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Two-stage multi-objective technology portfolio planning under resource constraints (case study: Iranian technology development fund)

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Abstract. This study proposes a novel two-stage multi-objective framework for optimal technology portfolio planning and resource allocation under constraints, specifically for Technology Development Funds (TDFs). The integrated methodology combines the analytic network process for prioritizing strategic technology fields with a multi-period mixed-integer linear programming model, solved using a revised multi-choice goal programming approach. The model's objectives are to maximize technological export potential, maximize international technological cooperation, and minimize financial risk, while incorporating critical real-world mechanisms such as staged financing contingent on technology readiness level (TRL) progress, loan moratorium, and repayment periods. The framework was validated through a real-world case study of an Iranian TDF, involving eight technology fields and up to 30 projects per field. Key quantitative results demonstrate model's efficacy: by reducing the risk objective's weight from 0.3 to 0.1, the number of approved projects increased over fivefold (from 12 to 65), and the total allocated resources surged nearly tenfold (from \$22.2 million to \$217.5 million). Sensitivity analysis revealed that fields with high export potential and collaboration capacity (e.g., Advanced Machinery) received the highest funding, while the staged financing mechanism successfully identified and terminated 25% of projects for insufficient technical progress after the first stage. The proposed model provides a robust decision-support tool for policymakers to enhance the strategic impact and financial efficiency of national technology investments.

Keywords: Financial resource allocation, moratorium period, reinvestment strategy, staged financing, technology prioritization, technology portfolio selection.
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1 Introduction

The governance of innovation and technological advancement is typically carried out within a structured and interconnected framework known as the national innovation system (NIS). This system encompasses a network of institutions including public and private enterprises, academic institutions, and governmental bodies whose collective mission is to generate, disseminate, and utilize knowledge within a nation's borders [29]. Within this framework, the Innovation Financing System (IFS) operates as a critical subsystem, tasked with mobilizing financial resources to support technological development. Technology financing refers to the strategic funding of innovative enterprises, enabling them to transform technological inventions into market-ready products or services [27]. One of the persistent challenges faced by governments is the prioritization of technologies and the allocation of financial support to firms engaged in technological innovation. Financing plays a pivotal role in sustaining high-tech firms throughout the various stages of the innovation lifecycle. In the early phases, when firms are newly established and the risk of failure is high, private investors often hesitate to provide funding. Consequently, start-ups frequently encounter barriers in securing capital from banks and other financial institutions [28]. As firms begin to grow and gain financial traction, they may attract investment from both public sources such as Technology Development Funds (TDFs) and private entities. Eventually, mature firms may access broader financial markets through mechanisms like initial public offerings (IPOs) and stock exchanges [27]. Given the strategic importance of technological innovation and the rise of knowledge-based economies, several studies have examined national approaches to technology financing and commercialization [11, 27, 28]. These investigations have provided a macro-level view of innovation financing policies, institutional arrangements within IFS, and their respective roles across different stages of technology development. Despite the strategic importance of TDFs in financing national innovation, a critical gap persists in the literature regarding quantitative decision-support frameworks tailored to their unique context. Existing portfolio selection models, predominantly designed for corporate R&D or financial markets, fail to address the integrated decision-making problem faced by TDFs. Specifically, they lack a unified methodology that simultaneously (1) prioritizes technology fields based on national strategic objectives, and (2) selects and finances individual projects based on their technological maturity (e.g., Technology Readiness Level (TRL)) through dynamic mechanisms such as staged financing with moratorium periods. This gap leads to a suboptimal allocation of scarce public financial resources, potentially diminishing the impact of national innovation investments. To address this specific problem, we are motivated to propose a novel two-stage multi-objective model. The two-stage structure is essential to systematically bridge the high-level strategic prioritization of technology fields with the operational-level selection and dynamic financing of projects, thereby providing a comprehensive tool to enhance the efficacy and strategic alignment of TDFs.

The structure of the paper is as follows: Section 2 presents a review of relevant literature. Section 3 details the formulation of the proposed model for technology portfolio selection and staged financing. Section 4 outlines the solution methodology. Section 5 discusses the application of the model to a real case and provides managerial insights derived from computational results. Finally, Section 6 offers concluding remarks and suggestions for future research.

2 Literature Review

2.1 Portfolio selection literature: from financial markets to technology strategy

Portfolio selection, since the seminal mean-variance framework of Markowitz [16], has been a cornerstone of financial decision-making. While the core principles of balancing risk and return remain, the application of portfolio theory has expanded significantly into other domains, including project and technology management. This evolution reflects a recognition that resource allocation problems whether financial capital, R&D projects, or strategic technologies share fundamental structural similarities. This section provides a critical synthesis of the portfolio selection literature and analyze dominant methodological streams and their limitations. The literature can be broadly categorized by its application domain and methodological focus. In financial portfolio optimization, research has advanced from single-period models to sophisticated multi-objective frameworks. For instance, Kocadagli and Keskin [13] employed fuzzy logic to incorporate subjective market trends, while Kucukbay and Araz [14] demonstrated the efficacy of Linear Physical Programming (LPP) as a viable alternative to fuzzy goal programming. A prominent stream of research has integrated Data Envelopment Analysis (DEA) with traditional models to incorporate efficiency as a key dimension, as seen in the work of Mashayekhi and Omrani [17]. These financial models are highly mature in quantifying risk and return but have weaknesses in capturing the non-financial, strategic criteria and complex interdependencies inherent in project and technology contexts. Recognizing these limitations, a second major stream focuses on project portfolio selection, particularly for R&D and new product development. Here, the complexity escalates due to multiple conflicting objectives, uncertainties, and project interactions. Early works, like that of Dickinson et al. [6] at Boeing, introduced dependency matrices to model these interdependencies. A critical shift in this domain has been the integration of Multi-Criteria Decision-Making (MCDM) methods with mathematical programming. Studies by Tavana et al. [24, 25] exemplify this trend, combining DEA for initial screening with methods like TOPSIS for ranking and fuzzy programming for final selection. Similarly, other researchers have incorporated project duration and reinvestment potential (Jafarzadeh et al. [10]) or used robust optimization to handle deep uncertainties (Hassanzadeh et al. [9]). While these models handle project-level complexity adeptly, they largely remain confined to a firm-level perspective, prioritizing commercial objectives like cost, profit, and risk. A third, more specialized stream applies portfolio theory to technology selection and management. This domain introduces unique, technology-specific metrics. Yu [30] and Sattari Ardabili [22] laid early groundwork with models incorporating budget and workforce constraints under uncertainty. A significant contribution was the introduction of Technology Readiness Level (TRL) as a critical risk and maturity metric, as demonstrated in the qualitative framework of Terrile et al. [26] at NASA. Subsequent models have increasingly incorporated TRL and other strategic factors. For example, Shaverdi and Yaghoubi [23] developed a two-stage stochastic model that integrates TRL with staged financing and moratorium periods, while Belz et al. [2] applied a real-options framework using TRL to guide flexible, strategic R&D investments. Concurrently, the field has expanded to include sustainability criteria, as seen in models for green technology and energy systems (Alvarado et al. [1]). Recent advances continue to push methodological boundaries, tackling multi-annual planning (Etgar & Cohen [7]), complex scheduling (Ramedani et al. [19]; Qiu et al., [18]), and hybrid algorithmic solutions (Ramedani et al. [19]). Despite the strategic importance of TDFs, a significant gap persists in the literature regarding quantitative, decision-support frameworks for their resource allocation dilemma. Existing portfolio selection models are predominantly designed for corporate R&D or financial markets,

Row	Authors	Variables Type		Time Period		Problem Type		Modeling Methods				Factors Considered in Model									Application Context			
		Deterministic Variables	Uncertain Variables	Single-period	Multi-Period	Single-Objective	Multi-Objective	Nonlinear programming	MILP/ Linear Programming	MCDM	DEA	Different Technology Fields	Efficiency Assessment	Cost	Risk	Return	Technolgy Export Market	Staged financing	Technical Progress Assessment	TRL	R&D/TP/PP* at Company Level	TP/PP at National Organization	Stock Market Portfolio	TP at TDF**
1	Dickinson et al., 2001	✓			✓	✓		✓						✓		✓					✓			
2	Yu, 2006	✓	✓	✓		✓			✓	✓					✓	✓					✓			
3	Li et al., 2010		✓	✓		✓			✓	✓				✓							✓			
4	Sattari Ardabili, 2011		✓	✓			✓		✓					✓	✓	✓					✓			
5	Davoudpour et al., 2012	✓			✓	✓			✓	✓				✓							✓			
6	Tavana et al., 2013		✓	✓		✓					✓		✓	✓								✓		
7	Hassanzadeh et al., 2014		✓	✓			✓		✓					✓	✓						✓			
8	Jafarzadeh et al., 2015	✓			✓		✓		✓					✓		✓					✓			
9	Tavana et al., 2015		✓	✓		✓			✓		✓		✓	✓	✓	✓					✓			
10	Kocadagli et al., 2015		✓	✓			✓		✓						✓	✓							✓	
11	Mashayekhi et al., 2016		✓				✓				✓		✓		✓	✓							✓	
12	Alvarado et al., 2016		✓	✓			✓		✓					✓							✓			
13	Mokhtarzadeh et al., 2016	✓			✓	✓			✓						✓						✓			
14	Arratia M. et al., 2016	✓		✓			✓		✓					✓							✓			
15	Kucukbay et al., 2016		✓	✓			✓		✓						✓	✓							✓	
16	Karasakal et al., 2017		✓	✓		✓				✓	✓		✓			✓						✓		
17	Shaverdi et al., 2021		✓		✓		✓		✓			✓					✓	✓	✓					✓
18	Etgar et al., 2022	✓			✓	✓						✓									✓			
19	Qiu et al., 2024	✓			✓		✓	✓				✓	✓	✓							✓			
20	Ramedani et al., 2024		✓		✓	✓		✓				✓						✓			✓			
21	Belz et al., 2025		✓		✓	✓		✓							✓			✓	✓			✓		
22	This paper	✓			✓		✓		✓	✓		✓		✓	✓	✓	✓	✓	✓	✓				✓

