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RESEARCH PAPER

How to make an artificial satellite out of a nuclear reactor. An exploration of research-technology emergence and management at INVAP*

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ABSTRACT
This paper analyses research-technology (RT) emergence and management at INVAP. INVAP is an Argentinean state-owned enterprise based in Bariloche, Patagonia. Most INVAP decision-makers find it challenging to develop technology to meet client-specific needs. RTs exploit interstitial boundary-crossing knowledge. Organisational technology-rooted R&D learning can be characterised as a joint, transverse, inter-departmental and interdisciplinary process. RT-related technologies have the potential to be dis-embedded from a specific development-project and/or technological area and re-embedded in another project or area. This paper traces the historical dynamics of six RTs at INVAP. Its perspective marginalises the conventional R&D emphasis on the generation of new products and the improvement of production processes, and highlights the importance of monitoring RT emergence. It argues that technology-based product portfolio strategies can profit substantially from good RT management and planning.

Introduction – the research case

INVAP is a technology-driven company located in Bariloche, Argentina. INVAP is also a state-owned enterprise. An agreement between the government of the Province of Rio Negro in Patagonia and the Atomic Energy National Commission (CNEA in Spanish) gave birth to INVAP in 1976. Río Negro's government, the CNEA and INVAP personnel regularly appoint the members of the INVAP board of directors. According to an important INVAP decision-maker, the CNEA originally conceived INVAP as a technology development company (a device-assembling organisation). INVAP was never intended as an academic research forum with scholars attending conferences and publishing academic papers. INVAP was born in the late 1970s under the aegis of the linear model on innovation (Bush, 1945/1999): the CNEA was originally meant to be the forum for academic research and INVAP the hands-on artefact constructor.

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The activities of INVAP can be grouped into five different technological project-areas (nuclear, aerospace, industrial, medical and scientific equipment, and government and defence). During the late 1970s and 1980s, INVAP started with preliminary nuclear developments – a uranium enrichment plant and a series of experimental nuclear reactors built for the CNEA. The evolution of the product portfolio of INVAP has followed an extremely eclectic diversification pattern. For instance, INVAP produced experimental nuclear reactors, artificial satellites, wind-power generators, a transportation system, freeze-drying (lyophilisation) plants for food, industrial hazardous waste treatment facilities and containers, cobalt-therapy units and radiotherapy simulators for cancer treatment, vacuum chambers, and different types of radar systems among other products and joint technological developments. Most of those interviewed at INVAP made clear that INVAP is unable to reject any request for technological development. Since INVAP does not receive government subsidies and the company is not included in any regular source of state funding or budget, company members claim repeatedly that they have to make ends meet from what they do. Despite being state-owned, the company is reliant on these projects to fund its regular activities. Finally, it is worth adding that INVAP has been granted NASA certification for its ability to complete aerospace projects (except for the launching phase of a satellite). The company has also up-to-date ISO 9001 and ISO 14001 certifications at corporate level.

INVAP technicians and managers find technology development challenging and motivating. This love for technology development constitutes the main organisational driver leading to such a diversified product portfolio. Since INVAP is the offspring of two organisations related to the Argentinian state, the company management has always been free of conventional shareholder pressure, including financial pressure. Nevertheless, it is worth noting that a few organisational setbacks in the past have been related to the fact that the CNEA (the Argentinian state) was INVAP's main and sole client (and, therefore, source of funding) for nearly a decade and a half. From the late 1980s, the nuclear area began to participate in tenders for international experimental nuclear reactor. INVAP, by itself and without the CNEA, built nuclear reactors for the governments of Algeria (the NUR reactor, 1985–1990), Egypt (the ETRR reactor, 1992–1999), and Australia (the OPAL reactor, 2001–2006). The nuclear area is the only area of INVAP technological activity truly emancipated from the Argentinian state.

