The Hungarian field artillery fire control system ARPAD and its comparison with other systems

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The Hungarian field artillery fire control system ARPAD and its comparison with other systems

JÓZSEF GYARMATI[1], GYÖRGY KENDE[1], TAMÁS RÓZSÁS[2], KÁROLY TURCSÁNYI[1]

[1] *Miklós Zrínyi National Defence University Department of Military Technology, Budapest H-1581, Hungary*
[2] *MoD Technology Agency, Budapest, Hungary*

Beginning with the early 1980s, development of three generations of the ARPAD system has continuously proven that Hungarian artillery specialists and engineers are capable of keeping pace in the field of artillery fire control systems. In Part 1 the reader will become acquainted with the formation and the present features of the ARPAD fire control system including the phases of its development and an outlook of the possible future improvements. In Part 2 the ARPAD system is compared with other systems using a new approach based on mathematical methods of theory of complex systems.

Introduction

The need for machines capable of performing difficult ballistic computation played a key role in the early development of the first computers. Considering this, it is not surprising that field artillery was among the first to apply computers on battlefield.

Hungary, with the development of the first generation of its computerised field artillery fire control system ARPAD in the 1980s, has started an evolutionary process, which proves our capability to develop and maintain an up-to-date, competitive fire control system for the field artillery of Hungarian Home Defence Forces.[1]

Due to the latest developments and its original structural flexibility, today's ARPAD can be a good solution to any country looking for NATO interoperability and that is equipped with artillery fire control systems and artillery pieces of Soviet origin.

Part 1. The history and features of the ARPAD system

Evolution of the ARPAD FCS

Development of the first generation of the fire control system ARPAD took place between 1982 and 1986. The main contractor for the project was the Hungarian MMG Company for Automation. The professional development team of the company had considerable experience in the development of control systems for the oil industry, so

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Address for correspondence:
GYÖRGY KENDE
Miklós Zrínyi National Defence University, Department of Military Technology,
P.O. Box 15. Budapest H-1581, Hungary
E-mail: kende@zmne.hu

they had the knowledge and experience necessary for developing electronic systems operating reliably in extreme environments.

The system had two different versions, one for artillery battalions with soviet-made MASHINA type command post vehicles, and the other for artillery battalions with wheeled command post vehicles. Concerning organisational structure and functions, the two versions were identical.

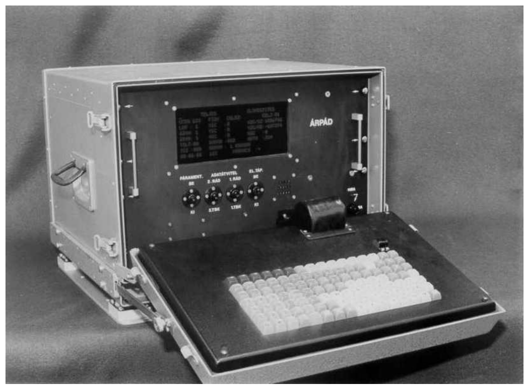


Figure 1. Command Post Microcomputer of the ARPAD system with gas plasma display
(Photo: MoD Institute of Military Technology)

Figure 2. Gun Display Unit of the ARPAD system for towed battalions
(Photo: MoD Institute of Military Technology)

Field tests and a comparative live firing tests conducted in mountainous areas proved the capabilities of the system, but – at the same time – drew the attention to some deficiencies. The most significant of these was the fact, that navigation and target acquisition equipment deployed in the command post vehicles had no digital output. For this reason, all input data needed by the computers of the fire control system had to be typed in manually.

The other major problem was the 8 bit computer architecture applied in the system which caused limited computing performance and memory capacity hindering further software improvements.

During the 1987 to 1991 development period of the second generation the following improvements were achieved:

- digitalisation of the laser rangefinders of command post vehicles;
- digitalisation of the navigation equipment of command post vehicles;
- software improvements and supplements in the software package of command post computers;
- new 16 bit, multiprocessor command post computer using CMOS components and VME-bus.

The system designated as ARPAD M was deployed to only one 2S1 self-propelled field artillery battalion because of financial reasons, but it was also able to serve the needs of towed battalions equipped with 152 mm D-20 howitzers and appropriate command post vehicles.

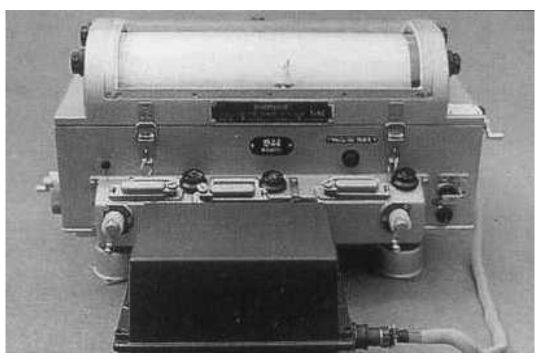


Figure 3. Digitised navigation unit of the ARPAD M system
(Photo: MMG AM Co. Ltd.)

Figure 4. Digitised external laser rangefinder of the ARPAD M system
(Photo: MMG AM Co. Ltd.)

Figure 5. Interface and control unit of position data transformer of the ARPAD M system
built in the battalion commander vehicle turret
(Photo: MMG AM Co. Ltd.)

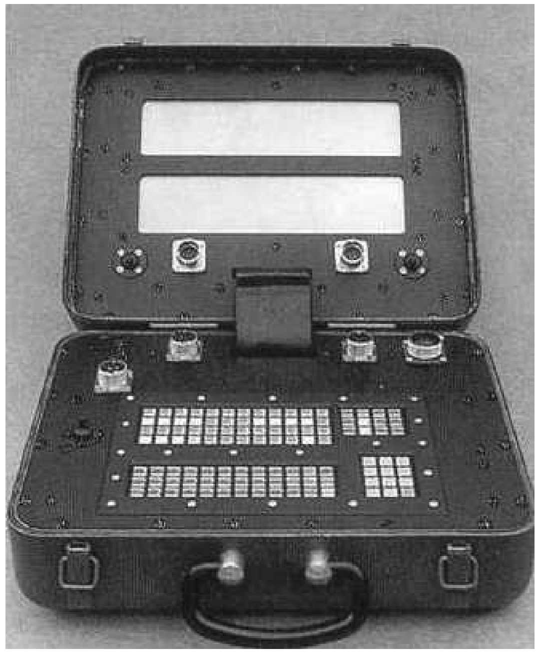


Figure 6. Digital Message Device of the ARPAD M system for Reconnaissance Units
(Photo: MMG AM Co. Ltd.)

