Setting the three-stage R&D shared portfolio methodology: an innovative approach to industry–university collaboration

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Abstract

Purpose – The purpose of this paper is to present an approach to start industry–university (I-U) collaboration through a stepped process aimed at building a portfolio of research and development (R&D) projects.

Design/methodology/approach – It devises from an 18-month action-research program held between a multinational automotive manufacturer and the a top-ranked Brazilian university.

Findings – The three-stage R&D shared portfolio methodology results from a combined application of quality function deployment-like correlation matrices and roadmapping. A first matrix tackles industry interests and correlates product performance dimensions and components to reveal broad research areas of interest. A second matrix correlates research areas and engineering competences, highlighting the types of the required know-how from the university standpoint. Thirdly, academic experts help to fill a roadmap-like layer with possible collaborative R&D deliverables over time.

Research limitations/implications – Since the study lies on a single experience, extensions to other contexts should be made with care. However, the proposal offers robust rationale and a set of supporting tools to nurture new applications.

Practical implications – Theoretical and methodological reflections help managers tackling the long-standing problem of setting a shared R&D agenda.

Originality/value – Literature on I-U collaboration tends or to over-emphasize the role of technology transfer offices in promoting the partnerships or to seek implications for public policy. This research offers a valuable approach to build shared R&D project portfolio from a managerial viewpoint, filling an academic gap and offering guidance for managers in both sides.

Keywords Industry–university collaboration, Open innovation, Research and development

Paper type Research paper

1. Introduction
In the past few decades, innovation has acquired increasing importance for organizations, especially in industrial sectors, where technology plays a key role. In this context, the notion of inter-organizational collaboration has been dictating the pace of competitive advantages in companies (Enkel, Gassmann, & Chesbrough, 2009) and regions (Berman, 1990; Scandura, 2016). Since the term "open innovation" was coined by Chesbrough (2003), much effort has been reported on how to openly innovate in organizations. Despite that, the practice of industry–university (I-U) partnering is not recent: Cole (1959) argued that "*Even in the great self-contained industrial laboratories (. . .) there is always a need for the skills and knowledge possessed by others, and the university fills a unique niche.*" On his turn, Berman (1990) analyzes industry-funded university research and development (R&D) in American setting using data from 1953. On a larger scale, however, it can still be said that formal collaboration between universities and industries is a recent phenomenon (Lai, 2011).

Etzkowitz (2010) emphasizes that university–industry–government interactions are the key to innovation in increasingly knowledge-based societies. The central role of the university is to develop new knowledge and test its applicability. On the other hand, industries have real demands for which university resources are important ingredients to leverage the performance in innovation (Barnes, Pashby, & Gibbons, 2002; Berman, 1990; Scandura, 2016; Shane, 2004). This kind of cooperation can connect the network of university researchers to industry demands by several forms of interaction, such as direct transfer of intellectual property, consultancy, services, cooperative research centers, research consortia or R&D projects (Scandura, 2016).

The literature on the field is vast and somewhat recent: a search in the Web of Knowledge database on December 07, 2021, showed 3,818 records for the topic ["industry-university" OR "university-industry"], out of which 2,828 were published over the past 15 years. A quick analysis over the titles and keywords of the first 100 records (listed by relevance) revealed 12 words that may summarize how industry and university work together (i) and 12 other words that may describe the reasons by which they get together (ii): (i) partnership, collaboration, contract, relation, engagement, interaction, network, connection, liaison, synergy, dynamic and link; (ii) patents, knowledge, research, R&D, startups, innovation, strategy, funding, entrepreneurship, efficiency, technology and learning.

Despite its importance, there are relevant barriers to implementing I-U collaborations effectively, e.g. differences in the pace of work, strategic and long-term vs operational and short-term focuses, institutional guidelines for the relationship or disparate research interests (Barnes *et al.*, 2002; Belkhodja & Landry, 2007; Bruneel, d'Este, & Salter, 2010; Dagnino, 2009). Bruneel *et al.* (2010) list some points that reinforce the I-U relationship: (i) experience of collaboration, (ii) breadth of interaction channels and (iii) inter-organizational trust.

