Aspects Regarding Technical and Economic Upgrade Elements in the Case of an A.D. Missile System

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Abstract. Confronted by the spectacular evolution of the aircraft and other aerial assets, the systems destined to combat them, especially air defense missile systems, went through an accelerated loss of their performance. Even during their active life-cycle, the majority of these systems are exposed to a dramatic decreasing of the operational parameters; among them, the single shot kill probability is one of the most important, hereby the up-grade necessity is directly revealing to the user. Many times is better to improve an existing system than to buy a new one.

This is a triple problem, including the cost vs. performance and the cost vs. the remaining life time or technical resource. The paperwork proposed a schedule of work in such a case, on the basis of the authors' experience in the A.D. missile system up-grade activity.

Keywords. Improve, growth, ADMS, life-cycle, cost/performance

INTRODUCTION

In modern battlefield the airpower represents a support for any military operation.

The modern aircraft design and building met a spectacular evolution (*Spassky, 1996*), including:

- multiplication of the menace, confronting the defense with a lot of different enemy's assets like drones and small dimensions cruise missiles and up to high altitude and high velocity aircrafts;
- the growth of the aviation resistance structure using some materials with new characteristics;
- the growth of the board systems reliability and redundancy, that allow a significant enhancement of the target's survivability;
- small radar cross-section (RCS) combined with active / passive countermeasures in entirely radiation;
- high speed maneuver capacity;
- tactical engagement with a combined forces assembly, so being created complex situations, over passing the defense reaction possibilities (*McEven, 1962*) .

All these evolutions, makes the real results of air defense operations using missile systems (ADMS) to be more modest than those estimated by calculus, or obtained in training firings.

Practically the aircraft vulnerability decreases from a former generation to a new one, in connection with more performing aeronautical designs.

The ground-to-air missiles - or air defense missiles (ADM) - represent the main assets against the aerial enemy threats, for an adequate and technological response.

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1 RELATIVELY DECREASING OF THE ADMS EFFICACY PARAMETERS

The single shot kill probability (or P_{01}) is a synthetic efficacy indicator that allows to characterize an A.D. weapon system.

The real operational conditions dramatically decrease the theoretical values, obtained in a standard field range hypothesis:

- the target inside of the engagement envelope
- the target has a constant velocity and no maneuver is done
- a single target appears in sight once in a time
- the target doesn't actively counteract (SEAD) and doesn't use ECMs

The analytical expression (*Cernăianu, 1982*) for the single shot kill probability applied to missiles is:

$$P_{01} = \iiint_{-\infty}^{+\infty} \varphi(x, y, z) G(x, y, z) dxdydz \qquad (1)$$

where:

– φ(x,y,z) represents a function characterizing the missile shot precision (firing error);

– G(x,y,z) represents the target's destruction probability with a detonation in the point of (x, y, z) coordinates.

The function G(x,y,z) express the destruction probability at least one of the vital aggregates of the target with individual splinters, causing the fall off the aircraft mission. The coordinates target destruction law depends of the following main factors:

– the target vulnerability characteristics;

– the energetically performances of the warhead.

We can easily observe that both φ and G functions are variable in time, because a more agile target make the precision poor and a much resistant one reduces its vulnerability.

2 MEDIUM RANGE AIR DEFENSE MISSILE SYSTEMS

The air defense is organized by layers as is shown in figure 1 (*Raytheon, 2011*). Close range (up to 5 km) is covered by small caliber/high rate-of-fire gun systems and MANPADS (man portable air defense missile systems). Short range (up to 15 km) is covered by SHORAD (short range air defense missile systems) and the last (obsolete) radar guided heavy A.A. artillery systems.