ARPAD M had the new, 16 bit command post computers in battery officer command posts and in the command post of chief-of-staff of the battalion.

With the help of the new generation fire control computers, quicker and more accurate firing data calculation and wider analysis of the conditions prohibiting fire were made possible.

In addition to demonstrating the outstanding capabilities of the system, expansive field trials and live firing tests conducted on ARPAD M provided useful experiences to further developments.

Present state

The development of the latest version of ARPAD fire control system took place between 1992 and 1994. While the system structure remained the same, significant technical improvements were made in order to enhance system performance and improve system services.

The main technical modifications include the followings:

- a new unified command post computer was developed with 16 bit VME architecture;
- a new unified gun display unit was developed with less weight, smaller size and more services;
- the command post computers were equipped with a new universal command post computer software package;
- the gun display units were equipped with new universal gun display unit software;
- the system was also made able to serve artillery battalions and batteries with reactive weapons (BM21 multiple rocket launcher).

In the new system generation, each command post computer has identical hardware and software. The appropriate command post function of the individual computers can be set by addressing the given computer.

Figure 7. The new Unified Command Post Computer of the ARPAD M1 fire control system (Photo: MMG AM Co. Ltd.)

Firing data calculation is performed at the battery officers' level separately for the individual guns. The appropriate weapon type – which can be one of 2S1 self propelled or D-20 towed gun and BM21 multiple rocket launcher – can be set on the unified command post computers of the battery officer command posts.

Gun display units also have identical computer hardware and software. The weapon type of the battery can be set on the individual microcomputers. The gun display units are designed to be able to handle peripheries such as muzzle velocity meters or gun navigation devices.

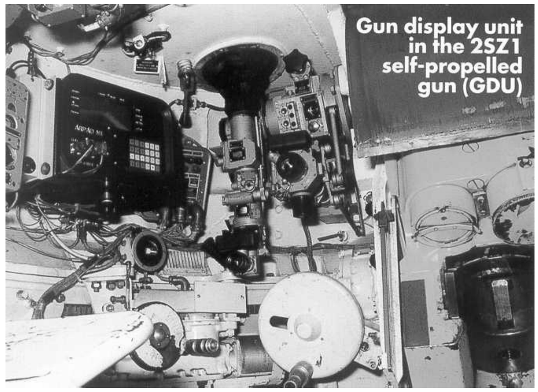


Figure 8. The new Unified Gun Display Unit of the ARPAD M1 fire control system
built in a 2S1 self-propelled gun
(Photo: MMG AM Co. Ltd.)

In addition to the features described above, both the hardware and the software of the system have been developed with the full consideration of the potential for further changes and improvements, so the system can be easily modified to address new user needs, including new command structure, new weapon types, peripheral devices, etc.

The modifications described above resulted in significant improvements in the tactical characteristics of artillery battalions and batteries equipped with ARPAD M1 fire control system including:

- greater survivability due to the unified command post computer hardware and software and the separate firing data calculation;
- higher precision in firing data calculation due to the unique firing data calculation method applied;
- short response time through the automation of command and control processes and quick firing data calculation;
- greater structural flexibility due to the original system flexibility of the ARPAD M1 fire control system;
- potential for automated use of new communication and reconnaissance devices, navigation equipment or other peripherals due to the modular flexibility of the hardware and software components of the system.

Besides firing data calculation, ARPAD M1 is able to support the activities of field artillery battalion or battery in the whole process of fire mission. The most important function groups are the following:

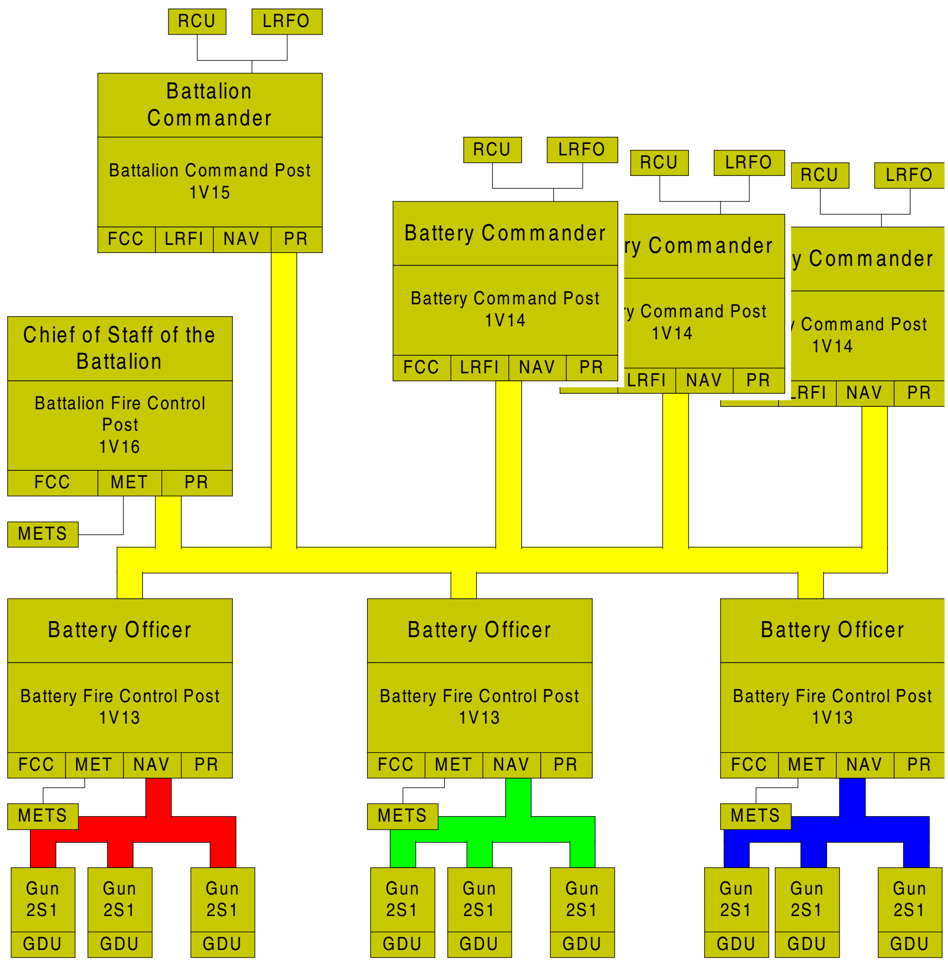
- transmission of commands, reports, reconnaissance (target) data, firing data and other messages;
- firing data calculation;
- performing other necessary calculations such as geodesic calculations, ammunition consumption, etc.
- storing data necessary for the efficient execution of fire missions such as
    - position data of observation posts;
    - position data of firing positions;
    - target positions;
    - safety zones, safety sectors, etc.
- automatic reception and procession of meteorological, navigation and other data from the peripheral devices;
- continuos documentation of commands and orders.

