Evolutionary learning methodology: A case study of R&D strategy development

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Abstract

This article concerns the notion of methodology in strategic management of R&D/technology. Though development of new tools and methods has received much attention during the recent decades, attention to understanding methodologies has remained disproportionally low. In this study we distinguish two methodologies that are used in strategic management of R&D/technology: planning methodology and evolutionary learning methodology. We mainly focus on defining and describing the origins, nature, and characteristics of the latter. We propose a framework for methodology selection by investigating context, content, and process factors. Using this framework, we provide supportive evidence for appropriateness of evolutionary learning methodology to develop a robust R&D strategy for Iran’s power industry. We then describe the details of operationalizing the methodology for the Iranian power industry. This study is particularly focused on delineating how evolutionary learning methodology can be applied as an effective framework to improve the formation method and content of R&D strategy. We conclude that methodological knowledge can provide a powerful lens with which to understand performance of methods, and we suggest that evolutionary learning methodology is particularly appropriate for the following situations: when the environment is uncertain or fast changing, when there exist many stakeholders with conflicting interests, and when a method needs to be applied in a context other than the one for which it was initially developed.

Keywords: Methodology; Evolutionary epistemology; Learning; R&D strategy; Roadmapping; Expert judgment

1. Introduction

Literature of R&D and technology management contains several methods of strategy development. Methods usually come with explanations and sometimes with arrow-box algorithms to outline how to operationalize them. Practitioners and scholars readily distinguish methods based on their steps and procedures. Nevertheless the profusion of methods brings about a natural yet important question: ‘how can one select among methods?’ This is a question not extensively investigated in the literature. Recognizing stepwise and procedural distinctions, though helpful, may not provide adequate insight to select and operationalize the appropriate method, especially if the selection process is not supplemented by knowledge of methodological underpinnings. In this article we explore the methodological origins of methods and introduce the concept of methodology selection to delineate how one may approach the problem of method selection. We start by investigating the fundamentals of differences among methods and how such differences affect R&D strategy and its formation process. Then we introduce the issue of methodology selection as a way to decide between methods at a meta-level.

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A noticeable deal of ambiguity surrounds the expression ‘the methodology of ...’. The term ‘methodology’ is sometimes used simply as a more impressive-sounding synonym for method [1]. However as the etymological roots of the term suggests, methodology denotes an investigation of concepts, theories, and basic principles of reasoning of a subject [1]. We adopt this wider conceptualization of the term in this article.

Methodological origins are the root of some of the most significant differences between methods of crafting R&D strategy. Some methods look at R&D/innovation strategy from the perspective of planning or positioning schools and have a rational approach to strategy formulation [2–5]. Alternatively, some recent methods apply an incremental, evolutionary approach to craft R&D/innovation strategy and have a learning perspective to the process of strategy formation (e.g. [6,7]). Such differences are meta-level to methods; i.e., they are not simply differentiated by the steps taken by the methods, but rather the differences stem from the adoption of different methodologies.

Although attributes of different strategy formation methods have been discussed in a few studies (e.g. [2]), the notion of methodology, on the one hand, and methodological differences, on the other, have not been explicitly employed. In this article, based on attributes of a number of widely applied methods of crafting R&D strategy, we distinguish two methodologies: planning methodology and evolutionary learning methodology. We then employ a case study to explore the issue of deciding between methodologies and applying an evolutionary learning methodology to develop and improve method and strategy.

This study contributes to the literature of R&D, innovation, and strategic management in three ways. First it enhances the familiarity of management scholars and practitioners with the notion of methodology. This familiarity helps managers select more effective methodologies and apply them more efficiently in the development of strategies. For scholars, familiarity with the notion of methodology is a prerequisite for further elaborations and applications of the concept. Furthermore, it helps scholars to find a deeper understanding of the strategy formation process and the role of methodology.

Second, this study distinguishes two major methodologies in strategic management of R&D, planning methodology and evolutionary learning methodology. In particular we delineate the origins of, rationale behind, anticipated consequences of applying, and associated attributes of evolutionary learning methodology. Our article is also among the first that explicitly studies the problem of methodology selection rather than method selection and introduces context, content and process factors [8] to investigate appropriateness of a methodology.

Finally this paper includes a case study that illustrates the application of evolutionary learning methodology. Using this case study, we present the procedure through which we investigate context, content, and process factors [8] to decide on methodology. We further show how the methodology can be applied to tailor methods in order to better respond to a specific problem and how the R&D strategy, along with its method of formation, may evolve.

2. Methodology in R&D strategy

Role of industrial research and development in determining the outcome of World War II was so influential that the next two decades after the war were dominated by the widely adopted belief that R&D inevitably brings rewards [9,10]. Though questioning this belief started in 1960’s, it took until the 1970’s and early 1980’s for several companies to realize that a considerable amount of their R&D effort was misdirected and had indeed remained unrewarded. It was then that managers began to pursue developing an explicit strategy for their R&D activities [9–12]. Strategy was a relatively young field of business studies at the time and not well connected to the practice of R&D management. Strategy formulation was known as the act of devising a medium- to long-term plan. It was mainly done by using a number of methods to systematically gather and thoroughly analyze data [13]. Expectedly, early attempts to introduce and develop R&D strategy or technology strategy applied the readily available planning perspective [14,15]. However, about the same time as the notion of R&D/technology strategy was emerging in the literature of technology management [9,16], so too was the perspective of learning in the literature of strategic management [17]. It again took a few years for the learning perspective to fully work its way into R&D/technology strategy in the 1990’s, when methods that relied on learning were widely introduced and employed [6,18].

Current literature on R&D and technology management contains several methods to develop R&D strategy. Hence a decision-maker regularly finds herself in a position of selecting a method that best matches the requirements of her case. Such a decision requires understanding of concepts, theories, and basic principles of reasoning in methods, which in turn requires methodological investigation or at least methodological understanding. Reviewing the history of as well as current literature of R&D management helps distinguish two major methodologies to develop R&D strategy. We name them ‘planning methodology’ and ‘evolutionary learning methodology’. In the following sections, we describe and contrast these two methodologies, though the emphasis is on introducing the latter methodology.

2.1. Planning methodology

A so-called ‘rational’ or ‘analytical’ approach dominated the early years of strategic management and has maintained its relevance and value, though not dominant, to the present. Using this approach Stewart [19], Ansoff [20], and later Porter [15,21], and recently Kim and Mauborgne [22], among others, introduced a number of methods to formulate a strategy. Planning methodology in R&D strategy has borrowed the rational approach from strategic management [13–15]. Passion to minimize the level of potential inaccuracies and the chance of making mistakes lies at the heart of planning methodology. Satisfying this passion is pursued through systematic data gathering followed by systematic data processing in the strategy formulation [not formation] process. The presumption is that validity and reliability of crafted strategy are straightforward consequences of
accurate and precise data analysis [2]. Among the R&D/technology strategy formulation methods that were developed based on planning methodology are Hax and Majluf’s method for technology strategy formulation [23], Porter’s technology value chain [21], Morin’s portfolio analysis matrix [24], Hax–Porter–Morin combined method [25], Chiesa’s method for strategic management of R&D projects [26], and Ford and Saren’s model to select between development modes [27].

In planning methodology, R&D strategy is formulated by operationalizing a method that is already almost fully developed. Hence the method is not subject to improvement during the strategy formulation process, and the entire effort is focused on increasing the quality of strategy by best operationalizing the selected method. Those who operationalize the method mainly consist of strategy experts, but the output of the process, i.e., the R&D strategy, must be further implemented by managers. Hence strategy is considered as a deliberate plan with formulation and implementation being separate processes [2]. Strategy formulation is either a one-time event or a sequence of one-time formulation events that are far apart in time and not systematically connected through their method and/or content of strategy.

2.2. Evolutionary learning methodology

Evolutionary epistemology as a framework for growth of scientific knowledge was introduced by Popper in the 1950’s [28]. In this framework, “the methodology of science consists of learning from our mistakes systematically: first by taking risks; by daring to making mistakes – that is by boldly proposing new theories; and secondly, by searching systematically for discovering the mistakes we have made – that is by critical discussion and critical examination of our theories [29]”. Popper propounds four steps for his framework (Fig. 1): i) selecting a problem to solve, ii) proposing a tentative solution (e.g. a theory, a method, or a plan), iii) critical discussion on a proposed solution to detect and eliminate some errors and flaws, iv) further critical discussion as even our best solutions are not flawless. Most characteristic of a scientific methodology, as delineated by the above four steps, is error-elimination through criticism [28].