During the 1990s, INVAP had to strive – in commercial and technological terms – for access to new technological markets. The aerospace area and NASA recognition became the main focus of this process. However, only the nuclear area has managed to offer and sell INVAP products and services overseas. Most of the other INVAP products are only for the Argentinian market. The only exceptions to this are a large batch of cobalt therapy units for cancer treatment produced mainly for the Venezuelan government, and a space-bound computer INVAP built for the Brazilian government.

Aerospace is the second largest area of INVAP. This area builds satellites for the Argentinian state. INVAP began its aerospace activities with the SAC satellites series (SAC A to SAC D). The SACs are scientific mission-specific satellites (e.g. SAC satellites collect land, marine and weather data). INVAP has recently developed the SAO COM, a heavy satellite with a radiating module (a synthetic aperture radar) which allows it to 'see' in the dark of the night, as well as through clouds and foliage. This radar can be used to analyse the composition of the soil.

INVAP combines vertical technological areas with horizontal transverse service areas. Hence, according to the structure design, these service areas can be of use to any project. As is the case in most matrix-shaped organisation charts, it is not uncommon that the duties of a particular service work group change from one technological area to another according to the project work flow of the company. Even though INVAP produces a single product (technology), the company cannot be regarded as a high-tech ground-breaking laboratory. Most of INVAP's developments involve existing (stabilised and uncontroversial) technology. Nevertheless, the company seldom uses popular copycat techniques, such as reverse engineering. The core expertise of INVAP lies in inter- and cross-disciplinary knowledge integration (Shinn and Joerges, 2002; Shinn, 2005), specific technological developments that can be transferred – after the necessary transformation (Callon, 1986) – from one technological area to another.

Conceptual framework

This study explores a number of research technologies (RTs) at INVAP. Terry Shinn (Shinn and Joerges, 2002; Shinn, 2005) coined the term while studying the emergence of generic technological devices in Germany in the late nineteenth century (Shinn, 2001a). During the first decades of the twentieth century, general purpose devices spread to other countries (the United States (Shinn, 2001b), France (Shinn, 1993), the United Kingdom, Japan and the USSR). This RT movement has produced a number of general purpose devices (e.g. the electric motor (Baird, 2004), the ultra centrifuge (Elzen, 1986), the rumbatron (Shinn, 2001b), the Fourier transform spectroscopy (Johnston, 2001), chemical engineering (Rosenberg, 1998), the steam engine, the C++ object-oriented simulation language, the transistor, the chip and integrated circuits, the computer and the laser. These general purpose devices are often said to be 'invisible' in that RT developments are hidden inside the 'visible' final products that marketing and finance scholars both praise and love to talk about. More often than not, users are unaware of even the existence of these general purpose devices. However, RTs can be easily found inside a myriad of the so-called radical or breakthrough market-driven innovations (von Hippel, 1985; Wheelwright and Clark, 1992a, 1992b; Pisano, 1996; Bogers *et al*., 2010).

Three main features are characteristic of RTs (Shinn and Joerges, 2002; Shinn, 2005). First, RTs entail generic production, be it a scientific instrument or a methodology for detection, measurement or control. The design of these generic devices has to be flexible enough to be incorporated into a variety of final products. General purpose devices should have the potential to be dis-embedded from a specific product or project and to be re-embedded into another one (*cf*. Latour's (1987) associations and substitutions). *Mutatis mutandis*, RTs can be re-incorporated into a myriad of other lines of technological activity. Since generic devices address multiple audiences, RTs should have the potential to be locally tailored time and time again to suit specific needs. Second, RT-related work takes place in an interstitial multi-professional boundary-crossing arena. This assumes movement and transformation from one department, discipline or organisation into another, as well as eclectic knowledge integration. Third, generic devices usually contribute to improve precision. RT efforts can transform forms of measurement, norms and standards. A new language and/or a change of paradigm can emerge from these developments. It is fair to point out that we were only rarely able to find this third characteristic in the RTs we explored at INVAP.

