INTRODUCTION TO THE ECONOMIC THEORY OF MILITARY ROBOTICS

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Abstract. The paper deals with the economic theory of military robotics demarcation. The paper is aimed at the description of theoretical rudiments and practical application of the economic theory of military robotics. The theory covers the areas of capital-labour substitution, barriers to the introduction and further development of military robotics, costeffectiveness of military robots, factors and limits to the market of military robots and the industry development. The paper is primarily focused on the economic dimension of military robotics and the necessity of in-depth research of economic aspects of this "game changing" phenomenon.

Key words: capital-labour substitution, economics of military robotics, economic principles, military robotics, military robots, military robotics industry.

Introduction

Nowadays military robots are considered to be the future of modern warfare. At the same time, military robotics is considered to be the game-changing technology that could change the structure and employment of armed forces. Society is aware of the military employment of robots today. During the last decade we witnessed a surge of military robots on the battlefield. Thousands are deployed in Iraq and Afghanistan, supporting troops on the land, at the sea, and in the air (Singer 2009) and nearly 41 percent of the U.S. military aircraft are unmanned at present.

The question is why we witness the massive use of military robotics only during the last decade. What factors determine such a development? Is this development a common trend in all armies or just some of them? What benefits can we gain by employing the military robots on the battlefield? The questions above may be answered by implementing the economic theory in the area of military robotics. The military robotics is the application of robotics in the military, such as remotely piloted vehicles operating on the ground, in the air or under water, automated ammunition and supply handling devices.

The economic theory of military robotics could be considered as the newest branch of defence economics (Katoch 2006). The general purpose of the economic theory of military robotics is to describe and explain the overall economic aspects and impacts of the military robotics. The analysis in the field of the economics of military robotics can range from considering solely economic aspects to the use of economic and econometric tools, such as cost-benefit analysis and modelling. Microeconomic issues are primarily examined in the economics of military robotics; sometimes these issues are indirectly linked with macroeconomics. For example, macroeconomic approach could be used in the analysis of the military robotics expenditure and the interrelationship between national or regional economy and the growth in the military robotics sector. Robotics is considered to be a cause of new industrial revolution and a potential source of economic growth (The Economist 2012). This opinion is supported by the macroeconomic theory of endogenous growth (Mládek 2015). The microeconomics comes into play when military robotics industries or military robots cost-effectiveness are examined.

The following fundamental questions are tackled, among others, in the economic theory of military robotics:

- What economic factors influence the foundation and further development of military robots?
- What factors drive the cost-benefit effectiveness of military robots employed in armed forces and a theatre of war?
- What are the relationships among autonomy, reliability and cost-effectiveness of military robots?
- What factors determine the development of military robotics industry and companies?
- To what extent is the government interested in regulating and supporting the producers of military robots?
- What role does the value of human life play in introducing military robots into armed forces?

The economics of military robotics could be understood as "the allocation of scarce resources to meet spending and policy goals concerning the development of military robotics". It is stated more broadly that "economics of military robotics" consists of applying the economic analytical tools into the area of military robotics. As economics or defence economics is, to a certain extent, the science of choice, the economics of military robotics may be perceived as a systematic study of choices among competing alternatives concerning the future shape of armed forces with different levels of integration of military robots.

Thus, the economic theory of military robotics is essentially the application of economic principles and analysis to the area of military robotics and the text below provides a partial insight into this subject matter.

1. The economics of military robotics demarcation methodology and literature review

Literature on the topic is extensive, but papers which place emphasis on economic aspects of military robotics are rare (see Table 1). Publications deal mainly with the importance and employment of robotics in armed forces from military (Aldridge 2003), legal and ethical points of view (Carr 2012). The authors paying attention to the economic aspects of the issue do it only partially.

Table 1. Classification matrix of publications within military robotics research area

Areas of scientific research	Type of publication		
	Monographs	**Articles**	**Popularization articles**
Military, technical and technological level of problem solving	Schneider, Roning 2006; Nath, Levison 2014; Boon, Lovelace 2014; Winnefeld, Kendall 2013	Horowitz, Scharre 2015; Work, Brimley 2014	Nail 2011; The Economist 2012; Ranasinghe 2015
Ethical, legal and societal level of problem solving	Kurzweil 2005; Krishnan 2009; Arkin 2009;Galliott 2015	McDaniel 2008; Foy 2014; Arkin 2015	Carr 2012; United Nations 2015
Economic and financial level of problem solving	Singer 2009; Springer 2013	Goos 2014; Haal, Coyne 2014; Scharre 2014; Burg, Scharre 2014	Strickland 2007; Francis 2013

Source: own elaboration.