Figure 1: Selected resources related to project portfolio and technology portfolio optimization

often overlooking critical operational mechanisms and strategic imperatives unique to public technology funds. Specifically, there is a lack of integrated models that simultaneously: (1) prioritize technology fields based on national strategic objectives, (2) select individual projects within those fields considering technical maturity (e.g., TRL), and (3) incorporate staged financing with moratorium periods based on periodic progress assessments. This gap leads to a suboptimal allocation of scarce public funds, potentially reducing the impact of national innovation investments. To address this problem, we propose a two-stage multi-objective model that systematically bridges strategic prioritization with operational project selection and dynamic financing, providing a comprehensive tool for enhancing the efficacy of TDFs. As Figure 1 shows, existing portfolio selection research is largely limited to stock markets and R&D projects.

2.2 Synthesis and identified research gap

This critical analysis reveals a clear evolutionary path: from purely financial models to sophisticated project portfolio tools, and finally to nascent technology-focused frameworks. However, while the project portfolio literature offers advanced methodologies for handling complexity and uncertainty, it systematically overlooks technology-specific attributes like TRL and Technology Leverage Factor (TLF). Conversely, the technology portfolio literature, while beginning to incorporate these metrics, often lacks the methodological rigor of multi-stage programming or fails to integrate strategic financing mechanisms (e.g., moratorium periods, reinvestment) at a systems level.

Most critically, the overwhelming focus of existing models is on firm-level optimization (Figure 2). The application of these advanced portfolio techniques to the problem of national-level technology strategy remains virtually unexplored. At this strategic level, the objectives shift from corporate profit to national competitiveness, security, and technological sovereignty. This requires a fundamental rethinking of the portfolio objective function and constraints to prioritize technology fields based on strategic national goals and to determine the optimal composition, scheduling, and financing of technological projects according to their technical maturity across the entire national innovation system.

Therefore, this study aims to bridge this gap by developing a novel portfolio optimization framework that synthesizes the methodological advancements from project portfolio literature (MCDM) with the technology-specific metrics of the technology management field (TRL, TLF), all within the unique and critically important context of national-level strategic planning.

2.3 Novelty and contribution

To precisely delineate the contributions of this study against the existing literature, we provide a comparative analysis in Table 1. While previous studies have explored individual components of our framework, the integrated combination of a strategic prioritization phase with a tactical multi-period optimization model, incorporating specific real-world financing mechanisms, constitutes the core novelty of this research.

The conceptual and methodological contributions of this work are therefore multifaceted:

- **Methodological:** It provides a novel, hybrid ANP-RMCGP (revised multi-choice goal programming (RMCGP)) framework for complex, multi-level decision-making under multiple constraints, tailored for public financing institutions.
- **Conceptual:** It bridges a critical gap between high-level national technology strategy and granular project financing decisions, operationalizing strategic goals into an executable financial plan.
- **Practical:** The model offers a decision-support tool that enhances transparency and accountability in public fund allocation, with built-in mechanisms (like staged financing) to mitigate risk and improve return on investment (ROI) on national innovation investments.

3 Proposed model

Our proposed model has a two-stage mathematical framework that integrates ANP with a mixed integer linear programming (MILP) model. The schematic view of this framework is presented in Figure 2.

3.1 Phase 1. Technology prioritizing

This phase is composed of four stages:

3.1.1 P1. Identify DMs

At this stage identification of DMs including senior managers or specific committee members in the field of science and technology policy and innovation financing is done.

Table 1: Comparative summary of methodological and conceptual contributions

Feature	Existing literature (Representative examples)	Contribution of this Study
Overall framework	Often single-level optimization (project selection only) or standalone MCDM for prioritization.	Proposes a novel two-stage framework that integrates strategic-level prioritization (via ANP) with tactical-level multi-period portfolio optimization (via RMCGP).
Strategic prioritization	Prioritization often based on financial metrics or integrated into a single objective function.	Uses analytic network process (ANP) to explicitly model interdependencies among strategic criteria (e.g., export potential, collaboration) for national-level technology field prioritization.
Solution methodology	Uses standard GP, fuzzy GP, or other standalone optimization techniques.	Integrates ANP weights into a revised multi-choice goal programming (RMCGP) model, allowing DMs to set flexible aspiration levels for conflicting objectives, enhancing realism and flexibility.
Financing mechanism	Largely ignores the dynamics of loans or uses simple budget constraints.	Explicitly models staged financing contingent on TRL progress, a moratorium period, and loan repayment with reinvestment into the available budget.
Technology assessment	Some studies use TRL as a static criterion or filter.	Dynamically links TRL progression to financing decisions across multiple stages, acting as a control and early-warning mechanism. Integrates TLF for strategic impact assessment.
Project interrelationships	Considers technical interdependencies and synergies.	Models complex project relationships, including mutual exclusivity and prerequisites.

3.1.2 P2. Identify criteria for technology fields' prioritizing

At the second stage, the important criteria in technology assessment and prioritizing were identified based on resources such as Karasakal and Aker [12], Davoudpour et al. [5], and Ghazinoori and Ghazinoori [8]. Then there were presented to the science and technology policy experts and based on their opinion, the final criteria categories and subcategories was developed (Figure 3).