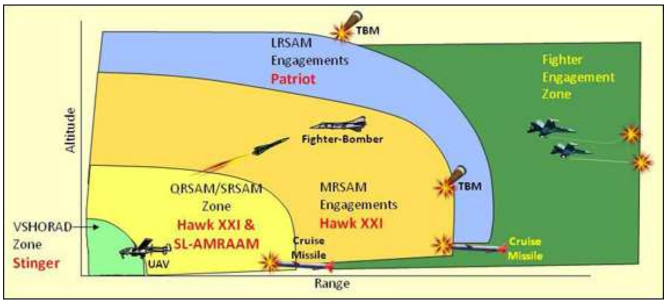

Fig. 1 – Layered air defense

Medium (15 to 35 km) and long ranges air defense are assured with missile systems only. Close and short range systems are destined mainly for self-defense or to protect small and hidden objectives, while the long range defense is a expensive strategic option and generally belongs of the Air Forces, reciprocally supporting the fighters in air space defense operations. In these condition, the pole of hole air defense architecture is representing by the medium range (up to 35 … 40 km), low and intermediate level (50 to 18000 m) air defense missile systems (MRADMS), the single capable to defeat a mass attack before the enemy air threat to take an advantageous stand-off launching position. Due to the necessary range, usually the guidance for these systems are semi-active radar homing (SARH) or command in radio-frequency (RF CLOS). Few of these systems, well know on the market are S125 (5V27) Neva, 2K12 (3M9) Kub and MIM-23 Hawk. According to public sources (*Internet tech-char*), some technical and operational characteristics – chose by us from contradictories data - were presented in table 1.

Table 1

System	S 125	2 K 12	MIM-23
Missile	5V27	3M9M	I-Hawk
Range [km]	25	16	27
Missile weight [kg]	950	600	640
Missile velocity [kg]	1150	950	800
Guidance	RF CLOS	SARH	SARH
Warhead weight [kg]	72	57	74
SSKP*	0.85	0.70	0.65
Resource	15	20	12

* for a standard fighter-bomber target and conditions

So, if the MRADMS only can combat with certain efficacy a well organized aerial operation so as by number and fire power but also as performance (P_{01}), these equipments cannot be easily replaced in the troops endowment when their characteristics don't keep the step with the potential targets progress.

The cost for these systems (at the battery level) reaches around 50 to 150 mil USD (*FAS, 2009*), depending of the size and the support equipments.

The up-grading such a system instead to buy a new one becomes many times an option, both from preserve the operational performance and to save spending, in case of the continuously financial constraints.

3 ANALYSIS OF A MRADMS STRUCTURE AND THE UP-GRADE PROGRAM OBJECTIVES

A MRADMS is an entire complex of platforms, cabins, launchers, antennas, electronics, and missiles and other equipments, which together realizes the task of searching, distributing fire, tracking and launching against the aerial menace. Operational we consider a minimum battery level in order to actions independently, covering a certain area. The system may assure also the training of crew, the technical checking, reloads and maintenance of own elements. For our study we consider a hypothetically but that may be true such a system, at the 3-launchers battery level, with a structure like in figure 2, as follows:

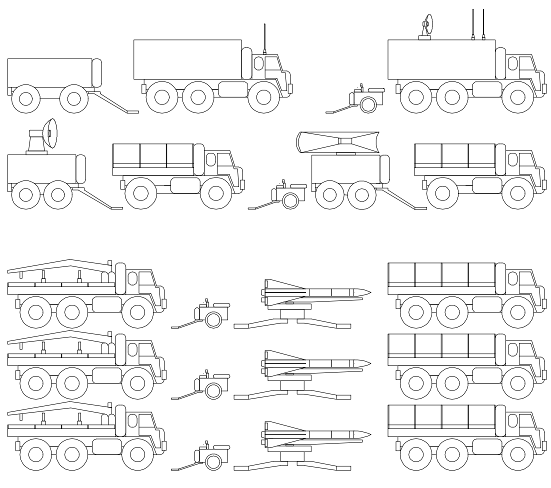

Fig. 2 – Un-modernized K_1 MRADMS structure (Theoretical study of case)

This structure comprises (from right-up to left-down):

- a tactical command point;
- a missile checking post;
- a towed search radar;
- a towed track / illuminating radar;
- three towed launchers;
- three reloading trucks;
- some tractor trucks;
- some power generators;
- battery radio network;
- different equipments.

The up-grade process can regards all features of the system or some of them, like the missiles or electronic of the system (*ACTTM, 2011*).

Once established the necessity of up-grade program and what exactly will be up-graded, the decision elements from politics, army and industry must look for an internal (domestic) scientific and technical competence and technological capacity, eventually with the producer support.

These objectives are pointed to a complete up-grade (more correct a re-building of the system) or a partial one. Here and now we are referring to the 1st possibility that means a system re-building, for a maximum life extend and a maximum performance increasing. As it shown in table 2, for the studied hypothetically system we are thinking a lot of possible improvements, regarding so the missiles but the system, the logistics and certification also.