Within the economics of military robotics demarcation it is assumed that new branches of defence economics can be derived from the basic definitions of defence economics. The definitions of defence economics developed by prominent economists are applied in case of demarcating the economics of military robotics. Hartley and Sandler have stated that the economics of defence is a study of basic issues of both defence and peace by applying modern economic tools (Hartley, Sandler 1995). Kennedy considers the defence economics to be an application of economics on defence issues (Kennedy 1984). Krč and Stankiewicz have demarcated the defence economics as a scientific discipline looking for economic relations that influenced national security (Krč 2001; Stankiewicz 1981). Olvey writes about the application of basic economic principles in the area of national defence (Olvey 1984). Based on analogy, comparison and simplification, there are selected the economic principles which are suitable for demarcating the economics of military robotics. Subsequently, these principles can serve for the explanation of economic aspect of military robotics, the examination of military robots cost benefit and the description of barriers to further development of military robotics.

2. Principles influencing the development of military robotics area

The economic theory can be very useful for understanding the development and current state of military robotics. The economic theory shows that the economic dimension has played a key role in the main military issues. Decision-making process under military conditions has often been influenced by certain fundamental economic principles. Final decisions in military affairs have been determined by the intensity of effects of such principles. The list of the principles is as follows (Van Tuyll, Brauer 2003; Krč 2008):

– the principle of the marginal opportunity costs,
– the principle of expected marginal costs and benefits,
– the principle of substitution,
– the principle of consumer and producer surplus,
– the principle of economies of scale,
– the principle of diminishing returns,
– the principle of the incentives role, and
– the principle of the customer and supplier relationship.

The evaluation of the influence rate of the principles mentioned above enables us to understand and explain the radical changes in the military robotics area. It is possible to assume that the most influential on military robots introduction and development in the theatre from the principles above are: principle of the marginal opportunity costs, principle of the economies of scale, principle of consumer and producer surplus and principle of the capital-labour substitution.

2.1. The principle of marginal opportunity costs

This principle can be linked with the increasing costs of training the professional soldiers and the possible loss of these soldiers in combat. The army loses trained, productive power and the society loses citizens as possible labour force, parents and voters. This is the reason of an increasing pressure on research, development and introduction of military robots into armed forces. The higher marginal opportunity costs will be the higher pressure on the military robotics can be expected.

2.2. The principle of economies of scale

Generally the economies of scale are linked with the decreasing unit costs due to the increase in production. Such a surge of production is reached by business operation efficiency. We can see the economies of scale in relation to the development of military robotics and the decrease in indirect costs (i.e. fuel, spare parts, and services) through growth in the quantity of consumed commodities.

2.3. The principle of consumer and producer surplus

This principle is the basis for financial and mainly economic (cost-benefit) analysis. The basic indicator is the crucial relation between the willingness to pay and supply. The determination of consumer surplus is the initial concept for impact evaluation and cost-benefit analysis. The producer surplus is connected with the value of opportunity costs. The opportunity costs are important for cost-benefit analysis, too. In this case, the consumer and producer surplus can be used for estimating the social willingness to pay for the employment of robotics in armed forces and the theatre of war.

2.4. The principle of capital-labour substitution

This principle is supposed to be the most powerful in relation to the expansion of military robotics. Usefulness of this principle in other areas of military and national economy is obvious (Procházka, Prochazková-Ilinitchi 2011). It can be stated in this context that military manpower can be, to some extent, substituted by capital, i.e. soldiers can be superseded by military robots. Substitution of labour by capital is encouraged by two fundamental rational motives. The first one is the protection incentive; the second one is the increasing productivity incentive. The protection incentive, demonstrated by the replacement of soldier´s performance by technology (in our case by military robots), makes the protection of specialized military manpower from death, loss of health and injuries possible. The consequence of such substitution can be twofold, the diminishing demand for labour and consequently personnel saving, and also the transfer of manpower to other lines of duty. On the contrary, the fact that soldiers are equipped with capital results in the increase of their productivity. Labour substituted by capital decreases the dependence of armed forces on the labour market or on the demographic development, and possibly on the development of pacifistic moods. The replacement of labour by capital and a simultaneous surge in the overall value of capital in relation to a labour unit is described as a capital deepening. The capital deepening in the armed forces contributes to their modernization and strengthens the technological aspect. The current introduction of military robots into armed forces is led by both above-mentioned incentives. All the four main principles mentioned above are going to accelerate the development of military robotics.

3. The principle of capital-labour substitution – the case of military robotics

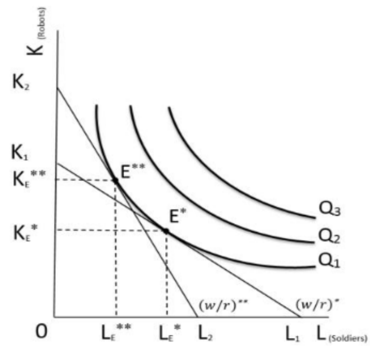
If the issue of capital-labour substitution is to be described in relation to the introduction of military robots in the theatre, the tools of microeconomic analysis can be implemented. The function of military production may be described by a two-factor model. The general two-factor production function may be given algebraically as

$$Q = f(K, L) \qquad (1)$$

where Q = amount of output, K = amount of capital input, and L = amount of labour input.

The production function expressed by the equation above is described in Figure 1. Each of the described curves in the figure is an isoquant. The isoquants represent various combinations of two inputs (in our case the labour of military professionals and the capital in the form of military robots) capable of producing the given output. The slope of the isoquant measures the rate at which capital and labour can be substituted reciprocally.