In its original configuration, the ARPAD M1 system of an artillery battalion consisted of the following command posts:

- battalion command post;
- command post of the chief-of-staff of the battalion;
- command posts of the battery commanders (up to 4);
- command posts of the battery officers (fire control officers of the batteries; up to 4);
- gun display units (up to 12 in each battery).

Using its Digital Message Device, the system is able to receive and process target and other data from reconnaissance units, as well.

Thanks to the great structural flexibility of ARPAD M1 system, configurations to support artillery battalions or batteries with a different organisational structure can be easily formed.



FCC fire control computer
GDU gun display unit
LRFI internal laser rangefinder
LRFO external laser rangefinder

MET meteo. interface device
METS meteo. sensor
NAV navigation equipment
PR printer
RCU remote control unit of FCC

Figure 9. Structure of a 2S1 self-propelled artillery battalion equipped with ARPAD M1 fire control system

Challenge of NATO interoperability

Original flexibility and versatility of the ARPAD M1 artillery fire control system entails the potential of NATO interoperability, but for a full interoperability some minor changes are necessary. The first steps towards a fully NATO interoperable ARPAD FCS were done in 1999, when the integration of Ericsson's ARTHUR weapon locating radar into the fire control process of the ARPAD M1 system was completed by MMG Company for Automation. Communication was established with MRR type radios of the Norwegian Kongsberg Ericsson, which were on trial in the US, as well. This integration then served primarily for demonstration purposes and the results were demonstrated only on the Central European Defence Industry and Security Exhibition C+D'99 in Budapest the same year.

The first time that ARPAD system had the possibility to demonstrate its capabilities in NATO environment was during exercise ARDENT GROUND 2000, which was the first major NATO exercise held in Hungary.

The exercise was executed with the participation of eleven NATO nations, including an increased number of artillery units from the participating nations. As a result of reorganisation for structural NATO interoperability, the Hungarian artillery battery taking part on the exercise had an organisational structure different from its former organisation. In addition to this, the Hungarian artillery battery has no modern communication devices which meets the NATO requirements.

The evident solution to these problems was the use of the ARPAD M1 system with MRR radios. After a few month of preparation and additional testing, the ARPAD fire control system was ready to ensure the success of the Hungarian artillery battery on ARDENT GROUND 2000 and proved that the Hungarian ARPAD fire control system is able to serve the needs of our artillery in NATO environment.

The necessary modifications were made by MMG Teknowledge company. The company was established in 2000 and inherited the experience of MMG Company for Automation in the field of defence technology.

The ARPAD M1 system modified by MMG Teknowledge has the following new features:

- fire control computers of the system are able to transform UTM grid coordinates to Gauss-Krüger and Gauss-Krüger position to UTM;
- the system is able to work either in 6000 mil system or on 6400 mil system;
- the system uses MRR type radios of Kongsberg Ericsson which are in service in the Norwegian Army and are on trial also in the US Army.[2]

During exercise ARDENT GROUND 2000, the fire control system ARPAD provided the full functionality of a modern automated fire control system to the Hungarian artillery unit, ensured the possibility of the co-operation with the ARTHUR weapon locating radar and proved that – using modern communication devices – Hungarian artillery already has the appropriate fire control system to work efficiently in multinational NATO environment.

Possibilities for further development

Although the latest generation of the fire control system ARPAD is able to address the present needs of the Hungarian field artillery, some problems remained unsolved and there is a significant potential for further development.

Concerning ARPAD FCS itself, major improvement could be achieved in speed, operability, ergonomy and maintainability by changing the hardware of the system. Another advantage of a new hardware would be the portability of the command post computer configurations, which can be an important factor in towed artillery units lacking appropriate command post vehicles.

The most urgent and important field of future development regarding fire control process is the development, acquisition and deployment of new peripheral devices. Our artillery needs new reconnaissance devices, such as modern laser rangefinders, night vision devices, target acquisition systems, and so on, but most of our command post vehicles, navigation equipment and meteorological stations also deserves replacement.

Integration of other devices and peripherals, like muzzle velocity meters or weapon locating radars is also possible and there are significant achievements in this field (development of a muzzle velocity radar is near to completion and co-operation between ARPAD M1 and ARTHUR weapon locating radar was demonstrated on ARDENT GROUND 2000).

Another important field of further development is definition and creation of other combat information systems based on our experiences in the development of the ARPAD generations. As an example, development of a reconnaissance data acquisition and procession system can be mentioned which started in the early 1990s, but was cancelled later because of financial reasons.

Concerning the future of the fire control system ARPAD and its environment, the most important thing to remember that we can improve the efficiency of our forces in the most affordable and profitable way by developing and continuously improving appropriate combat information systems.

Present situation

Upgrading artillery fire control is an actual task, as shown by two facts. First, the Artillery Department of Miklós Zrínyi National Defence University (ZMNE) headed by dr. István Szendy, presented a study for approval titled “Concepts for quality improvement and development of the artillery branch of the Hungarian Army in 2000-2010.” This concept discussing fire control improvement in detail is currently being evaluated by military and MoD leadership.

