Defence Science Journal, Vol. 53, No. 4, October 2003, pp. 371-391
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REVIEW PAPER

Technological Forecasting Applications: Framework and Case Study on Combat Vehicles

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ABSTRACT

The technological forecasting for predicting foreseeable scientific breakthroughs, refinements and discoveries has emerged as a serious professional activity in the recent years. In this era of highly competitive economy and cut-throat competitions, where technology change plays a pivotal role, the forecasting is of paramount importance to predict changes in advance and achieve the designated goals within specified time-frame so as to maintain the competitive advantage. The administration of military research and develop'ment has played a disproportionate role in the emergence of technological forecasting as a serious professional activity. This is one marketplace where an acute need for technological forecasting is felt as an adjunct to planning and execution, so as to maintain the much-needed cutting edge over the adversaries by fielding superior weapon systems. In this paper, an attempt has been made to apply some of the techniques to futuristic combat vehicles. To generate greater confidence in the results, validation has been attempted through analytic hierarchy process. Based on the case study, a generalised framework is also proposed for technological forecasting and technology transfer.

Keywords: Technological forecasting, analytic hierarchy process, nominal group technique, delphi approach, relevance tree, morphological approach, technology transfer, combat vehicles

1. INTRODUCTION

Present-day environment is characterised by a very high rate of change of technology. As a consequence, the life cycle of a product continues to shrink. The globalisation and technology changes are two mutually reinforcing factors playing the focal role for competitiveness. Under such turbulent environment, an organisation can only survive if it continuously upgrades its technologies through systematic-forecasts. The technological forecasts can address both the incremental changes for exploitation of current technologies and the long-run changes for exploration of emerging/pacing technologies. This would enable the organisation to remain a dominant leaaer and to ensure the first-mover advantage every time. Similar conditions apply to the defence sector also where every country is vying for technological supremacy over its adversaries. Therefore, there is a need to predict enemy capabilities in the future, simultaneously predicting defencive weapons as credible deterrence, at the same time, predicting newer and offensive weapons that are generations ahead of enemy capability. The future battlefields will witness quantum jump in technology demonstration. In Iraq and in the recent past in Afghanistan, the war bore mute testimony to the dependency on superior technology. The future

Revised 13 February 2003

theaters of war may be subjected to a host of weapons[1]. Some of these are:

- High velocity projectiles capable of defeating available armour
- Infantry-launched antitank missiles
- Ground-launched antitank guided missiles
- Seek and destroy missiles
- Heat seeking missiles
- Missiles launched from remotely piloted vehicles
- Missiles/projectiles launched from attack helicopters
- Nuclear weapons launched from air, missiles, artillary, or by tanks
- Chemical and biological bombs dropped through air/missiles/artillary/tanks
- Air interdiction
- High explosive minefields pressure-activated or remote controlled
- High energy laser
- Total communication blackout through electro magnetic induction (EMI), electronic counter countermeasures (ECCM) and nuclear radiation
- Supremacy in space and satellite-controlled weapons
- Defencive aid suite (DAS) for total protection
- Unmanned aeriel vehicles and robotic fighting machines.

The developing and the underdeveloped countries are caught between the wishful wants of sophisticated weapon systems and inability to get these due to generation gap in their technology. Such countries can ill-afford to buy the state-of-the-art weapon system of every type from the developed countries. Moreover, none of the developed countries would transfer their latest technology in these fields to maintain their superiority. It is, therefore, imperative that specific consideration be given to the make-some-and-buy-some technology strategy (which gives a country an opportunity to take advantage of its late starter status), the advantage of selecting an appropriate area of specialisation and the potential to exploit the advantage of technology exchange in the international marketplace. Due consideration must be given to technology life cycles (TLCs). The TLC should be seen in the context of global and zonal spheres. In advanced countries, the rate of change is so high that the TLCs have been reduced from couple of years to few months, depending upon the type of weapon system. It is, therefore, very essential for our country to use techniques of technological forecasting (aggregate approach) as an adjunct to perspective planning to leap through the generations in selected areas of weapon technology for achieving an edge over other countries (a global interest). Simultaneously, the same technique (disaggregate approach) can be used to modify and upgrade the existing weapon systems such that the dependency on import reduces, while one gains a competitive advantage over its adversaries in the zonal context. As an example, Israel had not only achieved advantage over its adversaries but also extended the usage value of obsolete tanks through upgradation.

2. SELECTIVE TECHNIQUES OF TECHNOLOGICAL FORECASTING

There are two fundamentally opposed ways of looking at the dynamics of technological change, which may be termed as the ontological (exploratory) and the teleological (normative) viewpoints. Ontological viewpoint is that inventions and innovations are visible manifestations of a self-generating process or an institution having a dynamism and life of its own. On the contrary, the teleological viewpoint is that inventions, or especially innovations are actually impersonal social processes, determined by social or military needs or by the existence of an effective economic demand. Based on these approaches, there are several techniques for technological forecasting[2-12] (Table 1). Mishra[13], et al. have reviewed some of the techniques of technological forecasting and their applications and have proposed a methodology for matching an appropriate technique to a technology. Interestingly, analytical hierarchy process (AHP) applied in this paper, had its beginning in the fall

Table 1. An overview of the techniques of technological forecasting

Subjective assessment methods	Exploratory methods of technological forecasting	Normative approaches to technological forecasting
• Jury of executive opinion	(a) Scenario developments	(a) Operational research models and simulations.
• Sales force composite methods	(b) Delphi approach	(b) Network techniques
• Formal surveys and market research-based assessments	(c) Cross impact matrices	(c) System of opportunities and negatives charts
• Individual subjective probability assessments	(d) Curve fitting and envelopes	(d) Relevance trees, planning assistance through technical evaluation of relevance numbers
	(e) Analogy methods	(e) System dynamics
	(f) Morphological research	(f) Dynamic modelling
	(g) Catastrophe theory	(g) Phenomenological modelling
	(h) Trend extrapolation	
	(i) Simple analytical models	
	(j) Multi-variate analysis	
	(k) Game theory	
	(l) Growth models	
	(m) Input-output models	
	(n) Contextual mapping	
	(o) Monitoring	
	(p) System for event evaluation and review	
	(q) Brain storming	
	(r) Substitution anaiysis	
	(s) Analytical hierarchy process	
	(t) Nominal group technique	

of 1971 while working on the problems of contingency planning for the Department of Defence as reported by Saaty[14]. Saaty and Vargas[15] have highlighted AHP applications for technological forecasting. Ramanujam and Saaty[16] have addressed technological choices in less developed countries with AHP approach.

2.1 Techniques for Forecast of Combat Vehicles

2.1.1 *Delphi Approach*

The delphi approach is undoubtedly the most commonly used qualitative method for technological forecasting. In the 1950s, the RAND Corp adopted the name delphi for a procedure to obtain the most reliable consensus of opinion of a group of experts by a series of intensive questionnaires interspersed with controlled feedback. The early pioneering work, dealing among other topics also with matters related to defence, was not widely publicised. The first extensively circulated delphi study appeared in 1964 as a RAND paper. Text book on the deiphi method, techniques, and application by H.A. Linston, and M. Turoff (Addison Wesley, Reading, Mass) was published in 1975. The procedure generally involves:

- First, a panel of experts on the topic(s) under study is created.
- A series of questionnaires is sent to each member of the panel.
- Soliciting both, a forecast for each event being studied and brief statement as to why the panelist has made that particular forecast.
- The second-round questionnaire asks for the same information, but also provides each panelist with his or her previous responses, statistical summaries of the overall panel response on the previous round and a brief summary of the reasons offered for each forecast.

