Managing Energy Technologies by Exploring Criteria for Technology Portfolio Selection – A Case in Petroleum Industry

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Abstract: Technology is a key element in the process of service and product development in energy sector. Therefore it is considered as an infrastructure for achieving organizational objectives and for supporting strategies. Selecting a technology portfolio which is a set of interdependent technologies to invest on can support a prompt and cost efficient achievement to objectives of energy plans. Such a selection in turn requires a set of reliable criteria to enable a portfolio management process which can guarantee a maximum return on investment having the minimum risk. In this paper after reviewing previous researches on criteria for technology portfolio selection and introducing a comprehensive list of such criteria, a new model based on a factor structure is introduced. The model is based on a set of criteria extracted from views of experts in some energy sector (i.e. Iranian petroleum industry) and classified into two groups namely values and risks. The validity of the proposed model is tested by Confirmatory Factor Analysis (CFA). Results of the analysis of the data gathered by questionnaires show that the proposed criteria can serve as a reliable tool to assist technological investment decision makers particularly in petroleum industry.
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1. Introduction

Investors expect certain returns on their investment and therefore the rate of return on investment (ROI) is a key element for decision making in any investment process. The higher the rate, the more attractive the investment becomes for the investor. However there exists another significant factor in this process which origins from uncertainties in investment processes and is referred to as "risk" in investment and finance literature.

In fact an attractive and reliable investment is one in which the overall effect resulted from both the expected return on investment and its risks satisfy the stakeholders and investors. According to the area of investment, an expected return on investment depends on different factors. Therefore risks originating from these factors are also very diverse. It is because of this interdependencies and complexities in forecasts that most professional investors do not invest all their money on one type of asset and select a portfolio of assets for their investment in order to guarantee a certain minimum return for their investment. The example of stocks market is very descriptive in this regard. The decision making process in stocks markets receives the mean value of a set of historical data on different stocks prices to represent the expected return on investment and compares it to what is expected. Also the standard deviations of the historical values of the stocks prices in a given interval of time is considered as a measure of risk involved in the investment process. Finally by modeling a problem based on the investors' expected return, their risk tolerance and investment limitations, one will select an investment portfolio by putting together a set of stocks belonging to a variety of enterprises so that the portfolio will provide a certain amount of maximum expected benefit to the investor.

Investments on research and development activities not only follow the same logic but also due to many different reasons measuring the expected returns on investments and the risks involved in R&D activities require dealing with more complexities. One of the most significant of these reasons is that R&D activities are time consuming and it usually takes a rather long time since an R&D activity starts until it reaches the expected achievements. Hence having a precise forecast and estimate of the amount of return at the time of making an investment decision on a research plan or a technology acquisition process is not easy at all and this in turn increases the related uncertainties and risks.

Another important factor is the presence of different technical, commercial or financial uncertainties during investments on research and development activities. Due to a variety of reasons it is likely that a technology development or acquisition problem is faced with unexpected technical difficulties and because of weaknesses in technical knowledge, methodological incapability or many different practical and operational limitations, the technology acquisition process will not

end to the expected result. These types of uncertainties are known as technical risks. It is also possible that a technical knowledge is acquired and a technology prototype is developed but due to limitations such as incapability in maintaining the necessary standards, lack of infrastructure for an economical mass production or lack of necessary financial resources to support the developed technology, taking advantage of the benefits of the technological achievement becomes impossible. These limitations are sources of commercial and financial risks. There could exist other sources of risk such as changes in related legal regulations and laws that can act as serious barriers to the completion of a technology acquisition process and stop the process of commercialization of a technology. These are known as institutional risks to a technology development process.

Therefore selecting a portfolio of technologies needed for promotion of an industry and investing on technology development projects needs criteria that could act as a robust measure of the level of contribution that the selected technologies provide to achieving the industry's major objectives and to supporting the organizational strategies. In fact from a technology roadmap point of view technology is an infrastructure for developing products and services and these products and services in turn serve the market objectives (Figure 1).