Figure 1. Production function of the defence – two-factor model



The production function itself (Figure 1) does not provide a guideline for an optimal allocation of two inputs – capital and labour. The instruction for the optimal allocation of resources is gained if the function is put into a cost framework. For a given budget constraint, the optimal allocation is the combination of capital (military robots) and labour (military professionals) that maximizes the output (in our case "Defence" is the output).

In the two-input model the total costs of using any combination of inputs can be expressed as

$$TC = rK + wL \qquad (2)$$

where TC = total costs, w = unit cost of labour, r = unit cost of capital services (military robots).

Considering the given budget constraints and prices (costs) of capital and labour on particular markets, the armed forces can afford to hire the labour of $0L_1$ and $0L_2$ values or purchase a capital of $0K_1$ and $0K_2$ values. As soldiers require certain equipment and weapons and we are not able to replace soldiers by military robots in the full extent, the armed forces are at the points of E* and E** on the line of budget constraints, i.e. they can afford to purchase the labour of the $0L_E$* and $0L_E$** values, which is equipped with the capital of the 0K* and 0K** values. The slope of the isocosts is given by mutual price relations of individual inputs (w/r)* and (w/r)**. Figure 1 shows the change when capital costs are decreasing, optimal relation between capital and labour is changing and (K_E*/L_E*) is moving toward (K_E**/L_E**). The optimum capital-labour ratio increases. The described event is the case of capital-labour substitution (Cooper 1974).

Figure 2. Optimal production of defence and costs minimization

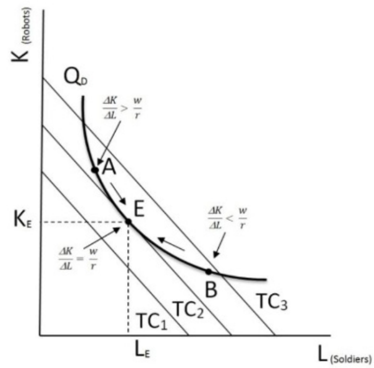
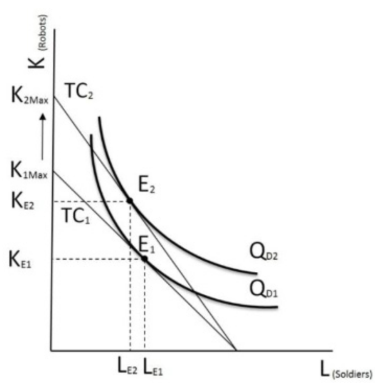


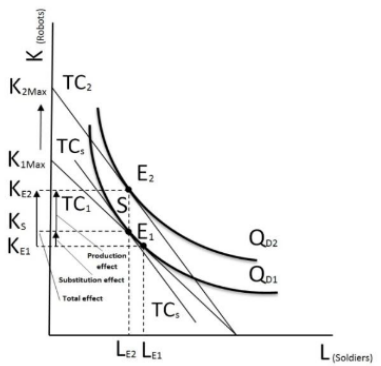
Figure 2 describes the situation when we try to reduce the defence production costs by finding the optimal ratio between capital (military robots) and labour (military professionals). This effort may be seen in almost all countries across Europe. In the Figure 2 there can be seen the point B describing the situation, in which marginal rate of technical substitution of military robots (capital) for military professionals (labour) is lower than the ratio between the labour costs and the costs of military robots employment. In this case it is more suitable to replace labour by capital. The situation in point A is the opposite and it is more suitable to replace capital by labour in this case. The optimal ratio between the employment of military robots and military professionals is seen at the point E. Now it is required to assess an impact of the change in the relative prices of inputs on an optimal production level (Figure 3).

Figure 3. Decreasing price of capital (military robots)



In case price of some inputs decreases, we can expect the increase in their employment for two reasons: firstly, certain inputs are cheaper than other inputs, so it is possible to substitute expensive inputs by cheaper ones. This phenomenon is called a substitution effect. Secondly, input price reduction decreases the costs and enables production (in our case "defence") to grow. It means that more inputs may be employed. This phenomenon is called a production effect (Figure 4). Military robots price reduction will probably lead to their massive employment in armed forces (Holman 2002). Thanks to simplified microeconomic analysis it is obvious that there is a whole range of factors having impact on implementing and developing the military robotics in the conditions of armed forces. These factors are in force in a particular state and its economy and it may be assumed that the employment of military robotics will vary from country to country due to above mentioned factors.

Figure 4. The effect of price reduction on the capital growth and the decomposition of overall effect on substitution and production effects



From the theoretical analysis point of view it is evident that military robotics and its development depend on the following factors:

- price of capital (military robots);
- marginal rate of technical substitution of inputs MTRS (marginal rate of technical substitution);
- capital-labour price ratio (w/r).

From the theoretical point of view, the future surge of military robots may be caused by their price reduction, the capability of reducing the requirements for the live human power and the favourable development of the military robots and professionals price ratio.