- The third-round questionnaire provides panelist with the information from the second round and so on. When responses begin to stabilise across iterations, or when resources are exhausted, the results of the final round are used as the forecasts produced by the study.
- Three rounds seem to be typical in the published literature. The median panelist's response is usually reported as the point of forecast.
- During the entire period of the procedure, the experts or panel members are kept apart from one another so that social pressure or other aspects of small group behaviour does not influence their judgment.

Since its inception, the delphi has been applied to technological, economic, social, political, demographical, market, road transport information system, environment standards, and host of other issues.

2.1.2 Nominal Group Technique

The nominal group technique (NGT) was an improvement over opinion polls, panel discussion, and brain storming in that it is a structured direct interaction aimed at creativity and group consensus. This technique employs the method when a group of experts associated with the problem sit around a table and write their forecasts on a paper. These papers move round the table with each member adding to other's estimate. The papers keep moving till such time everyone stops writing. The total of all predictions are then taken up for further analysis, ie, create and refine phases.

2.1.3 Analytical Hierarchy Process

The theme of analytical hierarchy process is decomposition by hierarchies and synthesis by finding relations through informed judgment. This technique falls in the category of quantitative judgment method of analysis (QJMA) and has proven to be a very powerful and effective tool in decision-making process. It can address both tangibles and intangibles of the problem under consideration. The hnderlying principle is that a hierarchy is an abstraction of the structure of a system to study the functional interactions of its components and their impact on the entire system. The functional interactions are made by pairwise comparison using a nine-point scale. The strength1 importance can be 1 for equal, 3 for weak, 5 for strong, 7 for very strong, 9 for absolute, and 2,4,6,8 as intermediate values.

For analytic hierarchy process (AHP), given the elements of one level, say, the fourth-level of a hierarchy and one element, e, of the next higher level, compare the elements of level 4, pairwise in their strength of influence on e. The agreed upon numbers are inserted in the comparison matrix and the eigenvector with the largest eigenvalue is calculated. The eigenvector provides the priority ordering, and the eigenvalue is a measure of the consistency of the judgment. In this process, the subjectivity of judgment is reduced. This method has found widest applications, especially in technnological forecast where expert opinions are of paramount importance.

2.1.4 Morphological Approach

The morphological approach to technological forecasting was developed by Zwicky in 1962. He was Swiss astrophysicist and a jet engine pioneer in his effort to discover new technologies in the field of jet engines. This approach is a kind of checklist, which, in a systematic manner, enumerates all parametric possibilities and combinations of technologies. In this, Zwicky was able to suggest several rather radical new conceptual inventions, such as aeroduct and aeropulse.

As per Zwicky, the probability of breakthrough in a technology area, per unit time is a decreasing function of its morphological distance from the exiting art, other things being equal. If the functional relationship is assumed to be an inverse quadratic, then a distance of 1 might correspond to (normalised) a prior probability of 1, a distance of 2 would then correspond to a relative probability of 114, a distance of 3 would correspond to a relative probability of 119, etc. In any case, new developments will obviously occur near older ones (in the morphological sense) essentially accretions from the borders of state-of-the-art cluster into adjacent undeveloped regions. The morphological analysis has been applied to many areas, such as food research planning, newer automobiles, etc.

2.1.5 *Normative Forecasting*

This is a goal-oriented forecasting technique where one establishes a future need and recedes backwards to the present and the intermediate technology needs so as to achieve the objective of the future. Relevance trees, and decision theories, and decision trees are very popular in this approach. One of the earliest, and perhaps the best known application of relevance tree is the planning assistance through technical evaluation of relevance numbers (PATTERN) that has been used by the military and space science Depts of Honeywell Corporation, for military, space and medical purposes.

Normative forecasting is a planning exercise where long-term objectives are specified, short-term realisable targets or goals are indicated, strategic alternative routes are analysed to choose the best one, resources are mobilised, institutions are organised, directed, and coordinated to achieve the stated goals. Mission-mode projects like Manhattan and launching of Man-on-Moon are some of the examples of management of technological changes by normative forecasting. Technology enthusiasts and visionaries often see their technology as the one that will be the hottest new thing in the years ahead. In contrast, Japan makes a crucial business point of normative forecasts in setting goals and directions. In the US, the Department of Defense as well as National Aeronautical and Space Administration (NASA) has, for years, used normative forecasting to help shape the next wave of technological development. The steps used for PATTERN are as follows:

Step 1. A relevance tree structure must be developed with the organisation's objective at the top and elements at various levels required to achieve the objective. The tree should extend to a low enough level, so as to identify the individual technologies required to be developed for achieving higher elements.

Step 2. A number of criteria must be established for each level so that priorities in ordering each of the variables can be determined in a meaningful manner.

Step 3. ***A*** panel of experts can be asked to weigh the importance of each criterion in relation to the others. Similarly, the panel could be asked to weigh each element at each level in relation to all other elements at that same level (Table 2).

Step 4. A partial relevance number (PRN) for level I can be computed by the relationship (Table 3): PRN = (Criterion weight) x (Element weight).

Step 5. Then, local relevance number for each level can be obtained by the relation $R_L = \Sigma \text{PRN}$

Table 2. Criterion weightages

Level 1		Level 2		Level 3		Level 4		Level 5	
Criterion	Wt	Criterion	Wt	Criterion	Wt	Criterion	Wt	Criterion	Wt
Increased Power-to-weight/volume ratio & low specific fuel consumption	0.5	Technology transfer	0.2	Time	0.4	Procure	0.4	Resistance to, wear	0.3
RAM-D features	0.2	Technology sustenance	0.2	Cost	0.3	Develop	0.6	Technical endurance	0.3
Familisation (adaptability to family of combat vehicles)	0.2	Adaptability (absorption)	0.1	Technology growth	0.2			Weight-to-strength ratio	0.2
Reduced cost	0.1	Cost	0.5	Technology diffusion	0.1			Ease of manufacturing	0.1
								Ease of maintenance	0.1

Table 3. Local relevance numbers for level 1

		Turbo charged		VCR		Adiabatic		Gas turbine		SCR		AIPS		SSCM	
Criterion	Crit wt	Wt	PRN	Wt	PRN	Wt	PRN	Wt	PRN	Wt	PRN	Wt	PRN	Wt	PRN
Increased power-to-wt/vol ratio	0.5	0.05	0.025	0.10	0.050	0.35	0.175	0.15	0.075	0.10	0.050	0.15	0.075	0.1	0.05
RAM-D features	0.2	0.10	0.020	0.10	0.020	0.25	0.050	0.15	0.030	0.10	0.020	0.20	0.040	0.1	0.02
Familisation	0.2	0.10	0.020	0.10	0.020	0.25	0.050	0.20	0.040	0.05	0.010	0.20	0.040	0.1	0.02
Reducedcost	0.1	0.20	0.020	0.15	0.015	0.30	0.030	0.05	0.005	0.05	0.005	0.15	0.015	0.1	0.01
Local relevance, number = Σ PRN			0.085		0.105		0.305		0.150		0.085		0.170		0.10

Step 6. The local relevance numbers can be used to find the cumulative direct relevance numbers for various levels and by the relationship; $R_D = R_{Li} \times R_{L(i+1)}$, here, R_{Li}, is the local relevance number of level i and $R_{L(i+1)}$ is the local relevance number of the next level (i + 1). The cumulative direct relevance number of lowest level will become the total direct relevance number, indicating the importance of each of the final technological requirements if the higher-level objectives are to be realised (Table 4).