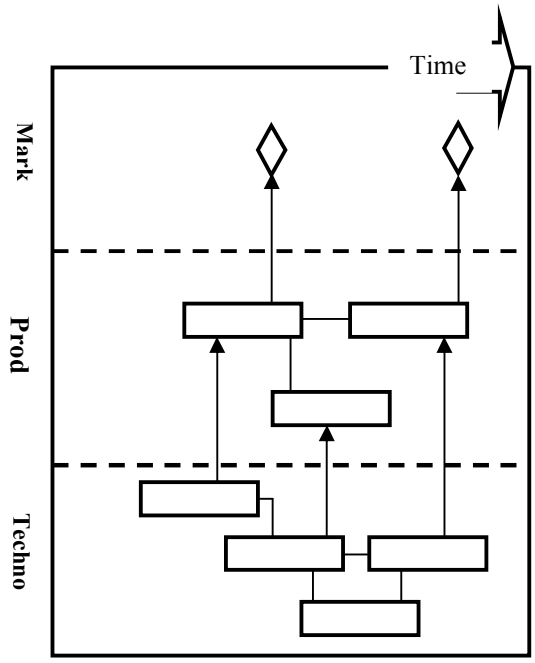

Figure 1. Technology Roadmap – Alignment of technology with products and services development, business strategy and market opportunities (Phaal et al. 2004).

Therefore the real nature of rate of return on investment in technology development plans can be considered as the amount of support the plans provide to the enterprise's objectives.

In the petroleum industry which is seriously sensitive to and dependant on technologies, a large portion of investments is dedicated to technology development. At the same time, according to rapid changes in global prices of oil products and dependence of these prices to a variety of security and economic variables, selecting an appropriate portfolio which can provide a maximum support to the industry's goals and objectives with minimum risk is very significant. These goals and objectives include targeting an acceptable share of a very competitive market.

This paper explains the results of a research which has been conducted to explore appropriate criteria for selecting and managing a technology portfolio in the Iranian petroleum industry. As a result of this research a set of criteria to facilitate decision making in the process of investment on technology development plans is introduced. Other sections of this paper are organized as follows: in section two seminal previous works are reviewed and some other approaches in technology portfolio selection are reported. Section three covers the methodology of the research and section four reports the research results. Finally the paper is concluded in section five.

2. Literature Review

The attention paid to technology portfolio selection to enhance investments on product and service development, should be considered as a late result of scientific management in the industrial development era. Meanwhile the term "technology portfolio" is a combinatory phrase whose words represent two different areas of knowledge: "portfolio management" and "technology management". The former was first introduced by Harry Markowitz's seminal work in 1952 in the area of financial management among investment and stock market activists. He introduced the mean of a set of historical data on an investment rate of return as an index to measure the ROI of a portfolio of assets. He also introduced the standard deviation or equivalently the variance of the same set of data as an index to measure the risk of the investment. Further he developed the concepts and introduced advanced techniques of portfolio management (Markowitz 1991).

The second area of knowledge (i.e. technology management) is very younger in theory. Among the earliest documented experiences in developing a technology roadmap we can name the work of Willyard and McClees (1987) for the American company, Motorola. They introduced technology Roadmapping as a powerful means for describing market, product and

process development planning, establishing technological capabilities and analyzing resources. They suggested that portfolio selection techniques could assist managers with evaluating corporate investments from long term growth, achieving strategic objectives and technology roadmap points of view. In other words they claimed that in order to achieve the expected objectives it is necessary to link portfolio selection and evaluation to technology roadmap objectives.

Many years later in 2010 the same issue was put forward by Oliveira and Rozenfeld. While pointing out to the bridge between technology roadmap and portfolio evaluation, they proposed the integration of the two methodologies as a means to improve and adjust both processes. This seems logical since a technology roadmap by its own does not lead to a portfolio of projects and on the other hand a portfolio needs a list of projects as input which needs to be future oriented and aligned with the corporate strategic objectives.