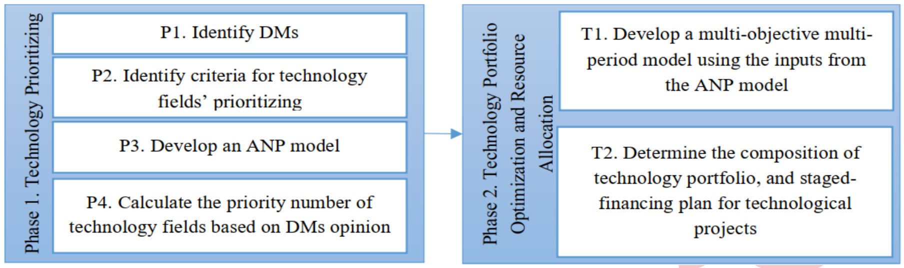


Figure 2: Proposed framework

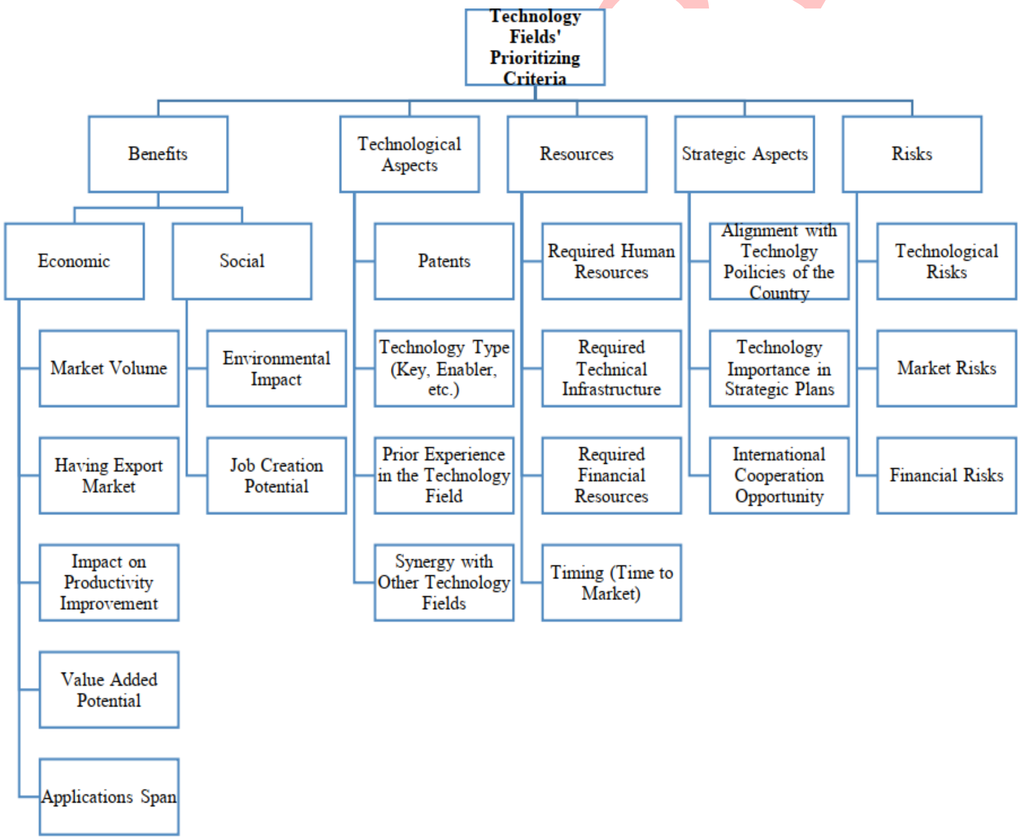


Figure 3: Technology fields' prioritizing criteria

3.1.3 P3. Develop an ANP model

The analytic network process (ANP) is the most comprehensive framework to analyze societal, governmental and corporate decisions. It allows to include all the tangible and intangible factors and criteria for making a best decision. The ANP method allows both interaction and feedback within clusters of elements (inner dependence) and between clusters (outer dependence) [20]. Based on the experts' opinion about the relationship among model's criteria and alternatives, an ANP model was developed at this stage in order to determine the weights of criteria and priority of technology fields. Figure 4 shows our

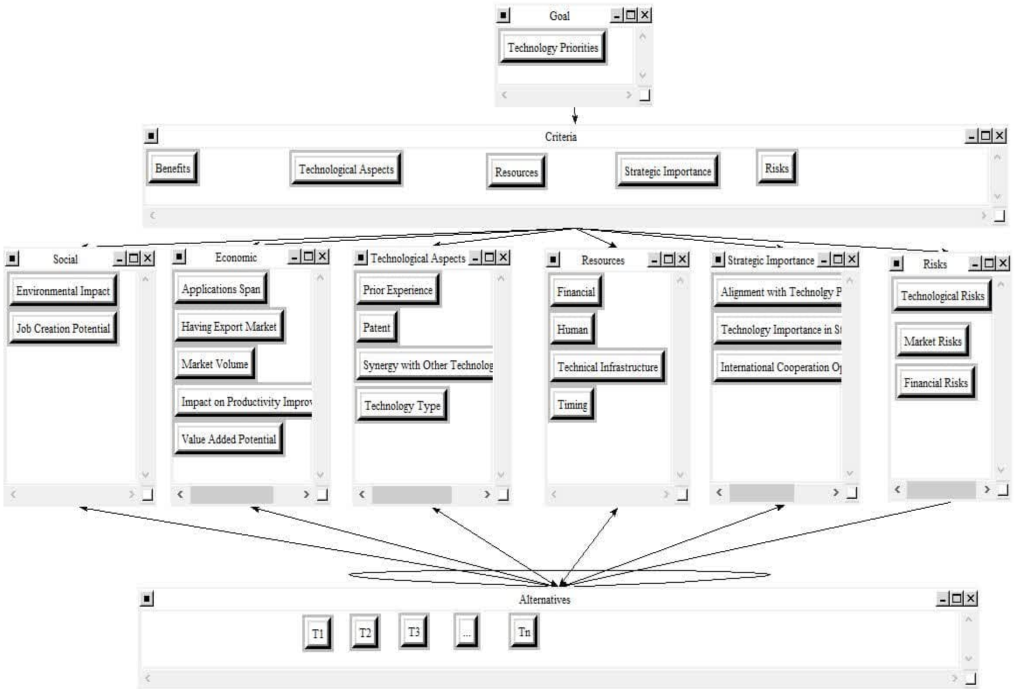


Figure 4: ANP model to determine technology priorities

proposed ANP model.

3.1.4 P4. Calculate the priority number of technology fields based on DMs opinion

To calculate priority number for each technology field, pairwise comparison matrices as proposed by Saaty [21] should be used in ANP method. According to the Saaty [20], in this method first the weight vector for priorities matrix should be determined. Then, for pairwise comparison, a scale of Tables 2 and 3 should be considered, and comparison of each pair of criteria with respect to the goal, comparisons of criteria in each cluster with respect to each alternative, and comparison of each pair of alternatives (technologies) according to each criterion should be done in the pairwise comparison matrices. After that, the average and weighted average matrices for criteria and sub-criteria could be constructed based on these calculations. In the next step, the super-matrix of ANP model will be shaped. The super-matrix shows the influence of elements in the network on other elements in that network. Finally, by solving the super-matrix and normalizing the results, the final priority number of each alternative (technology field) will be determined.

3.2 Phase 2. Technology portfolio optimization and resource allocation

At this phase, a multi-objective mixed integer linear programming model for technology portfolio selection is presented.

Table 2: Pairwise comparison scale (adopted form [21])

Scale of pairwise comparison	Numeric rating	Reciprocal (Inverse)
Equal importance	1	1
Moderate importance	3	1
Strong importance	5	$\frac{1}{5}$

Table 3: Pairwise comparison scale (adopted form [21])

Scale of pairwise comparison	Numeric rating			Reciprocal (Inverse)		
Very strong importance	7			1/7		
Extreme importance	9			1/9		
Intermediate Values	2	4	6	1/2	1/4	1/6

3.2.1 T1. Develop a multi-objective multi-period model using the inputs from the ANP model

Our proposed model is a multi-objective multi-period model to determine optimal composition of technology fields and technological projects in order to finance by TDFs. This model, considers moratorium period for loans, repayment and reinvestment strategy, and also staged-financing of technological projects with regard to their technical progress. The following notations are used in problem mathematical modeling (Table 4).

Table 4: Definition of notations

Notations	Description
Indices	
t, t'	Time periods ($t = 1, \ldots, T$)
j	Technology field ($j = 1, \ldots, J$)
g, q	Technological projects ($g = 1, \ldots, G$)
s	Payment stages ($s = 1, \ldots, S$)
Sets	
I_g	The subset of the inconsistent projects ($I_g \subseteq [1, \ldots, G]$)
L_g	The subset of the interdependent projects ($(q, g) \in L_g$ if and only if the project g couldn't be selected until the project q has been selected)
R_g	The subset of the projects that their start period (t') is before the period t and their installments should be paid in the period t ($R_g = \{g \mid t' + t_{gr} \leq t - 1$ and $t' + t_{gr} + t_{re} \geq t\}$)
Parameters	
P_j	Priority number of the j^{th} technology field
$Ca_{\max}$	Maximum level of capital that could be allocated to the organization at the beginning of the period t

Continued on next page

Table 4 – continued from previous page

Notations	**Description**
$Ca_{\min}$	Minimum level of capital that could be allocated to the organization at the beginning of the period t
$\mathrm{ROI}_{\min}$	Minimum acceptable level of return on investment
$P_{\min}$	Minimum acceptable level of priority for technology fields
$\Delta\mathrm{TRL}_{\min}$	Minimum acceptable level of project progress in each stage
n	The number of the loan's installments
r	Interest rate of the loan
A	Minimum percentage of the loan that should be paid at each stage
K	Total number of the financing stages
M	Big M (A sufficiently large number)
t_{gr}	Moratorium period of the loan
t_{re}	Repayment period of the loan
TRL_{jgs}	TRL of technological project g in technology field j in the stage s
TLF_{jg}	Technology Leverage Factor coefficient of the technological project g in technology field j
ROI_{jg}	ROI of the technological project g in technology field j
Tech_{jg}	Technological cooperation coefficient of the technological project g in technology field j
pr_{jg}	The success probability of technological project g in technology field j
Ma_{jg}	Potential export market for technological project g in technology field j
D_{jg}	Total cost that requested for executing the technological project g in technology field j
Variables	
C_t	The budget available in the period t
Ca_t	Capital that allocated to the organization in the period t
B_{jt}	Allocated resources to the j^{th} technology field in the period t
X_{jgts}	Allocated resources to the technological project g of technology field j in the stage s of the period t
γ_j	Binary decision variable that takes 1 if the technology field j is selected and 0 otherwise
σ_{jgt}	Binary decision variable that takes 1 if the technological project g of technology field j is selected in the period t and is 0 otherwise
λ_{jgts}	Binary decision variable that takes 1 if the technological project g of technology field j has had at least the minimum progress and received financial resources in the stage s of the period t and is 0 otherwise

Table 5: TLF description (Own construction based on [2] and [26])

TLF_{jg} **Level**	**Description**	TLF_{jg} **Coefficient (%)**
Low	Component level technology	10
Medium	Subsystem level technology	30
High	System level technology	70
Enabling	Enabling level technology	100

3.2.2 T1.1. Objective functions

Since high-tech export market, and technological cooperation are important indices in the assessment and rankings of the countries' innovative performance, our model objectives are maximizing export market, maximizing technological cooperation, and also minimizing risk. This model determines the prioritized technology fields, the selected technological projects in those technology fields, and the amount of the resources that should be allocated to the technological projects in each stage of financing.