Second, a Hungarian Army artillery battery in the process of being converted to reach NATO interoperability achieved a 50% readiness level in December 2001. As a result, this unit will consist of the standard NATO elements (battalion fire support element, company fire support and observation post, etc.) and will operate in a way consistent with NATO norms.

Part 2. Comparison of the ARPAD system with other sysemts

The purpose of the second part is two-fold. First, it is an attempt to draw up a comprehensive set of general criteria for evaluation and comparison of fire control systems based on the structure and main characteristics of modern fire control systems. Second, it serves to compare ARPAD sytems with other, contemporary systems by using the appropriate mathematical methods to analyze data in the tables developed based on this system of criteria. The results of this comparison give a relatively accurate picture of how advanced ARPAD systems are, while they highlight possible ways for improving on these systems and making them interoperable with NATO forces. Overall, this publication contains new research results made possible through a totally new approach and the necessary mathematical methods.

Possible methods for comparing artillery fire control systems

Among professional writings on the subject we cannot find one that would compare fire control systems in a comprehensive way using mathematical methods. The reason for this could be found in the history of the development of fire control systems and the complexity of the issue. A 1987 publication[3] compares computers in fire control systems, however this is only part of the answer. Although today’s fire control systems are very sophisticated, their structure follows a general pattern: subsystems for target acquisition, connections with national (and Alliance) combined arms systems, and for weaponry linked to a central computer and communications system. Various systems based on such vastly different traditions and developmental concepts as the German ADLER[4] and the Russian Kapustnik system[5] are characterized by this structure.

Since these subsystems are made up themselves of several independent and complicated equipment, their in-depth comparison would probably mean the handling of hundreds of parameters, and would presumably require an inproportionate effort not yielding a concise result. The polar opposite of this complicated approach is the position taken by Brigadier J. Bailey, Director of the UK Royal Artillery on page 67 of Ref. 6: "…the effectiveness of the indirect fire artillery system is broadly governed by that of the weakest link in the system..." We hold that this is a simple but practical way of looking at the problem.

The only Hungarian to compare artillery fire control systems at the battalion level is Sándor Felházi. On page 137 of his doctoral dissertation,[7] nine systems are examined (ARPAD among them) using tables to establish comparisons. His study is based on data published in 1995–98; his criteria (7 in all) are important, proper and correct. These are the following: the number of batteries and artillery pieces controllable, type of weapons used, storage of target data, weight and dimensions of the central computer and finally, the reaction time of the system. On the latter, the author adds that "the meaning of reaction time differs according to the country." Out of 7×9=63 cells in the table, 16 are empty (no data) due to the fact that publications presenting fire control systems often contain scarce data.

The task at hand, namely the comparison of fire control systems is no small feat thanks to their complexity. When it comes to acquisitions of military equipment *Complex system analysis* is already being used to assess investments, assets, etc. Adapting this practice, we use the theory in our publication to compare fire control systems.

The theoretical basis for comparing complex systems

Definitions and methods, the sequence of comparison

The theory of complex system comparison measures different systems against each other and sets an order of preference between systems based on a specified set of criteria. According to the definition "a system is complex if it can be qualified by more than one characteristic simultaneously" (Ref. 8 page 12). If any instrument or system has at least two qualities to give its definition by, it is then considered complex. The methods of examination used here are described in detail in the source quoted.[8]

The examination consists of three steps. First, a set of criteria that serves as a departing point for the analysis is drawn up. The second step is to select the method that is to be used to make the comparison. Various methods are described in the sources ranging from simple to more complex solutions. There are procedures developed for qualifying specific systems, but most of them can be applied universally. It is important to choose the method based on the degree of the system's complexity. Step three uses criteria and methods to make the comparison and to assess the results.

The set of criteria is made up of the most important qualities as given by the object of the examination and the numbers showing their value. The qualities selected for the examination we term *evaluation factors* (E_i), the numbers *value factors* (v_i).

Evaluation factors are defined under title "The suggested set of criteria". For determining value factors three methods are referred to in the sources: *direct estimation*, the procedure developed by *Churchman–Ackoff* and the *Guilford method.* We have chosen to use *Guilford's method* since it is the best established both mathematically and psychologically, while from among procedures for comparison *Kesselring* and *KIPA* have been selected.

Guilford's method for determining value factors

The Guilford method is based on the so-called comparison-in-pairs procedure. This is significant because it gives results on an interval-level scale, that is, it does not simply put evaluation factors in order but makes it possible to compare the proportionate difference between value factors of individual pairs of evaluation factors.

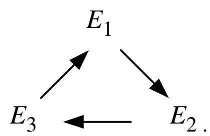
The method is presented through the work of an expert. Individual evaluation factors need to be paired; $\binom{n}{2}$ pairs can be formed from n factors. The expert then marks the pair's more important evaluation factor. The preference table (Table 1) is prepared based on filling out the sheet containing pairs for comparison of evaluation factors.

Table 1. Table of preference

	E_1	E_2	E_j	E_n	a	a^2	p	u	Z
E_1									
E_2									
E_j									
E_n									
Σ									

The rows and columns of the table both contain evaluation factors. In the first row for evaluation factors a "1" (number one) needs to be put in the cell of the factor to which it was preferred during the course of making the comparison-in-pairs. The occurrence of preference has to be added up in column a.