Although technology selection for an investment process is an indispensable part of technology management, the precise concepts of technology portfolio selection and management and developed tools for measuring the return and risks of technology development projects and portfolios of technologic investments are not too old. Khalil introduced several criteria for evaluating technology portfolios (2000). He counts the potential for creativity and innovation, alignment with corporate business plan, availability of continuous financial resources and technological risks as some criteria for evaluating technology portfolios.

Dickinson et al. (2001) introduced strategic leverage of an enterprise as the most significant criterion for evaluating a technology portfolio as a result of a research conducted for Boeing. Later Jolly categorized technology portfolio evaluation criteria in two groups of attractiveness and competitiveness each including 16 sub-criteria. Among the most applicable ones in competitiveness group are the relation between R&D and marketing, number of registered patents and also capabilities and competencies of research teams. Meanwhile, some major attractiveness criteria in his work include position of the technology in its own life cycle, barriers to copy or imitating the technology and span of application opened by the technology. In his paper Jolly has determined the relative significance of each sub-criterion by referring to experts' views in different areas of technology (Jolly 2003).

Chiesa (2001) also mentioned the relation between technologies and organizational strategies, also the relation between existing technologies and potentials for options creation as the most important criteria for evaluating R&D and technology portfolio. Coldrick et al. studied methods of decision making in R&D investment portfolios in 2005 and ended up with a list of criteria including compatibility with company's business plan, product growth potential, synergy with other products/ processes, effect on current and future markets, return on investment and protection provided to design and inventions to be most significant in selecting an R&D/technology portfolio.

Yu (2006) proposed major criteria in 8 categories including benefits, quality, prestige, strategic significance, business values, and current position of the technology in its life cycle, availability and affordability. Eilat et al. (2006) used a Balanced Score Card approach to divide the criteria into four groups of customers, financial, internal business and learning and growth. Wang and Hwang (2007) used a fuzzy approach and a real options technique to select an R&D technology portfolio and proposed lead time of R&D projects and market dynamics of the technology as their portfolio evaluation criteria. Huang et al. (2008) introduced a comprehensive list of criteria for selecting and evaluating technology portfolios. Their list includes level of innovation achieved, level of high-tech developed, sensitivity of the technology to changes, diversity of applications, possibility of extension to other areas, effects on research potentials, effects on market, alignment with strategies, improvement of quality, impacts on quality of life, effects on promoting knowledge fronts, technical content, potentials for researchers, time, cost, environment and safety concerns, equipments and potential to implement the results.

Floricel and Ibanescu (2008) also developed a theoretical framework to model the management of innovation project portfolios in different firms. Their theory focused on the dynamics of competitive environments as a key contingency factor for innovation. They used four dimensions to characterize the patterns of environmental dynamics: velocity, turbulence, growth and instability and proposed the concept of dynamic risk as a determinant of portfolio management processes.

Finally, Lin and Chen (2005) examined the relations between technology portfolio strategies and five commonly used R&D performance measures i.e. Tobin's q, patent quality (citations received per patent), R&D efficiency (logarithm of the number of patents received per million R&D expenses), R&D effectiveness (logarithm of the number of citations received per million R&D expenses), and intellectual assets intensity (logarithm of the number of patents received per total assets). While proposing that a technology portfolio could be characterized by its composition and technology concentration, they emphasized that a valuable technology portfolio that consists of patents with higher average citation made

and self-citation ratio could have a positive effect on the firm value.

3. Research Methodology

3.1. *Questionnaire*

To explore appropriate criteria for selecting a technology portfolio for an investment process in the energy sector, 79 criteria were gathered from previous researches. The criteria were then brought into a questionnaire including a brief definition of any proposed criterion and a Likert scoring table scaled from 1 to 10. The participants were asked to based on their knowledge about the petroleum industry and the technologies it needs, score the significance and the appropriateness of each criteria from 1 (least significant) to 10 (most significant). The 79 criteria gathered from the literature are listed in Table 1.