Aside from contractual issues related to universities' technology transfer offices (TTOs) – a bias that strongly marks the literature (Berbegal-Mirabent, García, & Ribeiro-Soriano, 2015; Rajalo & Vadi, 2017), the clarity companies have on which technologies to invest in (those they could develop under collaborative work) is a relevant question that needs to be answered to boost I-U relations. In this context, the innovation management literature reveals some difficulties faced by companies in dealing with the preliminary stages of the innovation process (the so-called fuzzy front end (FFE)), typically those related to the efforts of pre-competitive R&D. These stages present higher levels of uncertainty, both concerning the market and the technology to be employed (Khurana & Rosenthal, 1998; Oliveira, Bagno, Mendes, Rozenfeld, & Nascimento, 2019; Salerno, Gomes, Silva, Bagno, & Freitas, 2015; Verworn, Herstatt, & Nagahira, 2008). As a result, poor and loosely defined R&D portfolios are commonly used as rudimentary starting points for I-U collaboration, and this constitutes an important gap. Moreover, these are both the most strategic initiatives for companies and the most interesting to universities.

This problem is summarized in our research objective: to devise an appropriate methodology for setting a shared R&D agenda between a company and an academic institution. To do so, an 18-month action-research program was held between a large multinational automotive manufacturer and the engineering school of a top-ranked Brazilian university. This paper discusses the program's main results and proposes the three-stage R&D shared portfolio (RSP) methodology to deal with the challenge posed by the research question.

As stated, the literature on I-U collaboration tends to over-emphasize the role of TTOs in promoting partnerships. Moreover, studies that bring R&D collaborative projects to the forefront are scarce, and most of them are focused on debating implications for public policy. So, the main intended contribution of the present research is to offer a robust approach to build a shared R&D project portfolio from a managerial viewpoint, filling an academic gap and offering guidance for managers on both sides of the partnership. As additional contributions, techniques developed and used for data collection, analysis and visualization to support decision-making in each stage of the proposed methodology are presented, and possibilities of customizing the process are suggested, when appropriate.

2. Theoretical background

2.1 Fuzzy front-end: triggering technological innovation in established companies

Risks and uncertainties are remarkable characteristics of any technological innovation (Rice, OConnor, & Pierantozzi, 2008). In this context, R&D may play the role of an interface function between technology management – focused on the acquisition of knowledge – and the management of innovation per se – focused on driving innovation to the market (Bagno, Salerno, & Silva, 2017; Roberts, 1988). On their turn, typical roadmapping approaches (Freitas et al., 2019; Freitas, Oliveira, Bagno, Melo Filho & Cheng, 2020; Phaal, Farrukh & Probert, 2004, 2010) consider technology domains as resources for innovation, fed by R&D projects and that enables the development of new products targeting desired markets. So, technology development and product development play their roles at different levels, pointing to the need of effectively integrating them (Roberts, 1988). Several problems in companies' innovation processes (e.g. interruptions, uncertainty concentration, resource unbalancing) are associated with difficulties in managing such kind of integration (Salerno et al., 2015).

Khurana and Rosenthal (1998) recognize important technological challenges to be faced before triggering a new product development. This preliminary phase is well known as the FFE of the innovation process. The FFE includes all the actions undertaken in the innovation process before a new project is formally approved for development, including product strategy formulation and communication, opportunity identification and assessment, product specification and project planning.

Front-end fuzziness is defined as uncertain information about the customer, technology and competition. It is related to unclear team vision and may cause a series of jobs performed without the desired effectiveness (Zhang & Doll, 2001). Moreover, the early reduction of market and technology uncertainty provided by efforts made in FFE has a positive impact on new product development project success (Verworn et al., 2008). At this point, it is important to add that in the past decades, the innovation debate has grown in scope (going much beyond product development) and complexity (e.g. new tools, methods and approaches to bring innovation to the organizational environment in an openness context). So, new proposals to support university–industry (U-I) partnerships aiming at technological innovations could contribute to improving the FFE performance in established companies (Oliveira et al., 2019). Lastly, the management of the FFE is a difficult challenge: high levels of risk and uncertainty claim for more structure to FFE in established companies, so such organizations need to

develop proper FFE processes and practices (Bagno, Mudrik, Freitas, Cheng, & Melo, 2020; Khurana & Rosenthal, 1998; Oliveira *et al.*, 2019).