The next step is to examine the consistency of the expert, meaning the person filling out the comparison sheet. The relation of preference among the individual evaluation factors is of a transitive quality, that is if $E_1 \to E_2$ and $E_2 \to E_3$ ("$\to$" refers to the relation of preference, $E_1 \to E_2$ means E_1 is preferred to E_2), then this means that $E_1 \to E_3$. However, comparison in pairs may not necessarily lead to the same result, in which case filling out the sheets can leave us with a so-called inconsistent triad:



The number of inconsistent triads is

$$d = \frac{n(n-1)(2n-1)}{12} - \frac{\sum_{i=1}^{n} a_i^2}{2},$$

the maximum number of inconsistent triads (if n is an even number) is

$$d_M = \frac{n^3 - 4n}{24},$$

the consistency indicator is

$$K = 1 - \frac{d}{d_M} \ .$$

It can be seen from the formula that $0 \le K \le 1$ and the closer it is to 1, the more consistent the expert will be. Significance-examination of consistency, if $n > 7$, is done by χ^2 trial since the dispersion of d approximates it. Trial statistics and degrees of freedom are calculated as thus:

$$df = \frac{n(n-1)(n-2)}{(n-4)^2},$$

$$\chi^2 = \frac{8}{n-4}\left[\frac{1}{4}\binom{n}{3} - d + \frac{1}{2}\right] + df \ .$$

In column p of Table 1, the correlation of preference is calculated:

$$p = \frac{a + 0{,}5}{n} \ .$$

In the next column correlations of preference are transformed to u values of standard deviation based on the equation $p = \Phi(u)$. These now give interval level scale values. To get a 0–100 scale the following transformation needs to be made:

$$Z = \frac{u - \min(u_i)}{\max(u_i) - \min(u_i)} \ .$$

On the scale further transformations are possible using the equation $x' = ax+c$ (where $a \neq 0$), for example to get whole number value factors.

The Kesselring method

The procedure places the systems to be compared on a five-level verbal scale based on their evaluation factors, where the first, least favorable level is worth 1 point, the second 2 points and so on (p_{ij}). Value factors ranging from 2 to 10 are attributed to the evaluation factors marking their importance (v_j). Calculating the total score of individual systems follows the pattern in Table 2, where three systems $T_1 \ldots T_3$ are examined based on five evaluation criteria $E_1 \ldots E_5$.

It is important to note that points scored have a meaning of their own, since evaluating on a verbal scale means that the system examined is measured against an ideal system.

$0.8<P<1$	Very good
$0.6<P<0.8$	Good
$P<0.5$	Unsatisfactory.

Table 2. Kesselring matrix

	E1	E2	E3	E4	E5	$\sum_j p_{i,j} v_j$	P_i
T_1	$p_{1,1}$	$p_{1,2}$	$p_{1,3}$	$p_{1,4}$	$p_{1,5}$	$\sum_j p_{1,j} v_j$	$\frac{\sum_j p_{1,j} v_j}{\sum_j p_{i_{max},j} v_j}$
T_2	$p_{2,1}$	$p_{2,2}$	$p_{2,3}$	$p_{2,4}$	$p_{2,5}$	$\sum_j p_{2,j} v_j$	$\frac{\sum_j p_{2,j} v_j}{\sum_j p_{i_{max},j} v_j}$
T_3	$p_{3,1}$	$p_{3,2}$	$p_{3,3}$	$p_{3,4}$	$p_{3,5}$	$\sum_j p_{3,j} v_j$	$\frac{\sum_j p_{3,j} v_j}{\sum_j p_{i_{max},j} v_j}$
v_j	v_1	V_2	V_3	V_4	V_5		
$p_{i_{max},j} v_j$	$p_{i_{max},1} v_1$	$p_{i_{max},2} v_2$	$p_{i_{max},3} v_3$	$p_{i_{max},4} v_4$	$p_{i_{max},5} v_5$	$\sum_j p_{i_{max},j} v_j$	

where v_j is the value factor of evaluation factor number j, $p_{i,j}$ is the point value of system number i as given by evaluation factor number j, P_i is final point value of system number i.

The KIPA method

This procedure examines the systems to be compared using the individual evaluation factors and a five-level verbal scale. Scale size is determined using value factors and as scale units it generally proposes the value factor itself. For example, the level “Bad” means 0 as point value, “Acceptable” gives the value factor itself, “Average” is double the value factor, while “Good” is the factor times three and “Very good”, times four. Following this transformation, a so-called basic KIPA table can be prepared, which will serve as a basis for further calculations (Table 3).

Table 3. The basic KIPA table

	Evaluation factors/Value factors							
	E_1		E_2		E_3		E_4	
	v_1 (10)		V_2 (40)		V_3 (30)		V_4 (20)	
Systems	Verbal	Number	Verbal	Number	Verbal	Number	Verbal	Number
T_1	Average	20	Good	120	Average	60	Very good	80
T_2	Good	30	Good	120	Good	90	Average	40
T_3	Acc	10	Acc	40	Acc	30	Acc	20

The next step is to determine $c_{i,j}$ preference (advantage) indicators. $c_{i,j}$ values have to be calculated in relations between all systems. We demonstrate the method for its calculation through the example of systems T_1 and T_2. We add up the value factors of the evaluation factors where T_1 is preferred or is indifferent towards the T_2 system and divide the total by that of the value factors. The quotient is multiplied by 100 to get the result in percentages. In this case:

$$c_{1,2} = [(40+20)/100]\cdot 100 = 60\%.$$

Having computed the advantage indicators, we now calculate disqualification indicators or disadvantage indicators $d_{i,j}$. To calculate this in the case of T_1 T_2: look for the greatest scale difference where $T_2 \rightarrow T_1$, which is now at evaluation factor E_3, where T_2 is preferred to T_1 and the value thus arrived at we divide by the size of the greatest scale, which in this case is the scale attributed to evaluation factor E_2, its size 4×40. The result is multiplied by 100 to get the indicator in percentages.

$$d_{1,2} = [30/(4\cdot 40)]\cdot 100 = 18.75\%.$$

Advantage and disadvantage indicators are put into a new table, the so-called KIPA matrix (Table 4).

Table 4. Preference and disqualification matrix

	T_1	T_2	T_3
T_1		$c_{1,2}$	$c_{1,3}$
		$d_{1,2}$	$d_{1,3}$
T_2	$c_{2,1}$		$c_{2,3}$
	$d_{2,1}$		$d_{2,3}$
T_3	$c_{3,1}$	$c_{3,2}$	
	$d_{3,1}$	$d_{3,2}$	

The comparison is made based on the data in Table 4. In order to do this, preference levels (p) and disqualification levels (q) need to be determined. The first level is $p \geq 100\%$ $q \leq 0\%$. A T_i T_j preference relation can be established where $c_{i,j} \geq 100\%$ and $d_{i,j} \leq 0\%$. Naturally, it is rare that all systems can be compared at this level, so further comparisons can be made by decreasing p value and increasing q.