The reliability of the designed questionnaire was tested by distributing the questionnaire through a sample of experts and then by measuring the Cronbach's α (Alpha) which is a means of testing the biasness of judgments and computing the internal consistency of the questionnaire. This test whose result is a coefficient named Cronbach's α is used to test the reliability of our questionnaire designed on a Likert scale basis. To compute the Cronbach's α coefficient we used

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K}\sigma_{Y_i}^2}{\sigma_X^2}\right)$$

where K is the number of questions (which represent variables), σ_X^2 is the variance of the observed total scores, and $\sigma_{Y_i}^2$ is the variance of question i for the current sample of persons. The reliability analysis in our research questionnaire was done with SPSS which resulted in 0.953 as the Cronbach's α coefficient. This indicates a good reliability and an acceptable consistency of the questionnaire.

3.2. *Participants*

The statistical population in this research included all experts in different areas of research and technology development in the Iranian petroleum industry. Hence the questionnaire was distributed among a random sample of 300 experts of the above mentioned fields. Results were analyzed based on 207 completed questionnaires. Statistical theories approve the validity of results based on such a sample size and for implementing a factor analysis approach which will be discussed in section 3.3.

3.3. *Criteria Categorization*

In order to validate a set of technology portfolio selection criteria, a factor analysis has been implemented. First the 79 criteria explored from different references and resources were divided into several categories based on their common characteristics. The categorization was repeated several times based on the researchers' views regarding the common characteristics of the criteria. Therefore several factor models were created. The validity of each factor model was then tested by implementing a confirmatory factor analysis (CFA). Every categorization of criteria was introduced in context of a general model for portfolio analysis and based on the researchers' knowledge from the technology portfolio selection criteria and also from the Iranian petroleum industry requirements. In this general model, major criteria are divided into two groups of values and risks. Finally the factor model having a better X^2 than the others was selected (Table 2). In our validated approach the value of a portfolio is based on factors such as technical superiorities of the technology, preparedness of the organization to host and promote the technology, support that the technology provides to strategic objectives and goals, support that the technology Provides to stakeholders and investors expectations, technological, financial and human capital resources available to support the technology, market driven factors and finally inter related factors that support competitive capabilities of the organization.

Meanwhile a variety of technical, commercial, economical and institutional uncertainties and risks originating from them have significant roles in selecting appropriate technologies for investment.

3.4. *Data Analysis and Research Results*

To perform a confirmatory factor analysis on the proposed model with the gathered set of data, we have used LISREL 8.8. The procedure to perform this test is as follows:

1. Description of the factor model: the first step in confirmatory factor analysis is to describe the model by categorizing the criteria into groups whose precision and appropriateness is to be tested. This was done in LISREL by the Path Diagram tool.

2. Data gathering: in this step data gathered from experts on each of the criteria (now sub-criteria) is inserted into the software as input.

3. Computation of correlation or covariance matrix: this aims at computing the correlation between all research variables by the software.

4. Selection of appropriate fitting function: This is to research how close are the two covariance matrices, one belonging to the data and the other to our desired factor model. To perform this there are several fitting functions and we have taken advantage from a common method i.e. Maximum Likelihood Estimation (MLE) to test our proposed model.

5. Evaluation of the goodness of fit: for this part of the methodology there exist a variety of tests and indices to evaluate the fitness of the proposed model

with our data. X^2 is a classic index to measure the precision of the model. This index is used to test the zero hypothesis which claims that the desired covariance matrix matches with the data covariance matrix. If X^2 is very large the zero hypothesis is rejected which indicates that the two covariance matrices do not match. On the other hand a small X^2 indicates that the proposed model is appropriate.