4. The benefits and costs of robotics employed in armed forces

It is evident from the literature research, that a lot of authors have communicated their own views on the reasons for the implementation of robotic technology into armed forces. The most frequently stated reasons are the increased efficiency, better performance and saving of lives. Mainly benefits are discussed in the majority of publications, costs are analyzed much less. However, the decision-making process about the implementation of robotics into armed forces and the purchase of military robots require sufficient amount of information. The classification based on traditional approach expressed by Musgrave (Musgrave, Musgrave 1994) is offered for the unification of costs and benefits of the employment of robotics in armed forces (Table 2).

Table 2. The classification of costs and benefits of the employment of military robotics

Category		Costs	Benefits
Direct	Tangible	Costs of purchase of robotic system (developmental costs, acquisition costs, adjustment costs). Recruitment and training costs of operators and mechanics of robotic system.	Lower costs of specific function of armed forces reached by savings from capital-labour substitution (military training area).
	Intangible	Hostility to the robotic systems and their implementation into armed forces, fears of the loss of job and job opportunities. Loss of the combat sixth sense of the troops.	Increase in soldiers security (saving soldiers lives, prevention of injury in combat). Increase in troops combat performance. Increase in troops survivability .
Indirect	Tangible	Repair costs of robotic systems. Operating costs of robotic system. Salary costs of robots operators and technicians.	Lower costs of troops logistics ("Manned versus unmanned vehicles").
	Intangible	Posttraumatic stress disorder costs of unmanned systems operators. Costs of resistance against "lethal autonomous vehicles".	Development of new branch of defence industrial base (spin offs of military robotics development and research). Benefits from the next new industrial robotic revolution (development of new technologies).
Partial		Costs of robotic systems integration into armed forces structure (command, coordination, determination of the areas of responsibility for the employment of robotic systems, synergic effect of cooperation among army, navy and air forces).	Capability of conducting a modern warfare, supported by flexible and faster command and control system of armed forces (more effective military leadership).
Final		Government transformation cost of armed forces and support costs of new branch of defence industrial base.	Supremacy over the enemy, improvement of defence and combat capabilities of armed forces.
Internal		Costs of malfunction of military robots (costs of friendly fire). Costs of hostile takeover of military robots by the enemy.	Implementation of robotic system as a multiplier of military power (one operator controls more unmanned vehicles, swarm combat).
External		Costs of civil population losses due to the malfunction of military robotic system. Costs of civil population lost privacy due to the employment of UAVs for reconnaissance purposes).	Decrease in veteran care costs (health services and social security). Decrease in social payments for the families of killed soldiers) Possibility of better peace-keeping by violence mitigation, the monitoring of violations of international humanitarian and war laws.

Source: own elaboration.

Finally, the knowledge of costs and benefits provides the possibility to realise in first step financial analysis of military robots usefulness and subsequently to accomplish full economic analysis which takes into account all societal costs and benefits.

5. The economic aspects of military robots and their introduction into armed forces

Over 40 countries have military-robotics programs today. The U.S. and many other countries around the globe realize an important role of unmanned systems: even Hezbollah, the Iranian-backed Shiite guerrilla force in Lebanon, flew four Iranian-made drones against Israel during the 2006 Lebanon War. The age when unmanned robots will replace soldiers on the battlefield is not really far off.

An attempt is made to find relationships among the theoretical preconditions of the development of military robotics, the current situation and the prospects of future development in this area. The research outcomes should answer the following two questions:

– is technology (military robots) ready to be fully employed in the armed forces from the technical point of view? This question is connected with the issue of military robots autonomy and reliability (Rybak 2009; Stodola, Mazal 2010) The autonomy of military robots is crucial for the substitution of capital for labour; this capability limits the real replacement of soldiers by military robots on the battlefield. The autonomy of military robots includes two levels – the decision level autonomy and the energy level autonomy;
– is technology (military robots) acceptable for producers, armed forces, departments of defence and national governments from the economic point of view? There are some problems: the first problem is the economy of scale, the second problem is the unit price level of military robots, the third problem is the relationship between military robots unit costs and the costs of soldiers′ military training.

The following subchapters deal with the mentioned problems.

5.1 The economic aspects of introducing military robots in the theatre from perspective of industry

The future of military robotics market and industry depends on the following preconditions:

– successful military tests of the developed military robots,
– ability to reach the economies of scale in a short time,
– requirements to reach a competitive advantage or competitive threats,
– solvency of potential customers (mainly national governments),
– pace of robotization in other branches of national economy.

Tangible evidence of the ability of military robotics industry to produce reliable military robots is the boom of robots in Iraqi and Afghan theatres of war. When the U.S. forces came to Iraq, they had no military robots on the ground. By the end of 2004, the number was up to 150. By the end of 2005, it was up to 2400 and by the end of 2006, the number was 5000 (Singer 2009). It was predicted in the statement of The International Federation of Robotics (IFR) published in 2009 that about 42, 000 military robots will be in operation (Kabeš 2010). The rapid growth of the military robotics markets has been announced in the Winter Green Research 2010 study. This study predicted that military robotics markets worth \$831 million in 2009 would have reached \$9.7 billion by 2016 and military ground robot markets worth \$3.4 billion in 2011 would have reached \$12.3 billion by 2018 (Curtis 2010; Eustis, Curtiss 2012) (Table 3).