3. TECHNOLOGICAL FORECASTING FOR COMBAT VEHICLES

To meet the combat potential of any Armed Forces, the requirement is that the weapon systems should be available in desired quantity and quality at all times. The quality stipulates the capabilities that are superior to that of its adversaries. This

Table 4. Cumulative direct relevance numbers

Corresponding elements of higher level	Local relevance number of higher level	Elements of immediate lower level	Local relevance number of immediate lower level	Cumulative direct relevance number
Level 1	Level 1	Level 2	Level 2	
Adiabatic	0.305	Indigenous technology	0.575	0.175
Adiabatic	0.305	Import technology	0.425	0.130
Level 2	Level 2	Level 3	Level 3	
Indigenous technology	0.176	Design	0.500	0.088
Indigenous technology	0.176	Manufacture	0.440	0.077
Level 3	Level 3	Level 4	Level 4	
Design	0.088	System hardware	0.220	0.020
Design	0.088	Metallurgy	0.560	0.050
Design	0.088	Accessories	0.220	0.020
Level 4	Level 4	Level 5	Level 5	
Metallurgy	0.05	Ceramic lining	0.530	0.027
Metallurgy	0.05	Composite lining	0.470	0.023

requirement brings in a virtual race for 'supremacy between the players. Technology of the weapon system is the single most important variable in this competition. Therefore, continuous upgradation and radical developments in this area are of utmost importance. The users may be in a position to predict their requirements of futuristic weapon systems in broad statements, such as number of weapon platforms of a particular type and certain improvements in capabilities through a comparison of state-of-the-art weapon systems available elsewhere. However, the technologies are not specified through scientific forecasting techniques. Actually, this is where the experts and forecasters must join to identify specific futuristic capabilities and the technology areas needing research and development.

Most advanced technologies, especially for defence applications, are clusters of multidisciplinary, and technologies needing multidimensional competencies and multi-integration of forecasters are essential. At this stage, the technology options can also be evaluated against the core competencies, leading to important decisions regarding develop here, develop elsewhere or buy from global market when required. Unfortunately, in the absence of such actions, the projections are unrealistic/unclear. As a result, the research and development may have to grope in the dark without a clear-cut mandate, playing with their concepts on a stand-alone mode. The project tends to slip in the absence of a specific vision1 goal. In the mean time, the users, also working in isolation, tend to redefine their requirements and the vicious cycle becomes a never-ending process since the design does not get frozen.

If the technological forecasting is applied to get appropriate directions and concurrent engineering attempted for technological transfer, then such shortcomings can be overcome. With this in mind, technological forecasting techniques have been applied to one of the weapon systems, ie, combat vehicles as an example. It is to be noted that, the sole purpose is to demonstrate the use of techniques in this paper. The forecasts arrived at are purely for academic interest and by no means any requirements projected by any department of the defence. The forecasts are solely based on the past and future trends as obtained from books/published literature (open literature) and expert opinions.

An attempt has been made to apply technological forecasting technique to various systems of combat vehicles so as to identify futuristic developments in each of these areas. Techniques applied are relevance tree, ie, PATTERN for engine and transmission, morphological research for main armament and delphi/NGT for suspension, tracks, armour protection, gun control equipment/fire control equipment, vision devices, and vehicle electronics (vetronics).

To enable forecasting, requisite data in terms of future trends in technological developments in each area were collected from several articles published by Benz[17], Hare[18], International Defence Review (IDR) Research Team[19], Kennedy[20] and Left[21,22] and collated. Large sample of expert opinion were collected from the environment for application of these techniques. Raghunathan and Mishra[23] have proposed a methodology based on PATTERN for the evaluation of various technologies for main battle tank. In this paper, in addition to further refinements, AHP technique has been applied to validate sample result obtained from relevance tree (PATTERN) so as to establish greater confidence in the forecast.

To apply AHP technique, twenty experts were selected from the environment science who were intimately associated with combat vehicles, both in the field and in the research and development. These experts having 15 to 30 years of work experience, had undergone specialised advanced training in this area and both the experience and the knowledge make them suitable respondents for AHP. Various techniques applied and the results are discussed.

3.1 Forecast of Engines

The combat vehicle's mobility, in addition to its armament and protection, has acquired new significance, for gaining tactical edge over the enemy through swift deployment/redeployment. The futuristic combat vehicles will need considerably more propulsion power to deal with their expected weight increases in the areas of armament and

