Critical Factors toward Successful R&D Projects in Public Research Centers: a Primer

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ABSTRACT
Mexican Public Research Centers (PRCs) have become one of the most important actors in technology development for most enterprises they interact with. Nevertheless, knowledge generated and accumulated by PRCs is being underutilized or not utilized at all in the advance of new projects to benefit productive sectors. In this paper we review a number of variables to pinpoint factors that either promote or hinder successful R&D projects; i.e. those transferred to the industry. We conclude that it is feasible to design policies to boost positive factors while preventing or reducing the impact of the negative ones.

Keywords: Public Research Centers, management of R&D projects, successful R&D projects, knowledge transference.

RESUMEN.

Los Centros Públicos de Investigación (CPI) mexicanos se han convertido en uno de los actores más importantes en el desarrollo tecnológico de numerosas empresas. Sin embargo, el conocimiento generado y acumulado por los CPI está siendo subutilizado o no utilizado del todo en el diseño de nuevos proyectos que podrían beneficiar al sector productivo. En este artículo analizamos una serie de variables con el propósito de identificar los factores que promueven u obstaculizan la transferencia de proyectos de I+D a la industria. Se concluye que es posible diseñar políticas que fomenten la acción de factores positivos al tiempo que prevengan o eviten el impacto de los negativos.

1. Introduction

One of the most important engines for innovation has been described through the Triple Helix model, in turn based on Sabato's triangle, where interactions among academia, government and business or industries are highlighted. Such model has proven to be a good generator of adequate environments for innovation since it fosters the emergence of spin-offs from universities and research centers, just like some other initiatives based on stakeholders' knowledge, strategic alliances among businesses, public research and development (R&D) laboratories, and research groups [1, 2, 3].

Most academy–industry interactions in Latin America have emerged from two different mechanisms. The first one refers to public entities shaping up academic teams in universities to search for solutions to some particular problems of the private sector; the second and most recent one operates through formal contracts between researchers and businesses [4]. Both mechanisms are frequently utilized in most Mexican PRCs.

Some interpretation of Mexico's lack of competitiveness might be connected to its apparent inability to link enterprises with an efficient public sector. The same goes for the lack of competitive infrastructure to facilitate an adequate development and growth of economic activities [5]. In addition, this country is characterized by its small Scientific and Technological (S&T) System; for its incipient innovation processes in most of its enterprises; and also by the scarcity of successful tripartite relationships (academia, enterprises, and government). This situation is even more acute since most S&T activities are carried out by universities and PRCs. Even though they have accumulated capacities to build favorable environments to design and perform innovation processes, there´s a poor tradition in setting up linking processes [6].

PRCs have been recognized for the important role they could perform in the impulse of high technology while interacting with a certain type of organizations [7]. There is no doubt they could benefit from technologies derived from research projects but they still have to realize the profits arising from projects developed for commercial purposes [8]. One obstacle PRCs are currently facing is the underutilization or null utilization of self-generated knowledge [9], which might be inhibiting the start of new technological developments and their transfer to industrial sectors.

Generation of technology developments within academia (universities and research and development –R&D– institutions) involves different stages, like the transformation of basic knowledge to laboratory prototypes, the project specific know how, among many others. In some cases these become protected by intellectual property mechanisms to later on get transferred to the industries [10]. In this sense, planning for the generation of technological developments within these institutions is an element that can help to enhance the transfer of their inventions.

Nonetheless, several papers have pointed out that the implementation of any strategic plan is usually accompanied by problems deviating its results from expected completion dates, increasing costs and sometimes missing previously stated objectives [11]. In order to improve the success rate of planning exercises within PRCs a review of various examples was carried out, emphasizing knowledge transfer to industry through R&D tasks. The results clearly show there are factors that either promote or hinder the success of such projects. Thus, it is important to identify those that should be encouraged or avoided in order to increase any project's likelihood to be transferred and as such, become successful.