2.2 University–industry research and development shared project portfolios: a lever for open innovation

Open innovation has become a very important topic in innovation management and can be implemented in many different ways (Chesbrough, 2019; Huizingh, 2011). The term "open innovation" refers to the various initiatives intended to seek external sources of knowledge, technology and/or innovation to drive organizational growth (Chesbrough, 2003, 2019). Engaging in an innovation strategy demands the establishment of relationships with a variety of partners, in particular, universities and research institutions, suppliers, = and even users (Melo, Salerno, Freitas, Bagno, & Brasil, 2020; Veugelers & Cassiman, 2005). In such a context, universities are considered to be central within the science and technology ecosystem, as a strong source of knowledge and technology capabilities (Berbegal-Mirabent *et al.*, 2015). Therefore, in established companies, tying partnerships with universities may be one of the most important assignments of a team engaged in building an organizational capability for systematic innovation (Bagno, Salerno, & Dias, 2017; Melo *et al.*, 2020).

Common interests of companies and universities, as well as their complementary vocations, are reasons for working together in R&D projects (Veugelers & Cassiman, 2005). Regarding resources, a university typically provides infrastructure and expertise for applied science and technological advance (Debackere & Veugelers, 2005), whereas they need businesses' knowledge of the market from industry practitioners to develop new, applicable and successful technologies (Berbegal-Mirabent *et al.*, 2015).

On their turn, companies have specialized knowledge about markets (Berbegal-Mirabent *et al.*, 2015), users (Siegel, Waldman, Atwater, & Link, 2003), manufacturing (Shane, 2004) and funding options (Lai, 2011) for the development of innovations. Furthermore, collaborating with a university is an opportunity for a company to make technological advances at lower costs and risks (Barnes *et al.*, 2002; Scandura, 2016). Notwithstanding, this kind of interface may demand changes (general approaches, tools, organizational culture, structure, etc.) whether in university or in the company (Bagno, Salerno, & Dias, 2017; Barnes *et al.*, 2002; Debackere & Veugelers, 2005).

The effectiveness of the knowledge transfer in I-U collaborations diminishes when the mechanism for it has an inefficient design (Veugelers & Cassiman, 2005). Plewa *et al.* (2013) propose a process of I-U collaboration divided into the following steps: (i) Pre-linkage/ initialization (identifying individuals or teams as potential research partners); (ii) establishment (focused on the debate about partners' needs and expectations, objectives, content and deliverables of each project, aiming at a contract signing); (iii) engaging/ development (project execution); (iv) advancement (making value from the project and seeking to consolidate an ongoing partnership); and (v) latent phase (continuing personal linkage even if there are no projects at hand). Methods and tools to support an RSP would focus mainly on the first two phases of this process. Barnes *et al.* (2002) identify factors by which the probability of a collaboration being perceived as successful by both academic and industrial partners could increase. These authors organize the factors in six key areas: partner evaluation; project management; trust, commitment and continuity; flexible management processes; clear outcomes for industry; and mutual benefit.

Motivation and absorptive capacity (the capacity of a company to assess and use external knowledge) are highlighted as preconditions for the success of I-U collaborations (Rajalo & Vadi, 2017). Conversely, companies have typically assumed a peripheral role in R&D projects conducted with universities, performing just a few support activities and relying on academic researchers to do most of the work (Barnes *et al.*, 2002). Barnes *et al.* (2002) argue that a successful I-U R&D project requires a previous alignment of priorities, perspectives and time-

lags between the partners. Likewise, the dependence between the partners may directly and positively influence the success of the whole collaboration initiative (Dollinger, Golden, & Saxton, 1997).

3. Method

We adopted action research (AR) (e.g. Bargal, 2008; Checkland & Holwell, 1998; Coughlan & Coghlan, 2002; Eden & Huxham, 1996) as our research method for several reasons, among which we highlight the following. First, it is focused on problems of genuine concern for practice, as is the case in building R&D portfolios for I-U cooperation. Second, the researchers shared the premise that one cannot devise a methodology to tackle this kind of problem unless he or she attempts to actually build a portfolio through action-focused and theory-informed interventions in real-world settings. Third, the active collaboration between researchers and people – from both industry and university – directly involved with R&D turns out to be the most suitable strategy to approach the research problem.