Though some pioneering scholars of strategic management, such as Ansoff [30] and Mintzberg [2,17], elaborated on how to incorporate the notion of incremental learning into strategy development, several attributes of evolutionary epistemology, in particular systematic involvement of experts to critically discuss the strategy, were missing from their initial approach to strategy development [31]. A few methods of crafting R&D strategy or policy, such as roadmapping and technology foresighting [32–34], which had been publicly introduced in the 1980’s [35,36], were reintroduced during the 1990’s [37,38] when they were transformed to conform to the methodological framework of evolutionary epistemology [6,39–41]. In these methods, R&D strategy is as an emergent entity that is incrementally formed [not formulated] through decisions made, actions taken, and directions set by people who are involved in the strategy formation process [2]. A basic assumption is that the complex and uncertain nature of R&D activities, coupled with the diffusion of bases necessary for R&D strategy, precludes planned control. So, strategy-making takes the form of a process of learning over time in which, at the limit, formation and implementation become indistinguishable [2]. A well-crafted R&D strategy is sought through continuous repetitions of the process. Both content and process (including method of strategy formation) are subject to improvement. What is learned can be applied to subsequent repetitions; and thereby an evolutionary system is created for continuous improvement [6]. The methodology of this set of methods hereafter is referred as ‘evolutionary learning methodology’.

Popper’s epistemological framework has contributed to evolutionary learning methodology in many ways. Evolutionary learning methodology has an incremental approach [5,42,43] to strategy, in which both process and results are criticized by experts in all iterations. Through an interactive critical discussion, errors are first identified, and then some appropriate solutions are proposed to eliminate them. In this methodology, the role of strategy experts is not to implement preconceived methods, but to facilitate the process of collective learning, whereby methods and strategies can emerge.

In evolutionary learning methodology, our knowledge about appropriateness of the strategy and its formation method is hypothetical and conjectural and can be grown by learning from mistakes. Even the best methods and strategies are not completely flawless. The results of discussion are very often inconclusive in the sense that we cannot conclusively verify or falsify any of the solutions under discussion. If we are lucky, however, we may sometimes conclude that one of the solutions has greater merits than the others. In such instances we may decide to accept the solution or theory, of course only for the time being [28,29].

The emphasis of evolutionary learning methodology on error-elimination makes it suitable for dynamic, complicated, unstable, or uncertain contexts [44] where new findings or situations may make previously appropriate decisions inappropriate. Since the methodology takes advantage of extensive critical discussions and judgment of experts, it is particularly strong in exploiting non-codified and tacit knowledge [45]. The methodology also proves suitable when decision-makers have incongruent or unstable interests since discussions increase the chance of reaching consensus or agreement on a decision [44]. Finally the first version of R&D strategy may be developed at a faster pace using methods that conform to evolutionary learning methodology.

Competence in exploiting non-codified knowledge makes the codification of many intermediary results unnecessary. The faster

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Fig. 1. Steps of the evolutionary epistemology methodology (adopted from [28,29]).
pace is also a consequence of decreased emphasis on gathering extensive data and employing complicated analytical techniques, which can be time consuming and costly, particularly in complicated, uncertain, and changing environments.

2.3. Complementary or mutually exclusive?

Planning methodology and evolutionary learning methodologies differ in a variety of categories. Table 1 summarizes the categories of differentiation. Nevertheless such differences do not necessarily make the two methodologies drastically distinct. Methods that conform to evolutionary learning methodology still need to take advantage of some data and analytical tools. Evolutionary learning methodology should not initially welcome errors in order to later eliminate them! The methodology encourages a reasonable effort to do a good job in each of the iterations; however, it does not obsess over the accuracy of any single iteration. Some data gathering and analysis can also work as a judgment support tool for experts. Judgment of experts may be affected by group thinking and a number of other biases. It has been shown that presence of informed facilitators and access to supplementary information can help prevent undesired effects of such phenomena [44]. On the other hand, methods that conform to planning methodology do not intend to preclude learning or critical discussion. It is natural to think that organizations add to their experience—i.e., learn from—a strategy formulation event no matter which methodology they use. However, opposed to evolutionary learning methodology, planning methodology is not systematically focused on taking advantage of learning, critical discussions, and error elimination. Though the two methodologies are theoretically distinct, they are not necessarily mutually exclusive in practice. Scholars and managers usually find methods dominated by one methodology and supplemented by the other, so two methodologies normally turn out to be complementary in practice [2,46].

3. Crafting R&D strategy: The case of Iran’s power industry

This section is devoted to a case study of the electric power industry in Iran. The case study represents how evolutionary learning methodology can be applied in the process of crafting R&D strategy. We particularly focus on three aspects: exploring the issue of deciding between methodologies, delineating roles of critical discussion and experts’ judgment, and illustrating the evolution of methods.

Iran’s power industry consists of both governmental and private sectors. By the end of 2011, 79% of total installed electricity generation capacity of the country was government-owned. A privatization plan is ongoing in the industry, but the pace of its advancement drastically differs across segments. The transmission segment has remained completely government-owned. In the distribution segment, many operations have been contracted out regionally, but its management and a minor share of operations have remained governmental. Government-owned corporations used to have a dominant role in production and procurement of equipment and other goods and services, but this has changed radically during the last two decades. Currently almost all production, procurement, and professional service activities are performed by private corporations. Management of governmental operations and development of industry-wide policies are done mainly by Iran Generation, Transmission, and Distribution Management Corporation (TAVANIR), which is a subdivision of Iran’s Ministry of Energy. TAVANIR administers 16 Regional Electric Companies (REC) that together cover all parts of the country. Each REC manages all governmental operations in its assigned geographical area. R&D activities of the industry have also been divided between governmental and private sectors.

Table 1

<table>
<thead>
<tr>
<th>Categories of differentiation</th>
<th>Planning methodology</th>
<th>Evolutionary learning methodology</th>
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<tbody>
<tr>
<td>Underlying logic</td>
<td>Minimize the potential of making errors Strategy</td>
<td>Maximize the potential of detecting problems/ errors Method Strategy</td>
</tr>
<tr>
<td>Objects of excellence</td>
<td>Emphasis on extensive data gathering followed by systematic data mining</td>
<td>Emphasis on critical discussions based on judgment of experts and managers</td>
</tr>
<tr>
<td>Means</td>
<td>A one-time strategy formulation event or a far-apart sequence of loosely connected strategy formulation events</td>
<td>A continuum of deliberately connected strategy formation events</td>
</tr>
<tr>
<td>Process</td>
<td>Separate or loosely overlapped More suitable when interests of stakeholders are stable and generally congruent</td>
<td>Highly overlapped More suitable when interests of stakeholders are unstable and incongruent</td>
</tr>
<tr>
<td>Developer-implementer linkage</td>
<td>Characteristics of stakeholders Excellent at exploiting codified knowledge</td>
<td>Competencies employed Excellent at exploiting non-codified knowledge</td>
</tr>
<tr>
<td>Environmental context</td>
<td>More suitable for stable, linear, certain environments</td>
<td>More suitable for dynamic, complicated, uncertain environments</td>
</tr>
<tr>
<td>Codification</td>
<td>Codification and storage mainly required for intermediary information, emphasis on excellence in codifying the strategy</td>
<td>Codification and storage kept at minimum required level, emphasis on excellence in transferring a tacit mutual understanding of strategy</td>
</tr>
<tr>
<td>Time to craft first version of strategy</td>
<td>Relatively long Strategy</td>
<td>Relatively short</td>
</tr>
</tbody>
</table>

An iterative process to improve method and strategy Strategy
Niroo Research Institute (NRI) is by far the largest research institution of the industry and is government-owned. Niroo Technology Center (MATN) and Abbaspour University are two other research institutions. The former has been privatized recently, and the latter is a state university established and supported by the Ministry of Energy. In addition, TAVANIR and each REC have their own R&D departments, which usually perform research projects related to regional or organizational operations [47]. In our case study, NRI is employed by TAVANIR (as the project employer) to develop the R&D strategy of Iran’s power industry.

Several factors make the case of Iran’s power industry a rich context for our purposes. First, the case of R&D strategy development for Iran’s power industry is a large-scale initiative that includes many governmental or public institutions and private corporations with, at times, incongruent or conflicting interests. Hence the case study presents a context with complexity of dynamics, impacts of interests, and uncertainty about the nature of interactions. Second, the case happens in a developing country and a distinct socioeconomic context, which provides a rich environment for exploring difficulties with applying a method in a context dissimilar to that in which the method was originally developed. Third, the case explicitly addresses the issue of methodology selection and introduces and employs a framework for investigating factors that are related to a methodological decision. Finally, as a result of relatively low competitive pressure and reliance on governmental support, the electric power industry in Iran, as in some other countries [48], has traditionally suffered from undervaluing research, hence under-investing in research activities other than applied ones. In such a context, R&D strategy might remain largely a plan on paper unless the link between development and implementation of strategy was deliberately and continuously established and strengthened.