2. Literature on factors associated to successful and unsuccessful R&D projects

Out of a bibliographical search of papers related to various industrial environments we found hundreds of factors described [9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23]. Among them, some are favorable to the success of R&D projects; others to the development of new products (DNP). Even more, best practices in a large range of processes and sub-processes were also identified, besides other types of performance factors. A number of studies on networks of R&D projects was also reviewed with some attention to those conducted by Mexican academic institutions. The study and analysis of the last two allowed for more detailed examination of both kinds of factors determining the success of R&D projects.

Based on the analysis of these studies and our own personal experience, we proceed to select a total of 71 factors that could be either positively or negatively associated to the development and administration of new R&D projects in the context of Mexican PRCs. These factors were grouped in eight different categories: 1) R&D process; 2) Project planning; 3) Work and collaboration networks; 4) Human resources; 5) Market; 6) Financial resources; 7) Organization; and 8) Quality.

The process of studying and selecting factors turned out to be crucial for the design of a methodology to identify the most relevant ones. It also assisted in the description and characterization of each of the eight cases selected for analysis.

3. Methodology to reveal factors contributing to the success of R&D projects

Based on a case study where two Mexican PRCs were included, it became possible to tackle the dynamics of specific environments in which R&D projects are conducted. Different data gathering methods were combined since evidence called for qualitative as well as quantitative approaches. With all these inputs, an explicative method allowed us to build new knowledge through the study of multiple R&D projects [24, 25, 26].

In order to include some degree of heterogeneity, centers aimed at different areas of expertise were selected: the first one is committed to applied electronics and technology development for automation processes; the second one focuses on basic research in biotechnology, biochemistry and plant genetics. Four R&D projects were then identified in each center, two of them had been transferred to the productive sector and thus, they could be regarded as successful while the other two were unsuccessful (See Table 1).

PRCs	Successful R&D projects	Unsuccessful R&D projects
A	Portable system for the analysis of electricity cable vibrations.	Design and construction of an equipment to eradicate an aquatic plague.
A	Design and construction of two particular assembly lines.	Appliance for cardboard production.
B	Method to isolate certain bacteria (*Bacillus subtilus*).	Viral massive production (baculovirus) to exterminate an agricultural plague.
B	Method for the selection and characterization of *Trichorderma* rootstalks.	High efficiency fertilizer with controlled solubility.

Table 1. Selected R&D projects

In pursuing a full description and characterization of each project, an interview outline was defined and later on applied to 19 persons involved in those projects under study in both PRCs (researchers, technicians, project leaders and research assistants). It should be noted that all of them had extensive experience within their areas of technical expertise and that their education ranged from undergraduate to postdoctoral studies.

At the end of each interview, these persons were requested to fill out a questionnaire to identify influencing factors. Both instruments –the interview outline and the questionnaire– were previously validated by university researchers specialized in Technology Management, in order to guarantee pertinence, clarity, and an effective design, while preventing interviewers from inducing responses [27]. Besides *in situ* observation, a round of additional interviews was carried out involving decision makers and clients for each specific project.

Since stakeholders related to the eight projects were involved in the identification of supporting and obstructing factors, a good coordination and understanding of the goals pursued in this exercise were actually achieved [28]. Tables 2 and 3 show a brief summary of the main characteristics of those eight projects.