Table 3. The size of military robotics market and the forecast of its development

Observed period	Real value of military robotics market in the initial year of observed period (million US \$)	Anticipated value of military robotics market in the final year of observed period (million US \$)
2007-2014	145	6 900
2009-2016	831	9 700
2011-2018	3 400	12 300
2013-2019	4 500	12 000
2014-2021	3 200	10 200

Source: adapted according to Curtiss, Eustis 2010; Eustis, Curtiss 2012.

The increasing number of military robots on the battlefield and the expansion of military robotics market is an impressive signal of success of military robots producers. A large-scale production and a growing market share of military robots industry are fundamental preconditions of decreasing unit costs and reaching the breaking point in production. No company is able to play an important role on the market without these preconditions. Military robots producers have another alternative possibility of market force consolidation. Producers will attempt to reach a competition advantage. The uniqueness of the product means that the company can set higher price, hit a record amount of profit and improve its position on the market. The U.S. government has declared its preparedness to fund the military robotics research in 2009 and 2011. The 2011-2015 President's budget for unmanned systems reached the total value of \$32,705 billion (Kendal 2010: 89) (Table 4).

Table 4. President's budget for unmanned systems 2011-15 (mil. US $)

Year		2009	2010	2011	2012	2013	In total
All unmanned systems	RDTE*	2695,5	2126,4	1275,8	1336,1	865,3	8302,7
	PROC**	1965,6	2126,8	1854,1	1885,4	1701	9532,9
	O&M***	162,2	260,1	263,3	301,1	344,2	1330,9
Year in total		4,823	4,513	3,393	3,260	2,911	18,900

* research, development, testing and evaluation; ** procurement, ***operating and maintenance.
Source: adapted according to Kendall 2010.

The previous 2009-013 President´s budget for unmanned systems was planned to reach overall value $18 billion (Table 5).

Table 5. President's budget for unmanned systems 2009-13 (mil. US $)

Year		2011	2012	2013	2014	2015	In total
All unmanned systems	RDTE*	1,434.11	1,590.00	1,910.07	1,647.84	1,501.50	8,083.52
	PROC**	3,383.93	3,825.62	3,607.02	3,897.95	4,337.53	19,052.04
	O&M***	1,809.59	1,869.67	1,710.75	1,823.15	2,075.44	9,288.59
Year in total		6,627.63	7,285.28	7,227.85	7,368.94	7,914.46	36,424.15

* research, development, testing and evaluation; ** procurement, ***operating and maintenance.
Source: adapted according to Clapper 2008.

The surge of spending is evident (Clapper 2008). The conflicts in Iraq and Afghanistan proved the usefulness of military robots in the theatre of war. Military robots have the prospects of future development. However, future, large-scale acquisition of these devices in a post-conflict environment is not certain, despite the data from the tables presented.

5.2 The economic aspects of introducing military robots in the theatre from perspective of the armed forces and government

There are the following main reasons for introducing the military robots in the theatre of war:

- protection of human (soldier) life,
- higher level of efficiency and effectiveness of robotic systems,
- armed forces attractiveness, increasing with regard to the recruitment goals,
- modernization of armed forces.

The public opposition to the war losses has been growing recently, but this phenomenon is not new. If we look at the U.S. casualties in armed conflicts, beginning with almost half a million killed in the World War II, over 35, 000 killed in Korea, more than 50, 000 killed in Vietnam and zero combat deaths in Kosovo, it is understandable, why the society is not willing to bear the costs of "the black bag" effect. The loss of any human life has strong impacts – both economic and social. National economy loses productive labour and army loses a trained soldier. The society has to face the broken homes, pay the supplementary benefits to veterans and heath care to the soldiers who sustained severe injuries. Further economic aspect is a higher degree of effectiveness and efficiency of robotic systems. The military robots create new combat possibilities; on the one hand robotic systems enable armed forces to hit a new level of combat capabilities with decreasing operating costs. Unmanned combat aerial vehicles (UCAVs) will, for example, reach much higher speed and conduct more flights compared to manned aircraft. At the same time these unmanned devices increase the safety of not only soldiers, but also civilians. We can compare the price of military robots production and development with the value of human life. The value of human life varies between 2 and 11 million US $ (Stiglitz, Bilmes 2008). The price of military robots varies between $10 000 – iRobot 110 FIRSTLOOK and $104 000 000 – RQ-4 Global Hawk (Table 6). The comparison is not easy and the outcomes are not unambiguous.