3.1. Deciding the methodology

Distinguishing between planning methodology and evolutionary learning methodology begs the question of how to evaluate appropriateness of a methodology for a R&D strategy development event. De Wit and Meyer [8] discuss attributes of the context in which strategy development takes place, requirements and preferences regarding the process of developing the strategy, and requirements and expectations about the content and the implementation of strategy as triple factors in any decision about methodology. They name these factors, respectively, context, process, and content factors [8].

Context factors originate from extant conditions and facts in the industry. In our proposed framework, context factors include organizational structure of the industry, status-quo of R&D projects portfolio, and existing related strategies and policies. Process factors correspond to issues that stem from courses of actions required to develop R&D strategy. In the proposed framework, process factors include procedural requirements and expectations (answers to the question of ‘who?’), characteristics of main players in the process of strategy development (answers to the question of ‘who?’), and timing requirements and preferences (answers to the question of ‘when?’). Content factors concern expectations and requirements about ingredients of the strategy (answers to the question of ‘what?’) and characteristics of those who are expected to implement the strategy (answers to another question of ‘who?’).

We applied the triple factor framework to perform methodological investigations in the case of the Iranian power industry. As the first step to operationalize the framework, a group of strategy and R&D management experts 1 (the executive group of the project) explored context, process, and content factors in the industry. They searched for and studied important documents (namely policies, plans, and major regulations) and conducted interviews with a dozen middle managers from some major organizations of the industry. By doing so, the executive group enhanced and updated their familiarity with the industry in terms of triple factors and also prepared a list of issues that could possibly be related to each of the context, content, and process factors. Following Gregory, Fischhoff, and McDaniel [44], we expected that prior exposure to such explicit as well as tacit information would help our executive group members better play their role as facilitators in the next step of methodological investigations.

In the next step we invited a number of R&D managers from NRI, MATN, and the R&D department of TAVANIR to focus group meetings. Each focus group consisted of 5 to 6 managers, 2 strategy experts, and a university professor whose expertise was in R&D management. Each panel was aimed at discussing one of the context, process, or content factors. Strategy experts played the role of facilitators in these meetings, where they could take advantage of their knowledge of the industry and the initial prepared list of related issues to supplement discussions so as to better exploit the participants’ knowledge of potentially related factors. Each meeting lasted 4 to 5 h, out of which was prepared a summary of important findings regarding one of the triple factors along with their implications for development of R&D strategy. Tables 2, 3, and 4 present summary findings and implications respectively for context, process, and content factors.

As these summary tables show, findings from applying the triple factor framework and their implications suggested that we needed to address the interests and comments of multiple stakeholders, provide flexibility to revise the strategy, help inexperienced decision-makers to learn-by-doing throughout the process of strategy development, and craft the first, even if not the best, version of strategy as fast as possible. These requirements were more harmonious with attributes of evolutionary learning methodology as summarized in Table 1. Furthermore, another implication suggested that we might need to design a method of R&D strategy development and further modify it rather than use a readily available method. Evolutionary learning

1 The group consisted of six members with master degrees either in management of technology or economics. The group members had from at least one to up to seven years of management consulting experience in strategic or R&D/technology management. Four of them had done their undergraduate studies in power engineering, and out of the four, two members had also some work experience before they started to work as consultants. Two out of six members had also experiences with R&D strategy development projects in other industries. One of these two was the manager of the project.

2 Those interviewed consisted of managers from the first and second largest research institutes in the industry (namely NRI and MATN), two government-owned policy-making organizations, and eight of the largest Regional Electric Companies.
methodology came with a built-in potential to modify and improve methods. Finally some other implications required linking vaguely defined upper-level policies to R&D strategy despite the fact that intermediary action plans were not documented. Evolutionary learning methodology again could meet this requirement better, since it could provide the chance to interpret vague plans through discussions and was superior in exploiting non-codified or tacit knowledge. Considering the above requirements, making a final decision about the methodology did not seem to be a marginal one in our case. Since the majority of requirements were clearly in favor of evolutionary learning methodology, this methodology was opted for.

Fig. 2 illustrates the steps of evolutionary learning methodology taken to craft R&D strategy in Iran’s power industry along with corresponding steps from evolutionary epistemology. Step one introduces the focal problem, which is rooted in the lack of R&D strategy in the power industry. This problem can be solved by designing and implementing a strategy formation method. Whatever the content and the formation method of the strategy are, evolutionary learning methodology requires them to be critically discussed, as the third step of the proposed methodology suggests. These critical discussions result in realizing new problems or shortcomings in one or both of the formation method and the content of strategy. Discovering new problems necessitates proposing a new method and/or strategy to resolve them, and the new method and/or strategy again go through the process of critical discussions and error-elimination.

### 3.2. Evolution of method and strategy

Once a problem is recognized and a methodology is selected, proposing a method to solve the problem is the next step. An appropriate method should provide us with a procedure to develop a solution while meeting the methodological requirements. In the case of the Iranian power industry, we needed a method to craft an R&D strategy. The method and the strategy should have the potential to be improved throughout the iterations of evolutionary learning methodology.

### Table 2
Investigating context factors: A summary of findings and implications.

<table>
<thead>
<tr>
<th>Organizational structure</th>
<th>Existing R&amp;D portfolio</th>
<th>Related upper level strategy/policy documents</th>
</tr>
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<tbody>
<tr>
<td>Findings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Strong dominance of governmental ownership in generation and transmission sections</td>
<td>• Existing R&amp;D activities encompass several highly diverse technological as well as non-technological domains such as engineering, design, social science, economics and management, environmental science, and safety</td>
<td>• ‘Vision of power industry’ as an existing document</td>
</tr>
<tr>
<td>• Ongoing privatization plan in generation, transmission, and distribution sections</td>
<td></td>
<td>• Technology strategy of power industry has long been under development and remained unfinished</td>
</tr>
<tr>
<td>• Presence of both private and governmental ownership in equipment manufacturing and design and engineering sections (decreasing share of government as a consequence of privatization)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Governmental funding (either direct or indirect through subsidies and loans) as the main source to finance R&amp;D activities in all sections</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Existence of several research organizations, (both governmental and private) some of them concurrently working on similar projects</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Necessity of adopting a methodology that provides the opportunity to consider the opinions of various stakeholders in strategy formation process</td>
<td>• Formulating R&amp;D strategy may require extensive work in data gathering and analysis</td>
<td>• Necessity to link the industry vision to R&amp;D strategy</td>
</tr>
<tr>
<td>• Necessity of aligning R&amp;D strategy with governmental strategies/policies along with adopting flexibility to promptly revise the strategy as privatization progresses</td>
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### Table 3
Investigating process factors: A summary of findings and implications.

<table>
<thead>
<tr>
<th>How?</th>
<th>Who?</th>
<th>When?</th>
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<tbody>
<tr>
<td>Findings</td>
<td>• Necessity to link the industry vision to R&amp;D strategy despite the fact that vision was stated in very general terms and intermediary documents, such as industry strategy/policy, didn’t exist</td>
<td>• Diversity of stakeholders whose participation in strategy formation process is crucial.</td>
</tr>
<tr>
<td></td>
<td>• R&amp;D strategy development methods that exist in the literature have been neither developed for nor ever applied in Iran’s power industry</td>
<td>• No experience in developing R&amp;D strategy inside the industry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Top managers of the industry strongly preferred fast development of the R&amp;D strategy</td>
</tr>
<tr>
<td>Implications</td>
<td>• Need to use a method that allows for readily generating (though not necessarily documenting) required intermediary information</td>
<td>• Need to give stakeholders the chance to communicate their interests and assure them sure that they have been heard</td>
</tr>
<tr>
<td></td>
<td>• Chances are high that the development method requires modifications before and/or during the development process</td>
<td>• Preference to use a methodology that allows for learning by doing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Need to develop the first version even if it’s not the best version of strategy as soon as possible</td>
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</table>
The case of Iran’s power industry started with an iteration to devise a first version for R&D strategy formation method. The executive group of the project closely collaborated with experienced industry managers and researchers during a two-month period to develop the first version of the method. The main work at this stage consisted of exploring the literature, engaging in theoretical discussions, and embarking on theoretical development of the method. Members of the executive group were the same as those who worked through the methodological investigation. The executive group was supplemented by full-time help from three engineering, environmental, and safety researchers with at least ten years of research experience in the power industry and part-time help from one of the top managers of NRI as well. The group also received consulting advice from a university professor whose expertise is in technology and R&D management and has experience in the power industry. Researchers and managers were involved in the process to ensure that the steps and notions that were adopted in the method could be conceived by them, as they and their colleagues were expected to play a further major role in the process of operationalizing the method to develop the R&D strategy.