Among the various AR approaches available (Cassell & Johnson, 2006), we chose the one proposed and exemplified by Eden and Ackermann (2018), because it is distinctively design-oriented. This means that it is explicitly driven from its outset by the purpose of developing methods, processes and/or tools from theories to practice, and back again (Eden & Ackermann, 2018). This particular emphasis contrasts with the ones of pragmatic local improvements, or theory elaboration on organizational development (OD), that typically characterize AR projects (van Aken & Berends, 2018). On the other hand, it is very similar to the motivation driving the design science research (DSR) paradigm (e.g. van Aken & Berends, 2018; van Aken, Chandrasekaran, & Halman, 2016). However, differently from DSR, Eden and Ackermann's (2018) AR (a) focusses on the development of concrete/visual management tools, i.e. not design principles, propositions or related mechanisms; (b) involves the continuous search for diverse theories to get a better understanding of relevant aspects of the targeted phenomenon, i.e. not the *a priori* literature review to derive evidence-based prescriptions to be tested; (c) conceives of researchers' main role as process facilitators, i.e. not domain experts; (d) envisages to validate its resulting tools by appealing to their internal reasonableness, i.e. not to a repeatedly confirmed pragmatic validity of application effectiveness in diverse cases; and (e) takes engaged intervention to be essential to the research process, i.e. not an optional way to test designed solutions (cf. van Aken & Berends, 2018; van Aken *et al.*, 2016). Thus, although this AR approach converges with DSR in its broader problem-solving aims, it differs from the latter in many of its other emphases along the research process. At the same time, the content of its central step – i.e. reflective practical interventions – closely resonates with the more traditional AR cycle already well established by Coughlan and Coghlan (2002).

Our research endeavor was conducted at a large industrial multinational automotive manufacturer (MNM). MNM is a 45-year-old branch in Brazil, operating with a production capacity of about 800,000 cars (three cars per minute). It employs more than 25,000 people (directly and indirectly) and presents a US$11bn annual gross revenue. The company's strategy and innovation manager approached our research group's coordinator looking forward to establishing a collaborative research program. Increasing incentives from the Brazilian federal government for automotive innovation initiatives was the main driver for the company to engage in this topic.

In that context, a consensus quickly emerged that the priority for MNM to benefit from these incentives would be to build a consistent portfolio of R&D projects that would allow the company to start beneficial I-U collaborations. Thus, our research group was contacted to facilitate the process of portfolio construction, by intervening in practice with tools transposed and adapted from our previous research experiences. Hence, our first idea was to

adapt the quality function deployment (QFD) correlation matrices rationale (Cheng & Melo Filho, 2010) and the technology roadmap (TRM) layer-filling procedures (Phaal *et al.*, 2004, 2010) to the problem of establishing a trustworthy logic of portfolio construction.

Having a preliminary conception of how these tools could be used for this purpose, we started an 18-month AR program of cycles of intervention, until no further improvement was suggested to our in-development methodology. The program included researchers from the innovation management research group of the Production Engineering Department of the Federal University of Minas Gerais (NTQI/UFMG); R&D experts from the engineering school of this university (well known by its innovative R&D capacity, as evidenced by its patent-related indicators); and both managers and technicians from MNM, totaling more than 40 participants.

Data gathering, feedback and analysis were constant throughout the whole process. Every other week, the team had in-person appointments of data collection in the company (e.g. individual/group interviews). In between these, documents provided by the interviewees (such as lists of projects, databases, reports, etc.) were internally analyzed. During these analyses, QFD-like matrices were sketched, and further data collection was guided by the main informational gaps persisting in the in-progress frameworks. Thus, the process was similar to the theoretical sampling procedure of grounded theorizing, and its comparative method used to constantly compare new evidence to previously collected data, until categories of data and relations between them stabilized.

In terms of these data-related processes, more than 20 formal interviews and many weekly informal conversations were conducted, with interviewees ranging from marketing personnel to specialized technicians and support functions' representatives (e.g. quality, innovation, engineering areas). Moreover, various internal documents were analyzed, especially consortium-paid market research reports, long-range product feature plans and product standard taxonomies. External documents were also reviewed, particularly industrial scenarios, projections and forecasting papers focused on the automotive sector.

Action planning, implementation and evaluation were conducted jointly with MNM's local coordination team. Following Lüscher and Lewis's (2008) AR benchmark publication in the management field (Lê & Schmid, 2019), "Implementation involved conducting 'sparring' intervention sessions during which participants dug into their initial concerns to examine more specific issues. Evaluation denoted reflection sessions wherein participants would assess their sparring sessions and subsequent actions. The process cycled as evaluation offered feedback with which researchers and managers could revise the focal issues and intervention plan" (Lüscher & Lewis, 2008, p. 225). In our case, "initial concerns" and "specific issues" had to do with what the matrices and maps were possibly missing and how their logic could be adjusted to better fit the particular context and problem at hand. These considerations led to intervention sessions, in terms of changes in the artifacts being developed and, consequently, in the portfolio being prioritized and in the collaborative portfolio construction. Intervention sessions were held monthly and evaluation sessions every three months, averaging 2 h each. Hence, we had approximately six complete cycles of reflective interventions, until saturation was reached, and the tool was considered to be satisfyingly adequate by MNM's key personnel.