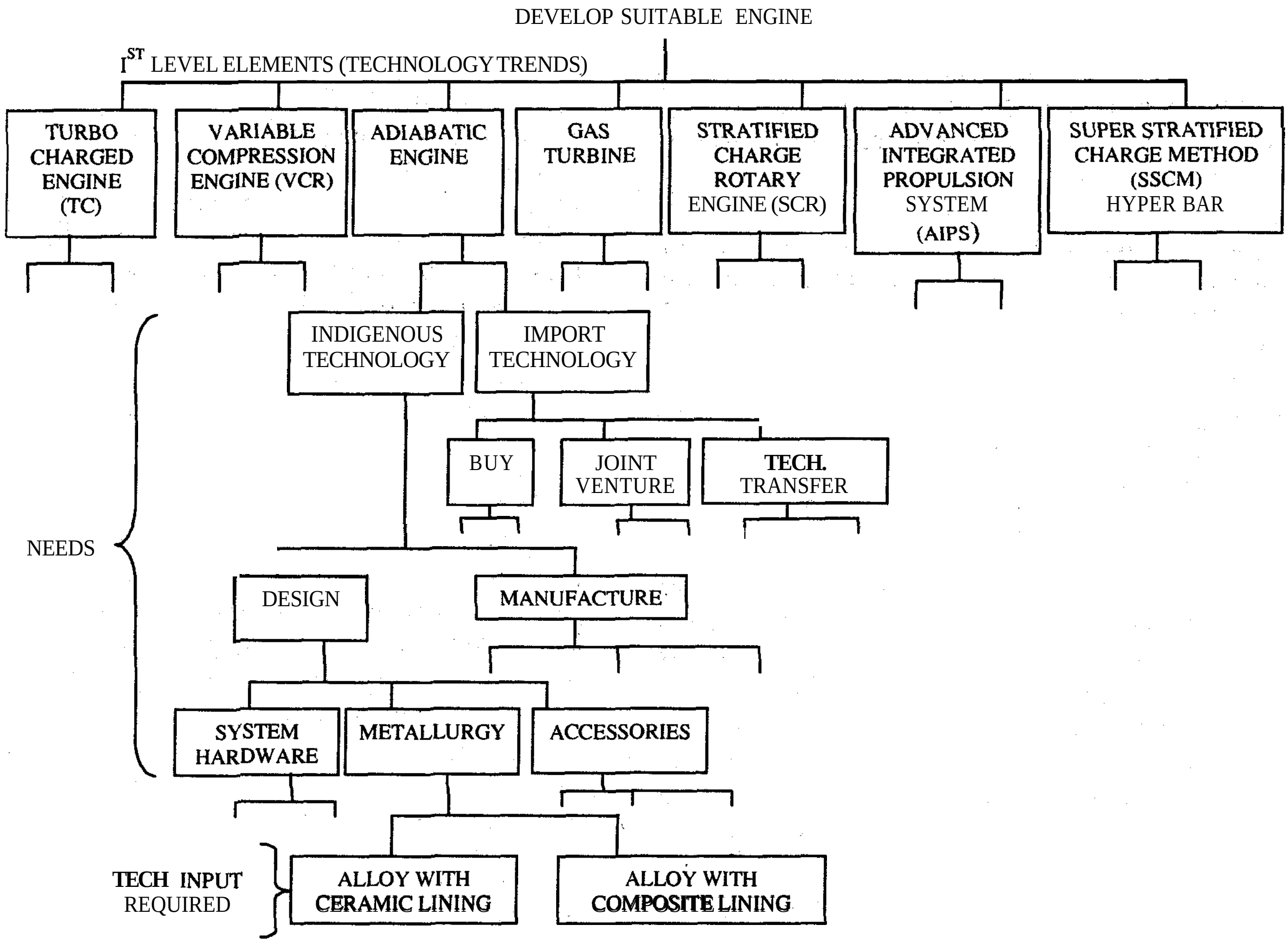

Figure 1. Relevance tree

protection. And if an electric gun becomes available for the future combat vehicle, it will need additional charge power.

These emerging parameters represent the basis for future propulsion systems. The engines available today and their development potential can be described only in terms of general estimates, as a result of limitations on information concerning foreign projects and developments. The engines considered are likely contenders for futuristic combat vehicles. Each of these engines varies in its technological content as described by Schenk[24]. These are briefly described as follows:

Turbo Charged Engine: Exhaust gas-driven turbo-super chargers, were introduced since 1950 in tank diesels for increasing the brake mean effective pressure (bmep), and hence, the hp. At that time, bmep of 8.5 bar to 9.5 bar was achieved. Recently developed diesel engines with turbo chargers, such as the Rolls-Royce/Perkins CV 12TCA, Fiat V 12 MTCA and MTU MT-883, have achieved bmep of 19.3 bar to 19.9 bar and an output of 43.1 hp dm^3 to 58.9 hp dm^3 of swept volume. Thereafter, charge coolers were introduced and swept volume was further improved, resulting in a 1500 metric hp engine for the original version of Leopard 2 (German MBT). Further improvements are being attempted in this type of engine to meet future needs.

Variable *Compression* Ratio Engine: The variable compression ratio pistons were originally developed in the 1950s by the British Internal Combustion Engine Research Association and consisted, in essence, of an inner part pin-jointed to the connecting rod and an outer shell which could move relative to the inner part to alter the overall height of the piston assembly, and consequently, the compression ratio. The relative positions of the two parts of the piston were controlled through a relief valve by the pressure of the oil trapped between these. This resulted in the engine having a high compression ratio as required for starting at light loads and a lower compression ratio at full loads, so that its power gets increased without a corresponding increase in the peak cylinder pressure. In 1960, the Continental Motors in the USA applied variable compression ratio piston to AVDS-1100 version to raise its hp from 550 to 1100 and renamed the engine as AVCR-1100. It was then transformed into AVCR-1360-2 of 1500 hp, which powered the General Motors XM-1 prototype.

Adiabatic Engine: The adiabatic engine essentially utilises nonferrous material like ceramic and stabilised zirconia as moving components and cylinder liners that can withstand very high operating temperatures so that there is a sharp increase in thermal efficiency, thus increasing the hp per cylinder for the same size compared to a conventional engine. Tremendous space saving is envisaged since cooling system, which forms the main bulk, can be dispensed with and further space reduction would be due to minimum lubrication requirements. Adiabatic engines are in the advanced stage of development for combat vehicle applications. US had tasked Cummins Engine Company to develop a thermally insulated or quasi-adiabatic engine in 1984.

Gas Turbine: Major contribution in this field was development of the Army Ground Turbine (AGT)–1500 MBT gas turbine, which was derived from an aircraft engine, and was selected as propulsion system for the US main battle tank M1 that entered service in 1980. The gas turbine's system-inherent advantages are its high power density, its relative fuel in-sensitivity, and its low noise. Such advantages are, however, counterbalanced by its weighty disadvantages, such as high fuel consumption, high development/procurement cost, limited capability for derivative versions, and increased logistics. These problems are being addressed to make it competitive with piston engines.

Stratified Charge Rotary Engine: The genesis of this engine is traced back to rotary engine developed by F Wankel in Germany, in 1958, which adopted epitrochoidal chamber in a stationary housing. The development of the stratified charge version was prompted by the military requirements for engines operating not only on high octane gasoline but also on less volatile fuels, and followed the example of stratified piston engines with fuel injection and spark ignition set by Texaco TCCS, Ford Proco, and Honda CVCC engines. Rolls-Royce built a two-stage rotary diesel in 1970, which embodied high and low pressure rotors working in series. By 1984, model 2116R was built for US Marine Corps developing 750 hp.

Advanced Integrated Propulsion SystemProgramme: The advanced integrated propulsion system programme was set up in the US to develop a new generation of engines. Cummins piston engine developed within AIPS was a V-60 12–cylinder using high temperature-resistant synthetic oils. The operational temperatures were to be considerably increased for greater thermal efficiency. It would also favourably affect the dimensions of heat exchangers.

Super Stratified Combustion Method or Hyperbar: The system is based on the use of a high-pressure turbo charger driven not only by the exhaust gases but also by the additional energy by a gas turbine-type combustion chamber operating in parallel with the engine. Apart from remarkably high bmep and specific output, this system also provides the engine with good torque-speed characteristics and a rapid response. It also provides good cold starting at low ambient temperatures because the turbo charger can easily be started by itself, like a gas turbine, and can then provide hot air for starting the engine. This approach requires considerable sophistication in design and control technology. This type of engine was first adopted in France in the mid 1970s. To forecast futuristic requirements, the normative approach, ie, PATTERN was adopted for the selection of appropriate engines from current and pacing technologies described and also for identifying technological input needed to satisfy this objective and other elements at higher levels of the relevance tree.