In contrast to the conventional techno-scientific disciplinary regime, RTs usually stem from a transverse regime of knowledge production. Shinn's transverse regime entails crossing the boundaries of the traditional academic disciplines, echoing John Law´s (1986) heterogeneous engineering. According to Shinn and Joerges (2002; p.207), 'Research technologies stand between science and engineering, between academia and enterprise'. Although we took on board the RT insight, INVAPs RTs do not fully match Terry Shinn's (Shinn and Joerges, 2002; Shinn, 2005) emphasis on instrumentation and concrete (general purpose) devices. According to INVAP fieldwork data, RTs (a transverse learning process) stand for a series of technological developments that were disembedded from a particular project in order to be re-embedded later on into another project or line of departmental activity. In the majority of the analysed RTs, this cross-departmental knowledge integration also entailed crossing discipline-specific borders (e.g. from physics to engineering in structural analysis).

Finally, we also traced managerial and organisational transformations relating to the analysed RTs (see Weick, 1995). According to most of those we interviewed at INVAP, every time INVAP had to devise a specific technological artefact (or to work in a specific area, such as optics) from scratch, inter-disciplinary and inter-area groups were assembled. The ordinary departmentalisation of the company was literally irrelevant to the conformation of these *ad hoc* development groups. In addition, most of the major projects of INVAP entailed learning a few managerial lessons, such as the importance of documentation procedures for the OPAL reactor in Australia (2001–2006). Hence, as part of this study, we also traced the organising underpinnings behind each analysed RT.

Research questions

The work of Thomas *et al.* (2005) identifies a number of historical socio-technical trajectories at INVAP. This paper also highlights the importance of INVAP's cross-departmental regime of knowledge production. It outlines four phases of socio-technical development by following a series of historical and technological trajectories at INVAP. The authors identify and thoroughly describe each of these phases of development. Following this line of enquiry, INVAP first constructed and then drew on various 'technological capabilities' (the authors use this specific term) to develop its eclectic product portfolio. Nevertheless, Thomas *et al.* (2005) do not address the actual nature and dynamics of this cross-border knowledge and the transformation process these embryonic developments had to undergo in order to become technological capabilities. Nor are the organisational underpinnings of these technological developments analysed in this paper (Weick, 1995).

The present study focuses on two forgotten blind spots. Drawing on Shinn's insight (Shinn and Joerges, 2002; Shinn, 2005), the initial research identified and characterised RTs. The study began with the following query: Which were the elaborations or the developments of a specific area or discipline that, by having crossed departmental and disciplinary borders, became of use – after the necessary transformations – to other technological areas or departments? From the collected fieldwork, a preliminary non-exhaustive list of six RTs was confirmed. Each of the six identified RTs is connected to two or more lines of techno-scientific development at INVAP. Since organisational transformation and change can be related to the emergence of these RTs, the second research question of this study addresses these potential implications: Are there any organisational and/or managerial transformations connected to the progressive development of the six RTs? With a new brief set of questions, we re-visited interviewees from the first phase of research and asked them to expand on these issues.[1]

Methods

The first exploratory research phase involved the following sources of data:

⇒ an interview with Hernán Thomas (a researcher who analysed INVAP's socio-technical trajectories);

⇒ a bibliographic review of techno–scientific knowledge production and RT theoretical underpinnings;

⇒ secondary sources of data, such as the scientific papers of INVAP employees,[2] institutional publications of INVAP, the INVAP webpage, and non-academic articles about recent INVAP projects; and

⇒ academic material and informal conversations with specialists on nuclear and aerospace engineering.

Fieldwork involved narrative interviews (Silverman, 1993; Jovchelovitch and Bauer, 2000) with 22 employees (including both decision-makers and project members) from all the technological and service areas of INVAP. The research schedules for the interviews included five exploratory areas: (a) company/area characteristics, (b) RT characterisation, (c) intra-organisational evolutionary path of RTs, (d) extra-organisational evolutionary path of RTs, and (e) future sustainability and specific actions of RT management. Interstitial cross-border affiliations were used to select the interviewees for this study. All the interviews were digitally recorded. ATLASti software was used to compile and to codify the data.