Throughout the work, following AR best practices (Lüscher & Lewis, 2008), an online research diary/logbook was maintained to keep track of the learning process. We also had a six-person research team attending together the vast majority of the meetings and triangulating notes and observations throughout the whole research process. In addition, the recoverability criterion (Checkland & Holwell, 1998) was explicitly taken into consideration so that the rationale underlying methodological choices needed to be clear and agreed upon by all coordinators for a decision to be made.

4. Results: the three-stage research and development shared portfolio methodology

The AR program resulted in a methodology based on a three-stage process to build an initial portfolio of R&D projects to start I-U collaboration. It begins by identifying product performance dimensions and finally delivers an RSP built collaboratively in an I-U partnership setting. The three-stage RSP methodology is presented in Figure 1.

The work begins with two sequential QFD-like correlation matrices construction stages, with similar process steps (cf. Cheng, 2002, 2003; Cheng & Melo Filho, 2010). They differ in the dimensions under analysis (i.e. *performance versus product components* in Stage 1 and *R&D strands versus competences* in Stage 2) and are linked by the "R&D strands" output from Stage 1. The third stage is a typical roadmapping process that results in an initial R&D project portfolio. The R&D strands identified in Stage 1 turn into a layer of the roadmap that will be filled by the experts selected in Stage 2 with R&D project proposals. The items presented in Figure 1 are further described and exemplified in the remainder of this section.

4.1 Stage 1: research and development strands identification, using the PERFxCOMP correlation matrix

The main result of the first stage is the R&D strands derived from product performance versus product component (PERFxCOMP) correlation matrix. Following QFD correlation matrix construction guidelines (Cheng, 2002, 2003; Cheng & Melo Filho, 2010), three steps were necessary to obtain a PERFxCOMP complete matrix: PERF table construction; COMP
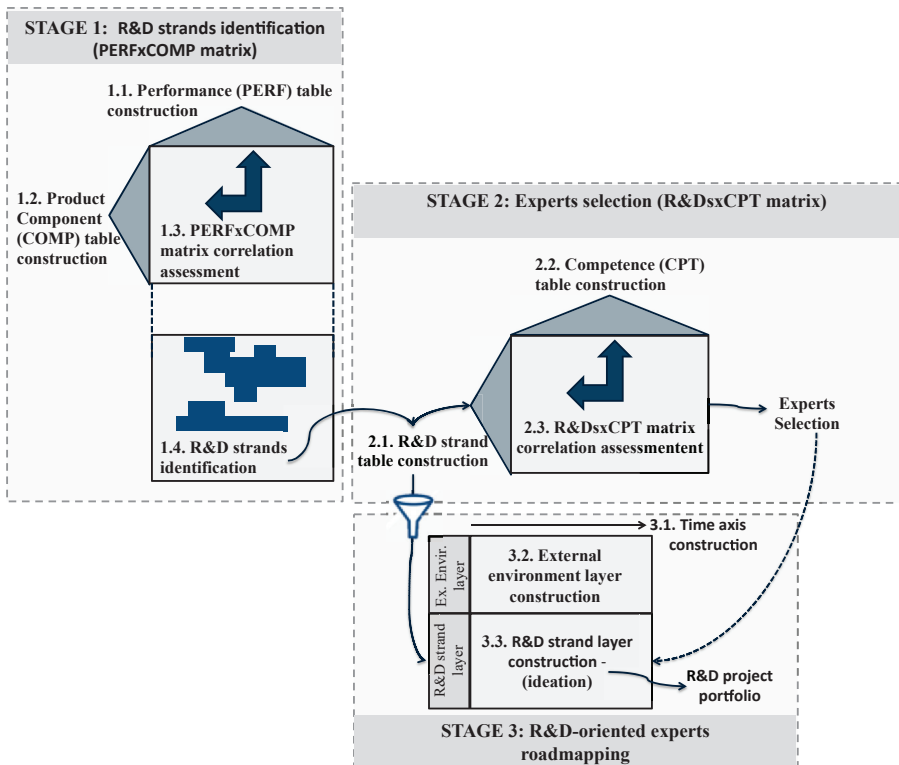

Figure 1.
The three-stage RSP methodology

table construction; and PERFxCOMP correlation assessment. In the end, heat clouds emerge from the various correlations in the matrix, feeding a cluster analysis that supports the identification of R&D strands. These strands will be further refined and prioritized in the following stages of the methodology.