Once the first version of the method was developed, we proceeded to operationalize and critically discuss it to eliminate its flaws. Lessons learned from literature on launching new products and applications proved to be insightful at this stage. Gradual increase in the scope of launch of a new product/process is a widely adopted strategy in many industries, as it is known to help in identifying and diagnosing problems with and enhancing the performance of the product/process without largely affecting its public image or incurring the high costs of a large-scale launch [49,50]. Borrowing insights from these findings, we decided to start to implement and critically discuss the method on a small scale. Hence we used focus groups instead of large-scale panels and concentrated the operationalization only on the technical domain, which was one of the seven domains of excellence that had been introduced into the overall process by the industry vision document. As it was conceived, the technical domain was broken into three subdomains: power generation, power transmission, and power distribution. We only focused on power generation. We held three focus groups. Each was devoted to implementing all of the steps of the method that were associated with one layer of a roadmap that we later describe. Each focus group was attended by three researchers with at least ten years of experience related to power generation, three top managers of NRI, two experts in strategic management of R&D, and two facilitators. Researchers and industry managers were mainly focused on step-by-step implementation of the method. R&D management experts were mainly focused on monitoring the process and building an understanding about the problems of the method. However all participants continuously communicated during and at the end of the process so as to make sure that R&D management experts received the maximum attainable intake of information regarding difficulties and problems experienced by researchers and managers.

The process of detecting evidence of flaws and imperfections in the method or strategy and deciding how to respond to them worked as follows. Existence of evidence had to be suggested by at least one of the focus group participants or occasionally by one of the project executive group members, consultants, or facilitators. There was no restriction as to what might constitute evidence of an imperfection in the method or strategy. In practice, focus group participants deemed a variety of phenomena as evidence for possible flaws or imperfections. Incompatibility with certain characteristics of Iran’s power industry, procedural or operational inefficiency, difficulty of use, lack of desired function, missing steps or content, and incompatibility with methodological requirements were among the phenomena that experts perceived as evidence for some kind of flaw or imperfection. If the collective judgment or consensus of the experts was unambiguously confirmative of the presence of a serious imperfection, they could immediately proceed to decide on the nature of and procedure for realizing the required solution. However, the experts sometimes came to the conclusion that although some evidence might be indicative of an imperfection, it was not compelling.

Table 4
Investigating content factors: A summary of findings and implications.

<table>
<thead>
<tr>
<th>What?</th>
<th>Who?</th>
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<tr>
<td><strong>Findings</strong></td>
<td><strong>Findings</strong></td>
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<tr>
<td>• R&amp;D strategy should cover almost all technological as well as</td>
<td>• R&amp;D strategy is a sectoral level strategy and TAVANIR (as a</td>
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<td>non-technical domains that exist in current R&amp;D portfolio of</td>
<td>policy-making organization) is responsible for the</td>
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<td>Iran’s power industry</td>
<td>implementation of strategy. TAVANIR by no mean intends to</td>
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<tr>
<td><strong>Implications</strong></td>
<td>involve with operational or strategic activities of other private or</td>
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<tr>
<td>• Formulating R&amp;D strategy may require extensive work in data</td>
<td>governmental institutions in Iran’s power industry; however it will</td>
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<tr>
<td>gathering and analysis</td>
<td>try to promote the strategy through policy tools.</td>
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<tr>
<td><strong>Implications</strong></td>
<td>• Output of R&amp;D strategy of the power industry in Iran must be broader</td>
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<tr>
<td>• Formulating R&amp;D strategy may require extensive work in data</td>
<td>than R&amp;D projects. This is desired because project definition is an</td>
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<tr>
<td>gathering and analysis</td>
<td>activity that is usually expected to be done at the corporate level.</td>
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<tr>
<td><strong>Implications</strong></td>
<td>Although a sectoral strategy should be promoted in organizations and</td>
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<tr>
<td>• Formulating R&amp;D strategy may require extensive work in data</td>
<td>corporations, its content should not explicitly interfere with those</td>
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<tr>
<td>gathering and analysis</td>
<td>decisions that are conventionally expected to be made at the corporate</td>
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<td><strong>Implications</strong></td>
<td>level, such as project definition.</td>
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3 The seven domains of excellence included technical (consisting of power generation, transmission, and distribution), customer service, finance, management, environmental issues, human resources, and safety.
4 NRI’s Research Director, NRI’s Collaboration and Commercialization Director, and Head of related research departments in NRI or his/her representative.
5 Both of them were also present in the methodological investigation group (the professor of R&D management and the strategy/R&D management expert who had experience as a manager of R&D strategy development projects).
6 Two were management of technology graduates with backgrounds in power engineering. Both were also present in the group that worked on methodological investigation and development of the first version of method.
enough to warrant changing course. In such cases, they could decide to proceed to the next round of operationalization of the method or some of its steps while being mindful of any growing or more convincing evidence of problems with the method or strategy such that they would change their conclusion. If the experts believed that additional theoretical or empirical information was required to decide on the relevance and seriousness of some previously suggested evidence, they could ask the project executive group to perform a literature review or an exploratory study on specifically determined subjects. In such instances, findings of the requested study or literature review were then presented to the experts, either individually or during a focus group meeting. Additional supportive information from some or all of the above-mentioned resources supplemented expert judgments during focus groups meetings in which all claims for possible existence of evidence for an imperfection were critically discussed to decide whether the evidence was indicative of an actual flaw and what the most appropriate solution could be. A summary of detected imperfections and flaws and recommended solutions was prepared at the end of each focus group meeting. All summaries were later added together to build a final report of detected problems and related recommendations for their resolution. The final report was approved by R&D management experts, industry managers, and researchers.

Soon after the first iteration, a second iteration was initiated to develop, operationalize, and critically discuss a second version of the method. Similar to the previous iteration, the second iteration also took advantage of an initial effort to gather and analyze related information through exploring the theoretical and empirical literature, discussing the findings and ideas in executive group meetings, and consulting with industry researchers and managers. To inject new ideas into the executive group and to train additional facilitators for future large-scale panels, we added four new group members who had experience as strategy or R&D management junior consultants. The project group frequently consulted the two R&D management experts who had been present in the focus groups. Each recommendation for a change or modification was first studied, discussed, and summarized in the minutes of the meeting. Additional supportive information from some or all of the above-mentioned resources supplemented expert judgments.

Operationalization of the second version of the method was no longer only aimed at evaluating the performance of the method. Crafting R&D strategy for selected domains was the main goal at this iteration. Nevertheless, consistent with our policy of gradual increase in the scope of application of the method, we did not suddenly expand the scope. We focused on crafting R&D strategy for two domains only, namely technical (and in this domain, only generation and transmission) and environmental issues. These areas had already been determined as priority domains by the project employer. To develop the strategy, we decided to conduct three large-scale panels. In addition to our prior justification for gradual increase in the scope of application of a new method, three other factors motivated our decision. First, we were developing an industry-level strategy. Hence industry-wide participation was needed to achieve the diversity of judgments desired for developing such a strategy. Second, evolutionary learning methodology required that strategy be an emergent outcome of a collective effort during which critical discussions took place. Holding a large scale panel could provide the chance to invite enough participants (with various interests and expertise) from several organizations, which was necessary to have fruitful multidimensional discussions. Third, evolutionary learning methodology encouraged that as many as possible of those who would be expected later to implement the strategy be given the chance to play an active role in the process of strategy formation. Considering the above motivations, we opted for holding panels of 30 to 40 participants. The experienced industry researchers who had attended the focus groups were also invited to the panels. In addition, we invited the research director or a researcher with related expertise from each of the 16 Regional Electric Companies of Iran. We also invited research directors of a number of large private firms whose business was related to the domain of the panel, a number of university professors whose expertise was either in R&D management or related to the domain of panel, and representatives of a few organizations whose interests or policies seemed to be related to the domain of panel. To play the role of facilitator, we established a team consisting of the Vice-Chancellor of the Science Policy Research Center of Iran, Vice-Chancellor of Research of NRI, and Vice-Chancellor of Research of TAVANIR. The facilitation team was also helped by the group of strategy/R&D management experts who had previously worked as facilitators in focus groups. Facilitators were responsible for directing discussions to an expectedly fruitful path and preventing or resolving clearly unproductive conflicts.