No.	Successful projects	Description
1	Portable system for the analysis of electricity cable vibrations	Unlike some conventional equipment, this development can be mounted in high voltage energized lines; it has an integrated self–calibrating system and some other advantages in terms of weight, non-volatile memory, etc. This portable system is currently operating with complete approval and full satisfaction from the client.
2	Design and construction of two particular assembly lines	Two assembly lines were designed and constructed for a company manufacturing electric motors for windshield wipers. The new assembly lines are semiautomatic, presenting highly versatile advantages when compared to the existing ones, partly due to smaller operating times. The new design allows for the simultaneous production of different models thus becoming more dynamic, meeting high security standards and pleasing manufacturers.
3	Method to isolate certain bacteria (*Bacillus subtilus*)	This technological development isolates sporulated bacterium (named *Bacillus subtilus*) for bio-control. In particular, it fights a plant disease which impacts the price of the product. The new method also controls other pathogens and has some other advantages in terms of its adaptation to diverse geographic and climate conditions while increases the volume and quality of the crop, benefiting agricultural production.
4	Method for the selection and characterization of *Trichorderma* rootstalks	The isolation and selection of a *Trichoderma* rootstalk (fungus) was carried out in order to biologically control different phyto-pathogens. As a result of this project, a patent is pending in several countries. One of the most important characteristics of this rootstalk is its adaptability to different climate conditions. Nowadays, the PRC still consults and trains this client, since some problems arose while trying to keep rootstalks alive, favoring both actors to remain associated.

Table 2. Successful projects under study

No.	Non-Successful projects	Description
1	Design and construction of an equipment to eradicate an aquatic plague	The design and construction of an equipment to collect water lilies in order to alleviate water channels and canals pollution was requested by local government officials. This appliance was intended to harvest, cut and grind water lilies to clean water ways; however, it started to show problems arising from its technical design and operation. Aside from the lack of an integral feasibility study, some other prior requirements were not fully observed and the project was not finally transferred to the client.
2	Appliance for cardboard production	A station to produce cardboard was required. Serious problems arose when it became obvious that the PRC involved had not properly considered the cost and technical viability of the project when it was initially agreed upon with the client. This research center finally negotiated the end of the project and took on all related costs.
3	Viral massive production (baculovirus) to exterminate an agricultural plague	A method for the massive production of baculovirus for the bio-control of cabbage looper was developed. Since economic losses related to this moth are common in many regions, efforts were made to transfer the technique of a new bio-insecticide to the client. Both parts expressed interest to join in business but unfortunately their efforts proved unsuccessful due to the lack of funds and commitment from the private party. It is worth to mention that the research center involved in this project did develop a product which proved adequate in controlling the plague.
4	High efficiency fertilizer with controlled solubility	A highly efficient fertilizer was developed with controlled solubility containing three main macronutrients (nitrogen, phosphorus and potassium), as well as zinc, an important micronutrient. Contrasting with other fertilizers available in the market, this one does not have sulfates or polymers which have shown to be highly polluting. A patent was generated and the product attracted the attention of some firms and producers; however, it soon became clear that its high production costs, as well as the lack of adequate investment hinder its transference.

Table 3. Unsuccessful projects under study

3.1 Identification of factors

Once each of the previously described R&D projects was properly characterized, the next step was to identify which factors had a positive or negative influence in the knowledge transfer process, bearing in mind those previously identified in the literature, as well as the specific characteristics of the Mexican context in which these PRCs operate.

A questionnaire was designed to rank those factors, following Likert-type scales to allow for rankings of attitudes and opinions, ranging from total agreement to total disagreement [29, 30]. It is worth to mention that in the first part of such questionnaire, all 71 factors were written in an affirmative mode; i.e. with a positive connotation. Participants were asked to express themselves using a one to five scale; i.e. from total disagreement to total agreement. High values were therefore related to positive factors while low numbers were associated to negative factors.

In order to reduce the likelihood of personal biases affecting factors' assessment, weighted averages were calculated considering answers from all 19 participants for each and every one of the 71 initial factors. Results from this exercise pointed at 11 positive and 10 negative factors (shaded in gray in Table 4). Where ties were found, the standard deviation was used to favor factors with lower spreading since small values represented lower dispersion in the opinions of participants.

The second part of the questionnaire requested participants to select five positive and five negative factors, according to their influence in the transference process, and allowed the addition of new relevant factors excluded from the initial list. It should be noted that the selection process of those factors was carried out according to each participants' perceptions.