4.1.1 Product performance table construction. Initially, a product performance (PERF) table must be constructed. This means that product performance aspects have to be listed and then grouped, according to their affinity, into more abstract levels of analysis. The table of row labels in Figure 2 provides an example for vehicle performance dimensions. The construction of this table was based upon the comparison of automotive performance taxonomies. MNM headquarters had already developed an internally used taxonomy, which has served as a starting point. Other classifying systems were searched for on automotive-oriented journals and engineering society publications. Comparisons were conducted collaboratively between researchers and MNM employees. The list and its groupings were reviewed by representatives from market, product and technology organizational functions in MNM.

4.1.2 Product component table construction. A second step, which can be done in parallel to the first, is to construct the product component (COMP) table. The same basic construction procedure adopted for the PERF table should be followed, but now focused on product component aspects. The column labels in Figure 2 provide examples of car components/subsystems. The QFD typical "extraction" operation (Cheng, 2002, 2003; Cheng & Melo Filho, 2010) – i.e. extracting component aspects from performance aspects (and vice-versa) – pointed to some refinements and led to the final format of both COMP and PERF tables.

Figure 2.
Example of part of a
product performance
versus product
component correlation
matrix

4.1.3 PERFxCOMP matrix correlation assessment. After the construction of PERF and COMP tables, the third step is the assessment of the correlation between these aspects. "Correlation" is here taken to be not a standardized statistical measure of covariation, but an intersubjective degree of impact of one dimension on another – as it is meant in QFD. Thus, correlation values are usually imputed as a result of a consensus-seeking discussion between well-informed people (Cheng, 2002, 2003; Cheng & Melo Filho, 2010).

Throughout the case, this assessment was made by two quality managers of the company, once they were knowledgeable of both PERF and COMP aspects. For each cell of the matrix, they were asked: "To what extent does this product component have an impact on this product performance criterion?". A five-point scale was used to code the answers, as follows: 0 (*none*), 1 (*weak*), 3 (*medium-low*), 5 (*middle-strong*) and 7 (*strong*). The resultant matrix was plotted to an A0-size chart that was placed at the entrance of the Technology Innovation Department of the company, with the following question: "What is wrong, in your opinion?" Innovation-oriented employees had one month to circle the correlations with which they disagreed and to write down what correlation values they believed would be most appropriate and why. Lots of suggestions were made, each of which was revised by the quality managers, together with the innovation manager, leading to the final correlation values shown in Figure 2. This matrix correlates (cell values) product performance (rows) with product components (columns).

4.1.4 Research and development strands identification. Once the PERFxCOMP correlation matrix is constructed, R&D strands can be derived from it. In this context, these strands are taken to be highly correlated clusters of performance and component aspects. That is: if a component grouping is observed to be highly correlated to a performance grouping, but not to other performance aspects, then an R&D strand focused on this component–performance combination can be distinguished.

An underlying premise is that an R&D strand is best defined by a combination of product component and performance, rather than by any of these dimensions in isolation. This assumption was consensual among MNM participant managers. Thus, the PERFxCOMP matrix was visually analyzed by researchers and MNM employees to identify these clusters of high correlation values. As a result, 16 R&D strands were identified by researchers and MNM's innovation department employees. An example is circled in Figure 2 showing the R&D strand entitled "Body's structural optimization."

4.2 Stage 2: experts' selection, using the R&DSxCPT correlation matrix

The expected result of the second stage of the methodology is the identification and selection of academic experts to participate in the roadmapping stage (Stage 3). Similar to the result of the first stage, this matrix correlates (cell values) R&D strands (rows) with competences (columns).

4.2.1 Research and development strands table construction. Initially, the R&DS table must be constructed. In the AR program, this was done through the comparison of R&D strands identified in Stage 1 to R&D areas previously listed internally by MNM innovation managers. Nineteen final strands were consolidated and grouped into eight broader categories, named, whenever possible, according to the nomenclature of the strategic research agenda used by MNM headquarters (e.g. "combustion"). This was important to improve the internal alignment in terms of vocabulary while similarities and priorities got gradually better known.