1. The first objective function is about maximizing resources that allocated to the technological projects that have a big reward. According to the Terrile, Jackson, and Belz [2], the reward of technology is associated to the Technology Leverage Factor (TLF) and its market. TLF is a measure of the potential leverage a technology could have for creating the market. So, the first objective function defined as follows:

$$\max Z_1 = \sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T} \text{Ma}_{jg} \times \text{TLF}_{jg} \times \sigma_{jgt} \tag{1}$$

   in which Ma_{jg} is the potential export market of the project g in technology field j. TLF_{jg} is the "Technology Leverage Factor" coefficient of the technological project g in technology field j and is determined based on the Table 5. σ_{jgt} is a binary decision variable that takes 1 if the project g in technology field j starts receiving fund in period t and 0 otherwise.

2. Technological cooperation is a critical factor in improving technological capabilities of firms, and is an important index in assessing countries innovative performance, too. Therefore, the second objective function is about maximizing international technological cooperation in projects, as follows:

$$\max Z_2 = \sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T} \text{Tech}_{jg} \times \sigma_{jgt} \tag{2}$$

   in which Tech_{jg} is the probability of the presence of foreign partner in the execution of technological project g in technology field j. This probability is determined in the project's BP and with regard to the firm's cooperation and negotiation capabilities and prior experiences, as follows:

$$\min Z_3 = \sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T}\sum_{s=1}^{S} (1-\text{pr}_{jg}) \times X_{jgts} \tag{3}$$

   in which pr_{jg} is the success probability of technological project g in technology field j and X_{jgts} is the allocated resources to the technological project g of technology field j in the stage s of the period t.

3.2.3 T1.2. Model constraints

There are various criteria and constraints for deciding about technology fields, technological projects and their financing in each stage.

1. Technology fields selection: The technology fields could be on the portfolio only when their respective priority number (adopted from ANP model) be higher than the minimum acceptable priority level, and there should be selected at least one technology field in each period:

$$\gamma_j \times P_{\min} \le P_j, \quad j = 1,2,\ldots,J \tag{4}$$

$$\sum_{j=1}^{J} \gamma_j \ge 1, \tag{5}$$

where γ_j is a binary decision variable that takes 1 if the technology field j is selected and 0 otherwise. P_j is the priority number of technology field j that is calculated by ANP model, and $P_{\min}$ is the minimum acceptable level of priority.

2. ROI: One of the projects' approval criteria is their ROI and there is a minimum and acceptable level of return on investment:

$$\mathrm{ROI}_{\min} \times \sigma_{jgt} \le \mathrm{ROI}_{jg}, \quad j = 1,2,\ldots,J; \quad g = 1,2,\ldots,G; \quad t = 1,2,\ldots,T \tag{6}$$

in which $\mathrm{ROI}_{\min}$ is the minimum acceptable level of return on investment and ROI_{jg} is the return on investment of technological project g in technology field j.

3. Technology Readiness Level (TRL) constraint for technological projects: Mankins (2009) has defined TRLs in 9 level from "Basic principles" to "Actual system" (Figure 5). Our model is for technology development funds that finance only technology development phases, not R&D phases (i.e. TRL 3 to TRL 8). So, the following constraints are added to our model.

$$3 \times \sigma_{jgt} \le \mathrm{TRL}_{jgs}, \quad j = 1,2,\ldots,J; \quad g = 1,2,\ldots,G; \quad t = 1,2,\ldots,T; \quad s = 1, \tag{7}$$

$$\mathrm{TRL}_{jgs} \times \sigma_{jgt} \le 8, \quad j = 1,2,\ldots,J; \quad g = 1,2,\ldots,G; \quad t = 1,2,\ldots,T; \quad s = 1. \tag{8}$$

4. Technological projects selection: Technological projects could be selected only when their respective technology field has been selected, and if a technological field be selected, at least one project in that field should be selected.

$$\gamma_j \le \sum_{g=1}^{G} \sigma_{jgt} \le \gamma_j \times M, \quad j = 1,2,\ldots,J; \quad t = 1,2,\ldots,T \tag{7}$$

in which M is a large number.

5. Timing: Each project could be started once in the planning period:

$$\sum_{t=1}^{T} \sigma_{jgt} \le 1, \quad j = 1,2,\ldots,J; \quad g = 1,2,\ldots,G. \tag{8}$$

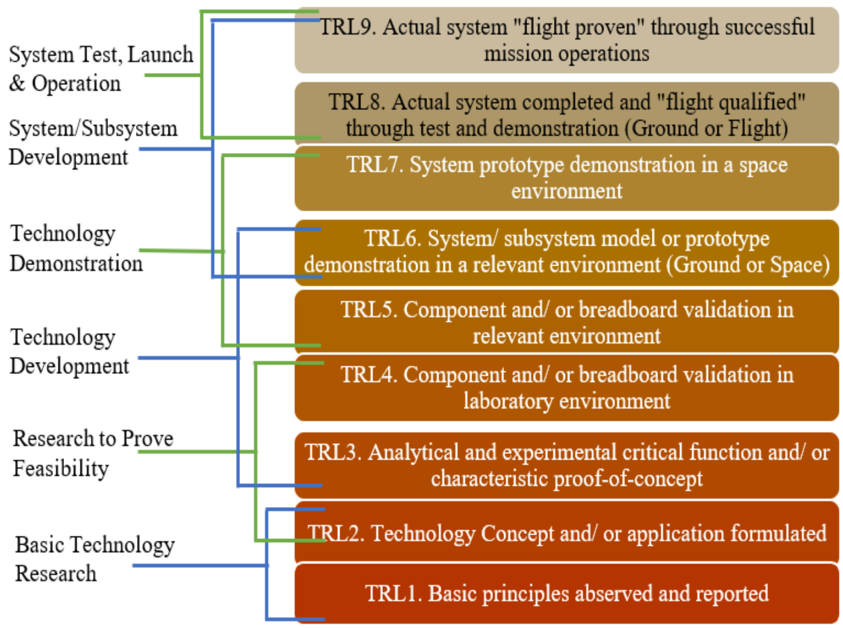


Figure 5: Technology readiness levels definition [15]

6. Technical progress and staged financing: If a project is selected in a period, the first stage financing in that period is necessary and all the financing stages of that project should be done in that period. For the purpose of staged financing, the technical progress of the projects would be assessed by the comparison of the TRL in two consecutive stages. If there is a minimum acceptable progress in the project, its financing will be continued, otherwise the financing will be stopped. Financing in each stage should be greater that the determined minimum level and the sum of staged financing should be less than or equal to the project's cost. So, the following constraints is added to the model:

$$\lambda_{jgts} = \sigma_{jgt}, \quad j = 1,2,\dots,J; \quad g = 1,2,\dots,G; \quad t = 1,2,\dots,T; \quad s = 1 \tag{10}$$

$$\sigma_{jgt} \le \sum_{s=1}^{S} \lambda_{jgts} \le \sigma_{jgt} \times K, \quad j = 1,2,\dots,J; \quad g = 1,2,\dots,G; \quad t = 1,2,\dots,T \tag{11}$$

$$\Delta\mathrm{TRL}_{\min} \times \lambda_{jgts} \le (\mathrm{TRL}_{jgs} - \mathrm{TRL}_{jg(s-1)}) \times \lambda_{jgt(s-1)} \le \Delta\mathrm{TRL}_{\min} \times \lambda_{jgts} \times M,$$
$$j = 1,2,\dots,J; \quad g = 1,2,\dots,G; \quad t = 1,2,\dots,T; \quad s = 2,\dots,S \tag{12}$$

$$X_{jgts} \ge A \times D_{jg} \times \lambda_{jgts}, \quad j = 1,2,\dots,J; \quad g = 1,2,\dots,G; \quad t = 1,2,\dots,T; \quad s = 1,\dots,S \tag{13}$$

$$\sum_{t=1}^{T}\sum_{s=1}^{S} X_{jgts} \le \sum_{t=1}^{T} D_{jg} \times \sigma_{jgt}, \quad j = 1,2,\dots,J; \quad g = 1,2,\dots,G \tag{14}$$

in which λ_{jgts} is a binary decision variable that takes 1 if the technological project g of technology field j has had at least the minimum progress and received financial resources in the stage s of the period t and is 0 otherwise, K is the total number of financing stages, $\Delta\mathrm{TRL}_{\min}$ is the minimum acceptable level of project progress in each stage, X_{jgts} is the allocated resources to the technological project g of technology field j in the stage s of the period t, A is the minimum percentage of the loan that should be paid at each stage, and D_{jg} is the total cost that requested for executing the technological project g in technology field j.