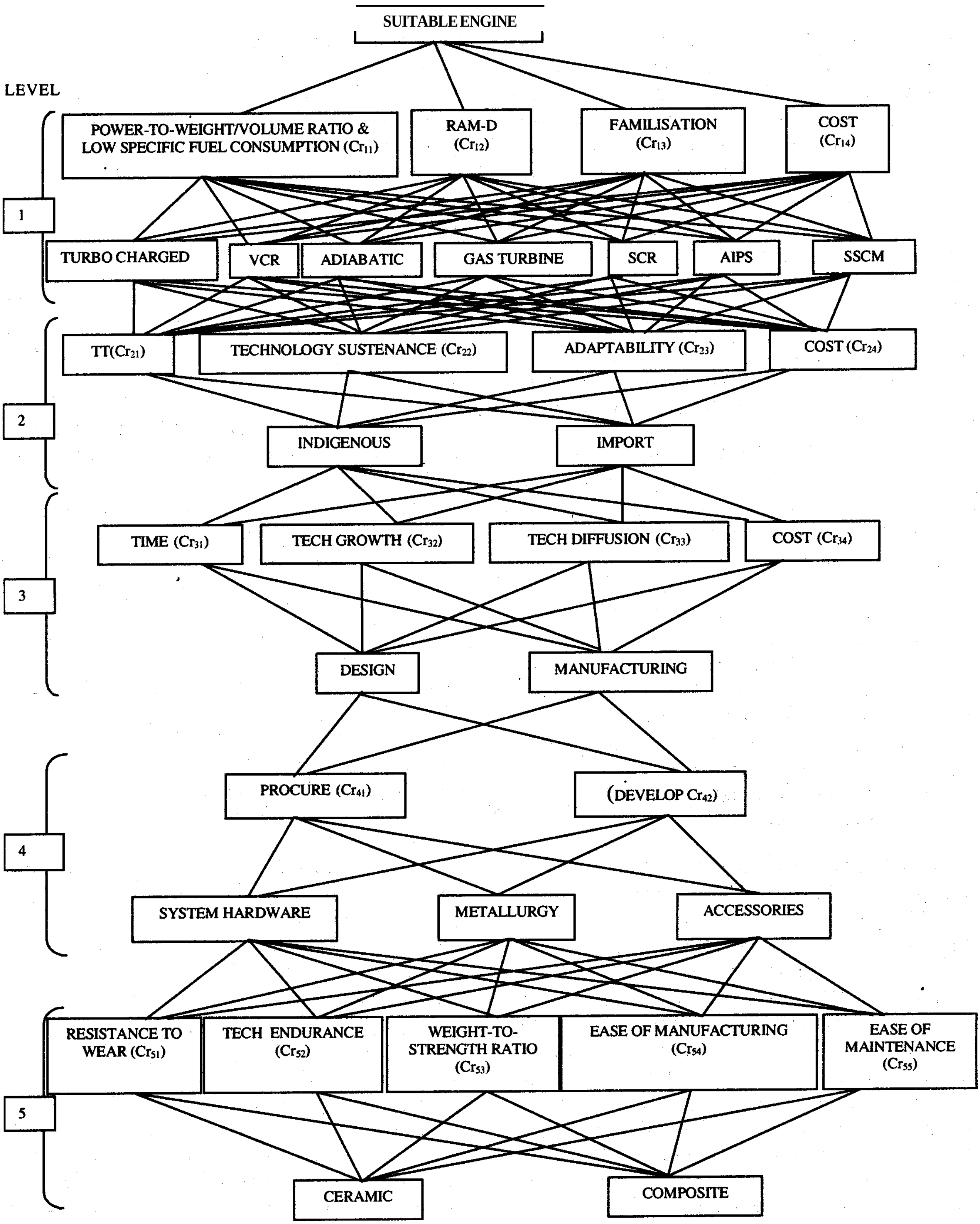

Figure 2. Hierarchy for selection/development of a suitable engine

The application of relevance tree shows that adiabatic engines have a bright future in this area since these have the highest cumulative direct relevance number. Cumulating the relevance number of each level, it is seen that at the lowest level, ceramic linings for moving components has greatest cumulative direct relevance number, implying that there will be high demand for technological breakthrough in suitable ceramics that can be used as lining in the moving components of the engine. This gives directions for future research in this area.

3.2 Result of Relevance Tree Validated by Analytic Hierarchy Process

In the next step, an attempt was made to validate the technological forecast obtained using the relevance tree analytic hierarchy process has been used for this validation process. Analytical hierarchy process has been used by **Madu**[25], et al. for validation of the results of a delphi study. In the present case, applying analytic hierarchy process, hierarchy was constructed with same criteria and elements of relevance tree. This hierarchy is shown in Fig. 2. Thereafter, questionnaires were sent to 20 experts in this field for assessing relative importance of each criterion with others and relative importance of each element with others against each criterion at the lower level. There are four criteria and seven **elements/attributes**. Tables 5(a) to (e) give relative importance of criteria at various levels. The relative importance on 1-9 scale was obtained from 20 respondents and was averaged.

It can be seen from the results that adiabatic engine gets the highest priority with 0.419 (0.466 against power-to-weight ratio, 0.376 against RAM-D features, 0.377 against familisation, and 0.317 against cost). This leads to a conclusion that the adiabatic engine is an appropriate technological forecast since it is the outcome of both the techniques, viz., relevance tree and analytical hierarchy process.

Table 5(a). Comparison matrix for attributes

Criteria	Power-to-weight/volume ratio & low specific fuel consumption	RAM-D features	Familisation (adoptability to all variants of AFVs)	Cost	Weight
Power-to-weight/volume ratio & low specific fuel consumption	1.00	4.00	4.90	3.45	0.538
RAM-D features	0.25	1.00	6.40	3.15	0.281
Familisation	0.20	0.16	1.00	2.35	0.098
Cost	0.29	0.29	0.43	1.00	0.083

Forecast of engine (Level 1), max eigenvalue = 4.5425, consistency ratio = 0.2009

Table 5(b). Comparison matrix for various alternatives on power-to-weight/volume ratio and low specific fuel consumption

Power to wt/vol ratio and low specific fuel consumption	Turbo charged	VCR	Adiabatic	Gas turbine	SCR	AIPS	SSCM	Weight
Turbo charged	1.00	0.50	0.14	1.50	0.50	0.50	0.50	0.057
VCR	2.00	1.00	0.17	3.55	1.25	1.20	1.80	0.125
Adiabatic	7.00	6.00	1.00	6.60	4.60	4.86	5.00	0.466
Gas turbine	0.67	0.23	0.15	1.00	0.50	0.33	0.50	0.045
SCR	2.00	0.80	0.22	2.00	1.00	1.00	1.00	0.101
AIPS	2.00	0.83	0.21	3.00	1.00	1.00	3.00	0.125
SSCM	2.00	0.56	0.20	2.00	1.00	0.33	1.00	0.081

Power-to-weight ratio (level 2), maximum eigenvalue = 7.2044, consistecy ratio = 0.0258

Table 5(c). Comparison matrix for various alternatives on RAM-D features

RAM-D features	Turbo charged	VCR	Adiabatic	Gas turbine	SCR	AIPS	SSCM	Weight
Turbo charged	1.00	1.38	0.50	3.22	1.50	1.00	1.50	0.146
VCR	0.73	1.00	0.25	3.00	1.40	1.00	1.00	0.112
Adiabatic	2.00	4.00	1.00	6.66	4.40	3.40	4.66	0.376
Gas turbine	0.31	0.33	0.15	1.00	0.50	0.25	0.33	0.041
SCR	0.67	0.71	0.23	2.00	1.00	0.50	1.00	0.084
AIPS	1.00	1.00	0.29	4.00	2.00	1.00	3.14	0.154
SSCM	0.67	1.00	0.21	3.00	1.00	0.32	1.00	0.087

RAM-D features (level 2), maximum, eigenvalue = 7.1448, consistency ratio = 0.0183

Table 5(d). Comparison matrix for various alternatives on familisation (adoptability to all variants of AFVs)