Six RT-related speculative analytical categories were constructed from the data collected in interviews. Interview data were then complemented with document analysis when available. All of these six analytical categories complied, at the very least, with two of the characteristics of the RTs: (i) generic-purpose production, and (ii) cross-border technological developments. Drawing on the second round of collected data, we traced organising transformations related to the emergence of these RTs.

Research technologies

The first activities of INVAP in the nuclear field date from the late 1970s and 1980s. The activities of most of the other INVAP areas (aerospace, industrial, medical and scientific equipment, and government and defence) started, at different times, from the mid 1990s. The abrupt re-allocation of public expenditure and cutbacks by the Argentinian government in the 1990s drastically changed INVAP's nuclear activities and began to shape its current organisational chart. Given the new political scenario, INVAP had to seek international markets for its nuclear activities, cut organisational spending drastically, dismiss personnel and look for promising new lines of technological activity.

Each RT originated in a specific techno-scientific development (and/or technological area) and, later on, became of use to a different area and/or project. This passage entailed transformation of the original development in all cases. These initiatives were always conceived as generic-purpose developments. The RTs identified from the fieldwork are:

(a) electronics
(b) guidance/instrumentation and control
(c) structural analysis
(d) thermal simulations
(e) software development
(f) specialised mechanical treatment.

Electronics

Nearly all the technical areas of INVAP involve electronics development. The fabrication and testing of the green boards of integrated circuits (similar to the ones that can be found inside a computer) lie at the heart of the activities of the electronics people at INVAP. Electronics is not an organisational area because most areas at INVAP are involved in electronics development. These green electronics boards can be found inside the vast majority of INVAP products; for instance, the control panels of nuclear reactors, satellites, and cobalt-therapy equipment for cancer treatment.

According to two interviewees from the aerospace area, the extensive use of these electronic boards across all the INVAP technological areas contributed to the development of similar techniques in (a) the production process of the boards (techniques such as computer numerical control and sheet metal forming), (b) testing procedures, (c) the integration of these boards into specific devices, and (d) the fine tuning of these circuit boards once they were operational (i.e. in quality assurance and device certification procedures). Furthermore, keeping pace with the fast and dynamic evolution of electronic components literally and regularly updates the entire technological infrastructure of most INVAP products. As electronics engineers and technicians work in nearly all the areas of INVAP, electronics knowledge and learning can be easily transferred from one area to another at INVAP.[3]

Guidance/instrumentation and control

This is a conventional aerospace-rooted technological area. The name of this department actually translates as ‘the guidance and control module of a satellite’. This organisational area is in charge of the sets of sensors and actuators of a satellite. Sensors and actuators account for a series of mathematical algorithms which act according to the data the sensors (of a satellite) collect. For instance, the fix (the location) of a satellite in space depends on the combined data collected by three sensors: a sensor pointed towards the sun, another one pointed towards the earth and, a final one, which locates the satellite inside a stellar map. Thus, guidance and control are extremely relevant to aerospace developments since the (solar) energy supply depends on the fix of a satellite in space.[4]

Instrumentation and control also play a central role in the nuclear realm with regard to safety and reliability. System redundancy constitutes one of the central design parameters in the nuclear area. For instance, the control rods constitute the main control mechanism of a nuclear reactor: a set of cadmium bars can bring fission reaction and potential neutron overflow to a halt.[5] In the nuclear design it is not unusual for different safety and control systems to work as alternatives. Thus, earthquake sensors can also (and automatically) activate the cadmium bar control system. There is also an alternative system for bringing a nuclear reaction to a halt, used only in extreme emergency. If the control rods fail, the reactor vessel can be flooded with a neutron-absorbing gadolinium solution. Therefore, 'redundancy control' can either stand for the same instrument (the cadmium bars) or for alternative safety mechanisms (the neutron-absorbing solution) in the nuclear realm.