7. Budget constraint: It is assumed that in each period some part of state budget is allocated to the TDF and there is a minimum and maximum level for that. On the other hand, budget allocation to each technology field is done only when that field is selected and the total amount that is allocated to technology fields in each period should be lower than the total budget available in that period. The sum of financing for technological projects of one field is constrained by the total budget of that field. With considering reinvestment, the loans' repayments after their moratorium period will be added to the available budget. So, the following constraints is added to the model:

$$\mathrm{Ca}_{\min} \leq \mathrm{Ca}_t \leq \mathrm{Ca}_{\max}, \quad t = 1,2,\ldots,T \tag{15}$$

$$C_t = \mathrm{Ca}_{\min}, \quad t = 1 \tag{16}$$

$$B_{jt} \leq \gamma_j \times M, \quad j = 1,2,\ldots,J; \quad t = 1,2,\ldots,T \tag{17}$$

$$\sum_{j=1}^{J} B_{jt} \leq C_t, \quad j = 1,2,\ldots,J; \quad t = 1,2,\ldots,T \tag{18}$$

$$\sum_{g=1}^{G}\sum_{s=1}^{S} X_{jgts} \leq B_{jt}, \quad j = 1,2,\ldots,J; \quad t = 1,2,\ldots,T \tag{19}$$

$$C_t = C_{t-1} - \sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{s=1}^{S} X_{jgts} + \mathrm{Ca}_t + \sum_{j=1}^{J}\sum_{g\in R_g}\left(\frac{\left(\sum_{s=1}^{S} X_{jgts} \times r\right)/n + \sum_{s=1}^{S} X_{jgts}}{n}\right), \quad t = 2,\ldots,T \tag{20}$$

in which Ca_t is the capital that allocated to the organization in the period t, $\mathrm{Ca}_{\min}$ and $\mathrm{Ca}_{\max}$ are the minimum and maximum level of capital that could be allocated to the organization at the beginning of the period t, respectively. C_t is the budget available in the period t, and B_{jt} is the allocated resources to the j^{th} technology field in the period t. r is the interest rate of the loan and n is the number of loan's installments. R_g is the subset of the projects that their start period (t') is before the period t and their installments should be paid in the period t, i.e., $R_g = \{g \,|\, t' + t_{gr} \leq t-1 \text{ and } t' + t_{gr} + t_{re} \geq t\}$.

8. Inconsistency of projects: If there is an inconsistency between specific projects, the related constraint should be added to the model. If $I_g \subseteq \{1,\ldots,G\}$ denotes the subset of the inconsistent projects, the following constraint ensures that only one of these projects could be selected:

$$\sum_{g\in I_g} \sigma_{jgt} \leq 1, \quad j = 1,2,\ldots,J; \quad t = 1,2,\ldots,T; \quad I_g \subseteq \{1,\ldots,G\}. \tag{22}$$

9. Dependency of projects: D_g is defined as a set of dependency relationships between projects. $(q,g) \in D_g$ if and only if project g cannot be selected until project q has been selected:

$$\sigma_{jgt} \leq \sigma_{jqt}, \quad t = 1,2,\ldots,T, \quad j = 1,2,\ldots,J, \quad (q,g) \in D_g. \tag{23}$$

10. Decision variables: The decision variables are binary or non-negative variables:

$$X_{jgts},\ C_t,\ \mathrm{Ca}_t,\ B_{jt} \geq 0 \quad \text{and} \quad \gamma_j,\ \sigma_{jgt},\ \lambda_{jgts} \in \{0,1\}. \tag{24}$$

3.2.4 T2. Determine the composition of technology portfolio, and staged-financing plan for technological projects

This step involves proposing an appropriate solution method for the model and solving the model. The solution method for the model is presented in the next section.

4 Solution method

One of the popular approaches to solve multi-objective problems is goal programming. For the first time, Charnes and Cooper [4] proposed this method that makes it possible to achieve multiple goals simultaneously based on their importance and priority. Recently, Chang [3] has proposed a new method of "revised multi-choice goal programming (RMCGP)" for multi-objective decision making problems. This method allows the decision maker to set multi-choice aspiration levels for each goal and can easily be understood and solved by linear programming models.

4.1 The RMCGP

In this model, the new idea of upper ($G_i^{\max}$) and lower ($G_i^{\min}$) bound for the ith aspiration level (y_i) is introduced, in which y_i is a continuous variable between two bounds ($G_i^{\min} \leq y_i \leq G_i^{\max}$).

The RMCGP-achievement in the case of "the more the better" (i.e., maximizing the objective function) is as follows:

$$\begin{aligned} &\min \sum_{i=1}^{n} \left(\alpha_i(d_i^+ + d_i^-) + \beta_i(e_i^+ + e_i^-)\right) \\ &\text{s.t.} \quad f_i(X) - d_i^+ + d_i^- = y_i, \quad i = 1,2,\ldots,n \\ &\qquad y_i - e_i^+ + e_i^- = G_i^{\max}, \quad i = 1,2,\ldots,n \\ &\qquad G_i^{\min} \leq y_i \leq G_i^{\max}, \quad i = 1,2,\ldots,n \\ &\qquad d_i^+, d_i^-, e_i^+, e_i^- \geq 0, \quad i = 1,2,\ldots,n \\ &\qquad X \in F \quad (F \text{ is a feasible set and } X \text{ is unrestricted in sign}), \end{aligned} \tag{25}$$

in which d_i^+ and d_i^- are the positive and negative deviations for the ith goal (i.e., $|f_i(X) - y_i|$), and e_i^+ and e_i^- are the positive and negative deviations of $|y_i - G_i^{\max}|$, respectively. α_i is the weight of the ith goal and β_i is the weight of the sum of the deviations ($|y_i - G_i^{\max}|$). In the case of "the less the better", RMCGP-achievement is as follows:

$$\begin{aligned} &\min \sum_{i=1}^{n} \left(\alpha_i(d_i^+ + d_i^-) + \beta_i(e_i^+ + e_i^-)\right) \\ &\text{s.t.} \quad f_i(X) - d_i^+ + d_i^- = y_i, \quad i = 1,2,\ldots,n \\ &\qquad y_i - e_i^+ + e_i^- = G_i^{\min}, \quad i = 1,2,\ldots,n \end{aligned} \tag{26}$$

$$G_i^{\min} \leq y_i \leq G_i^{\max}, \quad i = 1,2,\ldots,n$$
$$d_i^+, d_i^-, e_i^+, e_i^- \geq 0, \quad i = 1,2,\ldots,n$$
$$X \in F \quad (F \text{ is a feasible set and } X \text{ is unrestricted in sign}).$$

Now, our model could be rewritten as follows:

$$\min Z = \sum_{i=1}^{n=3} \left(\alpha_i(d_i^+ + d_i^-) + \beta_i(e_i^+ + e_i^-)\right) \tag{27}$$
$$\text{s.t.} \quad \left(\sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T} \mathrm{Ma}_{jg} \times \mathrm{TLF}_{jg} \times \sigma_{jgt}\right) - d_1^+ + d_1^- = y_1 \tag{28}$$
$$y_1 - e_1^+ + e_1^- = G_1^{\max} \tag{29}$$
$$G_1^{\min} \leq y_1 \leq G_1^{\max} \tag{30}$$
$$\left(\sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T} \mathrm{Tech}_{jg} \times \sigma_{jgt}\right) - d_2^+ + d_2^- = y_2 \tag{31}$$
$$y_2 - e_2^+ + e_2^- = G_2^{\max} \tag{32}$$
$$G_2^{\min} \leq y_2 \leq G_2^{\max} \tag{33}$$
$$\left(\sum_{j=1}^{J}\sum_{g=1}^{G}\sum_{t=1}^{T}\sum_{s=1}^{S} (1 - \mathrm{pr}_{jg}) \times X_{jgts}\right) - d_3^+ + d_3^- = y_3 \tag{34}$$
$$y_3 - e_3^+ + e_3^- = G_3^{\min} \tag{35}$$
$$G_3^{\min} \leq y_3 \leq G_3^{\max} \tag{36}$$
$$(4\text{-}24) \tag{37}$$
$$d_i^+, d_i^-, e_i^+, e_i^- \geq 0, \quad i = 1,2,\ldots,n.$$

5 Case study: Technology portfolio selection on an Iranian TDF

This model was designed with a focus on an Iranian TDF, whose primary mission is to elevate Iran's standing in the global knowledge-based economy. It aims to do so by fostering the development and commercialization of advanced technologies within innovative and high-tech enterprises. The ITDF targets eight strategic technology domains for support, including:

1. Biotechnology,
2. Advanced Materials, Polymers, and Chemical Products,
3. Power Electronics, Laser Systems, and Photonics,
4. ICT and Software Development,
5. Advanced Machinery and Industrial Equipment,

6. High-tech Pharmaceuticals,
7. Medical Devices and Diagnostic Equipment,
8. Other cutting-edge technological products.

During the four-year study period, ITDF has allocated more than 500$ million financial support to approximately 3,000 high-tech firms. However, due to the absence of clearly defined national priorities for technology sectors, the fund's resources have been distributed without strategic focus or differentiation among fields. Moreover, the allocation process has not considered the relative contribution of each technology domain to the broader knowledge-based economy. As a result, concerns have emerged regarding the effectiveness of ITDF's resource allocation and its overall performance. To address these challenges, our proposed model introduces a structured approach for selecting technology portfolios and optimizing resource distribution across technological projects within the ITDF framework.