4.2.2 Competence (CPT) table construction. CPT is the other table that has to be constructed to build the matrix. In the MNM-UFMG case, the company managers decided to focus on technical (not organizational) competences, once their goal was to start the cooperation with the engineering school of the university. Hence, the (technical) competence table was constructed by comparing several curriculums from the top Brazilian automotive-related engineering courses, considering both undergraduate and post-graduate levels. The

resultant know-how domains were grouped into eight broad competence areas (e.g. "telecommunications").

4.2.3 R&DSxCPT matrix correlation assessment. The next step is the assessment of the correlation between R&D strands and competences to identify which competences are necessary to propel each R&D strand. In the MNM-UFMG AR program, this activity was performed by three different respondents at separate times: the product innovation manager, the technology innovation manager and a researcher from the NTQI/UFMG group who was formerly an innovation manager at MNM. Then the answers were compared and discussed in two workshops until they agreed upon the final values.

Once the R&DSxCPT correlation matrix is constructed, relevant CPT experts can be selected to participate in a roadmapping process aimed at identifying potential R&D deliverables over time. University experts are usually specialized by competence and know-how (i.e. CPT) – not by product performance or component. Therefore, to identify and select which expert would be most prone to contribute to an R&D strand (i.e. a performance–component combination), an R&DSxCPT priority analysis needs to be performed (as detailed below). In the MNM-UFMG case, all researchers from the university engineering school were listed in a database and sorted by area of expertise, as informed in their standard curriculum vitae. Then, for the main CPT groupings, at least one university expert was selected to contribute to the roadmapping of relevant R&D strands.

The priority analyses of R&DS and CPT aspects enriched the case with some other valuable information. For instance, three types of R&D weights were compared in a radar chart: demand for "technical" competences (i.e. average row correlation), market importance (i.e. impact on customer/legislation) and investment intention (i.e. managers' ratings). Figure 3 shows an example of an R&D tactical planning rationale that was derived from these radar comparisons.

These 2×2 matrices suggest which innovation management tactics to adopt depending on an R&D strand weight, considered in terms of two of the three weighting possibilities.

4.3 Stage 3: research and development-oriented experts' roadmapping

In the final stage of the three-stage RSP methodology, the experts selected in Stage 2 were invited to participate in a roadmapping process focused on potential collaborative R&D efforts with the company. Figure 4 provides an example of this result from the MNM-UFMG AR program.

This roadmap has two main layers (external environment and R&D strands) and a time axis. Inspired by basic roadmapping procedures (Oliveira, Amaral, Rozenfeld, & Fonzi, 2009; Phaal *et al.*, 2010), three steps were considered necessary to obtain a simplified R&D-oriented roadmap: time axis construction, external environment (EXT) layer construction and R&DS layer construction.

4.3.1 Time axis construction. Initially, a time axis has to be defined. In the MNM-UFMG case, the timeframe was nine years divided into three time brackets: 1–3, 4–6 and 7–9 years. These three-year intervals corresponded to different generations of products to be launched,
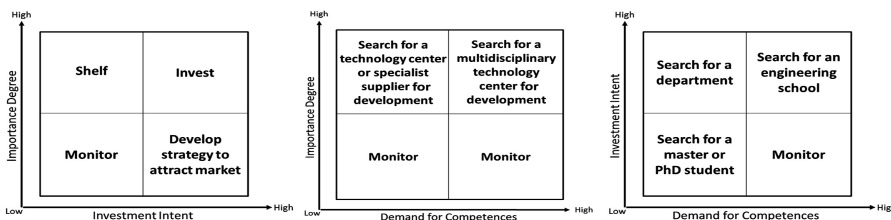