Thus, this RT produced the two control sub-systems (one from the satellites and one from the nuclear reactors) which are similar and different at the same time. The space and the nuclear issues (locating the satellite in space and the potential radio-active overflow) do not resemble each other. However, control mechanisms to secure safe operation play an important role in both environments and the same organisational department was involved in the production of both sub-systems. It is worth pointing out that a considerable part of the expertise involved in guidance/instrumentation and control was also transferred into a number of recent INVAP products. For instance, the Measure While Drilling (a device that guides drilling activities for petrol extraction) uses a space-developed camera that was designed by the guidance and control department. These satellite cameras have also been used for other products, providing an early detection of forest fires (the SPLIF) and monitoring illegal commercial fishing activity (the SIMPO).

Structural analysis

This RT addresses the behaviour of a given structure under stress. For instance, similar vibration tests and analyses were developed at INVAP for a) the nuclear reactor building (an *ex ante* assessment of the impact of a potential earthquake on the building), and b) the potential damage to the components of a satellite caused by rocket take-off vibration. Although the stresses of a potential earthquake and the rocket take-off are completely different (different vibratory magnitudes as well as different types of impact on each structure), the analytical equations and the devices used for the vibration tests are similar. In addition, in the past, the same group of engineers developed the nuclear equations before moving into the aerospace area. Furthermore, a vibrating table ('the shaker' in industry jargon) was used to test the components of a satellite before launching as well as the behaviour of a dummy column holding a cadmium bar, part of the certification procedures for the OPAL nuclear reactor. This second test certified that, in case of an earthquake, a cadmium bar was not going to fall inside the reflector tank of the nuclear reactor. The final certification of the entire reactor (by Arpansa, the Australian nuclear regulatory authority) hinged on this specific test.

Thermal simulations

By and large, INVAP's expertise in the nuclear field is circumscribed to small reactors (reactors devised for academic purposes and the production of radioisotopes). Experimental reactors are usually smaller than the well-known power plant reactors. Any nuclear reaction generates heat and, therefore, power plant reactors are built to generate the largest possible amount of energy in order to, in due course, transform that energy into electricity. Unlike with power plant reactors, in experimental nuclear reactors (the main expertise of INVAP) the energy the reaction liberates has to be removed and can be considered as waste.

A series of thermal equations related to energy and heat removal (large amounts of heat can even alter the characteristics of the materials a reactor uses) was developed in INVAP's nuclear area. Part of this thermal knowledge was transformed, at a later stage, into a different set of equations to monitor the internal dissipation of heat by the electronic components of a satellite. Large amounts of heat can generate steam and, therefore, ice, given the extreme low temperature of outer space. The thermo-hydraulics of reactors differs from the thermal-radiation of satellites.[6] In this particular case, two different groups of people at INVAP developed each of these sets of equations. Nevertheless, people were transferred from the nuclear area to the aerospace area to devise the second set of equations for heat transfer. The same software package was used to construct both sets of equations.

Finally, the beginning of this line of thermal enquiry is to be found in the 1980s with the GURI radioactive containers. These containers were constructed to transport radioactive materials (mainly waste) from the nuclear reactors INVAP built at this time. The radioactive materials inside the GURIs generate heat and the containers had to comply with international thermal standards and regulations. Thus, the design of the GURI containers produced the first set of thermal equations at INVAP.

Software development

Most INVAP areas carry out software development. Reliable software development entails (a) a thoroughly documented elaboration process, (b) an intensive testing schedule, and (c) design restrictions. In nuclear reactors, software contributes to safe operation. It is worth noting that this software is only a fairly recent incorporation into nuclear reactors. Old nuclear reactors (before the 1990s) relied on hardware.