7 For example we invited Iran’s Environmental Protection Organization to have a representative in our panel on environmental issues.
They were also responsible for making sure that: i) discussions were covering both the content and formation method of the strategy, ii) outputs of the process (i.e., content of the strategy and newly identified problems) were clearly worded and explained, and iii) the problems were accompanied by clues about how to solve them (if possible). The facilitation team was composed of high-ranking and respected managers and R&D management experts because their legitimacy could help them better to sell their intervening facilitating comments. As for the panelists, they were not restricted to participating only in discussions related to or based on their expertise. However, in practice, as expected, industry experts were mainly focused on discussing issues related to the content of the strategy, while R&D management experts and occasionally research directors engaged in monitoring the operationalization of the method and identifying flaws in the method. An approach similar to that used in the first iteration was employed to detect, suggest, and confirm evidence for flaws and imperfections and decide how to resolve them. Each panel was convened for two consecutive days and together consisted of six sessions of 2 to 2.5 h. The second version of the method was used as an algorithm to guide the flow of actions and decisions necessary to craft a R&D strategy. While oral consensus-seeking discussions dominated the process, voting was occasionally used when a consensus seemed to be unlikely to reach. Critical discussions on the method were partly done in a supplementary and separated two-hour session on each day. Additional discussions on the method were later done by two follow-up meetings in which R&D management experts, a number of research directors, and the facilitation team were present. Appendix A presents the demographics for each panel.

By operationalizing the second version of the method, we managed to generate a list of technical and environmental research priorities and map how they addressed ‘critical needs’ to fill the ‘gaps’ that had resulted in ‘limiting challenges’ for the industry. Meanwhile, we could identify a number of problems along with suggestions about how to modify the method so as to eliminate those problems. We then took advantage of these findings to develop a third version of the method. The nature of attempt to develop the third version of method was similar to that of the first and second versions in terms of systematic reliance on expert judgments and critical discussions supplemented by some information gathering and analysis. Though the third version of the method is the last one presented in this article and the one to be used to develop R&D strategy in the power industry’s five remaining domains, it should in no way be considered a “final” version. The third version of the method, similar to any prior or future version, should again be critically discussed while developing R&D strategy. As evolutionary learning methodology suggests, we expect to find some new problems to eliminate and new issues to address. So, very similar to R&D strategy itself, the method to form the strategy changes and evolves over time so as to respond to two factors: i) our growing knowledge—i.e., “learning”—about flaws in the method and possible ways to eliminate them, ii) likely change in methodological requirements as a consequence of changes in context, process, or content of strategy.

The following six subsections of the paper present the three versions of the method, the outcomes of critical discussion (in terms of problems identified and approaches suggested to solve them), and a brief description of the content of R&D strategy that was developed for the three specified areas using the second version of the method.

3.2.1. The first version of the method

Although evolutionary learning methodology extensively relies on detection and elimination of errors, it is not a framework for trial and error. In evolutionary learning methodology, a reasonable effort should be made so as to minimize the chance of making mistakes in the first place. That is why we employed a knowledgeable group to study the literature, generate and discuss ideas, and consult with experts to develop each version of the method.

The first version of the method inherently conforms to a roadmapping approach. The decision to incorporate a roadmapping approach into the method was based on a number of findings. Phaal and colleagues [6], Branscomb [51], Lee and Park [52], Phaal and Muller [40], and Kajikawa and colleagues [53], among others, describe roadmaps as a consensus articulation of a plan or perspective to scientifically inform a vision. Collective discussions and communication of stakeholders’ comments are central to the roadmapping approach [6,36,39,40,52]. It allows for fast development of a first version of a plan or strategy, and when entering the ‘roll-out’ stage, the roadmap can be revised while being implemented [54,55]. Thus, characteristics and potentials of the roadmapping approach seem to be highly harmonious with the requirements of evolutionary learning methodology, at least in the case of Iran’s power industry.

A roadmapping approach is flexible in scope, level, and domain of application [6,36,52,53]. The approach was theoretically suggested and has been practically confirmed to be applicable at firm, industry, national, and multinational levels. Phaal et al. [6] and Kostoff and Schaller [36] listed several purposes for which the approach can be applied, including capability planning, strategic planning, and long-range planning. Kajikawa et al. [53] provide evidence for and support the idea of using roadmapping to develop R&D strategy at the supra-corporate level. Lee and Park [52] showed applicability of the approach to develop R&D strategy in sectors where government organizations were influential players. Hence the literature seems to provide multiple supportive evidences for initially using the roadmapping approach to develop R&D strategy for Iran’s power industry.

In addition, a roadmapping approach was shown to be flexible in terms of structure of the output [36,56]. Phaal et al. [6] explain that roadmaps can be developed in multilayer, single layer, pictorial, text-based, or flow chart formats to establish and depict patterns of connection between actions, products, services, issues, limitations, needs, markets, vision, mission, long-term and/or short-term goals, and fundamental unknowns. Not all of these need to be present in a roadmap. The selection of notions to be included in a roadmap is done based on its purpose and the context of its development [6,37].

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8 The word “planning” in “strategic planning” is not an indicator of closeness to or relation with planning methodology. Here strategic planning is a general term used to point to strategy formation process.
Although the roadmap can take several forms, its content always needs to be aligned with higher level policies/plans (such as industry or business strategy, mission, or vision). In the case of Iran’s power industry, R&D strategy was required to help resolve the challenges on the way to realizing the vision of the industry. Hence the group decided to opt for an issue-oriented roadmap [37,52] that was aimed at resolving such challenges. Issue-oriented roadmaps can establish connections between related issues, required actions, or needed products/processes and the fundamental issue(s). In our case, R&D strategy was expected to suggest which R&D activities could best address ‘critical needs’ to fill the ‘knowledge, technology, or management gaps’ that had resulted in ‘limiting challenges’ to realizing the vision of the Iranian power industry. Thus we used a multilayer roadmap with four layers: limiting challenges, critical gaps, critical needs, and R&D priorities (Fig. 3).

Limiting challenges were defined as ‘conditions, events or trends that could potentially have considerable effects on the current or future capability or performance of the industry’. Critical gaps were defined as ‘deficiencies or capability gaps, which have resulted or can result in creation of challenges’. Gaps can be in but are not restricted to management, knowledge, technology, policy, product, and processes. Critical needs were defined as ‘activities that can directly or indirectly lead to eliminating or helping to fill the gaps’. And, finally, research priorities were defined as a ‘group of research activities that help fulfill critical needs’.

The scheme of a multilayer roadmap provides an insightful holistic visual and conceptual layout, but it gives little insight about how to generate the content of each layer and how to establish linkages between elements of multiple layers. Hence we needed an algorithm to use as a step-by-step guide to generate the content of the roadmap and to establish linkages between the layers. Looking for such an algorithm, the executive group did an extensive literature study and received helps and comments from several R&D management experts. Hax’s process of technology strategy formulation [23], Porter’s technology value chain [21], Morin’s technology portfolio analysis matrix [24], Phaal et al.’s T-plan roadmap [6], and EPRI’s innovation and technology development plan [57,58] were among the methods whose steps the group studied. Though no single method had an algorithm that reasonably matched the methodological and method-related requirements of the case of Iran’s power industry, each method included some steps that seemed to be useful to generate a specific part of the overall roadmap. Hence the group decided to devise an algorithm to generate the desired content for each layer of the roadmap. To match the steps that came from different methods, as Lee and Park [52] suggested, we concluded that the steps of our method should have the ability to employ inputs that were produced by immediately prior steps so as to produce a desired output that in turn should have the potential to communicate as an input to the next step. The first version of the proposed algorithm is shown in Fig. 4. Since this study mainly concerns the methodology rather than the method, we do not go through the details of each step of the method. Instead we focus on the process of evolution of a method through evolutionary learning methodology.

3.2.2. Uncovering problems in the first version of the method through critical discussions

Despite our effort to base decisions on existing theoretical and empirical knowledge, evolutionary learning methodology suggests that the outcome should not be considered immune from flaws. Collective learning through discussions is a deeply sociocultural phenomenon [59]. A strategy that is developed based on collective learning would naturally be a socially constructed entity. Therefore, characteristics of people, organizations, and society turn out to be highly important in designing a functioning method or developing the content of strategy. Much of the literature and many of the methods that we consulted to develop the first version of our method were based on experiences of countries whose sociocultural and political contexts were radically different from that of Iran. In addition, compared to developed countries, people in Iranian industries, including the power industry, have less experience in large-scale R&D planning initiatives. Hence intuitive evidences were supportive of the theoretical proposition of evolutionary learning methodology that the method might be improved through a process of detection and elimination of problems.

![Fig. 3. Roadmap layers (adopted from [6,41,56]).](image-url)
Holding the three focus groups to discuss the method critically helped uncover a number of problems and suggestions. First, there was a consensus that it was not appropriate to question whether a critical need was technological or non-technological (see step 6 in Fig. 4). Focus group participants discussed that a critical need might be fulfilled by a number of research activities, not all of which were necessarily either technological or non-technological. The extent of a critical need may cross boundaries of several technological or non-technological topics. For example, ‘promotion of using sustainable resources of energy to generate power’ required research on related technologies as well as non-technological topics such as pricing, finance, marketing, legislation, and public policy.