An earlier factor identification was available through the list of those with higher frequencies and low weighted averages. For our purposes, they represented high preferences for specific factors and implied some hierarchical order in the scale of preferences of each participant (see Table 5). This exercise yielded the addition of six new factors, three positive and three negative (shaded in gray). At a later stage, another four factors were added to this list (one positive and three negative) due to their recurrence in the interviews and in data gathered through the application of the questionnaire.

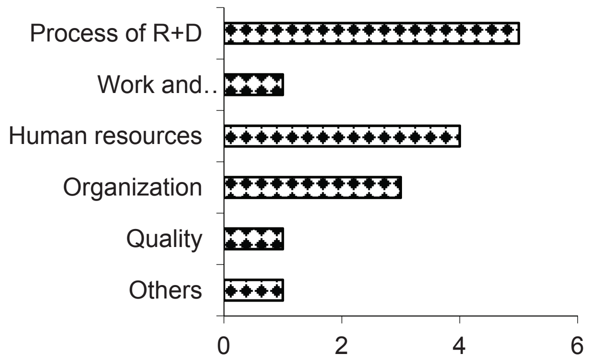
Hierarchy	Positive factors	$\bar{x}_w$	s_w	Negative factors	$\bar{x}_w$
1	3	4.8		27	1.7
2	6	4.7		26	1.7
3	33	4.6		43	1.8
4	1	4.4		51	2.2
5	5	4.4		42	2.6
6	28	4.4		38	2.6
7	63	4.4		37	2.6
8	67	4.4		44	2.7
9	4	4.3	0.78	64	2.8
10	29	4.3	0.85	55	2.8
11	32	4.3	0.85	39	3.0
12	13	4.3	0.95	54	3.1
13	22	4.3	0.96	53	3.1
14	59	4.3	1.09	40	3.1
15	15	4.3	1.23	34	3.1

Table 4. Positive and negative factors as evaluated in the first part of the questionnaire

Hierarchy	Factor	$\bar{x}_w$	Frequency	Factor	$\bar{x}_w$	Frequency
1	1	1.0	8	40	2.7	6
2	32	2.1	5	36	2.8	6
3	56	4.3	5	31	2.7	5
4	4	1.5	4	43	3.2	4
5	20	2.5	4	64	4.9	4
6	59	2.5	4			
7	7	3.5	4			
8	11	3.8	4			

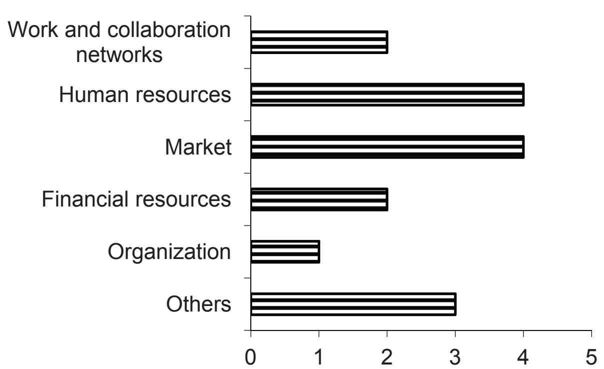
Table 5. Positive and negative factors as evaluated in the second part of the questionnaire

Mostly all positive factors were assigned to one of the following three categories: 1) R&D process; 2) Human resources; and 3) Organization, as shown in Graph 1.



Graph 1. Main categories associated to selected positive factors

Most of the negative factors were classified in either one of three categories, one of which had already been identified: 1) Human resources; 2) Markets; and 3) Others, where respondents clustered "technological transference", "technical and commercial viability", and "association with the client" (See Graph 2).



Graph 2. Main categories associated to the selected negative factors

These five categories grouped a total of 31 factors resulting from the process described above: 15 factors were considered positive and the remaining 16 as negative. However effective, this way of narrowing down the number of factors may have overlooked opportunity areas where the impact of positive factors could be fostered. Similarly, some limitations could arise from implementing corrective actions to attenuate negative factors, particularly during the initial stage of brand new projects.