6. Comparing with other models: for comparing different proposed models, we just examined the differences between their X^2 statistics (De Coster 1998). We have also compared the *Root mean square error of approximation* (RMSEA), which is an estimate of discrepancy per degree of freedom in the model and has been introduced by Stiger et. al. (1980).

In this research, the amount of X^2 has been computed to be 9.88 which is small enough to indicate that the proposed model matches with the factorial structure of the data. Also the RMSEA is computed to be 0.019. RMSEA is not sensitive to the sample size and if computed to be equal to or less than 0.05 it indicates the fitness of the model (Hu & Bentler 1999, Brown 2006).

We have also used the comparative fit index (CFI) to examine the range of deviations of the data from the proposed model structure. This index changes from 0 (for a weak model with no fitness) to 1 (for a model with maximum fitness). Our computation resulted in 1 for the proposed model. Table 3 shows the result of the confirmatory factor analysis performed by the software.

To conclude this part, although there exists no absolute comprehensive index to measure the real fitness of a model, according to references that recommend indices such as CFI or RMSEA in addition to X^2 all three indices were used in our research and all verify the validity and precision of the proposed model.

Table 1. List of technology portfolio selection criteria gathered from the literature

Row	Criterion	Row	Criterion	Row	Criterion
1	Lead times of R&D	28	Diffusion in the enterprise	55	Option creation
2	Ability to transfer the technology from one unit to another	29	Capability to keep up with fundamental scientific and technical knowledge	56	Quality of technology (Precision, Reliability and Durability)
3	Technology dynamics	30	Financing capacity	57	Number of stakeholders
4	Market volume opened by technology	31	Quality of relationships between R&D and production	58	Existence of an effective "champion"
5	Span of application opened by technology	32	Quality of relationships between R&D and marketing	59	Degree of existing staff capability
6	Market sensitivity to technical factors	33	Capacity to protect against imitation	60	"Sparkle factor" - Potential for high innovation
7	Continuing availability of funding	34	Market relation to company's design	61	Service to other corporate goals
8	Competitors' level of involvement	35	Time table relative to competition	62	Technology Effectiveness
9	Competitive intensity	36	Profitability of technology	63	Technology Efficiency
10	Impact of technology on competitive issues	37	Business sector priority	64	Technology Investment Decision Balance
11	Barriers to copy or imitation	38	Prestige of technology	65	Technology Flexibility
12	Dominant design	39	Strategic importance	66	Potential for implementation
13	Position of the technology in its own life cycle	40	Commercial value	67	Environmental/social/political impacts
14	Potential for progress	41	Current position	68	Compatibility with scenarios
15	Performance gap vis a vis alternative technologies	42	Technology availability	69	Serving as infrastructure
16	Appropriability	43	Technical resource availability	70	Strategic leverage
17	market dynamics	44	Fit with company business plan	71	Project complexity
18	Societal stakes	45	Synergy with other products/processes	72	Project interdependencies
19	Public support for development	46	Risk in obtaining regulatory clearances	73	Payback-cost benefit ratio
20	Origin of the assets	47	Ability to meet likely future regulations	74	Market or Spin-off potential
21	Relatedness to the core business	48	Effect on existing market outlook	75	Technical risk to project completion
22	Experience accumulated in the field	49	Development team competencies	76	Commercial risk of application
23	Registered patents	50	Potential return on investment	77	Economic Uncertainty
24	Value of laboratories and equipment	51	Ability to implement production/process	78	Threat of substitution technologies
25	Fundamental research team competencies	52	Relevance of the technology	79	Financial Risk
26	Applied research team competencies	53	Interdependencies with other technologies		
27	Institutional Uncertainty	54	New market potential		

Table 2. Categories of criteria for technology selection based on values and risks from table 1