Table 6. Price of the selected military robots (US $)

Type of military robot	Price	Producer	Notice
Talon	60 000	Foster-Miller	Price of set (1 UGVs, control unit and accessories)
Swords Talon	230 000	Foster-Miller	Price of set (1 UGVs, control unit and accessories)
iRobot 510 Packbot	77 000 – 100 000	iRobot	Price of the set including control unit
iRobot SUGV	20 000 – 195 000	iRobot	Price of the set including control unit
iRobot 110 FIRSTLOOK	10 000 – 15 000	iRobot	Price of the set including control unit
iRobot 710 Warrior	350 000	iRobot	Price of the set including control unit
Recon Scout XL	20 615	Recon Robotics	Price of set (1 UGVs, control unit and accessories)
Recon Scout Throwbot	7 500	Recon Robotics	Price of set (1 UGVs, control unit and accessories)
MQ-1B Predator	20 000 000	General Atomics Aeronautical Systems Inc.	Costs of system (4 UAVs with sensors, satellite links and local control unit)
MQ-9A Reaper	14 500 000	General Atomics Aeronautical Systems, Inc.	Unit costs
	64 200 000		Costs of system (4 UAVs with sensors, satellite links and local control unit)
QF-4 Drone	2 600 000	BAE Systems	Price of the unmanned version of the aircraft
RQ-11B Raven	173 000	Aerovironment, Inc.	Price of the vehicle with the control unit
RQ-4 Global Hawk	104 000 000	Northrop Grumman	Price of system with ground components

Source: own elaboration.

It is evident that military needed a new strategy to attract the youth to enlist. The more the military will use the cutting-edge technology, the more likely the armed forces will recruit the sufficient quantity and quality of human resources. Nowadays, young people are interested in learning about high-tech devices, so the introduction of military robotics to the armed forces could support the fulfilment of recruitment goals. The required modernization of armed forces is another reason for an increased interest in military robotics. Modern armies rely on flexibility and prompt response to potential dangers. Military robots are capable of meeting such requirements. On the one hand, we may predict high expenses connected with the armed forces modernization. On the other hand, robotics systems save the funds, for example, the employment of unmanned vehicles decreases the troops logistic burdens (reduced vehicle weight and volume means significant savings of finance – much less fuel, spare parts, supplies, better storage, large radius of action and so on) (Galloway 1999).

The rapid acquisition modernization strategy, particularly for military robots, can lead to an oversupply of systems accomplishing similar tasks, but without the inter-system compatibility. While this strategy encouraged market competition, it also created training and support challenges (problems of costs).

6. Economic aspects of military robotics development

It is crucial to recognize the factors which strongly influence further development of military robotics. The awareness of these factors enables us to make optimal predictions about this phenomenon. We may conclude from the literature research, that the further development and progress of military robotics are influenced by the following agents and factors (Barkan, Bland 2011).

6.1. The main agents influencing military robotics development

The main agents influencing the development of military robotics are as follows:

– governments (the size of military expenditure); this agent is influenced by the character of decision-making process (public choice). Further, the decision made about defence and security includes three levels – military, financial and political. Under these conditions the decision making process sometimes lacks the economic rationality;
– military (the strategy of real capabilities of military robots employment); Military is not a homogenous system. It consists of army, navy and air forces, each service has its own chain of command. Misunderstandings and lack of communication among them could result in an inappropriate strategy in the area of military robots and their employment in individual services;
– military robotics industry (the ability to develop applicable technology); The level of development of military robotics industry is fun-

damental for the future development of this part of defence industry (Řeřucha, Krupka 2005). We can predict its rapid growth. Bill Gates, for instance, describes robotics today as being where the computer industry was around 1980. Peter Singer noted that in 2004 the number of personal robots in the world was estimated at 2 million. By the end of 2007, the United Nations report revealed that there were 4,1 million robots around the world in people´s homes. By the end of 2008, the expected total number of robots was about 11 million. The trajectory of the growth is astonishing (Singer 2009). It is possible to monitor such development in the military robots industry as well.

6.2 The main factors influencing military robotics development

The main factors influencing the development of military robotics are as follows:

- value of human life – If the higher value of human life is accepted, the quick pace of growth will be reached;
- costs of military professionals training – if we take into account all the direct and indirect costs of military professionals training, it may be claimed that in some cases they are comparable with the procurement and maintenance costs of selected military robots;
- future development and the achievable size of military robotics market – this factor is mainly influenced by the level of competition, the level of monopoly and the range of state intervention;
- state and future development of public finance and budgets – this factor is crucial at present. State budgets burdened with debts result in the reduced capacity of national governments to fulfil their missions – security, economic development and social agreement.

Changes in the above-mentioned agents and factors directly influence the development of military robotics. Economic aspect of nearly all the above mentioned agents and factors is of a high importance.

Conclusions

Appeal for military organizations is the fact that robotic devices are able to change the essence of armed combat. It is a worldwide trend to have the decreasing military budgets. This direction is acceptable from human point of view; however, it is very dangerous from military point of view as it decreases the capability of responding to emergency events.

Attention is paid to human beings and societies which do not accept the losses of lives, including the lives of soldiers. These trends are visible, cause qualitative changes in the armed forces, and result in modernization, professionalization and reorganization. The changes should result in rapid reaction to invisible risks and threats. Unfortunately, new technologies are very expensive.