4. Validation of results

Our results were corroborated using the Delphi Method, where all requirements were observed [31]: 1) experts with a broad-spectrum of opinion on the referring subject; 2) anonymous participation; 3) well-structured questionnaires to moderate the discussion, facilitating feedback throughout the whole exercise; 4) more than one iteration; and 5) delivery of a final report. This validation process aimed at explaining the relationship between the final list of critical factors and the success or failure of the projects while suggesting actions to strengthen positive aspects or to attenuate those identified as negative.

Eight persons were invited to join in this exercise; some of them exposed great technology management expertise in R&D projects and others revealed extensive professional experience. The Delphi was carried out in two iterations. During the first one, participants were asked to select seven positive and seven negative factors from the original list of 31, with no hierarchy assigned to any of them but welcoming suggestions for new relevant factors not considered on that list.

During the first iteration, participants were also asked to debate the likelihood of a relationship between positive and negative factors with the final outcome of an R&D project. They also elaborated proposals to promote positive factors and to reject those regarded as negative. During the second iteration, a ballot to ponder the relationship and impact of positive and negative factors was conducted. Once more, participants were allowed to suggest factors not previously considered, following the same selection criteria established in the beginning.

High degree of consensus allowed for the ultimate selection of factors. A resulting group of 14 was finally accomplished for successful R&D projects (seven positive and seven negative), as shown in tables 6 and 7.

No.	Positive factors
1	Strong initial interest from potential client(s) to develop R&D projects.
2	Robust scientific and technological capacity in the Research Center to develop R&D projects.
3	Decision making autonomy for personnel involved in the development and management of the project (from top managers of the Research Center).
4	Efficient teams assigned to R&D processes to develop a project.
5	Highly qualified R&D work groups.
6	Assurance of resources required for the realization of an R&D project.
7	Adequate interpretation of a client's needs.

Table 6. Positive factors selected in the first round of the Delphi method

No.	Negative factors
1	Lack of the necessary conditions to encourage investment of risk capital to develop projects.
2	Insufficient actions to generate and promote public interest on R&D projects.
3	Lack of efficient link channels to transfer R&D projects.
4	Lack of understanding of the market and its dynamics.
5	Lack of operative, administrative and financial support from decision makers in PRCs.
6	Lack of knowledge of technology transfer mechanisms.
7	Absence of studies on technical and commercial viability.

Table 7. Negative factors selected in the first round of the Delphi method

The already mentioned ballot started with five proposals representing the majority of the group's votes. It is worth noticing how these proposals show a direct relationship with positive factors as well as a favorable impact for the project's final result, as can be seen in Table 8.

For negative factors, an analogous process was conducted: five proposals obtained during the first iteration were considered; once again, three proposals resulted from the group's consensus which in turn had a direct relationship with the negative factors (See Table 9).

No.	Explanation
1	A project success is favored by an adequate interpretation of the client's needs; an R&D well-structured work organization; highly certified human resources (quantity and quality); permanent personnel assessment; setting up a work plan; and timely decision making.
2	Personnel with solid scientific and technical capacities; proven work methodologies and project execution control; understanding clients' requirements in order to translate them with specific and correct techniques; and therefore boosting the likelihood of the project's success.
3	Identification of needs along with potential users helps in tracking down opportunity areas for the development of new projects. When problems are correctly identified and attended by well-organized teams, with delegated authority, timely access to resources, and constant evaluation then corrective actions may be carried out and thus increasing the chances for a project to succeed.