Second, participants, particularly R&D management experts, doubted the necessity of separating technological and non-technological paths in the proposed method. Nevertheless, they maintained that no modification could be initiated to resolve this issue until after the large-scale implementation and discussion of the method.

Third, participants found it difficult to build a clear understanding of the concept of technology domain (see step 7-1 in Fig. 4). They concluded that the definition was vague and would not be easily comprehensible to industry managers. They suggested

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9 Technology domain was defined as ‘a group of technologies that only together could realize an application’. For example, the set of technologies that were required to master producing a turbine could define a technology domain named ‘turbine technology domain’.
that either the definition of domain should be significantly improved or the concept of domain should be somehow bypassed or omitted from the method.

Fourth, managers did not feel at ease with answering the capability-attractiveness (C-A) evaluation questionnaire. Referencing Hax [23], R&D management experts commented that the C-A evaluation, though valid when done for a specific technology, may not work for a technological domain that usually comprises several technologies. Statistical analyses of evaluation results provided evidence for the presence of a bias toward the average, which could be a symptom of erroneousness. Managers and R&D management experts again suggested that no modification be initiated to resolve this issue until after a relatively large-scale implementation and discussion of the method further confirmed the presence of a problem.

Fifth, the majority of participants commented that since the R&D strategy was being developed at the industry level, it might not be appropriate to decide about the acquisition mode of technology (see step 8 in the method). The decision about how to acquire a technology, they argued, was a firm-level decision that rightfully should be left to the firms.

The above-mentioned problems prevented participants from completing the strategy formation process and determining research priorities. The situation, though undesirable, justified the expected usefulness of applying evolutionary learning methodology to improve the method. Having identified the problems, we then focused on solving the problems by proposing an alternative improved method to craft R&D strategy.

3.2.3. The second version of the method

The second version of R&D strategy formation method (Fig. 5) was developed so as to eliminate the flaws that were detected in the first version. On the basis of evolutionary learning methodology, elimination of errors is expected but not guaranteed to result in a better method.

In an attempt to solve the problem with definition of domain, the project group first tried to improve the definition through giving additional explanations based on how related concepts (such as the concept of strategic technology unit by Hax [23]) were defined in the literature. However, testing the seemingly improved definition proved that the concept was still difficult to comprehend. Thus the group decided to prepare a list of all technological and non-technological domains, which amounted to 350. The list could help individuals make use of domains while bypassing the need to theoretically conceptualize the notion of domain. As for the problem with separating technological and non-technological needs, the project group did a literature review that confirmed the viewpoint of focus group participants that fulfillment of critical needs may require both technological and non-technological research activities. To solve the raised problem, the question of whether a need is technological or non-technological was bypassed.

Fig. 5. The second version of the algorithm to implement the method.
Limiting challenges

Critical gaps

Weak belief in importance of environmental issues among high and middle level managers of power industry

Ineffective environmental standards and insufficient legislation to support implementation of standards

Lack or non-existence of an effective organization to manage environmental issues in power industry

Air, water, soil, electromagnetic, noise, and visual pollutants

Critical needs

Changing industry-wide attitudes and organizational cultures by educational programs and communicating information about severity of adverse effects of pollutants

Creating, revising, or strengthening the enforcement of required regulations, procedures, instructions, and standards regarding pollutants

Systematic continuous monitoring of and data gathering about levels of pollutants and their adverse effects

Critical needs

Research priorities

Creating, revising, or strengthening the enforcement of required regulations, procedures, instructions, and standards regarding pollutants

Systematic continuous monitoring of and data gathering about levels of pollutants and their adverse effects

Changing industry-wide attitudes and organizational cultures by educational programs and communicating information about severity of adverse effects of pollutants

Research priorities

Fig. 6. Four layers of a roadmap fragment and their linkages.
non-technological was changed to whether a domain is technological or non-technological. This change was expected to readily solve the problem because technological and non-technological domains had already been delineated and enumerated in a list. Finally, following the suggestions of participants, decision-making about how to solve other problems was postponed to after implementing and critically discussing the method in panels.

3.2.4. Content of R&D strategy

This section briefly illustrates the content of R&D strategy developed by implementing the second version of the method. Critical discussion on the content of strategy took place in the panels in a way that a conclusion about the exact wording and interpretations of ‘limiting challenges’, ‘gaps’, ‘critical needs’, and ‘research priorities’ was made. Fig. 6 presents a challenge named ‘mismanagement of pollutants in Iran’s power industry’ along with related gaps and critical needs. Appendix B presents a sample for a related research priority. Research priorities could help address critical needs, which in turn would reduce the gaps. Filling the gaps would help resolve the limiting challenge. This is how four layers of the proposed roadmap were practically linked together.

3.2.5. Uncovering problems in the second version of method through critical discussions

The process of implementation and critical discussion of the second version of the method was different from that of the first version in four aspects. First, the second version was implemented by large panels instead of small focus groups. Second, the scope of implementation was expanded to two domains, technical and environmental issues. Third, the process was no longer only to improve the method. Crafting R&D strategy for selected domains was now being pursued. Fourth, since the resolution of some problems in the first version of the method had been postponed until after this stage, the process was expected to result in more explicit suggestions to solve those problems. Implementation and critical discussions of the second version of the method entailed the following findings and conclusions.

First, there was a consensus among R&D management experts about excessive presence of data gathering, analysis, and processing tools, such as the lengthy list of domains, Chiesa’s method to rank research priorities [26], and detailed questionnaires to evaluate capability-attractiveness and determine the acquisition mode of technological domains. Extensive use of such tools could be inconsistent with our methodological requirements, which suggested minimal reliance on systematic large-scale data gathering and analysis.

Second, the difficulty with answering the C-A evaluation questionnaire that had already been identified in the first version (the fourth problem) was reconfirmed to be influential. In addition, R&D management experts and industry managers commented that deciding on the mode of acquisition (i.e., between transfer of technology and endogenous development) for which the C-A evaluation had been established, was a firm-level decision. Such a strategic decision, they argued, should not be

![Diagram](image_url)
made at a sectoral level or actually anywhere outside the firm that needs the technology or knowledge. A review of the literature on R&D/technology strategy mainly supported their account [23,60].

Third, almost all panelists had difficulty using the list of domains to determine research priorities. Some research topics seemed not to be bounded within a domain, and some domains seemed not to be addressed with any research priority. Panelists commented that although the list of domains was at times helpful to think about various research priorities that could help meet a critical need, many other times the necessity of linking research priorities to domains and then linking the domains to a critical need seemed to be restricting and unfruitful.

Fourth and finally, the only issue raised about the content was the need to add an estimation of the budget required to work on each research priority according to its description document.

3.2.6. The third version of the method

Following evolutionary learning methodology, we went through another iteration to develop a third version of the method that we hoped no longer suffered from the flaws found in the second version. The most evident difference between the second and third versions was the noticeable decrease in using quantitative information-gathering and processing tools.

To resolve the problem with using C-A evaluation for domains, in the third version of the method, C-A evaluation was replaced by feasibility-attractiveness (F-A) [61] evaluation for critical needs. Both the academic literature and empirical cases are supportive of the appropriateness of applying F-A evaluation at the supra-corporate level to decide among policies, technologies, or solutions [61–64]. F-A evaluation was expected to help select attractive and feasible needs whose fulfillment could later be promoted throughout the industry by appropriate policies, legislation, budgeting, and information-sharing arrangements. Since such measures were usually made by governmental or public institutions, the content of R&D strategy was no longer interfering with firm-level decisions.

Substitution of C-A evaluation of domains with F-A evaluation of critical needs was also helpful in resolving two other of the problems. Since the number of critical needs was considerably less than that of domains, the alteration led to reduction of time and resources required for data analysis. This could partly solve the problem of excessive analysis of data that was raised during the second iteration. Furthermore, by eliminating C-A evaluation, the only step in which technological and non-technological domains were treated differently was eliminated. Merger of technological and non-technological paths could resolve the problem that was raised about separating technological and non-technological paths. In addition, it helped to reduce the complexity of the method and the volume of required data analysis.

Replacing C-A evaluation with F-A evaluation seemed to help resolve some of the previously identified problems; however, additional attention was required to avoid creating new problems. Evolutionary learning methodology requires that major decisions rely on expert judgment and critical discussions. Though F-A evaluation could help decide priority needs, methodological requirements necessitated that evaluation results not be used to automatically replace expert judgments. To realize this goal, we planned to use F-A evaluation results to create a decision support tool that was more compatible with our methodological requirements. Attractiveness of a critical need would be evaluated based on its potential economic, commercial, social, environmental, political, legal, and technological contributions to fill one or a number of critical gaps. Feasibility of meeting a critical need would be evaluated based on potential to access required complementary resources, motivation of human resource in the industry or elsewhere, and existence of related accumulated technological and managerial knowledge. Critical needs would then be mapped in a diagram similar to Fig. 7 based on evaluation results. No strict cut off point would be imposed to determine priority needs. Instead the F-A space would be divided into four zones as described in Fig. 7. Panelists would have no restrictions as to from which zones priority needs could be selected. However, all decisions were to be made in the panels through critical discussions and collective expert judgments. As a decision support tool, F-A diagrams could help panelists make better informed decisions while not imposing any particular decision.