Comparing ARPAD and ARPAD M1 to contemporary systems

The suggested set of criteria

This publication compares ARPAD and ARPAD M1 systems to its contemporaries in the Warsaw Pact era and at the time of NATO-accession. The structure of comparative tables is similar. In Tables 5 and 9 tactical characteristics are under 1–12, while 13–26 describe technical attributes. Table 6 shows that technical and tactical characteristics are closely related, indeed tactical characteristics are determined by technical aspects.

It is natural to ask the question that why is it those 12 combat characteristics that serve as a basis for comparison? The justification is the following. Artillery fire has to meet the basic demands of timeliness and effectiveness. The NATO STANAG 2934 on artillery procedures[9] states its objective and that of necessary artillery fire control under 101 as thus: "The aim of this publication is to detail the procedures agreed upon by the NATO forces for use by NATO artillery units in order to produce *timely* and *effective* artillery support to manoeuvre units." The requirement of *timeliness* is shown by characteristic number one, which is reaction time. It is easy to see that the more pieces an artillery battalion has, the more effective its fire will be (characteristic No. 2), or the more pieces a battery has (No. 3). Effective fire control demands sufficient target detection capability (No. 4) and reliable calculation of firing data (No. 7). In case of deploying batteries effectiveness is determined by automated fire control (No. 6).

Tactical requirements also include survivability (No. 5), concealment of command elements (No. 8) and the need to avoid friendly fire accidents and firing by mistake (No. 10). Documenting the firing process is also important to make after-action evaluation and analysis possible and thus enhance training as well (No. 9). General operating principles call for interoperability with national (No. 11) and Alliance combined arms command systems (No. 12).

Tactical characteristics do not include those of the artillery pieces controlled since modern fire control systems can function regardless of the type of weapon (guns, howitzers, MLRS's, etc.) firing.

ARPAD in the Warsaw Pact era

Table of tactical and technical characteristics. Table 5. compares characteristics of 4 artillery fire control systems based on 26 criteria.

Table 5. Comparison of ARPAD with Warsaw Pact-era artillery fire control systems

	No.	Evaluation factors	WP			NATO
			ARPAD Hun	MASHINA Soviet	FALCET Soviet	ATILA French
Tactical characteristics	1	Reaction time (s)	50-60	120-130	120-130	15-35
	2	Number of batteries in a battalion (max.)	3	3	3	3-6
	3	Number of pieces in a battery (max.)	6	6	6	6
	4	Target detection capability	average	average	average	good
	5	Arbitrary deployment of artillery pieces at firing position, thus increasing survivability	+	–	–	+
	6	Automated battery fire control	+	–	–	+

(Continued on next page)

Table 5. (Continued from previous page)

	No.	Evaluation factors		WP			NATO
				ARPAD Hun	MASHINA Soviet	FALCET Soviet	ATILA French
Tactical characteristics	7	Accuracy of firing data	distance „D" (%)	0.5..0.7	0.7…0.9	0.7..0.9	No data
			azimuth "β" (mil)	2-3	3-5	3-5	No data
	8	EW detectability		slight	great	average	slight
	9	Automatic documentation of firing command data		+	–	–	+
	10	Probability of firing by mistake due to malcomprehension of command		slight	great	average	slight
	11	Automated interoperability with national command systems		–	–	–	–
	12	Automated interoperability with allied command systems		–	–	–	+
Technical caracteristics	13	Full automatization from issuing command to displaying it on gun display units		+	–	–	+
	14	Method of distribution of fire control data		fully digital	verbal	digital and verbal	fully digital
	15	Time required for radio communications before firing (s)		10-20	50-100	50-100	10-20
	16	Calculation of firing data for each piece		+	–	–	+
	17	Data Transmission Unit for target data		A	–	–	A
	18	Computer (Comp) or data transmissio n unit (DTU) at command posts (CP)	Battalion commander's CP	Comp	–	DTU	DTU
			Battalion fire control officer's CP	Comp	Comp	Comp	Comp
			Battery fire control officer's CP	Comp	DTU	DTU	Comp
	19	Gun display units at artillery pieces		A	–	–	A
	20	Interchangeability of fire control computers		–	–	–	–
	21	Computer recognizes weapon types		–	–	–	–
	22	Target detection	Pilotless drone	–	–	–	–
			Opto-electronic assets	C	C	C	A
			Sound detection station	C	C	C	–
			Target detection radar	C	C	C	A
			Fire-finder radar	–	–	–	–

(Continued on next page)

Table 5. (Continued from previous page)

	No.	Evaluation factors	WP			NATO
			ARPAD Hun	MASHINA Soviet	FALCET Soviet	ATILA French
Technical characteristics	23	Meteorological station	A	–	–	A
	24	Printer connected to computers	A	–	–	A
	25	Navigation equipment	–	–	–	A
	26	Muzzle velocity meter	–	–	–	A

Notes and abbreviations:

1. "A" – automatized interface
   "C" – conventional interface (verbal)
2. The Hungarian Army did not possess automated combined arms command and control systems at the time (as is the case today).
   Mashina and Falcet systems did not have automatized interface for Soviet combined arms control systems.
   (for No. 11)

Logically, the table can be divided into 2 parts: the first 12 criteria show easily definable, basic combat parameters while 13-26 contain the most important technical characteristics and solutions. Tactical characteristics are determined by technical parameters and they are closely related as shown in Table 6.

Table 6. Tactical characteristics as determined by technical parameters in Table 5

Technical characteristics		Tactical characteristics
13–26	⇨	1
18	⇨	2
16, 18	⇨	3
17,22	⇨	4
16, 18, 19	⇨	5
19, 20, 21	⇨	6
16, 18, 22, 23, 25, 26	⇨	7
17, 18, 19	⇨	8
24	⇨	9
16, 17, 18, 19	⇨	10
18	⇨	11
18	⇨	12

Calculating value factors with the Guilford-method

Evaluation factors are determined by tactical characteristics in Table 5. Filling out sheets containing paired-up characteristics gives the preference-table shown in Table 7.