		Criteria	Related Sub-Criteria
Expected Return from Investing on Technology Portfolio	Values	Technical Superiorities of the Technology	1, 2, 3, 13, 14, 38, 45, 53, 55, 56, 60, 65, 66, 69, 72
		Organizational Preparedness for Hosting and Promoting the Technology	20, 28, 29, 31, 32, 41, 51, 58
		Support that the Technology Provides to Strategic Objectives and Goals	37, 39, 44, 52, 61, 62, 70
		Support that the Technology Provides to Stakeholders and Investors Expectations	18, 36, 40, 50, 57, 63, 64, 67, 68, 73
		Technological, Financial and Human Capital Resources available to Support the Technology	7, 19, 22, 24, 25, 26, 30, 42, 43, 49, 59
		Market Driven Factors	4, 6, 17, 48, 54, 74
		Inter related Factors that Support Competitive Capabilities of the Organization	5, 8, 9, 10, 11, 12, 15, 16, 21, 23, 33, 34, 35
	Risks	Technical Risk to Project Completion	71, 75, 78
		Economic Uncertainties and Commercial Risk of Application	76, 77, 79
		Institutional Risk	27, 46, 47

4. A Case in Iranian Energy Sector

The Iranian energy sector involves a variety of ministries and organizations which are mainly known as energy sub-sectors. Among all of these sub-sectors the largest one is the Ministry of Petroleum (MOP) which plays a significant role in the country's oil and gas industry. In fact a big portion of the petroleum value chain from field exploration and management in upstream to petrochemical products and processes in downstream fall in this sub-section and are affected by policies and decisions of the related ministry. Since the petroleum value chain is very dependent upon technology, investment decisions on technology are very critical. Therefore having the right set of criteria to choose technologies that provide the most support to organizational strategies and objectives and consequently bring the most possible return on investment to the petroleum industry is very essential.

Table 3. Results of Confirmatory Factor Analysis for the Proposed Selected Model

Row	Model Evaluation Measure	Value
1	Minimum Fit Function Chi-Square	9.88 (p=0.2)
2	Normal Theory Weighted Least Squares Chi-Square	9.89 (p=0.19)
3	Estimated Non-centrality Parameter (NCP)	2.89
4	90 Percent Confidence Interval for NCP	(0.0 ; 15.4)
5	Normed Fit Index (NFI)	0.99
6	Parsimony Normed Fit Index (PNFI)	0.46
7	Comparative Fit Index (CFI)	1.00
8	Incremental Fit Index (IFI)	1.00
9	Relative Fit Index (RFI)	0.98

Based on this point of view MOP through its deputy for research and technology developed a new system for conducting research and technology development activities. This new system which is based on two pillars of the industry's technological needs and problems from one side and the society's capacities and capabilities to satisfy the needs and solve the problems from the other side, became efficient in 2009. A very brief, abstract and conceptual description of the system is depicted in Figure 2. Like any similar situations due to limitation of resources the problems had to be carefully selected and weighted and so there was a need to select a technology portfolio to provide a better understanding of problems and their weights for investment.

The proposed model in section 3 of this paper was introduced to select the technologies and make a portfolio of technology development projects for the following five year horizon. To implement the set of proposed criteria for the selection process a list of proposed technologies gathered from and suggested by engineers and experts from all over the industry and also by academia was generated. Suggestions were based on experts' understandings from the industry's immediate or short term/ midterm needs and also some foresight activities. These were organized in a separate questionnaire putting technologies against the criteria (Table 4).

Table 4. Typical questionnaire for scoring projects against criteria

Tech	Values							Risks		
	V_1	V_2	V_3	V_4	V_5	V_6	V_7	R_1	R_2	R_3
T_1										
T_2										
…										
…										
T_{n-1}										
T_n										

This list of projects was then distributed among all corporate experts and managers to reflect their views about the significance of each area of technology by scoring each technology development project against each criterion in a 1- 10 scale. The results were analyzed through a Delphi process and it was finalized into an integrated list of proposed technologies to invest on with a relative weight. The Delphi output was then proposed to MOP's research

policy council to be verified. The council approved the selected technologies while asking for some minor changes in the assigned weights. This indicated that explored criteria provided a suitable tool to policy makers for making robust decisions.