Table 2

No.	What will be upgrade	Object	Short description	Average costs
0	1	2	3	4
1	Increasing range	Missile	New fuel (ex. HTPB)	M1
2	Enhancement of efficacy		New warhead	M2
			Digital process of signals	M3
3	Growth of searching ability	System	New search radar	S1
4	Improve conditions for TCP	System	Changing TCP's IT network w. new computers and software	S2
5	Improve the designation	System	New processors for tracking radar	S3

	ability			
0	**1**	**2**	**3**	**4**
6	Reducing oil fuel consumption	System	Remove all trucks w. new ones having economical engines	S4
			Integrations of the equipments w. the platforms	S5
7	Improve the system mobility	System	New high mobility self-propelled platforms for battery	S6
			Adaptation of the launchers	S7
			Installed new radio-command (remote control)	S8
			Integration of the generators into the platforms	S9
8	Enhancemen t communicati on abilities	System	Remove all radio stations w. the new ones	S10
9	Preserve the maintenance capacity	Logistics	New maintenance kit	S11
10	Preserve the checking capacity	Logistics	New checking equipment	S12
11	Modernize the training subsystem	Logistics	New software and (maybe) computers	S13
12	Missile integration and certification	Certifi-cation		P1
13	System integration and certification	Certifi-cation		P2

With these improvements done the system gains another structure, more flexible, mobile and modern, comprising:
- an improved tactical command point;
- a digitalized missile checking post;
- a mobile phased array search radar;
- a mobile track / illuminating radar;
- a camouflage vehicle;
- a workshop vehicle;
- three self-propelled launchers
- three reloading trucks
- a self-propelled optical indicator
- a self-propelled assistance vehicle
- some new power generators
- a new battery radio network
- different improved equipments

The new aspect of battery (from right-up to left-down) is according to figure 3:

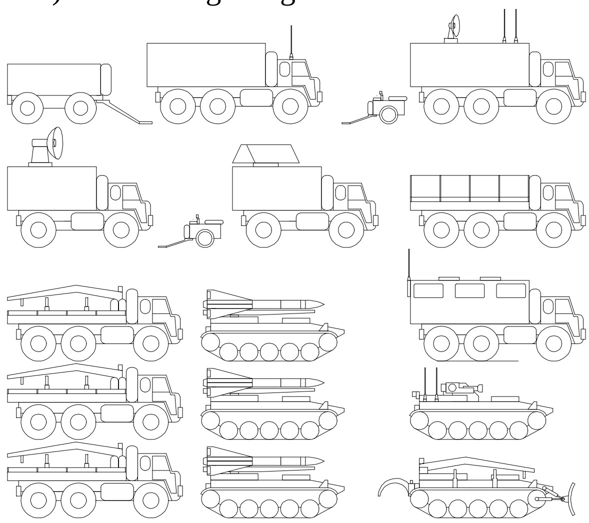

Fig. 3 - Up-graded K_1 MRADMS structure (Theoretical study of case)

Especially the missile itself will be up-graded ones, but may remember that the process is for an entire system and for all his new operational life, including:
- reloading;
- spare parts;
- maintenance;
- repairs;
- loses replacement;
- training.

It is difficult to suppose that a single industrial entity can provide all the work according with table 2.

All these impose a package of tasks and objectives in a relatively rigorous industrial development, for which a consortium of enterprises may be creates.

4 THE PROGRAM COST ANALYSIS

To study the cost of an up-grade program like that proposed in table 2 we try to calculate this value, as:

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$$\mathbf{CP = Sum\ (\Sigma M_i + \Sigma S_j + \Sigma P_k) + R_{sc}} \quad (2)$$

Where: CP - total cost of the up-grade program;
R_{sc} - residual system cost (at the upgrade moment); and
ΣM_i - cost of the missile improvement operations;
ΣS_j - cost of the system modernization (logistics included);
ΣP_k – cost of the program certification.

How generally R_{sc} = cost of system scraping we may consider $R_{sc} = 0$ in upgrade operations.
The values witch permits to take a decision are:
CP - cost of the upgrade program;
P_{01} - single shot kill probability (reached in program);
T - new life time;
N_m - number of the system missiles;
CT - cost of the entirely life time maintenance;
R_{ef} - new effective range.

With these values, we introduce an indicator technical and economic. So that:

$$\mathbf{W = 1000*(CP+CT)/T/(P_{01}{}^{A}*R_{ef}{}^{B}*N_m)} \quad (3)$$

where A and B are constants.
This is an indicator cost per efficacy which permits to compare the similar systems.
In the next calculus, for easy operation, we will consider (A, B) = 1
Relative to a new system characterized by the parameters set CP_n, CT_n, P_{01n}, Tn, R_{efn}, N_{mn}, with:

$$\mathbf{W_n = 1000*(CP_n+CT_n)/T_n/(P_{01n}{}^{A}*R_{efn}{}^{B}*N_{mn})} \quad (4)$$

we can compare:

$$\mathbf{Wn\ (>,<,=)\ W} \quad (5)$$

and can take a technical decision.
Practically, this approach may sustains a politically taken decision looking or to allows the program to some preferred ally or to guide the program to some own (internal) industrial companies.
For a numerical example we will compare the system K_1 upgraded with a new purchased system K_2. We assume the reliable cost for an entire rebuilding of the K_1 system as following in table 3:

Table 3

Average costs	**Value** [USD]	**pcs**	**Total** [USD]
M1	4000	90	360.000
M2	8000	90	720.000
M3	8000	90	720.000
Technology	about 14X a missile cost		25.200.000
ΣM_i	**27.000.000**		
S1	2.300.000	new search radar unit	2.300.000
S2	600.000	TCP modernizing	600.000
S3	1.200.000	new processors set and software	1.200.000
S4	85.000	10 new low consumption trucks	850.000
S5	15.000	10 car-assembly operations	150.000
S6	700.000	5 high mobility self propelled platforms	3.500.000
S7	100.000	5 adaptations	500.000
S8	150.000	3 remote control systems	450.000
S9	20.000	5 power generators	!00.000
S10	30.000	9 radio stations	270.000
S11	1.100.000	new maintenance kit	1.100.000
S12	600.000	improved checking equipment	600.000
S13	!.700.000	new training software	1.700.000
ΣS_j	**13.320.000**		
P1	10% of a new 50 batch of missiles		17.500.000
P2	about 50% of the integration cost		8.750.000
ΣP_k	**26.250.000**		

In this way, we have:

CP = 27 + 13.32 + 26.25 = 66.57 mil USD

We assume that this rebuilt system with 90 missiles can reach a new $P_{01} = 0.8$ (from 0.56) and has a new technical resource of 15 years. It is credited with a new effective range of 35 kilometers.

CT is around 45% of those from the system, that means: CT = 29.95 mil USD

With these values we have:

W = 1000x(66.57+29.95)/(15*90)/(0.8*35) = **2.554**

A new supposed K_2 system (considered in analyze) is characterized by the following parameters:

- cost of a new missile	0.85 mil USD
- cost of the battery equipments	61 mil USD
- number of a missile in fire unit	$N_{mn} = 64$
- maintenance cost system acquisition cost	45% of the
- single shot kill probability	$P_{01n} = 0.9$
- effective range	$R_{efn} = 55$ km
- service life (technical resource)	$T_n = 20$ years

So, applying (4) we obtain:

CP_n = 115.4 mil USD

CT_n = 51.93 mil USD

With these values result:

W_n = 1000x(115.4+51.93)/(20*64)/(0.9*55) = **2.641**

So that: $W_n > W$

Another synthetic indicator is the total cost per shot and probability C_S with relation:

$$\mathbf{C_S = (CP + CT) / (P_{01} * N_m)} \qquad (6)$$

For the considered K_1 and K_2 examples, this indicator becomes:

C_S = (66.57+29.95)/(0.8*90) = **1.34** mil USD/shot

and

C_{Sn} = (115.4+51.93)/(0.9*64) = **2.90** mil USD/shot

These indicators give us some arguments but the process trough which a decision is taken looks for many parameters.

5 CONCLUSIONS REGARDING THE DECISION FOR MRADMS UP-GRADE

The situation is quite different if the customer dispose of one or more of the following capabilities:

- a military program management group
- a scientifically capable group in up-grade program questions
- industrial facilities for:
  - machine-tooling operations;
  - rocket motors refueling and testing;
  - warheads charging and testing;
  - missile assembling and ground testing;
  - field range;
  - mechanical and electrical assembling;
  - cars and trucks equipments replacement and repair.
- skilful crew to operates and signals desired modifications;
- competitive tactical advisers to guide the up-grade program for the specific troops and terrain requirements.

Even some of these capabilities don’t exist at the moment, a political leadership can use such a program to create a base for the future developments.

In the modern warfare it is not realistic to believe that only foreign acquisitions can support the effort of an Army. A Ground Force which is larger than 20.000 soldiers has enough MR ADMS (and other missiles) in order to justify its own technical base with a number of facilities and qualified personnel.

Such a force has also an Academy at least, headquarters and an application school that being a sufficient argument for the existence of a human and technological support for an up-grade program when the time is coming.