In aerospace, software bugs can ruin an entire satellite mission. Only rarely can software patches be installed while the satellite is in orbit. Needless to say, this procedure is extremely expensive and rare. Compliance to reliable programming standards began in the aerospace area. Later on, this software expertise was transferred to the rest of INVAP. The industrial and the government and defence areas also carry out software programming for the more recent INVAP equipment.

Specialised mechanical treatment

The last interstitial RT is highly specialised machining related to the activity of the INVAP workshops. INVAP owns and outsources a variety of specialised workshops. These workshops have developed specific machining techniques over the years as a result of their involvement in nuclear and aerospace projects. Most of the INVAP devices require extremely rare (and custom made) components that cannot easily be found in the Argentinian market. For instance, the aerospace area requires fine machining procedures because mass (weight) minimisation constitutes the core design parameter of a satellite. Therefore, the aerospace area is accustomed to working with composite light-weight materials. Composite materials have to be hard and resistant but light at the same time. In addition, welded joints in a satellite (as well as in a nuclear reactor) have to support different thermal and vibratory stresses. Most of these composite materials cannot be welded with standard workshop techniques. A series of special welding techniques was developed to meet the specifications of all the technological areas at INVAP. In addition, the electrical conductivity properties of some materials depend on a number of workshop-specific techniques (e.g. surface treatment, paint techniques, rust control, and zinc, silver, and bronze finishing). All the INVAP areas can profit from the highly sophisticated components that can be manufactured thanks to these innovative workshop techniques.

Discussion

Instrumentation development lies at the heart of RT literature (Shinn and Joerges, 2002; Shinn, 2005). This paper makes clear that RTs were used to argue for both instrumentation development (e.g. electronics or software development) and knowledge creation, echoing Nonaka and Takeushi's (1999) asset-like knowledge idea. For instance, thermal or structural analysis equations cannot be considered a technological instrument *per se*, but they are certainly part and parcel of INVAP's knowledge base which, *mutatis mutandis*, can be dis-embedded from one line of technological activity and, potentially, re-embedded in a different one. Even though INVAP's knowledge base was never traded as such,[7] it is argued in this paper that its use of technical expertise provides a lesson from which R&D managers might benefit.

If we compare the six outlined RTs from a dynamic capability perspective (Teece *et al.*, 1997; Eisenhardt and Martin, 2000; Laaksonen and Peltoniemi, 2018), these RTs exhibit only a few aspects of dynamic capability. The 'new planned repeatable action' and the 'change and learning' aspects of dynamic capability were certainly taken into account in the construction of each of the six depicted RTs, but not 'changes in performance' and/or the 'uniqueness' which are also part of the dynamic capability insight (Winter, 2003; Laaksonen and Peltoniemi, 2018). Most of these RTs demonstrate learning and transformation at an organisational level when assessed using longitudinal data (Thomas *et al.*, 2005), but this type of change was not introduced to seek new business opportunities. This is because INVAP decision-making is technology-rooted, influenced more by *homo faber* aesthetics than the profit-driven agenda of conventional business.

The organising of RT development encompasses transformations in role specifications, departmentalisation criteria, workflow assignment, teamwork practice, decision-making and sense-making processes, as well as informal unplanned everyday communication, project management techniques, and emerging partnerships and inter-organisational alliances. Here we trace the organising background of these RTs, extremely important in RT development. By and large, INVAP's interstitial regime of knowledge production calls for the emergence of moving positions that can be assigned to a variety of projects and/or areas depending on the organisational workflow agenda.[8] Although most of our INVAP interviewees claimed to work to a matrix-shaped organisation chart that combines classical technological (vertical) areas and transverse (horizontal) services areas, many fleeting initiative-specific roles never actually incorporated into the formal organisational chart were repeatedly mentioned by interviewees.[9] By drawing on fieldwork data, we were able to trace two expressions of this transitory work regime.