Familisation (adoptability to all variants of AFVs)	Turbo charged	VCR	Adiabatic	Gas turbine	SCR	AIPS	SSCM	Weight
Turbo charged	1.00	0.33	0.20	4.00	0.33	0.33	0.33	0.057
VCR	3.00	1.00	0.50	5.75	1.00	1.00	1.00	0.151
Adiabatic	5.00	2.00	1.00	7.25	4.00	4.00	4.50	0.377
Gas turbine	0.25	0.17	0.14	1.00	0.25	0.25	0.33	0.031
SCR	3.00	1.00	0.25	4.00	1.00	1.00	1.00	0.130
AIPS	3.00	1.00	0.25	4.00	1.00	1.00	2.20	0.145
SSCM	3.00	1.00	0.22	3.00	1.00	0.45	1.00	0.109

Familisation (level 2) maximum eigenvalue = 7.3191, consistency ratio = 0.0403

Table 5(e). Comparison matrix for various alternatives on cost

Cost	Turbo charged	VCR	Adiabatic	Gas turbine	SCR	AIPS	SSCM	Weight
Turbo charged	1.00	4.00	1.00	7.00	4.00	4.00	4.50	0.314
VCR	0.25	1.00	0.25	3.75	1.00	1.63	2.00	0.102
Adiabatic	1.00	4.00	1.00	8.00	4.00	4.00	4.22	0.317
Gas turbine	0.14	0.27	0.13	1.00	0.33	0.33	0.33	0.031
SCR	0.25	1.00	0.25	3.00	1.00	1.00	1.57	0.089
AIPS	0.25	0.62	0.25	3.00	1.00	1.00	2.00	0.086
SSCM	0.22	0.50	0.24	3.00	0.64	0.50	1.00	0.062

Cost (level 2), maximum eigenvalue = 7.1313, consistency ratio = 0.0166

Most important is that entirely different groups of experts were asked to fill the questionnaire for both the techniques. Further levels of analytical hierarchy process were not attempted since conclusive result was obtained as far as selection of engine is concerned.

3.3 Transmission

The relevance tree and PATTERN analysis for transmission is similar to all the engines. The following method was adopted. Expert opinion for selection of criteria, elements and their weightages were compiled for computing partial relevance number (PRN) and local relevance numbers. Table 6 shows criteria and elemental weights along with PRN and local relevance numbers thus calculated. Electrical transmission having highest relevance number seems to be the obvious choice for future research.

3.4 Suspension

A Delphi survey indicated the preference for active hydropneumatic suspension. The experts were of the opinion that high mobility, especially in cross-country terrain, and a stable weapon platform was

Table 6. Partial relevance number and local relevance number for transmission

		Elements of transmission					
		Semiautomatic		Automatic		Electrical	
Criterion	Criterion Wt	Wt	PRN	Wt	PRN	Wt	PRN
Reduction in volume	0.25	0.2	0.05	0.3	0.075	0.5	0.125
RAM-D features	0.30	0.4	0.12	0.3	0.09	0.3	0.09
Reduced cost	0.15	0.5	0.075	0.3	0.045	0.2	0.03
Minimum transmission loss and fast acceleration	0.2	0.2	0.04	0.1	0.02	0.7	0.14
Control capability	0.1	0.2	0.02	0.4	0.04	0.4	0.04
Local relevance number			0.305		0.270		0.425

possible with this type of suspension. This type of suspension would also save space, reduce weight, reduce height of tank, and provide driving comfort, all of which are very important considerations for a combat vehicle. Development of active hydropneumatic suspension is thus recommended.

3.5 Track

Same delphi survey preferred nonferrous composite alloys to replace existing steel forging's while satisfying the basic characteristics of resistance to wear, self-wrapping tendency, low power loss, and low noise. This would entail reduction in weight, and hence improved power-to-weight ratio.

3.6 Armour Protection

The delphi approach was again applied to arrive at armour protection requirements of combat vehicles. The omnidirectional threat, tactical deployment, and antitank warheads were the major factors against which protection has to be provided. In consideration to these factors and development trend in armour protection, the opinion poll narrowed down to the following conclusions for family of combat vehicles:

3.6.1 Heavy & Medium Tanks

Monolithic rolled steel base armour, composite layers (*Chobham/Kanchan*) on 60 per cent frontal arc, spaced or lead armour against chemical energy top attack, reactive armour on broad side/turret, active electromagnetic blanket, padding to absorb electromagnetic radiation and shaped hull and turret without sharp corners. The add-on armour should be so fitted that it can be changed easily as and when more effective forms of special armour are developed.

3.6.2 Light Armoured Vehicles & Infantry *Combat* Vehicles

Ballistic-grade aluminum or titanium alloy base armour, composite layers (*Chobham/Kanchan*), reactive/active armour, shaped hull/turret, lead armour are used against top chemical attack and padding to absorb electromagnetic radiation. The add-on armour is to be fitted, so that it can be easily replaced.

3.6.3 Firepower

The armament development is in perpetual competition with armour for supremacy. Discounting the nuclear, biological, and chemical (NBC) weapons and guided missiles, there have been tremendous strides in the fields of command, control, communication, and intelligence (C^{3}1) areas. The microelectronic and materials technology have added new'horizons to the development of armament and firepower. To forecast futuristic armament, the experts felt that Delphi technique was suitable for weapon and warheads whereas morphological approach was more appropriate for propulsion. Accordingly, the forecasts so arrived are:

Weapon: The experts were of the opinion that caliber of the gun should be increased from the existing 1201125 mm to 135 mm for enhanced

Table 7. Morphological box for propulsion

Combinations	Parametric possibilities	No. of alternatives
P1^{1,2}	Intrinsic or extrinsic chemically active mass	(2)
P2^{1,2}	Internal or external thrust generation	(2)
P3^{1,2,3}	Intrinsic, extrinsic, or zero-thrust augmentation	(3)
P4^{1,2}	Internal or external thrust augmentation	(2)
P5^{1,2,3,4}	Possible thermal cycles (adiabatic, isothermal, isobaric, isochoric)	(4)
P6^{1,2,3,4}	Medium (vacuum, air, water, earth)	(4)
P7^{1,2}	Motion (translatory, rotatory)	(2)
P8^{1,2,3}	State of propellant (gas, liquid, solid)	(3)
P9^{1,2}	Self-igniting or non-self-igniting propellants	(2)
P10^{1,2,3}	Cartridge case or bulk loaded or regenerative propellant	(3)

range and muzzle velocity. This would also enable firing of missiles through same barrel in addition to conventional warheads. The opinion poll also indicates use of improved material, such as vacuum arc re-melted and electroslag-refined steels for better life.

Warhead: The delphi panel was of the opinion that the current state of development in this area is indicative of the fact that the presently used armour piercing fin stabilised detachable sabot (APFSDS) would remain as the major armour killer for the next 10 to 15 years. Therefore, the APFSDS needs to be improved with depleted uranium as the core material, which has very high specific gravity and pyroforic effect on steel, and hence, would be the choice warhead.

Propulsion: The warhead propulsion can be addressed by morphological approach adequately. This is one area where tremendous developments are taking place using solid high explosive, liquid propellant or electromagnetic accelerators. In morphological sense, there can be large number of parametric possibilities. The morphological box indicates the possible combinations (Table 7).