For that reason, the employment and introduction of new technologies in the armed forces have to be cost-effective. With regard to military robotics it is obvious that we will be able to take advantage of capital-labour substitution in the foreseeable future. The mass production of military robotics enables the military robots producers to take advantage of economies of scale and to decrease unit price of military robotics systems. The substitution of labour by military robots will further progress with the higher autonomy of military robots. Consequently, capital deepening will lead to the more sophisticated technologies operating in the armed forces.

It could be beneficial for further advancement in the area of military robotics economics to create the theoretical model which enables us to predict the future development and employment of military robots.

The following basic variables could be considered to be used in this model:

- factors increasing the usefulness of military robots for armed forces;
- factors influencing the human life value assessment;
- factors that shape government's willingness to pay money for military purpose;
- factors that shape the stability and development of military robotics market;
- factors that influence establishment, size and competitiveness of companies producing military robots (military robotics industry);

Analysis of these factors and their interrelationships, assessment of their importance and their employment will result in better receptiveness of the military robotics development. The creation and verification of the model could be perceived as a valuable contribution of the economics of military robotics to the empowerment of national defence and security.

References

Arkin, R.C. (2009), Governing lethal behaviour in autonomous robots, Raton: Taylor & Francis Group.

Arkin, R.C. (2015), Warfighting robots could reduce civilian casualties, so calling for a ban now is premature. IEEE Spectrum: Artificial Intelligence, available at: http://spectrum.ieee.org/automaton/robotics/artificial-intelligence/autonomous-robotic-weapons-could-reduce-civilian-casualties?utm_source=-feedburner&utm_medium=feed &utm_campaign=Feed%3A+IeeeSpectrumRoboticsChannel+%28IEEE+Spectrum%3A+Robotics+2%29 (accessed 25 February 2016).

Aldridge, E.C., Stenbit. J.P. (2003), Unmanned aerial vehicles roadmap: 2002-2027, available at: https://www.nasa.gov/centers/dryden/pdf/111759main_DoD_UAV_ Roadmap_2003.pdf (accessed 25 February 2016).

Barkan, N., Bland, C. (2011), Robotics and autonomous systems industry (Final Report), Washington: National Defense University.

Boon, K.E., Lovelace, D.C. Jr. (2014), Terrorism – commentary on security

documents. The drone wars of the 21st century: Costs and benefits, Oxford: Oxford University Press.
Burg, D., Scharre, D. (2014), To save money, go unmanned, New York: Center for New American Security.
Carr, E. (2012), Morals and the machine, available at: http://www.economist.com/node/21556234 (accessed 25 February 2016).
Clapper, J.R. (2008), Unmanned systems integrated roadmap FY 2009–2034, available at: http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD =ADA 522247 (accessed 25 February 2016).
Cooper, R.V. L., Roll, Ch. R., Jr. (1974), The allocation of military resources: Implications for capital-labour substitution, Santa Monica: Rand Corporation.
Curtiss, E.T., Eustis, S. (2010), Military robots and unmanned vehicles markets, worldwide, market shares, strategies, and forecasts, 2010-2016, available at: http://www. slideshare.net/ReportLinker/military-robots-and-unmanned-vehicles-market-shares-strategies-and-forecasts-worldwide-2010-to-2016 (accessed 25 February 2016).
Eustis, S., Curtiss, E.T. (2012), Military ground robot market shares, strategies, and forecasts, worldwide, 2012 to 2018, available at: http://www.marketresearchstore.com/report/ military-ground-robot-market-shares-strategies-and-forecasts-2393 (accessed 25 ebruary 2016).
Foy, J. (2014), Autonomous weapons systems: Taking the human out of international humanitarian law, available at: http://www.cba.org/CBA/sections_military/pdf/2014-essay.pdf (accessed 25 February 2016).
Francis, D. (2014), Robots to replace troops on the battlefield, available at: http://www.thefiscaltimes.com/Articles/2014/01/26/Robots-Replace-Troops-Battlefield (accessed 25 February 2016).
Galliott, J. (2015), Military robots: Mapping the moral landscape, Cornwall: MPG Books Ltd.
Galloway, G.E. Jr. (1999), Reducing the logistics burden for the army after next: Doing more with less, available at: http://www.nap.edu/read/6402/chapter/1 (accessed 25 February 2016).
Goos, M. (2014), The economics of robotics, available at: http://www.eu-robotics.net/cms/upload/euRobotics_Forum/ERF2014_presentations/day_2/The_Economics_of_Robotics_-_Rovereto_20140313.pdf (accessed 25 February 2016).
Hall, A.R., Coyne, Ch. J. (2014), The political economy of drones, Defence and Peace Economics, 25(5): 445-460.
Hartley, K., Sandler, T. (1995), The economics of defence, Cambridge: Cambridge University Press.
Holman, R. (2002), Microeconomics (intermediate level), Prague: C.H. Beck.
Kabeš, K. (2010), Service robots conquest the world, Automa, available at: http://www.odbornecasopisy.cz/res/pdf/41046.pdf (accessed 28 February 2016).
Katoch, R. (2006), Defense economics: Core issues, Strategic Analysis, 30(2): 257-309.