In response to the problem with using the list of domains in the second version of the method, a shorter list was substituted for the lengthy one; more specifically, in the new list, the domains were more general and the number of them was reduced to about a half. In addition, the necessity to use any one domain as a means to link critical needs to research priorities was dropped. Thus, the list of domains was used only as a consulting tool to help panelists better to remember multiple domains that could be intertwined to develop a research priority. By changing the role of the domains list and eliminating C-A evaluation, we incorporated a less systematic way to link critical needs to research priorities into the method (the number of steps required to link critical needs to research priorities was reduced from four in the second version of the method to two in the third version of the method). Consequently, the third version provided panelists with more room to use their discretion on how to take advantage of their knowledge, experience, and judgment to define research priorities. This could be more harmonious with the spirit of evolutionary learning methodology.

Finally, in the third version of the method (Fig. 8), ‘challenges’, ‘gaps’, and ‘needs’ were prioritized and a limited number of them were selected to proceed to the next steps. This approach helped considerably to reduce the flow of information to the middle and final steps of the method, which in turn decreased the volume of data analysis. Such prioritization has been implicitly in the previous version, but conflicts of interest among panelists had sometimes precluded omission of the seemingly low-priority challenges, gaps, or needs. Having seen this problem, we explicitly added the prioritization steps to the method and developed a simple voting tool to determine priority challenges and gaps. Being too numerous, the identified critical needs required a more effective prioritization tool. Critical needs were prioritized by F-A evaluation.

Table 5 summarizes how each version of the method was expected to be an improvement over the previous version due to identification and resolution of problems. Expected improvements are suggestive that the third version is very likely to be an improvement over the previous version, which had already proved to be functioning in crafting the content of R&D strategy in a deliberately limited way. Hence the third version of the method was planned to be used to craft R&D strategy for all of the remaining domains of excellence that had been determined in the industry vision document. However, the third version would not be a final
version. Growth in our knowledge in identifying and resolving problems may help us determine and eliminate some flaws that we could not previously grasp or work around. In addition, changes in methodological requirements, which are rooted in changes in context, process, or content of strategy, may result in the emergence of new issues whose resolution requires developing better functioning methods. Thus we expect that the process of operationalizing the method and crafting R&D strategy will sooner or later reveal new problems in the formation method or the content of R&D strategy or both of them. The problems then can be resolved in the framework of evolutionary learning methodology by iterating the method and developing a revised strategy.

Table 5
Contrasting successive versions of the method in terms of expected improvements.

<table>
<thead>
<tr>
<th>Second version vs. first version</th>
<th>Third version vs. second version</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Increase in the functionality of the method by:</td>
<td>- Decrease in complexity and/or volume of systematic analysis of information through:</td>
</tr>
<tr>
<td>i) Eliminating the need to conceptualize the notion of domain based on its definition</td>
<td>i) Merging technological and non-technological paths</td>
</tr>
<tr>
<td>ii) Eliminating the need to judge whether a critical need is technological or non-technological</td>
<td>ii) Decreasing the number of steps in the method</td>
</tr>
<tr>
<td>iii) Decreasing the volume of information to be used throughout the method (e.g. by selecting prioritized challenges, gaps, and needs, and shortening the list of domains)</td>
<td>iv) Adopting procedures that let panelists use their discretion about how to use some information (such as the list of domains).</td>
</tr>
<tr>
<td>- Changes in the method to improve the content of R&amp;D strategy:</td>
<td>- Increase in the functionality of the method by:</td>
</tr>
<tr>
<td>i) Adding a section for budgeting to the research priority document</td>
<td>i) Eliminating the problem with applying C-A evaluation to domains</td>
</tr>
<tr>
<td>ii) Applying capability-attractiveness (C-A) evaluation to domains</td>
<td></td>
</tr>
<tr>
<td>iii) Using C-A evaluation to decide on the mode of acquisition at an industry level strategy</td>
<td>ii) Adopting procedures that let panelists use their discretion about how to use some information</td>
</tr>
<tr>
<td>- Alertness to possible problems with the following issues:</td>
<td>- Changes in the method to improve the content of R&amp;D strategy:</td>
</tr>
<tr>
<td>i) Having two separate technological and non-technological paths in the algorithm</td>
<td>i) Replacing the C-A evaluation of domains by feasibility-attractiveness (F-A) evaluation of critical needs so as to prevent the content of industry strategy to interfere with firm-level decisions</td>
</tr>
</tbody>
</table>

Fig. 8. The third version of the algorithm to implement the method.
4. Conclusions

The term ‘methodology’ has often been used as a synonym for ‘method’ in the management literature. However, the two notions, though related, are different. This article delineates the notion of methodology in the context of R&D strategy, illustrates the relation between method and methodology, and presents the practical appearance and relevance of them through a case study.

In this article we demarcate two methodological approaches to crafting R&D or technology strategy: planning methodology and evolutionary learning methodology. We focus on delineating the origins, attributes, and framework of evolutionary learning methodology. This article shows how evolutionary learning methodology conforms to evolutionary epistemology because the detection of problems and development of solutions that are fundamental to the process of retrospective learning are common to both. Evolutionary learning methodology is different from trial and error in that it is based on rational critical discussions and expert judgment and is complemented by taking advantage of existing theories, tools, models, and knowledge.

Neither planning methodology nor evolutionary learning methodology is inherently better than the other. We propose a framework that investigates how context, content, and process factors can help determine which methodology is more appropriate to be adopted for a given case. Using the case of R&D strategy in Iran’s power industry, we demonstrated the application of this framework. Having shown that evolutionary learning methodology better matches our methodological requirements, we operationalized the methodology through a number of iterations, which led to developing successive versions of method and crafting of the content of R&D strategy. We describe how collective learning, expert judgment, and critical discussions work in the framework of evolutionary learning methodology to generate emergent and improved versions of both method and strategy.

4.1. Implications for research and practice

This study has three major implications for research. First, by introducing the notion of methodology and distinguishing it from the notion of method, this article conveys the message for scholars that developing, assessing, or applying a method without considering its methodological framework may be misleading. Ignoring methodological origins can give rise to faulty negative or positive judgments about a method. It would be easy, but not so insightful, to criticize a method by adopting an unmatched methodological lens or to praise a method using a matched methodological framework. In each case a scholar should consider all possible worlds of method development (i.e. methodologies) that may suggest different requirements so as to develop a method and different criteria to judge the effectiveness and efficiency of that method.

Second, the effect of environment on the content of strategy has been discussed by several scholars (e.g. [21,23]). This study goes further by illustrating the effect of context (environment) on the process of strategy formation. This line of research is particularly fruitful at the supra-corporate level where the number, complexity, and influence of environmental factors are often much greater than at the firm level. This research stream can also be promising in investigating the effect of changing environment on the process of strategy formation. Change is an influential factor, particularly for developing R&D/technology strategy, which usually deals with the issue of innovation, i.e., bringing about change.

The third implication is both theoretical and practical. Roadmapping is a framework that has been the subject of several studies and widespread application and is a method that fits the requirements of evolutionary learning methodology. Despite the rapid spread of the roadmapping approach, some of its aspects are still subject to debate and require improvements. Among them is the process of customizing roadmaps [52]. Researchers and practitioners can take advantage of an enhanced knowledge of evolutionary learning methodology to understand antecedents, attributes, and consequences of roadmapping. Since evolutionary learning methodology specifically concerns the issues of modification and reshaping of methods, applying its knowledge can help develop a methodologically solid procedure by which to customize or tailor roadmaps.

In addition to its implication for research, a number of practical implications come with this article. First, this article gives R&D managers an insight about what methodology is, how it matters in practice, how the appropriate methodology may be selected, and how evolutionary learning methodology in particular can be applied.

Second, evolutionary learning methodology is an effective framework for strategy development when the particular method employed originates from a context other than where it is commonly being used. This can be particularly helpful for developing countries that frequently apply managerial methods devised in developed countries. Evolutionary learning methodology enables us to detect context-related theoretical or practical problems of a method and solve them by proposing revised versions of the method. If the rational, critical discussions and complementary studies are done properly throughout multiple iterations, the sequence of revised versions of a method can reach a satisfying level of applicability and effectiveness for any specific context in which managers intend to apply the method.