Taking the alternatives in the parenthesis, the total number of combinations can be 2×2×3×2×4×4×2×3×2×3 = 13824. However, some combinations are self-contradictory, such as distinction between internal and external is meaningless for the case of zero-thrust augmentation and extrinsic chemically active mass cannot apply if the medium is vacuum. Similarly, the mediums– vacuum, water, and earth are not relevant in this case. Even after short listing, the numbers of alternatives for propulsion are very large, of which, only a small number has been given serious attention. Also, the probability of a breakthrough in a technology area per unit time is a decreasing function of its morphological distance from existing art, other things being equal. The functional relationship is assumed to be an inverse quadratic. In any case, new developments will obviously tend to occur near older ones (in morphological sense) essentially accretions from the border of state-of-the-art clusters into adjacent undeveloped regions. In consideration to possible unique combinations and probability of success, the experts were of the opinion that intrinsic chemically active internal thrust generation-intrinsic thrust augmentation adiabatic cycle-air medium-translatory motion-liquid propellant-non-self igniting-regenerative propellant, would be the best alternative.This type of propulsion would have the following advantages:

- Bulky cartridge cases and charge bags avoided
- Additional space created for more number of projectiles

For disposal of stubs or non-combustible cases

Saving in overall firing costs

Low vulnerability of liquid propellant gives more safety

Storage problem due to secondary explosion reduced

Reductions in flash and blast during firing

Rate of fire would increase

Muzzle velocity can be made uniform over series of firings

More constant pressure gradient can be achieved, leading to much higher muzzle energies.

3.7 Gun Control Equipment/Fire Control Equipment

The delphi team narrowed their recommendations for improvements in laser-based instruments for accurate target acquisition/ranging, fully automated gun traverse/elevation, integrated ballistic computer and autoloader. These improvements are bound to enhance first-round hit probability in shortest possible time and also effectiveness of fire on the move against moving targets.

3.8 Vetronics

The forecast of technology for armoured vehicles earlier were mainly based on firepower, protection, and mobility. The chip revolution and disproportionate

Table 8. Salient results of forecast for combat vehicles

System	Technology details	Technique applied
Engine	Adiabatic	Normative results validated by AHP
Transmission	Electric	Normative
Suspension	Active hydropneumatic system	Delphi
Tracks	Nonferrous composite alloy	Delphi
Armour protection	Monolithic rolled steel armour, composite layers, spaced or lead armour against chemical energy top attack, reactive armour and active electromagnetic blanket	Delphi
Armament	135 mm calibre using superior material, such as vacuum arc re-melted and electro slag refined steels	Delphi
Warhead	Armour piercing fin stabilised detachable sabot (APFSDS) using depleted uranium as core material for long rod penetrator	Delphi
Propulsion	Adiabatic regenerative liquid propellant	Morphological approach
Gun/Fire control equipment	Laser range finder, fully automatic gun traverse/elevation, integrated ballistic computer and autoloader	Delphi
Vetronics	Nuclear, biological and chemical protection, fire fighting protection, early warning device, diagnostic and prognostics, ventilation, electronic countermeasures and electronic counter counter measures, interrogation friend or foe, navigational aids, position interrogation and transmission, surveillance, anti-laser electronic protection against guide missiles, digital database control and distribution, reduction in electronic emission, electronic blanket or camouflage net, electronic power generation management, computer resources (hardware and software), crew control and display process, directed laser beam to blind both the optical instruments and the person behind the lens	Delphi/NGT

developments in the field of semiconductors/electronics have revolutionised the fighting capabilities of the battle tanks. The new concept of forecasting for combat vehicles is to give equal weight to electronics along with firepower, protection, and mobility. Similar to avionics in the aircraft, the electronics in the armoured vehicles can be termed as vetronics. The future combat/armoured vehicles should be capable of winning electronic warfare. With these considerations, the experts of delphi survey opined that the futuristic combat vehicles should have the following features highlighted under vetronics in Table 8.

3.9 RAM-D Features

The availability/dependability is a function of reliability and maintainability. Higher the reliability, higher would be the cost. Therefore, a trade-off in terms of minimum mission reliability is a major consideration for combat vehicles. The panel of experts had expressed that engine life, mission reliability, mean time between failures for every system, barrel life and useful life of the combat vehicle should be enhanced using superior technology.

4. FRAMEWORK FOR TECHNOLOGICAL FORECASTING & TECHNOLOGICAL TRANSFER FOR COMBAT VEHICLES

This case study has given some insight into how technological forecasting techniques can be applied to arrive at technology levels for combat vehicles. If such technological forecasting exercise is incorporated in to the planning system, the organisation is bound to benefit as far as formulation of technology strategies are concerned. Also, the R&D would have clear-cut technology options to channelise their efforts. To assist the organisation for setting priorities for weapon systems, a framework for technological forecasting and technological transfer has been thought of as a common template. The steps of this framework are as under:

Step 1. Objective Formulation

The users with their experience on the weapon system and information from the environment or learning from similar systems held with contemporary armed forces will be able to spell out the broad futuristic requirements, such as type, quantity, and certain enhanced capabilities expected. This requirement of futuristic weapon profile could be evaluated with reference to future battlefield scenario at the level of Army/Air Force/Naval HQs, and established as the objective.

Step 2. Identification of Active Experts

The next step is to identify suitable multidisciplinary experts for the weapon system in question who are willing to take part in the NGT/Delphi process to identify the technology goals. The experts could be from the Group for Forecasting and Analysis of Systems and Technology (G-FAST) consisting of scientists of diverse disciplines, academic institutions, users, Confederation of Indian Industries (CII), Technology Information Forecasting and Assessment Council (TIFAC), and industries. These experts could be termed as the NGT/Delphi team. A coordinating agency at the highest level is required to set up this team.

Step 3. Goal Identification

The team of experts so selected can be tasked to forecast the futuristic technology goals related to the weapon systems under consideration. The experts can specify range of technology alternatives to satisfy the objective. Simultaneously, the time frame could be specified for outcome of the technologies. During this phase, due consideration should be given to the fact that technologies are time-specific, space-specific and object-specific.

Step 4. Decision Alternatives

For each technology forecasted, the decision variables/attributes need to be identified and weighed by the experts in relation to each other. For example, say five configurations of futuristic combat vehicles have been thought of as forecasts during goal selection. Each configuration will have many systems and subsystems for which technology input levels have to be identified. Therefore, decision tree or hierarchy has to be constructed till such a level is attained so that the technology input required to satisfy the goal are identified.

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Step 5. Criteria

The criteria against which the decision variables/attributes are to be evaluated are to be identified for each level of hierarchy/ relevance tree. These criteria are to be weighed by the experts at each level in relation to each other and in relation to the goal. The literature on the subject can also form important input at this stage. All such important factors like time, cost, adversary capability, make/ buy considerations etc can form part of the criteria.

Step 6. Analysis of Alternatives

The panel of experts may be now tasked to see the scientific and technological feasibility and apply techniques like relevance tree and AHP so as to analyse the range of alternatives. This step can be termed as weapon technology selection process.

Step 7. Selection of Alternatives

The analysis in the previous step would lead to the final selection of the technology options/ alternatives. The technological forecasting part would end here and the development and technology transfer phase will commence. At this step, important decisions like develop here, develop elsewhere, or buy can be taken based on cost, availability, and core competencies within the Country. Thereafter, the proposal is communicated to the Ministry of Defence through the apex body (AHQ/Air HQ/Naval HQ/ Integrated Defense Staff/R&D HQ) for resource and budgetary allocations and to sanction the development project/purchase as the case may be. The Integrated Defence Staff (IDS) could act as the command and control organisation for the implementation phase of the development project.