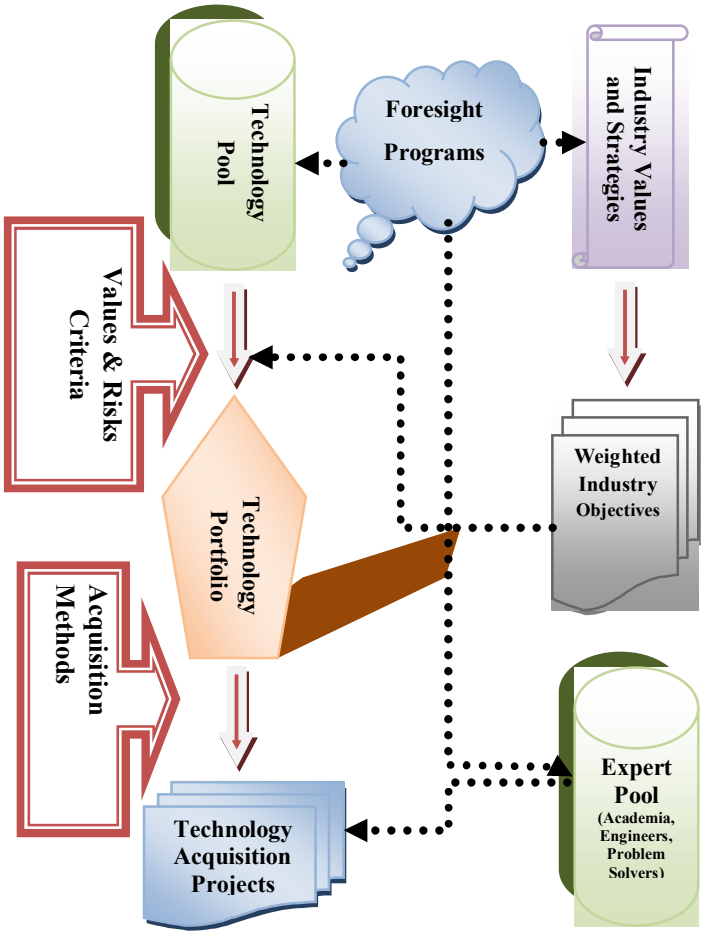

Figure 2. Schematic description of MOP's research and technology development management system

5. Conclusions

In this paper while reviewing previous studies and research results in the area of criteria for technology portfolio selection, a list of major such criteria were developed. After dividing the set of gathered criteria into several groups according to their common characteristics and building a couple of models, 10 major criteria to select a robust technology portfolio were extracted by using questionnaires and applying a confirmatory factor analysis. The ten extracted criteria are grouped under the two general categories namely values and risks and were tested and found to be suitable for technology portfolio selection based on data gathered from the Iranian oil industry.

According to research findings, technology superiorities (e.g. research and development lead time, technology dynamics and technology position in its life cycle) is among the significant value criteria for technology selection. Other significant criteria in the group of values include preparedness of the organization to host and promote the technology, support that the technology provides to strategic objectives and goals, support that the technology Provides to stakeholders and investors expectations, technological, financial and human capital resources available to support the technology, market driven factors and also inter related factors that support competitive capabilities of the organization. In the group of risks, three major criteria were identified and introduced: technical risks including any factors which face the completion of a technology development or acquisition plan with technical difficulties, financial and economical uncertainties and commercial risks including factors which limit or make impossible the practical application of R&D results and achievements and institutional risks including legal uncertainties which brings hesitations in a successful application of results.

Implementing the set of results in selecting a technology portfolio for the Iranian oil and gas industry via descriptive questionnaires, Delphi method and expert panels approved the robustness of the proposed set of criteria.

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