Third, evolutionary learning methodology can be very effective in highly uncertain contexts such as R&D. There is a stream of research about the ineffectiveness of extensive planning in highly volatile contexts [46,65–67]. It is known that in uncertain contexts, extensive planning may result in decreasing the ability to react to environmental change [66]. In such contexts, evolutionary learning methodology can provide managers with a framework for adapting their methods and strategies to the changing environment.

Fourth, managers should consider the advantages of using evolutionary learning methodology when there are several stakeholders with different and/or changing interests. Critical discussion in panels, if attended by various stakeholders, can be very effective in assuring that different interests are being considered to craft strategy. Moreover, evolutionary learning methodology provides a procedure to create necessary changes in the method to ensure its effectiveness when considering future changes in stakeholders’ interests. This capability is particularly useful when fundamentally new types of interests are expected to emerge (e.g. as a result of major changes in law, technological breakthroughs, or initial public offerings).
4.2. Considerations, limitations and further research

Not any kind of learning or any process of problem-finding and solution-providing should be attributed to evolutionary learning methodology. The proposed methodology has its own strict procedural requirements. Expert judgments and critical discussions are not intended to and should not fully replace analytical tools or traditional research methods, such as scientific theories, case studies, statistical methods, mathematical models, and decision support tools. In fact, the evolutionary process and critical discussions are most effective when used in conjunction with such tools.

Evolutionary learning methodology is not necessarily appropriate for all cases and all contexts. For example the methodology may not be suitable for small business planning, particularly when low uncertainty exists, because lack of access to knowledgeable and experienced experts may decrease the reliability of expert judgment and critical discussion. Furthermore, low uncertainty increases the effectiveness of planning methodology as an alternative. In addition, the fact that the methodology can be costly and time consuming can diminish its practical lure in some cases.

Finally, although this study shows how evolutionary learning methodology appears in practice and how it helps develop methods and craft R&D strategy, further case studies are required to fully present multiple aspects of the methodology. Case study can do only a little to scientifically justify a theory or method. However, a number of supportive case studies together can practically justify the appropriateness of applying a method or a methodology. Besides it seems that there still exists a need for further research on some dimensions of applying evolutionary learning methodology. For instance proposing a well-defined procedure to conduct critical discussion panels may considerably increase the applicability of the methodology.

Acknowledgment

It was not possible for the authors to conduct this study in general, and the case study in particular, if not for the unspiring support of the managers, help from researchers, and contribution of the engineers from Niroo Research Institute. Among them the authors would like to specifically thank Neda Mandegaran, Naser Bagheri Moghaddam, Malieheh Khanjari, Farrokh Amini, Alireza Mehri, Mohammad Jafari Anari, Masoud Narenji, Maryam Mohammadi, and Behshad Azodi. In addition, the lead author was supported by Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) through the Carnegie Mellon Portugal Program under Grant SFRH/BD/51159/2010 to prepare, revise, and finalize this article.

Appendix A. Demographics of participants of panels.

<table>
<thead>
<tr>
<th>Panelists</th>
<th>Environmental issues</th>
<th>Technical (generation)</th>
<th>Technical (transmission)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of participants</td>
<td>29</td>
<td>36</td>
<td>35</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>11/18</td>
<td>5/31</td>
<td>5/30</td>
</tr>
<tr>
<td>Age (average)</td>
<td>42.6</td>
<td>46.1</td>
<td>43.9</td>
</tr>
<tr>
<td>Research directors or experienced researchers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number from Public/private organizations</td>
<td>18/2</td>
<td>22/6</td>
<td>23/5</td>
</tr>
<tr>
<td>Average experience in power industry (years)</td>
<td>14.1</td>
<td>17.3</td>
<td>16.7</td>
</tr>
<tr>
<td>Average experience in other industries (years)</td>
<td>4.5</td>
<td>2.9</td>
<td>2.2</td>
</tr>
<tr>
<td>Managers from power industry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Average experience in power industry (years)</td>
<td>23.2</td>
<td>21.8</td>
<td>21.1</td>
</tr>
<tr>
<td>Representatives from related policy-making organizations or other industries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Average experience in their industry (years)</td>
<td>12.5</td>
<td>17.0</td>
<td>16.0</td>
</tr>
<tr>
<td>R&amp;D management experts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Average academic or research experience in R&amp;D management (years)</td>
<td>15.0</td>
<td>14.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Average consulting experience in R&amp;D management (years)</td>
<td>12.5</td>
<td>10.8</td>
<td>12.5</td>
</tr>
<tr>
<td>Facilitator and executive teams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Facilitator team</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (average)</td>
<td>49.6</td>
<td>49.6</td>
<td>49.6</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>0/3</td>
<td>0/3</td>
<td>0/3</td>
</tr>
<tr>
<td>Number</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Average experience in industry or research</td>
<td>25.3</td>
<td>25.3</td>
<td>25.3</td>
</tr>
<tr>
<td>Executive team (project team)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Gender (F/M)</td>
<td>4/2</td>
<td>4/4</td>
<td>4/4</td>
</tr>
<tr>
<td>Average experience in consulting or research in strategy or R&amp;D management (years)</td>
<td>8.2</td>
<td>7.0</td>
<td>7.0</td>
</tr>
</tbody>
</table>

* Sum of the number of participants may exceed the total because some participants were counted in more than one group.
** Exact age and experience information was not available for all panelists. Averages are based on best available information.
Appendix B. Example of a description document for a research priority

Title: Clean Development Mechanism (CDM)

Objectives

Article 12 of the Kyoto Protocol is assigned to the Clean Development Mechanism (CDM). According to this article, CDM is aimed at helping developing countries (non-members of Annex I of the Kyoto Protocol) to achieve sustainable development while helping the United Nations Framework Convention on Climate Change to achieve its goals in reducing emissions of greenhouse gases and helping developed countries and transient economies (the members of Annex I of Kyoto agreement) to fulfill their commitments to decrease emissions of greenhouse gases.

According to the CDM, countries that are not members of Annex I (generally developing countries), by implementing projects that reduce emissions of greenhouse gases, receive carbon emission reduction credits. They can sell these credits to Annex I members. The Annex I members (generally developed countries) can purchase these emission credits and use them to fulfill their commitments to the Kyoto Protocol. Depending on project characteristics, the credit period of a project can be 10 years with no extension or 7 years with two extensions (at most a twenty-year period).

The Executive Board of the Kyoto Protocol has declared a number of fields in which CDM projects can be defined, namely:

- Energy industries (renewable and non-renewable), energy distribution, energy consumption, manufacturing industries, chemical industries, construction, transportation, mineral industries, metal industries, emissions from volatile fuels, emissions resulting from volatile halocarbons and hexasulphuride, consumption of solvents, and transportation and exertion of residuals.

Historical necessity of research on this subject

The Kyoto Protocol was brought into force in February 2005. After approval of Parliament in 2005, Iran officially joined the Kyoto Protocol. Since Iran is a developing country, it has no commitment to reduce emission of greenhouse gases during the first period from 2008 to 2012. Therefore, Iran can benefit from financial resources generated by selling emission credits by conducting projects within the CDM framework during this period.

Advantages

In addition to the income from selling carbon emission reduction credits, implementing CDMs results in energy consumption optimization, fuel consumption reduction and promotion of renewable energies consumption, and may lead to technology transfer to the country. Furthermore, reduction in greenhouse gases emission and other pollutants helps preserve not only the national but also the global environment.

CDMs can affect Iran’s power industry’s strategic plans in several aspects, including technological, environmental, and financial. CDMs not only encourage organizations in the power industry (such as power plants, power transmission companies, equipment manufacturers, etc.) to improve their equipment for the purpose of reducing greenhouse gases and increasing production efficiency, but they also make environmentally friendly technologies economically feasible for new projects.

Water, fuel and electricity consumption reduction technologies, renewable energy technologies, pollutants filtration and control systems are examples of these technologies.

Conducting projects aimed at greenhouse gas emission reduction in the framework of CDM also have the following advantages:

- Fuel consumption reduction, or improvement of fuel consumption efficiency in the power production sub-sector
- Reduction of air pollutants as a result of improving fuel consumption efficiency in the power production sub-sector
- Generating revenue through selling the emission credits
- Making new environmentally friendly sources of energy more economically feasible
- Increasing the share of renewable energy sources in the power production sub-sector

Required time for fulfilling the objectives

Implementation of the projects should commence right now. However, complete implementation of the projects under this research priority needs at least three years and must not last more than five years. Samples of possible projects under this research priority are as follow:

1) Identification of existing potentials for greenhouse gas emission reduction projects in various sectors of the power industry
2) Proposing motivation plans for industry management to implement CDMs
3) Policy-making in order to create legal infrastructures for the formation of an emission credit market
References


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