The comparison is made using two methods: the Kesselring method and the KIPA method. Based on these methods two different scales of value factors are made using two scale-transformations, from Z value factors. These scales are similar regarding the information they contain: v1 designates a KIPA scale of 100, while v2 of 2–10 values will be used for the Kesselring method.

Number of inconsistent triads:

$$d = \frac{n(n-1)(2n-1)}{12} - \frac{\sum_{i=1}^{n} a_i^2}{2} = \frac{12 \cdot 11 \cdot 23}{12} - \frac{506}{2} = 0 .$$

The consistency-indicator:

$$K = 1 - \frac{24d}{n^3 - 4n} = 1 - \frac{24 \cdot 0}{1728 - 48} = 1$$

Since K=1, no significance-examination is needed. The expert's consistency is maximal.

Table 7. Preference table

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	a	a2	P	u	Z	v1	v2
E1		1	1	1	1	1	1	1	1	1	1	1	11	121	1	1.73	1	15	10
E2			1			1			1		1	1	5	25	0.5	–0.1	0.47	8	6
E3									1				1	1	0.1	–1.15	0.168	4	3
E4		1	1		1	1	1	1	1	1	1	1	10	100	0.9	1.15	0.832	13	9
E5		1	1			1	1		1		1	1	7	49	0.6	0.32	0.592	10	7
E6			1						1		1	1	4	16	0.4	–0.32	0.408	7	5
E7		1	1			1			1		1	1	6	36	0.5	0.1	0.53	9	6
E8		1	1		1	1	1		1		1	1	8	64	0.7	0.55	0.658	10	7
E9													0	0	0	–1.73	0	2	2
E10		1	1		1	1	1	1	1		1	1	9	81	0.8	0.81	0.735	11	8
E11			1						1			1	3	9	0.3	–0.55	0.342	6	5
E12			1						1				2	4	0.2	–0.81	0.265	5	4
Σ	0	6	10	1	4	7	5	3	11	2	8	9		506				100	

Using the Kesselring method

Table 8 contains the scores of individual fire control systems based on the evaluation factors selected and results of the calculations.

Table 8. Scores of individual fire control systems

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	$\sum_j p_{i,j} v_j$	P_i
ARPAD	3	2	4	2	4	4	3	4	4	4	0	0	206	0.85
MASHINA	2	2	4	2	0	0	2	2	0	0	0	0	88	0.36
FALCET	2	2	4	2	0	0	2	2	0	2	0	0	104	0.43
ATILA	4	4	4	3	4	4	4	4	4	4	0	0	243	1
v_j	10	6	3	9	7	5	6	7	2	8	5	4		
$p_{i_{\max},j} v_j$	40	24	12	27	28	20	24	28	8	32			243	

The order based on the results in the last (P_i) column of Table 8: ATILA→ARPAD→FALCET→MASHINA. Among the systems compared ATILA and ARPAD receive an evaluation of "very good" while FALCET and MASHINA "unsatisfactory." There are significant differences between scores which makes further examination unnecessary. The results are graphically demonstrated in Figure 10.

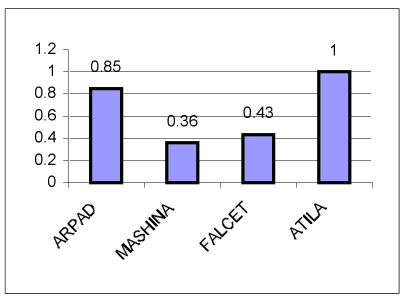


Figure 10. Results of the Kesselring method

ARPAD in the period of NATO-accession

Table containing combat characteristics

Calculating value factors with the Guilford-method. Table 9 uses the same evaluation factors as Table 5, consequently, the value factors are the same as those calculated in Table 7.

Table 9. Comparing ARPAD M1 with contemporary systems at the time of NATO-accession

	No.	**Evaluation factors**		*ARPAD M1* Hungarian	*KAPUSTNIK-B* Russian	*ADLER* German
Tactical characteristics	**1**	Reaction time (s)		50-60	40-50	30
	2	Number of batteries in a battalion (max.)		4	4	4
	3	Number of pieces in a battery (max.)		12	8	8
	4	Target detection capability		slight	very good	very good
	5	Arbitrary deployment of artillery pieces at firing position, thus increasing survivability		+	+	No data
	6	Automated battery fire control		+	+	+
	7	Accuracy of firing data	distance „D" (%)	0.5..0.7	0.5..0.9	No data
			azimuth „ß" (mil)	2-3	0.03..0.06	No data
	8	EW detectability		slight	slight	slight
	9	Automatic documentation of firing command		+	No data	+
	10	Probability of firing by mistake due to malcomprehension of command		slight	slight	slight
	11	Automated interoperability with national combined arms command systems		–	+	+
	12	Automated interoperability with allied command systems		–	–	+
Technical characteristics	**13**	Full automatization from issuing command to displaying it on gun display units		+	+	+
	14	Method of distributing target data		digital	digital	digital
	15	Time required for radio communications before firing (s)		5-10	5-10	5-10
	16	Fire data calculation for each piece		+	+	+
	17	Data Transmission Unit for target data		+	+	+
	18	Computer (Comp) or data transmission unit (DTU) at command posts (CP)	Battalion commander's CP	Comp	Comp	DTU
			Battalion fire control officer's CP	Comp	Comp	Comp
			Battery fire control officer's CP	Comp	Comp	Comp
	19	Gun display units at artillery pieces		A	A	A
	20	Interchangeability of fire control computers		+	+	No data
	21	Computer recognizes weapon types		+	–	No data
	22	Target detection assets	Pilotless drone	–	A	A
			Opto-electronic assets	A	A	A
			Sound detection station	C	A	–
			Target detection radar	A	A	A
			Fire-finder radar	A	–	A
	23	Meteorological station		A	A	A
	24	Printer connected to computers		A	No data	No data
	25	Navigation equipment		A	A	A
	26	Muzzle velocity meter		A	A	A

Comparison using Kesselring-method. Scores of individual fire control systems based on the evaluation factors determined and the results of calculations are shown in Table 10.