Table 8. Explanations on the impact and relationships among positive factors

No.	Explanation
1	The failure of an innovation project is favored by the lack of training for the promotion of a research center' technological potential or technology transference ability; lack of understanding market's needs; absence of a well established marketing department and of well-structured business plans.
2	The lack of an R&D culture within enterprises; scarce interest on projects' promotion; unawareness of market needs and viability of innovation projects; as well as lack of knowledge on transfer mechanisms and transfer channels.
3	The development of projects without clientele participation; inadequate studies to identify opportunity areas; poor identification of research center strengths; difficulties to link projects with final users; patents with no clear idea about their potential application.

Table 9. Explanations on the impact and relationships among negative factors

Finally, a process was conducted to select proposals to promote or attenuate critical factors starting with 15 for the positive ones and 18 for the negative factors. The same selection method was followed, where seven resulting proposals dealt with the promotion of positive factors and eight with undermining the influence of negative ones on the project's final outcome. They are listed in Tables 10 and 11.

No.	Proposal
1	To invest in *avant-garde* machinery and work tools, which allow the center's personnel to be highly competitive.
2	To establish a realistic and detailed plan so as to fulfill every project's objectives. Besides carrying out a permanent supervision in order to timely detect deviations and make adequate decisions.
3	To develop information systems that allow for the anticipation of problems and generation of solution alternatives.
4	Adequate setting of any project's objective and capable leaders to carry them out.
5	Development of a medium term vision for PRCs with an approach that increases trust in the center and in the final user.
6	To establish adequate communication channels between specialists (researchers and technologists) and clients which allows for the interpretation of actual technology needs.
7	To correctly identify and define competitive areas of research centers and their personnel.

Table 10. Proposals to promote positive factors

No.	Proposal
1	To reduce bureaucratic levels and increase operating support. For example, time reduction when signing contracts; support to accelerate temporary personnel hiring; financial support when necessary, etc.
2	To strengthen linking mechanisms and diffusion actions for technological activities and capacities as well as for research conducted at PRCs.
3	To develop norms and policies on industrial property and copyrights to protect work developed at PRCs.
4	To establish a proper regulatory framework for linking PRCs with the productive sector, as well as scientific knowledge conversion into transference technologies.
5	To analyze and study markets so as to identify opportunity areas according to the specialization spheres of each center.
6	To establish adequate mechanisms in order to encourage R&D culture in companies.
7	To provide personnel with economic incentives derived from successful projects.
8	Identification and attraction of financing so as to encourage technology transference and linking of PRCs to the companies.

Table 11. Proposals to attenuate negative factors

5. Discussion and conclusions

The methodological approach used in this paper suggests that in order to promote successful R&D projects six fundamental areas should be looked at: processes, human resources, organization, markets, technology transfer, and client involvement.

Results from a case study support the conclusion that the main strengths of any PRC lie in variables such as scientific competence; technological and material capacity; trained personnel in highly competitive work groups; adequate work environments; freedom to make project-related decisions; interest and commitment from clients; and, finally, adequate interpretation of their needs.

Empirical evidence shows that negative factors are centered in the lack of collaboration networks; absence of activities related to marketing; insufficient venture capital; scarce monetary and non-monetary recognition of PRC's personnel; limited association and restricted profitability from projects; lack of support regarding financial, administrative, and operational tasks; defective studies on technical and commercial viability; and finally, lack of knowledge on mechanisms making technology transfer a common practice.

Once these critical factors were rigorously identified, it became clear that it is feasible to design actions to enhance impacts from positive factors and to attenuate those springing from negative ones. Although this paper is a contribution to the understanding of technology management within Public Research Centers, it also suggests a methodology to identify critical factors for the success of any R&D project. Besides the provision of variables explaining relationships between projects and their success or failure, our results can help top managers and decision makers to improve the performance of R&D projects, for the sake of the very centers which are committed to carry them out.

Summarizing, a systemic approach to handle PRCs' problems and to envision opportunity areas while developing and managing R&D projects is necessary if these centers are to pursue successful knowledge transfer projects and new ventures with the private sector demanding them.

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