5.1 Data

In first step based on the proposed ANP model, the priority number of different technology fields was calculated. For this purpose, a questionnaire was developed for pairwise comparisons and distributed between C-level managers of ITDF. After gathering their opinion, model's calculations were done by using Superdecision 2.8. Validity and reliability in ANP method is determined by "inconsistency index" that should be below 0.1 for each pairwise comparison matrix. The inconsistency index for all matrices was between 0.04-0.09. So, the calculated priority numbers are rational and acceptable. Figure 6 shows ANP model that constructed in the Superdecision based on the ITDF's data. Figure 6 shows the software output window that includes the Ideal, Normal and Raw priority numbers. As seen in Figure 7, "Biotechnology" has the highest priority number (0.24) and "Medical Instrument" has the lowest (0.06). The normal priority numbers were used in the second step of our model.
The parameters and criteria used in our model, as detailed in Table 6, were rigorously sourced from official internal Iranian TDF documents. These included:

1. The ITDF statute and foundational bylaws.
2. Official operational guidelines and procedural manuals.
3. Historical project evaluation records and funding protocols.

This ensures that the model's inputs, such as budget constraints, strategic weighting criteria, and funding rules, are grounded in the actual operational framework of the fund, thereby enhancing the practical relevance and validity of our study.

In the second step, planning for 6 periods and 8 technology fields was considered and the number of technological projects (P) is among 10 to 30 for each technology field. Staged financing is done in three stages with regard to the technical progress assessment results, moratorium period for loans is considered 1 period and their repayment should be done in 3 periods. The problem parameter settings are presented in Table 6.

There were three sets of interdependent projects and three sets of inconsistent projects (Table 7). Inconsistent projects could not be selected and started at the same period.
The weights α and β used in the RMCGP model (row 1 in Table 8) were determined through a structured

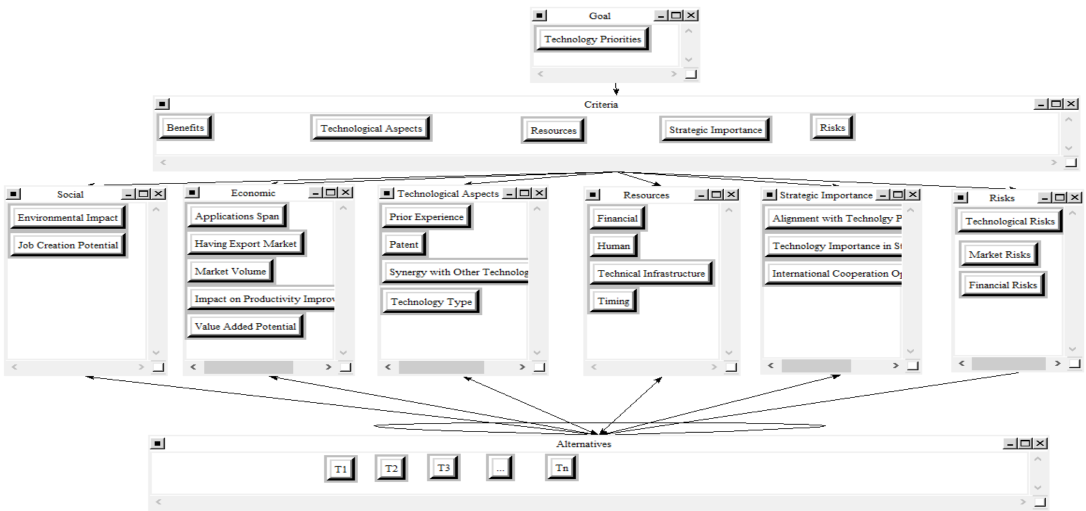
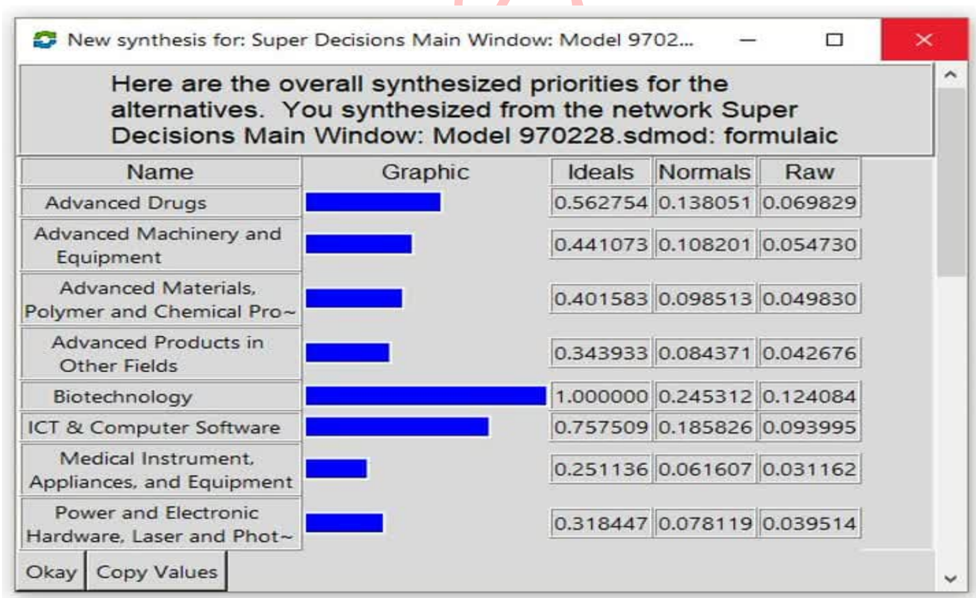


Figure 6: ANP model to prioritize technology fields in Iranian TDF


New synthesis for: Super Decisions Main Window: Model 9702...

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: Model 970228.sdmod: formulaic

Name	Graphic	Ideals	Normals	Raw
Advanced Drugs		0.562754	0.138051	0.069829
Advanced Machinery and Equipment		0.441073	0.108201	0.054730
Advanced Materials, Polymer and Chemical Pro~		0.401583	0.098513	0.049830
Advanced Products in Other Fields		0.343933	0.084371	0.042676
Biotechnology		1.000000	0.245312	0.124084
ICT & Computer Software		0.757509	0.185826	0.093995
Medical Instrument, Appliances, and Equipment		0.251136	0.061607	0.031162
Power and Electronic Hardware, Laser and Phot~		0.318447	0.078119	0.039514

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Figure 7: Priority number of technology fields

process involving five senior managers and policy experts from ITDF. Then, three objective functions were prioritized using the simple average method. The final weights used in the base scenario were $\alpha = (0.4, 0.3, 0.3)$ and $\beta = (0.4, 0.3, 0.3)$.

Table 6: Parameter settings

Parameter	Value	Unit	Parameter	Value	Unit
T	6	Number	r	0.11	%
J	8	Number	A	0.33	%
G	10-30	Number	P_j	0.06-0.24	%
S	3	Number	$P_{\min}$	0.09	%
$\Delta TRL_{\min}$	1	Number	ROI_{jg}	0.12-0.37	%
t_{gr}	1	Number	$ROI_{\min}$	0.13	%
t_{re}	3	Number	pr_{jg}	0.01-1	%
K	3	Number	$\mathrm{Ca}_{\max}$	200	M $
n	3	Number	$\mathrm{Ca}_{\min}$	100	M $
TLF_{jg}	0.1-1	%	D_{jg}	1.6-20	M $
$Tech_{jg}$	0.04-1	%	Ma_{jg}	0.6-5	10M $

Table 7: Technology fields and project relationships

Technology fields	Technological Projects	
Interdependent projects	T1	P1 and P7
	T2	P3 and P5
	T5	P1 and P4
Inconsistent Projects	T1	P15 and P30
	T4	P1 and P7
	T6	P3 and P18

5.2 Implementation and evaluation

The results of implementation of our model in the real case study, is presented in this section. These results are obtained by the GAMS 24.1.2 on a laptop with Intel core i5 processor with 1.6GHz of CPU and 4 GB Ram. Table 8 shows computational results of solving the problem under different weights of the objective functions and deviations. The rows 2 to 5 in table 8 shows the sensitivity analysis on the objective weights (α, β). As seen in Table 8, with decreasing the weight of the third objective function, i.e. the risk function, the value of the objective function Z improves while the number of approved projects and the amount of allocated resources increases significantly. The results show the great impact of risk objective function on the number of approved projects and allocated resources. For example, reducing the risk function weight from 0.3 to 0.1 (row 1 to row 5 of the Table 8) results in more than 5 times increase in the number of approved projects and about 10 times increase in the allocated resources to technological projects.

