Defence Science Journal, Vol 46, No 2, April 1996, pp 115-119

Performance Evaluation of Battle Tanks

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ABSTRACT

A model has been developed to evaluate the performance of tanks using analytic hierarchy process. This approach evaluates the relative performance of a particular system with respect to another system. The approach uses the qualitative information given by experts in tank warfare and technology to determine the relative rating of tanks. The method is useful where adequate data for rigorous analysis are not available.

1. INTRODUCTION

All major weapon system acquisition and development programmes in the defence forces have a long-term effect on the defence preparedness and the economy of a country. It is therefore imperative to conduct cost-effectiveness analysis of the systems. In this process, there are situations where sufficient information on operational features of the systems (or performance in field trials) is not available. This is particularly true for systems under development in the R&D laboratories. Therefore, performance evaluation of such systems cannot be conducted through analytical models of performance evaluation. Alternatively, the performance evaluation may be based on the opinion of experts in weapon technology and warfare.

For such studies, Saaty[1-3] suggested a technique called analytic hierarchy process (AHP). This management technique has been developed to handle multi-criteria decision making problems, using qualitative appreciation of the systems by experts from relevant disciplines and professions. The same technique can be adopted in evaluating the performance of the weapon system by rating its effectiveness in relation to another well-known existing system[4]. The details of the technique and its application to evaluate the performance of a tank are given here.

2. DETAILS OF AHP

To explain the application of AHP in the performance evaluation of tanks, the first step is to identify the factors that affect the performance of a tank in the battlefield. A general appreciation of the tank system[4-7] indicates that fire power, mobility, and survivability are the main factors concerning the operational performance of tanks.

The firepower of the tank refers to its capability to detect, acquire and fire the shots accurately to inflict reasonable damage to the target in minimum possible time. Therefore the target sighting systems (both during day and night), fire control system, ammunition loading system and the armament, affect the firepower of a tank. The mobility of a tank can be considered as its capability to move effectively in various types of terrains for long ranges and ability to change its position in short durations, i.e. agility. The survivability of the tank can be defined as its ability to evade and withstand enemy attack (as far as possible). Therefore with respect to each of these factors, several tank performance parameters (sub-factors) can be identified, e.g. rate of fire, maximum firing range, manoeuvring speed, armour thickness, etc. This information can be organised into a hierarchical structure (Fig. 1). The first two levels of the hierarchical structure contain the factors and sub-factors affecting tank performance. In the last level, one indicates the alternatives to be compared which include the tank whose performance has to be evaluated (say T-5) and some other well-known tanks whose performance can be treated as a standard for comparative rating of T-5 (say T-1, T-2, etc.).