On the one hand, members from one specific area can work for a series of projects and technological areas depending on INVAP's project workflow. For instance, everyone at INVAP was involved in the construction of the OPAL nuclear reactor in Australia between 2000 and 2005 owing to the limited time-frame for delivery and its large scale. On the other hand, a group of people with clear-cut expertise can change roles, moving from one area into another according to workflow assignment; for instance, the structural analysts performing two different vibratory tests and using the same software package as the thermal equation specialists. In these two cases, it is not the same knowledge or technological *savoir faire* (Weick and Sutcliffe, 2001) that travels along with the people from one project to another devoid of distortion. Rather, what moves is previous experience, transformed to be of use to another area or project. In other words, the new problem or challenge requires more than existing expertise.

In addition, the eclectic RT dynamics of INVAP demands the incorporation of new fully fledged areas and positions. INVAP members learned new techniques for the production, fine-tuning, testing, documentation and the final qualification of many technological artefacts. Furthermore, INVAP members became proficient users of software packages, specific tools and/or analytical techniques, they regularly built prototypes at the warehouses – such as the preliminary version of the reflector tank for the OPAL reactor and the dummy column for nuclear safety regulations – and they keep track of the commercial and technological evolution of a number of rare inputs (e.g. a wide variety of electronic components). All these changes in the organisational knowledge base necessarily transform the INVAP organisational structure even though some were never incorporated into any formal diagram. However, this knowledge-rooted (albeit invisible) structure is often taken into account for decision-making purposes.

Finally, two upper echelon interviewees portrayed INVAP as a flat organisational structure. In addition, these same respondents mentioned that, two weeks after joining INVAP, newcomers can find themselves involved in the construction of a nuclear reactor in a foreign land. However, this flat organisational structure and empowered newcomers do not mean that INVAP as a democracy. For instance, only five members of INVAP usually decide which projects are suitable for the company. Their decisions are not open for discussion and determine how hundreds of INVAP members will spend their time for years ahead.

An INVAP decision-maker claimed during interview that INVAP operations rely more on internal experience than university education. The same respondent heavily criticised the over-specialised engineering graduate coming from the vast majority of the Argentinian universities for being unable to meet INVAP's heterogeneous learning demands. This interviewee even argued that a new type of non-specialist engineer was needed in Argentina. Over-specialised engineers can be reluctant to swap organisational positions since they feel their technological expertise can turn open-ended and blurry. University education is often at odds with company demands (e.g. jumping from the debate surrounding the materials for the construction of the reflector tank of a nuclear reactor to discussions for the tune-up of a radar unit). Furthermore, changing projects regularly in conjunction with meagre involvement in key decisions can discourage young engineers. INVAP usually forces its members tacitly to sign a clear-cut and unmodifiable psychological contract whereby only a very limited range of professional expectations can be met (Argyris, 1960).

Most of the INVAP decision-makers interviewed mentioned that being able to manage highly complex projects constitutes the company's key expertise. Large technological projects (e.g. the OPAL nuclear reactor in Australia) involve, at the very least, the integration of a variety of tasks to be done following strict design parameters, sometimes with joint development partners. Therefore, the ability to map and split an entire project into manageable work packages has been a matter of expertise for INVAP over the years. INVAP technological partners are often in charge of a series of these work packages. For instance, Hungarian, Russian and French partners were part of the OPAL nuclear reactor project, aside from the Australian companies in charge of the construction of the site buildings. So, the organising dimension includes coordination of these joint efforts *vis-à-vis* an internal regime for technology development guided by *homo faber* aesthetics (Weick, 1995).