Kennedy, G. (1984), The economics of defence, London: McMillan.
Kendall, F. (2010), Unmanned systems integrated roadmap FY 2011-2036, available at: http://www.acq.osd.mil/sts/docs/Unmanned%20Systems%20 Integrated%20Roadmap%20FY2011-2036.pdf (accessed 25 February 2016).
Krč, M. (2008), Military-economic thinking (European middle ages, mercantilism, physiocracy), Brno: University of Defence.
Krč, M. (2001), The brief of defence economics history, Prague: AVIS.
Krishnan, A. (2009), Killer robots: Legality and ethicality of autonomous, Burlington: Ashgate Publishing Limited.
Kurzweil, R. (2005), The singularity is near: when humans transcend biology, New York: Viking.
McDaniel, E.A. (2008), Robot wars: Legal and ethical dilemmas of using unmanned robotic systems in 21st century warfare and beyond, available at: http://www.dtic.mil/get-tr-doc/pdf?AD=ADA502401 (accessed 28 February 2016).
Mládek, J. (2015), Industry 4.0, available at: http://www.mpo.cz/dokument162351.html (accessed 28 February 2016).
Musgrave, R., Musgrave, P. (1994), Public finance: Theory and practice, Prague: Management Press.
Nail, G. (2011), Unmanned aerial warfare: Flight of the drones. Why the future of air power belongs to unmanned systems, available at: http://www.economist.com/node/ 21531433# (accessed 1 January 2016).
Nath, V., Levison, S.E. (2014), Autonomous military robotics, Cham: Springer International Publishing.
Olvey, L.D. (1984), The economics of national security, Wayne: Avery Publishing Group.
Procházka, D., Prochazková-Ilinitchi, C. (2011), The IFRS adoption, foreign direct investments and migration: Mutual interdependencies, Proceedings of the 6th IASME/WSEAS International Conference on Economy and Management Transformation (EMT '11) (pp. 125-130), Angers: WSEAS Press, (accessed 25 February 2016).
Ranasinghe, D. (2015), How robots are stealing a march on the military. CNBC: News, available at: http://www.cnbc.com/id/102572288# (accessed 1 January 2016).
Rybak, V. (2009), Safety, uncertainty, and real-time problems in developing autonomous robots, Proceedings of the 8th International Conference on Signal Processing, Robotics and Automation (ISPRA'09) (pp. 31-44), Cambridge: WSEAS Press (accessed 25 February 2016).
Řeřucha, V., Krupka, Z. (2005), The pilot – aircraft intelligent interface concept, Proceedings of the 7th WSEAS International Conference on Automatic, Control, Modelling and Simulation (ACMOS'05) (pp. 552-556) (accessed 1 January 2016).
Scharre, P. (2014), Robotics on the battlefield: Part I: Range, persistence and daring, Washington, DC: Center for a New America Security.
Scharre, P., Horowitz, M.C. (2015), An introduction to autonomy in weapon

system, In: CNAS Working Papers: Project on ethical autonomy, available at: http://www.cnas.org/sites/default/files/publications-pdf/Ethical%20 Autonomy%20 Working%20Paper_021015_v02.pdf (accessed 10 December 2015).

Schneider, F., Roning, J. (2006), Bridging the gaps in military robotics: NATO studies near-term unmanned ground vehicles (UGVs), Military Technology, 30(11): 34-42.

Singer, P.W. (2009), Wired for war, robotic revolution and conflict in the twenty first century, London: Penguin.

Springer, P.J. (2013), Military robots and drones: A reference handbook, Santa Barbara: ABC-CLIO.

Stiglitz, J.E., Bilmes, L.J. (2008), The three trillion dollar war: The true cost of the Iraq conflict, New York: W.W. & Company.

Stodola, P., Mazal, J. (2010), Autonomous motion of unmanned ground vehicles in general environment, Proceedings of the 9th WSEAS International Conference on Signal Processing, Robotics and Automation (ISPRA '10) (pp. 226-231), Cambridge: WSEAS Press (accessed 25 February 2016).

Stankiewicz, W. (1981), Military economics, Warszawa: Ministry of Defence.

Strickland, J. (2007), How robot armies will work. Effectiveness, economics and ethics, available at: http://science.howstuffworks.com/robot-armies3.htm (accessed 25 February 2016).

The Economist (2012), The third industrial revolution, available at: http://www.economist.com/node/21553017 (accessed 1 January 2016).

Van Tuyll, H., Brauer, J. (2003), Colonizing military history: A millennial view on the economics of war, Defence and Peace Economics, 14(3): 155-173.

Winnefeld, J.A. Jr., Kendall, F. (2013), Unmanned system integrated roadmap FY 2013-2038, The reports of Department of Defense, available at: http://www.defense.gov/pubs/DOD-USRM-2013.pdf (accessed 28 February 2016).

Work, R.O., Brimley, S. (2014), 20YY: Preparing for war in the robotic age, New York: Center for New American Security.