Received 02 February 1995

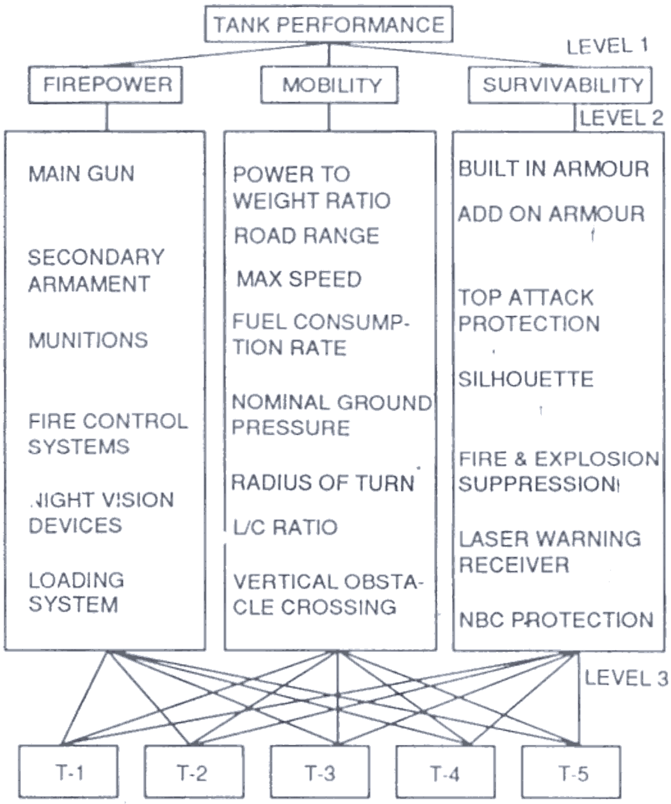

Figure 1. Hierarchical structure for tank performance rating.

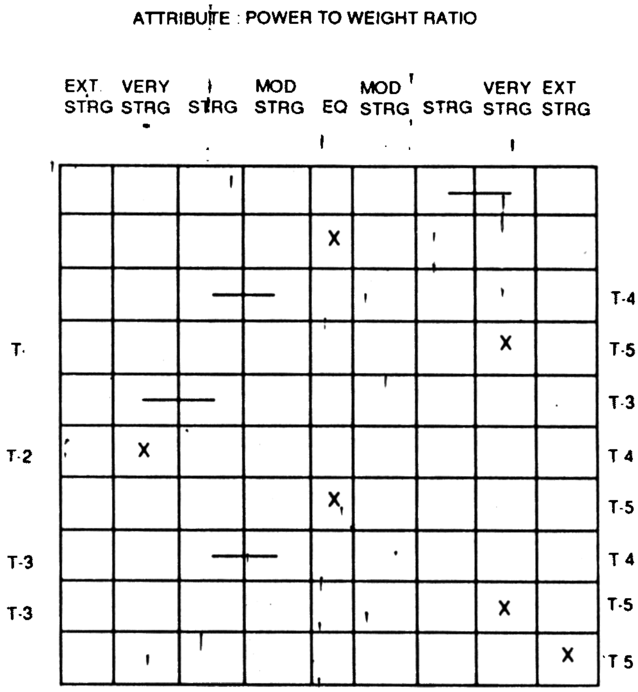

Figure 2. Data collection.

The hierarchical structure in Fig. 1 gives only few representative sub-factors. An exhaustive list of sub-factors can be obtained from Terry, *et al*[4] and Helmes[5]. It may be mentioned that since views of the experts have to be elicited on the elements of this structure, the factors which are amenable to qualitative appreciation may only be mentioned and others may be represented indirectly through these elements, e.g. it may be easier for an expert to comment on the fire control system of a tank or the dispersion of shots rather than hit probabilities.

After structuring the hierarchy of factors affecting the tank performance, the opinion of experts is elicited on the following issues:

(a) Comparative effect of various factors on the performance of the tank, i.e. firepower, mobility and survivability.

(b) Comparative contribution of various sub-factors on the factors mentioned above, e.g. effect of maximum firing range, accuracy, main gun calibre, etc., on the firepower of the tank.

(c) Relative ranking of each alternative tank with respect to each sub-factor, e.g. comparative rating of tanks T-1, T-2, T-3, etc., with respect to the accuracy of the main gun.

The qualitative information is obtained in a suitably designed format enabling pairwise comparison of factors, sub-factors and tanks (Fig. 2). In this format, the expert compares two tanks (or factors or sub-factors) say 'A' and 'B', and expresses his opinion in favour of or against any one (say A). This is communicated in the format by marking 'X' appropriately in one of the columns depending on the intensity of comparison, i.e. equal, moderate, strong, very strong and extremely strong. For example, let 'A' represent tank T-2 which has better (very strong) power-to-weight ratio than tank T-4 represented by 'B'. The respondent conveys this opinion as shown in Fig. 2 (in the 6th row, 2nd column). In situations where the respondent is indecisive with regard to the magnitude of the comparative ranking of factor 'A' over factor 'B', he can mark his opinion in two columns by a '—' (see comparison of tanks T-1 and T-2 in Fig. 2). This opinion is obtained at each level in the hierarchy with respect to the factors at the previous level.

