of this paper is to determine the model of objective technology selection that is based on consideration of the most significant performances and costs that are generated by considered piece of equipment and on their comparison. Since procurement of defence equipment is a very complex issue, making such a delicate decision requires consideration of various parameters. The co-authors simplified the model of the research and implemented the shorter version of it. Two different technologies are compared through key flight performances and costs that are generated.

Selecting the optimal technology is executed through three phases: determining key performances, determining technology effectiveness and efficiency, selecting the optimal option. The key performances do not have the same level of importance, the co-authors ranked them by determining their normalized weights. Performances values are normalized to be comparable.

On the basis of performance values and their normalized weights, the effect of technology implementation is determined. The optimal selection is made by combining of effects and costs that are generated by technology implementation.

The gap between curves that reflect cost-effect ratio for different technologies is determined by simulation of the objective technology selection model. The implementation of this model enables objective approach to technology selection and it can be applied in selecting a specific piece of equipment any organizations.

This model enables two main contributions. One of them is aimed at practical usage and other at science. The practical application is reflected in the process of making business decision. Also the model enables decrease procurement expenses, and manufacturers can recognize customers' needs.

At the science field, the results of this paper contribute on mechanical engineering, economics, and methodology. Especial endowment is reflected in mechanical engineering. Scientists and designers in the industry can use these results in the new technical systems development.

Shortly, the model enables following:

- objective overview of technology effects;
- different types of data used;
- different technology comparison;
- optimal technology selection;
- identification of most significant technical systems performances etc.

Aggravating factor in the application of this model are costs generated by technology implementation. The main issue is confidentiality of sales contracts, different approaches to resource maintenance, and different levels of resource consumption. In determining generated costs these observations should be taken into account.

Since this model is a dynamic model (performance selection is optional and it depends on decision maker's needs, according the purpose of the analysis) it can be implemented in defence sector in different states. Besides it, this model can be applicable in different segments of state administration, profit or non-profit organizations.

REFERENCES

[1] Kirkpatrick, D. (1997), Rising costs, falling budgets and their implications for defence policy, *Defence and Peace Economics*, 10-14.

[2] Pugh, P. (2007),Retrospect and prospect: trends in cost and their implications for UK aerospace, *Defence and Peace Economics*, 25-37,

[3] Kirkpatrick, D. (1995), The rising unit cost of defence equipment - The reasons and results, *Defence and Peace Economics*, 263-288.

[4] Kirkpatrick, D. (2004), Trends in the costs of weapon systems and the consequences. *Defence and Peace Economics*, 259-279.

[5] Davies, N., Eager, A., Maier M. and Penfold L.(2011),Intergenerational Equipment Cost Escalation, *Ministry of Defence UK.*

[6] Arena M. V., Younissi O., Brancati K., Blickstein I., & Grammich C. A. (2008),Why has the Cost of Fixed-Wing Aircraft Risen? – Macroscopic Examination of the Trends in U.S. Military Aircraft Costs over the Past Several Decades, *RAND National Defense Research Institute.*

[7] Xu, L., & Yang, J.-B. (2001),Introduction to Multi-Criteria Decision Making and the Evidential Reasoning Approach, Working Manchester School of Management. Manchester: *University of Manchester Institute of Science and Technology.* Paper No. 0106.

[8] Xia, M., Chen, J. (2015),Multi-criteria group decision making based on bilateral agreements. *European Jour. of Operational Res.*, , 240, 756-764.

[9] Ho, W., Xu, X., Dey, P. K. Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. *European Jour. of Operational Res.*, 2010, 202, 16-24.

[10] Rolland, A. (2013), Reference-based preferences aggregation procedures in multi-criteria decision making. *European Jour. of Operational Res.*, 225, 479-486.

[11] Velasquez, M., Hester, P. T. (2013). An Analysis of Multi-Criteria Decision Making Methods. *International Journal of Operations Research*, 2013, **10**(2), 56-66.

[12] Shanoy, R. P. (1996), Technology Management in our Liberalised Environment, *Defence Science Journal*, **46**(3), 181-193.

[13] Salwan, P. (2005), Technology Transfer and Technology Management in Strategic Systems, *Defence Science Journal*, **55**(2), 141-148.

[14] Mishra, S. N., Deshmukh, S. G. Vrat, P. (2003), Technological Forecasting Applications: Framework and Case Study on Combat Vehicles, *Defence Science Journal*, **53**(4), 371-391.

[15] *Internatioanal Monetary Fund*. (n.d.). [Accessed on 6 April 2015] http://www.imf.org/external/pubs/ft/weo/2014/02/weodata/index.aspx.

[16] Leber M., Bastič M., Buchmeister B.(2014): "The Trends in Usage and Barriers of Innovation Management Techniques in New Product Development", *Strojniški vestnik - Journa of Mechanical Engineering*, Vol.60. no. 6, p. 382-388