Finally, a key organising issue can be summarised with the managerial choice (with regard to technology development) between 'buying and doing'. Buying can spare a few development problems, but it might mean a hazardous technological integration at a later stage. In turn, the doing choice often demands a heuristic erratic process with an uncertain outcome in terms of time and expenditure planning. The buying/doing choice, like the selection of projects, is actually not a matter for debate at INVAP.[10]

Conclusions and managerial implications

This paper underlines the importance of research technology (RT) management in a technology-driven organisation. A number of organisational learning and managerial implications stem from this analysis. RT analysis at an organisational level must comprise, at the very least:

(1) The identification and thorough description of organisational RTs.
(2) A characterisation of the evolutionary path of these RTs. This includes, for instance, an active search for RT complementarities leading to an idiosyncratic and ubiquitous diversification pattern.

(3) The creation of interchange areas, liaison inter-departmental roles or transitory groups of people that contribute to fit techno-scientific developments to the flow of organisational projects.
(4) A thorough analysis of the organising dimension of the RTs. A planned diversification pattern should synchronise somehow the evolution of RTs *vis-à-vis* organisational transformations.

Even though many technology-driven organisations managed to develop a series of RTs, only rarely is a reflexive RT awareness incorporated into corporate agendas. RT management contributes to concentrate the efforts of different lines of inquiry thereby preventing unnecessary and unnoticed proliferations of isolated area-rooted or discipline-rooted initiatives. Therefore, monitoring RTs evolutionary paths has the potential to complement conventional decision-making and industrial sector analysis.

INVAP does not necessarily manage its RTs as we suggest. It was difficult to trace interviewees with a thorough RT awareness. Hierarchy precedes RT awareness and management at INVAP. Since RT development calls for time (even more if we take into account its organising underpinnings), a reluctance to incorporate this perspective into managerial practice might result in a scattered proliferation of short-term technological efforts. Despite this broad managerial characterisation, it is also fair to point out that many of the highly equipped workshops INVAP owns and the progressive conformation of its specialised teams also constitute indelible imprints of appropriate RT management.

For INVAP, a thorough RT awareness is required to accept or reject new development projects. Managers will thus know what was developed in the past, what elements might need minor or major adjustments, and what technologies have to be developed from scratch. Long-range R&D planning in a technology-driven company such as INVAP entails managing and balancing at the very least (a) the core set of the available RTs, (b) the set of RTs in need of transformation, and (c) developing entirely new RTs.

Notes

1. Only three respondents from the first research phase were emphatic about knowledge flowing from project to project. These interviewees were contacted, at least twice, for this research project. Two were extremely thorough in describing this issue.
2. Only a very limited number of scientific papers were written by company members. Most of these papers are conference presentations rather than actual academic publications. The content of all these papers is directly related to INVAP lines of technological activity.
3. For instance, a radiating module stemming from the INVAP radars can also be found inside the SAO COM satellite Although the watt power of the radiating module of the satellite is weaker than that of the radar, a similar centralised design (of the device electronics) was used for both radiating modules.
4. The solar panels of a satellite should face the sun at all times during the lifetime of a satellite. An entire satellite mission can be ruined if these panels fail to link to the energy supply.
5. Cadmium attracts the flowing neutrons. In an emergency, the reactor main operator can put these control rods inside the reflector tank of a nuclear reactor to reduce the number of flowing neutrons.

6. Thermo-hydraulics refers to mass and heat being transported whereas thermal-radiation means there is no mass involved in the heat transportation. This is, basically, the main difference between the two areas.
7. Trading part of a knowledge base is ordinary managerial practice in biotech firms, such as BioSidus (Seijo *et al.*, 2015). For instance, laboratory procedures to acquire bio-similar drugs can be traded between firms. Entire R&D centres and industrial plants can be purchased in the biotech field.
8. According to many respondents, the distinction between areas and projects can be blurred since large INVAP projects can gather a great variety of people and resources, disregarding conventional area affiliations.
9. Even though we requested a copy of the matrix-shaped organisational chart a number of times, we were unable to get an updated version of such diagram.
10. Only on extremely rare occasions, according an INVAP veteran, did the company reject a client demand. He could recall only one specific case.

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