While making a similar comparison of two factors, one may pose the objective in the questionnaire as 'which of the two factors, say firepower and mobility, is more important in evaluating the tank performance'. The qualitative opinion in the format in that case can be categorised as extremely important, very important, important, mildly important and equally important. For obtaining the views of the experts on the contribution of various sub-factors in determining the firepower, mobility and survivability of tanks, the opinion can be categorised as extremely strong, very strong, strong, moderate and equal contribution.

The qualitative opinion is converted into quantitative values by assigning numerical ratings to the qualitative judgments (e.g. equal: 1; moderate: 3; strong: 5; very strong: 7; extremely strong: 9). While assigning numerical values, if factor 'A' is better than 'B', the information with regard to comparison of 'A' and 'B' will take integer values as mentioned above (say 'A' is 5 times better than 'B'). The comparison of 'B' with 'A' will take the reciprocal value (i.e. 'B' is 1/5 times better than 'A'). The numerical values to the opinion expressed in two columns by a '—' can be assigned the values, 2, 4, 6 or 8.

The data obtained in this process are organised into square matrices, whose order is equal to the number of factors being compared at that stage. The elements in the upper triangle of these matrices are the numerical opinion generated above, the diagonal elements will be 1 and the lower triangle will have reciprocal values of the corresponding elements in the upper triangle.

3. SAMPLE DATA & RESULTS

The right principal eigenvector of these matrices is computed. The elements of this vector can be considered as relative weightage of each factor (or sub-factor or tank) being compared (Tables 1, 2 and 3).

Table 1. Evaluation of the relative comparison of tanks with respect to power-to-weight ratio

	T1	T2	T3	T4	T5	Eigenvector
T1	1	1/6	1	4	1/7	0.08
T2	6	1	6	7	1	0.41
T3	1	1/6	1	4	1/7	0.08
T4	1/4	1/7	1/4	1	1/9	0.03
T5	7	1	7	9	1	0.40

Eigenvalue = 5.20

While giving information, the respondents may be biased towards some particular factors/sub-factors. This will lead to inconsistency in the data generated from the survey. Saaty[2] has developed a procedure to identify some of these biases by evaluating the consistency index (CI) of each matrix. This CI can be evaluated as CI = (λ_{max} -N/N-1), where λ_{max} is the maximum eigenvalue and N is the order of the matrix. These indices can be compared with a random inconsistency index[1] (RI) given in Table 4 to give consistency ratio (CR), as CR = CI/RI. The RI values have been tabulated by Saaty for matrices of different sizes[3]. If the value of CR is less than 0.1, we say that the matrix is consistent and the data therein do not have contradictions. Otherwise, the respondent may be asked to review his opinion. This process has to be executed for all matrices till a set of consistent matrices and their right principal eigenvectors are obtained.

Table 2. Comparison of sub-factors affecting mobility of tanks

	PWR	RR	NGP	FCR	MSPD	ROT	L/C	VOC	Eigen vector
Power-to-weight ratio (PWR)	1	5	4	5	1	4	4	5	0.32
Road range (RR)	1/5	1	1	5	2	1/2	3		
Nominal ground pressure (NGP)	1/4	1	1	4	1	2	4	4	
Fuel consumption rate (FCR)	1/5	1/5	1/4		1/5	1/5	1/2	1/2	0.03
Maximum speed (MSPD)	1	1/2		5	1	2	5	4	
Radius of turn (ROT)	1/4	2	1/2	5	1/2	.	3		
Length/pitch ratio (L/C)	1/4	1/3	1/4	2	1/5	1/3	1	1	
Vertical obstacle crossing (VOC)	1/5	1/2	1/4	2	1/4	1/4	1	1	0.04