The optimal composition and schedule of technological project portfolio, their staged financing, moratorium period, and repayment period for a sample of projects is shown in Figure 8 and Figure 9. Thess results corresponds to the row 5 of the Table 8.

The key insights derived from Figure 7 and Figure 8 can be summarized as follows:

Table 8: Objective values and main decision variables

	Weights		Objective Function Values				Decision Variables			
Row	α_i	β_i	Z (GP)	Z_1	Z_2	Z_3	$\sum_j Y_j$	$\sum_{j,g,t} \sigma_{jgt}$	$\sum_{j,t} B_{jt}$	$\sum_{j,g,t,s} X_{jgts}$
1	$(0.4, 0.3, 0.3)$	$(0.4, 0.3, 0.3)$	18.392	1.227	4.383	3.478	2	12	22.176	22.176
2	$(0.35, 0.35, 0.3)$	$(0.35, 0.35, 0.3)$	20.131	1.227	4.383	3.478	2	12	22.176	22.176
3	$(0.4, 0.4, 0.2)$	$(0.4, 0.4, 0.2)$	21.517	4.099	15.549	25.659	5	41	94.71	94.71
4	$(0.45, 0.4, 0.15)$	$(0.45, 0.4, 0.15)$	20.474	4.99	18.228	34.124	5	48	127.6935	127.6935
5	$(0.5, 0.4, 0.1)$	$(0.5, 0.4, 0.1)$	18.762	6.764	26.202	70.893	5	65	217.4865	217.4865

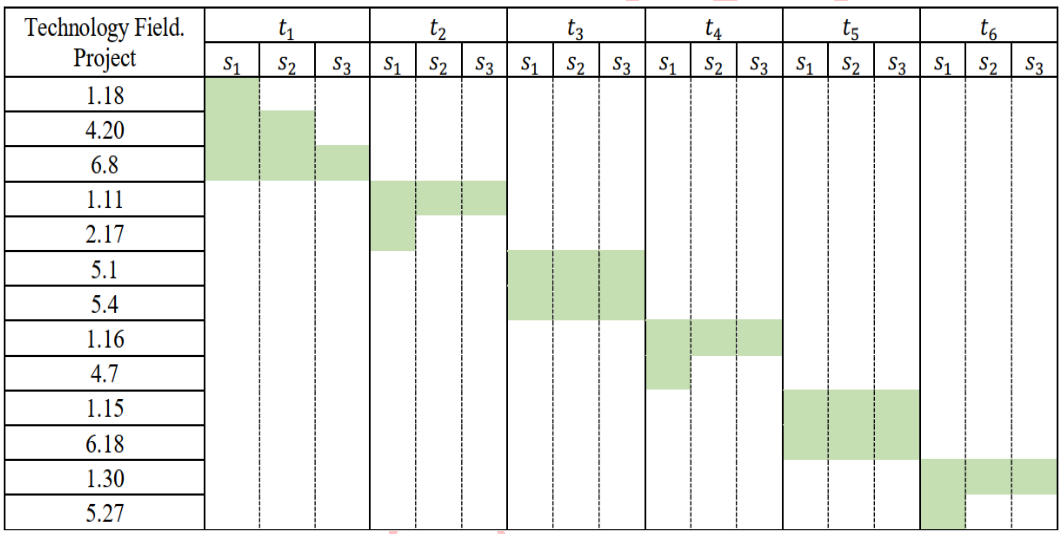

Figure 8: Sample technological project's scheduling and staged-financing

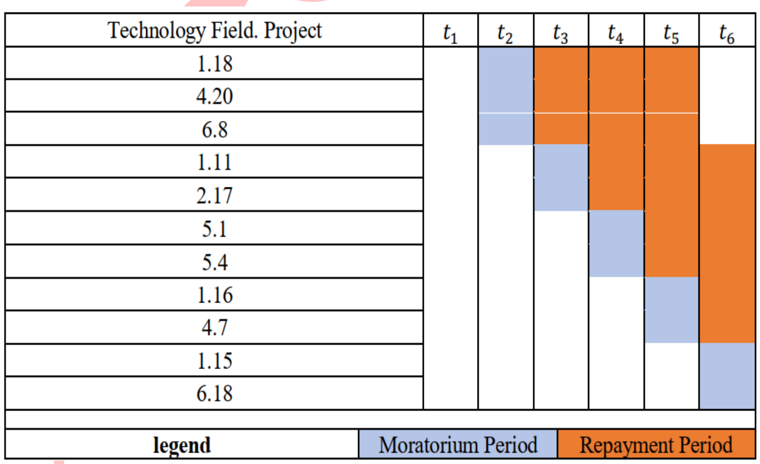

Figure 9: Sample technological project's Moratorium and repayment period

1. **Staged financing mechanism:** Project funding is administered incrementally, contingent upon technical evaluations at each stage. Projects that fail to demonstrate adequate progress are discontinued from further financing. For instance, projects P18, P17, P7, and P27—belonging to technology fields 1, 2, 4, and 5 respectively—did not meet the required technical benchmarks and were terminated after the initial stage.

2. **Selection of interdependent projects:** Among the interdependent projects, only P1 and P4 from technology field 5 were initiated concurrently in time period (t_3).

3. **Selection of inconsistent projects:** In technology field 1, both P15 and P30 were selected despite differing start times (t_5 and t_6 respectively). In contrast, within technology fields 4 and 6, only P7 and P18 were chosen, while their respective inconsistent counterparts P1 and P3 were not included in the final portfolio.

4. **Moratorium period consideration:** The model incorporates a grace period following project initiation, during which loan repayments are deferred. Repayment obligations commence after this moratorium period.

5. **Loan repayment schedule:** Repayment spans three periods following the moratorium. For example, projects P18, P20, and P8—associated with technology fields 1, 4, and 6 respectively—begin repayment in period 3 and conclude by period 5.

5.3 Analysis and managerial insight

In its approach to supporting knowledge-based enterprises, the Iranian Technology Development Fund (ITDF) adopts a risk-tolerant stance, prioritizing national strategic objectives—such as boosting high-tech exports and fostering international technological collaboration—over minimizing financial risk. Accordingly, we conducted a detailed analysis of the scenario in which the risk minimization objective carries the lowest weight (see Row 5 of Table 8).

Figure 9 presents data on total financing and the number of approved projects across technology fields. As shown in Figure 10.a, Technology Fields 3 (Power Electronics, Laser, and Photonics), 7 (Medical Devices), and 8 (Other Advanced Products) were excluded from selection due to their low priority scores. In contrast, Technology Field 5 (Advanced Machinery and Equipment) received the highest level of funding. This is attributed to its substantial export potential and the broad applicability of advanced machinery, which results in a higher Technology Leverage Factor (TLF) compared to other fields. Technology Fields 4 (ICT & Software) and 6 (Advanced Drugs) ranked second and third in terms of total financing, reflecting their strong prospects for export growth and international cooperation.

Figure 10.b illustrates the distribution of approved projects. The highest number of approvals 16 projects each occurred in Technology Fields 1 (Biotechnology) and 5 (Advanced Machinery and Equipment). Conversely, Technology Field 2 (Advanced Materials, Polymers, and Chemicals) had the fewest approved projects, a result of its lower priority score and limited export potential.

The key findings of the model and their managerial and policy implications are synthesized in Table 9.

This structured analysis demonstrates that the proposed model serves not only as a quantitative optimization tool but also as a framework for improving governance, enhancing accountability, and creating stronger alignment between resource allocation and national technology development goals. We also assessed the technology fields based on their potential in export markets. As illustrated in Figure 11,

Table 9: Managerial insights and policy implications

Category	Key insight	Recommended action
Strategic focus	Fields with high export potential and TLF (e.g., Advanced Machinery) deliver superior strategic returns.	Concentrate resources on 3-5 top-priority fields identified through ANP. Avoid dilution across too many domains.
Risk management	Staged financing with TRL gates successfully identifies and terminates 25% of underperforming projects early.	Implement mandatory periodic TRL assessments with independent review panels to monitor technical progress.
Portfolio optimization	Risk tolerance dramatically affects portfolio size: reducing risk weight from 0.3 to 0.1 increases projects 5x and funding 10x.	Use the model as a simulation tool to visualize trade-offs between project volume, export value, and risk before finalizing allocations.
Execution capability	Completion rates vary significantly by field: Drugs (high) vs. ICT (low), indicating domain-specific execution challenges.	Integrate firm capability assessment into project evaluation, with tailored support (e.g., mentoring) for high-risk domains.
Market realities	Global competition creates natural barriers in some fields (e.g., Drugs), limiting export potential despite high priority.	Calibrate export expectations by field; emphasize import substitution for domestically strategic but globally constrained fields.