With previous elements it is shown that many inputs concur to the basically judgments for adopting a decision in the case of a MRADMS up-grade needs. Between these we consider the following:

- technical and performance parameters imposed by the MoD structures (means effective range, single shot kill probability, system structure, etc.);
- agility / versatility of the main equipments (i.e. search radar unit can be used independently or integrated into the ASOC – Air Sovereignty Operation Center);
- the existence of the internal scientifically and industrial facilitie;
- the alliance politics;
- the doctrine of the armed forces regarding the unification of the equipments, tactics and training for the different categories of forces;
- available financial support;

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- strategic reasons which have to impose a certain time for the setup of such a system.

In any case, an ADMS up-grading program requires one or two years to complete (in the best logistic conditions) and can follow the schemas as in figure 4:

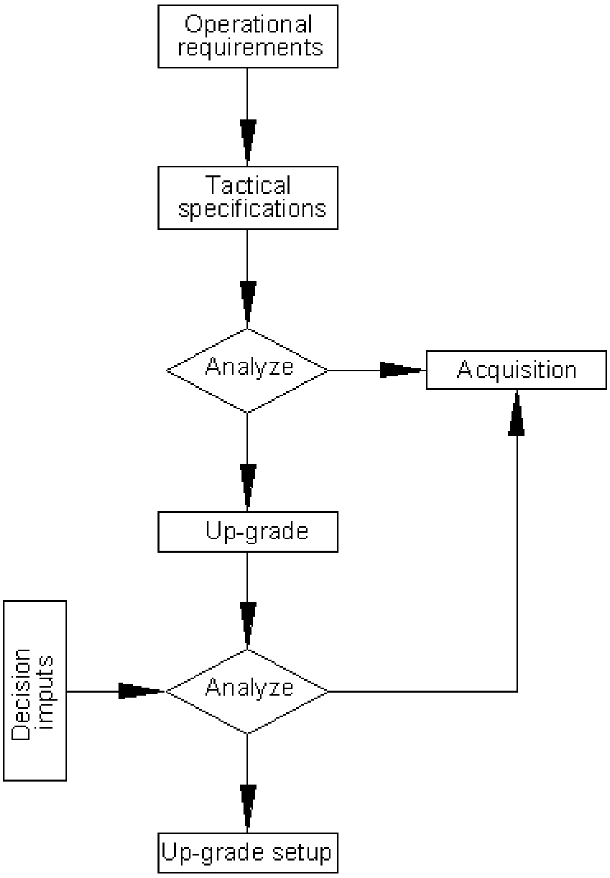

Fig. 4 – Logic of the decisional process

All these judgments are available in the case of a domestic existent system (or previously acquired) (*WZU, 2012*).

If for not known reasons, a limited resource and partially obsolete system was acquired from the market, the up-grading procedure should be regarded as an obligation inside the transaction package.

Any other approach represents an economical loosing because it is sum of the price of acquisition for a complete useless system with the cost of scraping operations, when the tactical needs remain uncovered.

The reality of the strategic environment shows that even the relatively rich armies (like UK or UAE) and the powers which posses state-of-the-art technologies in the A.D. branch (like US and Russian Federation) don't scrapping their AD assets until the technical resource doesn't consume and the up-grading possibilities are not completely introduced.

REFERENCES

[1] SPASSKY, N., (1996), *Russia's Arms Catalog*: Volume II, Air Force, Military Parade, Moscow.
[2] McEVEN, W. R., (1962), *The attack and defense of targets by missile*, Holloman AFB, New Mexico.
[3] CERNĂIANU, Gh., (1982), *Asupra probabilității de lovire cu un proiectil a țintei aeriene*, Buletin ICDA nr.8, Bucureşti.
[4] Raytheon Co., (2011), *Threats to India from the aie are a concern, but can be defeated*, available at http://www.raytheon.com/newsroom/technology/rtn11_aeroindia/news08/index.html, [accessed 04.2012].
[5] Internet tech-char, available at www.military-retia.cz, www.armyrecognition.com/russia, www.ausairpower.net, www.tetraedr.com, www.fas.org, s7.invisionfree.com, videos.mitrasites.com, www.harpoondatabases.com, www.oocities.org, [accessed 04.2012].
[6] FAS, *Hawk*, available at http://www.fas.org/spp/starwars /program/hawk.htm, [accessed 04.2012].
[7] ACTTM, (2011), *Cerere de informații privind Programele de modernizare a complexelorde rachete de apărare aeriană OSA - AKM (SA - 8) şi KUB (SA - 6),* available at http://www.acttm.ro/doc/RFIOSAro.pdf [accessed 04.2012].
[8] WZU, *Technology demonstrator: RIM-7 Sparrow missile integration with SA-6*, available at http://www.wzu.pl/ftp/ Sparrow_with_SA6.pdf [accessed 04.2012].