Table 10. Score of individual fire control systems

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	$\sum_j p_{i,j} v_j$	P_i
ARPAD M1	3	4	4	2	4	4	3	4	4	4	2	0	228	0.79
KAPUSTNIK-B	3	4	3	4	4	4	4	4	2	4	4	0	255	0.89
ADLER	4	4	3	4	4	4	4	4	4	4	4	4	285	0.99
v_j	10	6	3	9	7	5	6	7	2	8	5	4		
$p_{i_{max},j} v_j$	40	24	12	36	28	20	24	28	8	32	20	16	288	

The order is ADLER→KAPUSTNIK-B→ARPAD M1 based on the last (P_i) column of Table 10. Adler and KAPUSTNIK-B evaluated "very good" and ARPAD M1 "good." The results are shown in Figure 11.

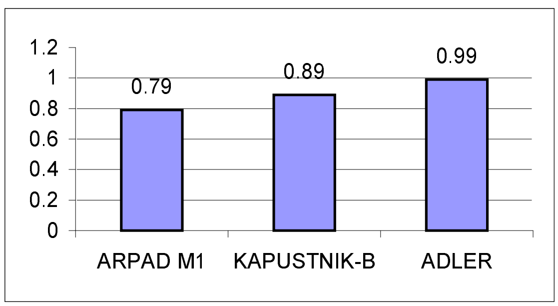


Figure 11. Kesselring method results

This results show no significant differences among these systems so it is expedient to use a different method as well.

Comparison using the KIPA method. A KIPA basic table is shown in Table 11. Evaluation of characteristics is based on table 9. Abbreviations of verbal evaluation are the following:

E → excellent
G → good
A → average
S → satisfactory
B → bad

The size of scales attributed to different evaluation factors is four times that of the attributed value factors. In the case of E_1 "B" means 0, and "S" means 15, while "G" is 45 points.

Table 11. KIPA basic table

E_i	E1		E2		E3		E4		E5		E6		E7		E8		E9		E10		E11		E12	
v_i	15		8		4		13		10		7		9		10		2		11		6		5	
T_i	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score	Verbal	Score
ARPAD M1	G	45	E	32	E	16	A	26	E	40	E	28	G	27	E	40	E	8	E	44	A	12	B	0
KAPUS T-NIK-B	G	45	E	32	G	12	E	52	E	40	E	28	E	36	E	40	A	4	E	44	E	24	B	0
ADLER	E	60	E	32	G	12	E	52	E	40	E	28	E	36	E	40	E	8	E	44	E	24	E	20

Table 12 shows advantage indicators based on preferences and indifferences between individual evaluation factors.

Table 12. Advantage indicators

	ARPAD M1	KAPUSTNIK-B	ADLER
ARPAD M1		72	52
KAPUSTNIK-B	94		78
ADLER	96	100	

Table 13 shows disadvantage indicators based on disqualifications.

Table 13. Disadvantage indicators

	ARPAD M1	KAPUSTNIK-B	ADLER
ARPAD M1		43	43
KAPUSTNIK-B	6,7		33
ADLER	6,7	0	

The comparison is begun on the levels *p*≥100% and *q*≤0%. Here, preference relations can be decided in ADLER's favor only in the ADLER–KAPUSTNIK-B relationship. To decide other relationships the lowest of the advantage indicators needs to be modified to *p*≥90% and highest of the disadvantage indicators to *q*≤10%. For better clarification Tables 12 and 13 are shown again, leaving out values not meeting the above mentioned criteria.

Table 14

	ARPAD M1	KAPUSTNIK-B	ADLER
ARPAD M1			
KAPUSTNIK-B	94		
ADLER	96	100	

Table 15

	ARPAD M1	KAPUST-NIK-B	ADLER
ARPAD M1			
KAPUSTNIK-B	6,7		
ADLER	6,7	0	

It can be seen in Tables 14 and 15 that given 90% advantage indicators and 10% disadvantage indicators any of the systems can be compared. Determining preference relations using KIPA method certainly leaves no doubt. The related assortative graph in Figure 12 shows the following order: ADLER→KAPUSTNIK-B→ARPAD M1.

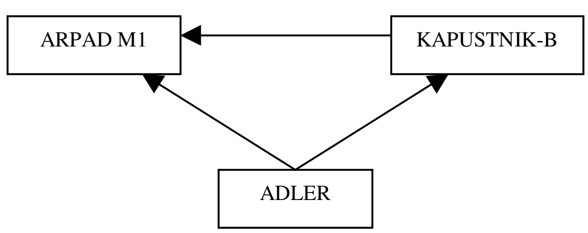


Figure 12. Assortative graph of fire control systems

Conclusions

As it was shown in Part 1, Hungarian field artillery fire control system ARPAD is a competitive rival to the modern western fire control systems as far as its functions and performance are concerned. The system has proved its capabilities in field tests, on live firing exercises and – last but not least – on ARDENT GROUND 2000.

With the strong support of the higher command of Hungarian Home Defence Forces and the Ministry of Defence of Hungary, the ARPAD system and its developmental process can not only be the cornerstone of the Hungarian artillery, but the exemplar of any other command and control system to be used in the Hungarian Home Defence Forces in this millennium. As a matter of course, in joining to NATO we have to exploit our new possibility of access to the advanced technologies in the process of improvement of the present system.

Part 2 comprehensively evaluates artillery fire control systems using a brand new approach to give a quantitative assessment surpassing other known qualitative methods.

Specifically, the result of the research described in this part is that it draws up a method based on a knowledge of fire control and complex comparison procedures offering a clear and comprehensive set of criteria for the comparative evaluation of fire control systems. It outlines a sequence of comparison consisting of three steps. Step one is to select the criteria that would serve as a basis for analysis. Step two involves choosing the method to be used for comparison. Finally, step three is to complete the comparison and assess the results using the criteria and method selected. As a further result, the modernity of the ARPAD M1 system in the Warsaw Pact and at the time of NATO-accession is quantitatively assessed.

Generally, the result is recognizing the value of the theory of complex systems and more specifically that of the Kesselring and KIPA methods and proving their usefulness. They can be applied not only for acquisition and development of artillery fire control systems but for other weapons systems as well.

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