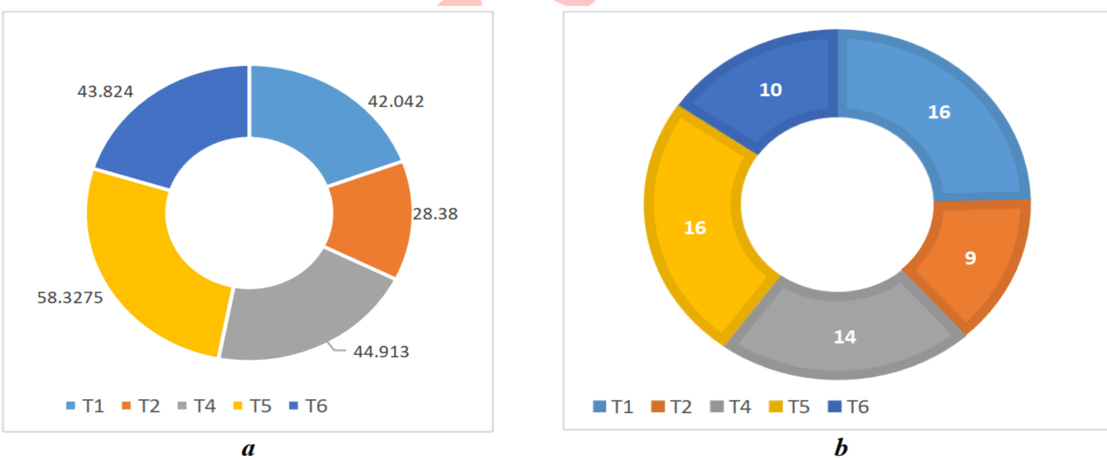

Figure 10: Total financing (a) and total approved projects (b) by technology field

Technology Field 5 (Advanced Machinery and Equipment) which has received the highest volume of financial support and hosts the largest number of approved projects demonstrates the strongest export potential. In contrast, Technology Field 6 (Advanced Drugs) shows limited opportunities for international market penetration. This is primarily due to the dominance of well established global pharmaceu-

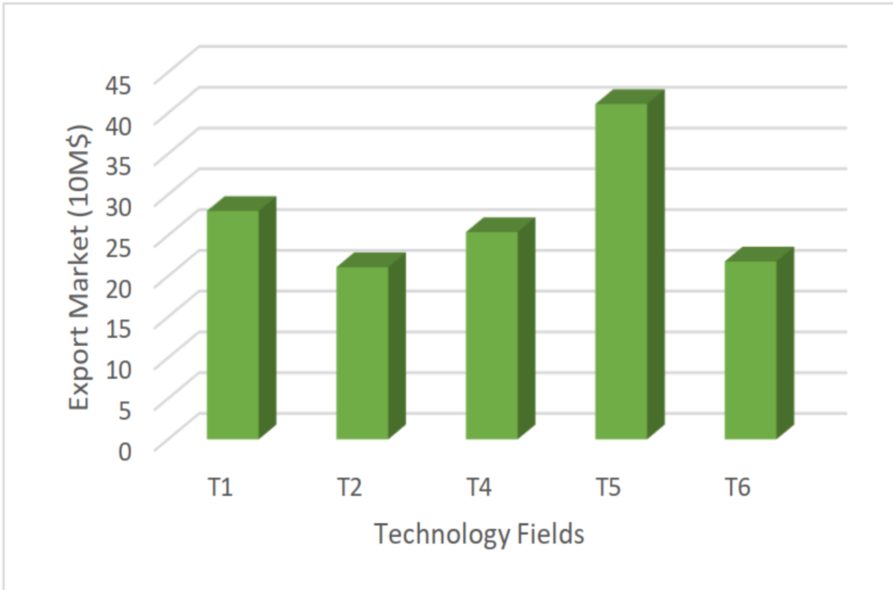

Figure 11: Export market by technology field

tical companies, which pose significant barriers to entry for emerging firms in this sector. To evaluate company performance across various technology domains, two key indicators were established:

1. **Completion ratio:** The share of completed projects relative to the total number of approved projects in each technology field.

2. **Financing efficiency:** The proportion of total funding allocated to completed projects within each domain.

Here, "completed projects" refer to those that have demonstrated sufficient technical progress at each stage and have successfully received funding across all three financing phases.
As illustrated in Figure 13, the highest number of completed projects is observed in Technology Field 6 (Advanced Drugs), indicating strong execution capabilities in this sector. In contrast, Technology Field 4 (ICT & Computer Software) shows the weakest performance, suggesting that while many firms initiate ICT-related projects, a significant portion fails to reach completion.
Regarding the second metric, Figure 12 reveals that Technology Field 1 (Biotechnology) leads in financing efficiency, with companies in this domain demonstrating higher success rates in executing their projects. Again, Technology Field 4 ranks lowest, reflecting a comparatively poor track record in project completion and effective use of financial resources.

Given the absence of systematically recorded project-level data tied to strategic outcomes in ITDF's historical allocations, we employ a qualitative approach to validate our model's advantages. Through structured interviews with five senior ITDF managers, we identified that the current resource allocation process, while nominally aiming to enhance high-tech exports, operates without a formal multi-criteria optimization framework and model. The evaluation of project proposals is conducted primarily based on financial viability and market analysis, with limited explicit consideration of:

Figure 12: The proportion of completed projects to the total number of approved projects

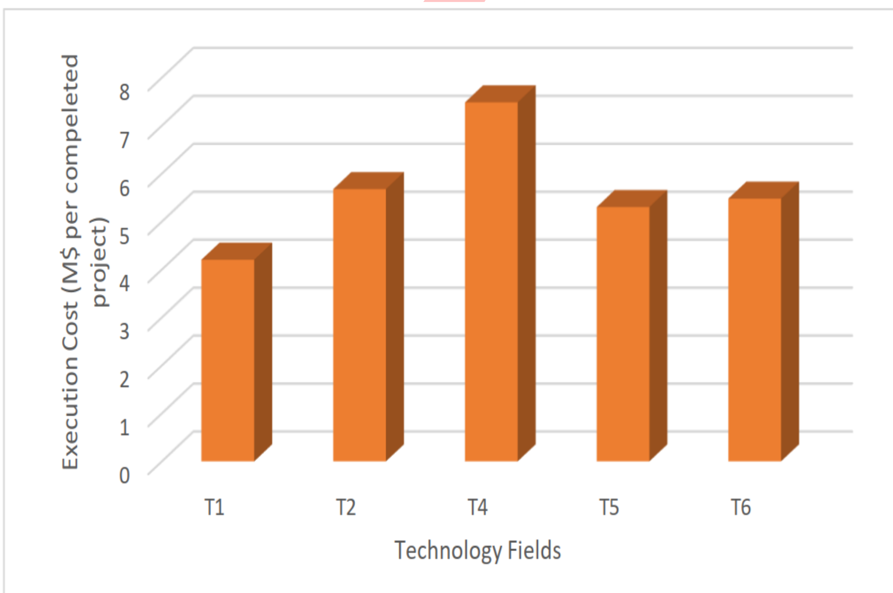

Figure 13: The proportion of total financing to completed projects

1. Strategic alignment with national technology priorities.

2. Potential for international technological cooperation.

3. Dependency and inconsistency between projects.

4. Systematic assessment of technological maturity and progress via TRL gates.

5. Portfolio-level risk management across technology fields.

This leads to a reactive, project-by-project approval process that results in a sub-optimal distribution of resources across technology domains, irrespective of their strategic importance, export potential or potential for technological cooperation.

6 Conclusion

This study proposed a novel two-stage multi-objective model to address the strategic challenge of technology portfolio selection and financing within national TDFs. By integrating the ANP for strategic technology field prioritization with RMCGP for operational project selection and dynamic financing, the framework effectively bridges a critical gap between high-level STI policymaking and project-level execution. The application of the model to a real-world case study of the Iranian TDF confirm that the model provides a rigorous, transparent, and data-driven tool for TDF managers to maximize the impact of public innovation investments.

Despite its contributions, this study is subject to several limitations that also present opportunities for future research. First, the model relies on deterministic input parameters. In reality, factors like project cost, return on investment, and technical success are inherently uncertain. Future work could significantly enhance the model's robustness by incorporating fuzzy logic or stochastic programming to handle these uncertainties explicitly. Second, while the model is computationally efficient for the presented case, solving the MILP formulation for extremely large-scale problems (e.g., involving thousands of projects) might become challenging. Exploring the development and application of metaheuristic algorithms, such as genetic algorithms or simulated annealing, would be a valuable direction for scaling the model to national-level portfolios with a vast number of proposals. Finally, the model's effectiveness is dependent on the availability and quality of data from the TDF. Broader application would benefit from the establishment of standardized data collection protocols across different national funds. By addressing these limitations, future research can build upon the foundation laid by this study to create even more powerful and adaptable decision-support systems for national innovation strategy.

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