Step 8. Implementation

The successful implementation would warrant requisite support system and enablers. These are the infrastructure, organisation readiness, core competencies, leadership, motivation, communication, industrial interface, etc. The cycle time, from conception to availability in the hands of troops, is very important consideration in the present-day context. The rate of change in technology is very fast, and hence, long development cycle time would tend to make the technology obsolescent/obsolete even before its realisation. The reduction in development cycle time is possible if the implementation is attempted as hybrid phases with a cross-functional project team having forecasters, scientists, engineers, industrial representatives, quality control experts, and the users associated throughout the gestation period of technology development. This team should be actively associated for subsequent improvements/ upgradations. The development cycle would warrant basic/applied research, followed by production of laboratory prototype, proving trials, user trials, engineering prototype, manufacturing prototype, pilot production, and bulk production. Traditionally, the technology transfer would have started sequentially after the completion of user trials. However, in the concurrent/ hybrid approach, the technology transfer commences right in the beginning to reduce the development cycle time.

Step 9. Exploitation

This is the domain of the users. The prolonged exploitation will bring out the strengths and weaknesses of the weapon system.

Step 10. Technology Performance Measurement & Quality Audit

The users can carry out the performance evaluation of the new technology as to how it compares with the older one and its status against similar equipment with the adversaries. The RAM-D parameters and quality can be assessed and improvements, if any, can be suggested to the control organisation and the cross-functional project team. Similarly, incremental upgrade and improvements can be recommended.

Step 11. Impact Evaluation of New Technology on Organisation & Stimulate New Objective

The users would be in a position to evaluate enhancement in their force structure and their force potential with the improved weapon system. The impact on other intangibles like training, morale, and confidence level can also be assessed. Such assessment will lead to further ideas that would

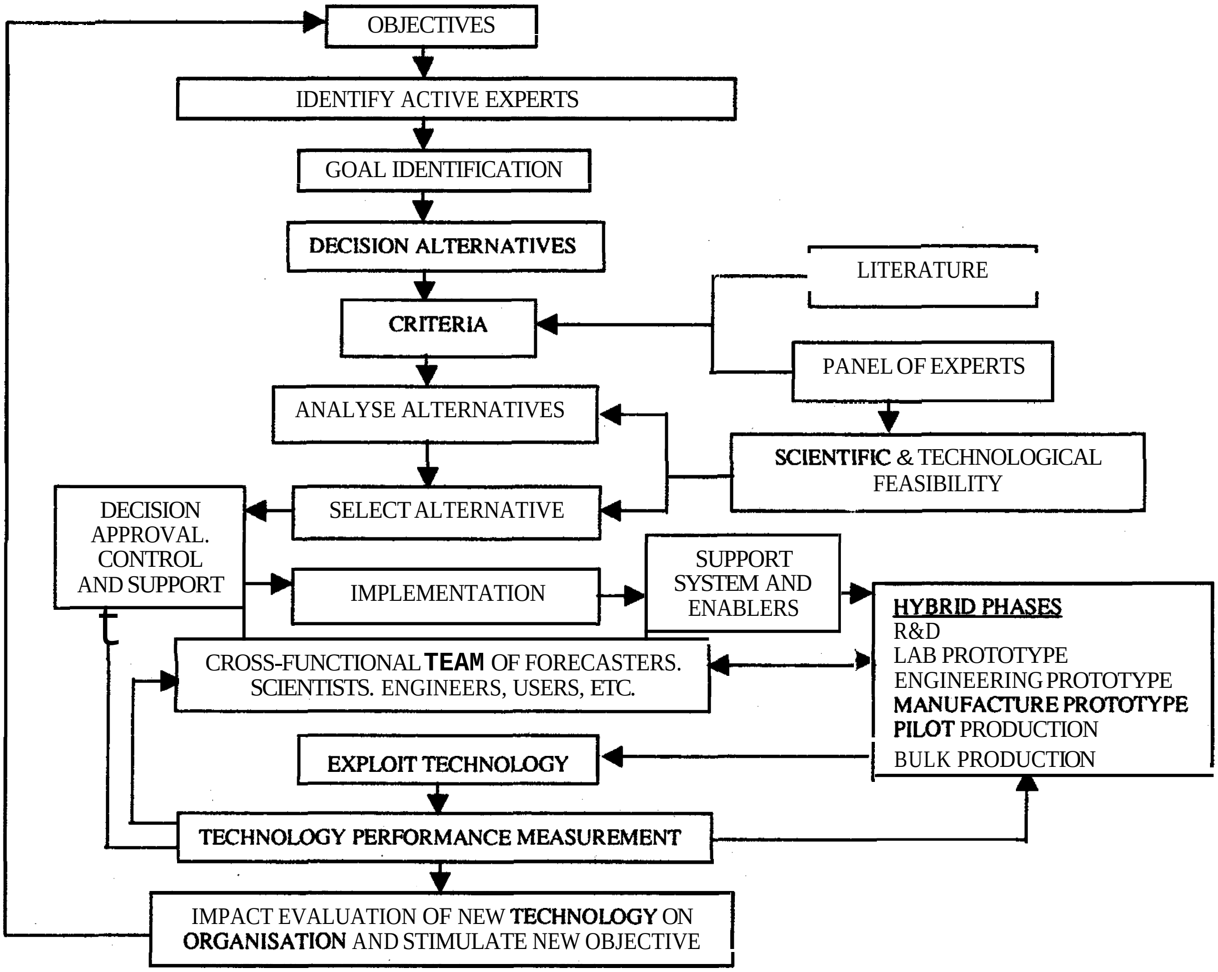

Figure 3. Framework for technological forecasting and technology transfer

stimulate new objective. With the identification of new objective, the cycle repeats itself. The framework for technological forecast and technological transfers has been schematically depicted in Fig. 3.

6. CONCLUSION

In this paper, the forecast of combat vehicles has been demonstrated through application of technological forcasting techniques. The structured analysis of trends in development as obtained from open literature and expert opinions from environment as input 'have enabled outlining the development requirements for various systems and subsystems of the combat vehicle as forecasts for the next ten years. The methodologies applied have wide applications to all types of complex weapon systems. If such projections are arrived at using technological forecasting, it can make perspective planning more meaningful and would also form a platform for coordination between the three services, ie, Army, Air Force, Navy with the Defence Research and Development Organisation (DRDO) at the time of objective formulation. It must be noted that most advanced technologies, especially for defence applications, are clusters of multidisciplinary technologies needing multidimensional competencies, and hence, multi-integration of forecasters is essential. Such techniques of technological forecast can also be extended to other areas of long-range corporate plans, production processes, materials, marketing, R&D, design, etc. Its uses will enable to leap across generation, engineer the future, extend the planning horizon, avoid surprises, initiate nonobsolete training, and be a leader. It should however be remembered that the technological forecasting is beset by hazards like the uncertainty and unreliability of data, the complexity of a real-world feedback interaction, the temptations of wishful or emotional thinking, the fatal attraction to ideology, failure to anticipate converging developments, concentration on specific configuration, incorrect calculation, and the dangers of forcing soft and somewhat pliable facts into a preconceived pattern. The technological forecasters must be aware of these pitfalls.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the referees and acknowledge their valuable comments. This has helped a great deal in improving the content and format of the paper.

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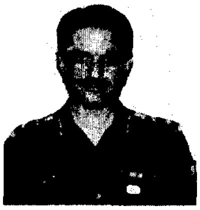

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