Eigenvalue = 8.67

Table 3. Comparison of factors affecting tank performance

	Mobility	Firepower	Survivability	Eigen vector
Mobility		1/3	1/2	0.16
Firepower	3	1	2	0.54
Survivability	2	1/2	1	0.30

Eigenvalue = 3.00

Table 4. Random inconsistency index

Size of matrix:	1	2	3	4	5	6	7	8
RI:	0.0	0.0	0.58	0.90	1.12	1.24.	.32	1.41

It may be mentioned that in a multidisciplinary situation, the opinion though consistent may be prejudiced towards a specific aspect of the system, e.g. an engineer may give more weightage to technical features of the tank, such as suspension system, gun movement systems, sight stabilisation, etc., a soldier may emphasise on importance of the main gun, ammunition, crew comfort, armour, etc., and a scientist may consider the sighting system, fire control system, etc., as more important factors in improving the tank performance. This may lead to personal bias in the analysis. It is therefore suggested that to eliminate such bias, the opinion of several experts from different disciplines may be elicited. To combine their opinion, geometric mean of the corresponding values of the paired comparisons at each stage in the hierarchy may be used for the final analysis.

Table 5. Aggregation of the data to evaluate mobility of tanks

Sub-factors	Relative weightage	T-1	T-2	T-3	T-4	T-5
Power-to-weight ratio	0.32	0.08	0.41	0.08	0.03	0.40
Road range	0.13	0.18	0.23	0.28	0.20	0.11
Nominal ground pressure	0.14	0.21	0.17	0.27	0.29	0.06
Fuel consumption rate	0.03	0.18	0.32	0.14	0.31	0.05
Maximum speed	0.17	0.15	0.38	0.07	0.04	0.36
Radius of turn	0.13	0.11	0.40	0.11	0.07	0.31
L/C ratio	0.04	0.11	0.43	0.09	0.09	0.28
Vertical obstacle crossing	0.04	0.08	0.34	0.11	0.07	0.40
Mobility		0.13	0.34	0.14	0.11	0.28

Table 6. Performance rating of tanks

Characteristics	Relative weightage	T-1	T-2	T-3	T-4	T-5
Mobility	0.16	0.13	0.34	0.14	0.11	0.28
Firepower	0.54	0.15	0.33	0.14	0.07	0.31
Survivability	0.30	0.19	0.33	0.12	0.06	0.31
Tank performance index		0.16	0.33	0.13	0.07	0.31
Performance rating		1.00	2.06	0.81	0.44	1.94

The relative weightage of each factor, viz., firepower, mobility and survivability, is suitably aggregated along with the relative weightage of each sub-factor and the ratings of each tank with respect to each sub-factor, to give an overall performance index of each tank. Table 5 gives an illustration of the approach used in aggregation of data to evaluate mobility of tanks. Similar approach can be followed for firepower and survivability of tanks. The results may be later aggregated as in Table 6 to evaluate the performance index of tanks.

We can infer from the results of the above analysis that the performance rating of tank T-5 is 1.94 times the performance rating of tank T-1. For a comparison of cost-effectiveness of two tanks, their relative ratings can be used as effectiveness index.

4. DISCUSSION

It may be mentioned that this approach is adventageous because it helps in incorporating the views and experience of senior Defence officers and technologists in the analysis. Furthermore, the respondents have a freedom to express their views qualitatively. Quantification can be done at the time of analysis. The negative aspect of this approach is that qualitative opinion of the experts may be subjective. The sharpness introduced by quantification in the analysis may overemphasise certain aspects of the systems. Therefore, it is suggested that the data collection should be undertaken from a large number of experts from different relevant disciplines.

This approach may be useful for performance evaluation of systems when adequate quantitative data on the performance parameters are not available. In cases where sufficient information can be obtained, a more rigorous analysis of the system must be done.

ACKNOWLEDGEMENTS

The authors thank Dr. N.K. Jaiswal for his guidance and Shri S.C. Jethi for useful discussions on an earlier draft of this paper.

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