Figure 3.
Tactical planning
derived from radar
chart comparison of
R&DS weights

		+ 3 years	+ 6 years	+ 9 years
External Environment	**Market**	Consumers seek quieter vehicles	Consumers seek more efficient vehicles	Consumers seek more compact vehicles
		China moves forward as a leading manufacturer of vehicles	Car sales grow more in emerging markets	More affordable electric vehicles increases competition with combustion vehicles
		Access to electricity increases worldwide		Industries, sensitized by global warming and changes in consumer habits, direct efforts to new projects with "green" appeal
				Energy dependence intensifies the demand for new propulsion solutions
	Infrastructure	Advances in the media, information technology and computer processing improves fleet controls, routing systems and transport analysis	Improving standards of infrastructure and services, from public-private partnerships for the construction and maintenance of new roads	
		Increases the demand for transport systems (passenger and freight)		
	Environment		Fuel consumption and toxic gases emission are benefited by new technologies for traffic management and pollution	Climate change and sustainability issues are pushing the development of new products
				Development raises concerns with environmental issues and tougher rules
				Increased use of recyclable parts
	Political Environment	Legislation prioritizes production linked to the environmental impact (eg: vehicles with lower emission rates and following the European	Políticas rígidas de regulação e legislação estimulam a evolução tecnológica para solucionar problemas de congestionamento, emissões, segurança e resíduos	
			Sistemas de taxação para racionalizar períodos de alto congestionamento se intensificam: populações passam a depender mais do transporte público a veículos são mais usados no fim de semana	
	Social Environment	Trânsito intenso nas cidades é beneficiado por novos desenvolvimentos em Software, Sensores, Eletrônicos e Telemática	Congestion grow and generate new problems for mobility	Alternative media are encouraged to reduce the number of trips
		Renda per capita brasileira cresce (compra de carros populares diminui / embarcação de novos conteúdos)		
		Regiões metropolitanas concentram maiores iniquidades sociais (amplitude da gama de veículos)		
	Technology	Simulação computacional reduz tempo e custo de desenvolvimento	Grow the solutions and advances in human-vehicle integration	Nanotecnologia traz peças não tóxicas, mais duráveis, impermeáveis, práticas, antimicrobianas, inteligentes, e resistentes ao fogo, à luminosidade e ao risco
		Aumento da convergência tecnológica e do uso de tecnologias eletrônicas e de comunicação de reconhecimentos / forços da engenharia do produto	Segurança veicular recebe maior ênfase: sistemas avançados são capazes de monitor ar o ambiente externo e interagir com o motorista para a reduzir acidentes e seus efeitos	Intensification of alternative, light and better durability materials
		Design and improvement serve niche markets	Desenvolvimento de célula de combustível	Telemática contribui para novos sistemas que, em sintonia com a infraestrutura e/ou taxação, amenizam os problemas da mobilidade urbana (ex: congestionamentos, consumo de espaço e combustível)
Research Strands	**Motor architecture**			
	Fuels		Optimization of engines with biodiesel operation	
	Combustion			Combustion techniques to engines that are while diesel and Otto
	Connectivity for Active Safety	Proximity sensor evaluation in the Brazilian reality (e.g.: decision making concerning the emergency braking)		
	Virtual Reality			
	Autonomous direction			
	NVH / Metrics			

Legend: Grade 7 | Grade 6 | Grade 5

Figure 4.
Example of part of an R&D-oriented experts' roadmap (some information was intentionally hidden or made unreadable due to confidentiality reasons)

once the manufacturer spends 36 months in general to develop and launch a new car. Therefore, the first time bracket corresponded to the current product mix; the second, to new versions; and the third, to a new product generation.

4.3.2 External environment (EXT) layer construction. Once the time axis is established, a roadmap layer related to the external environment aspects needs to be constructed. In the MNM-UFMG AR program, many sector-specific trends were reviewed to identify the most relevant EXT aspects. As a result, the six dimensions used in the Brazilian Industrial Development Agency (ABDI, in the Portuguese acronym) report for the automotive sector were adopted as sublayers. The MNM innovation manager was asked to rate each trend for each of these dimensions using the seven-point Likert scale, from 1 (completely disagree) to 7 (completely agree). The strongest trends in the manager's opinion were plotted in the time interval when he thought the trend would be most significant for the industry (EXT layer in Figure 4).

4.3.3 Step 3: research and development strand layer construction – the research and development shared portfolio. Finally, the R&D-oriented layer needs to be constructed. Its sublayers should be the R&DS table items, defined in Step 1 of Stage 2. As introduced in Section 4.2.1, only the high-priority R&D strands may be depicted.

To fill this layer, the university experts selected in Stage 2 should be involved. This can be done either through a traditional workshop-based discussion (the recommended way for cases in which several distinct technical competences are demanded by the same strand) or through individual interviews focused on the R&D-related expertise of each researcher. In the AR program, this second approach was adopted, once each expert was highly specialized in competences relevant to only one of the R&DS sublayers. Each interviewee was asked to answer the following question: "Assuming the external environment prospect represented in the upper layer of this roadmap, which R&D results do you think the engineering school (and, particularly, your own research team) could deliver in a joint R&D program with MNM over the next decade?" The lower layer of Figure 4 highlights some of the R&D projects pointed by the experts.

Once the R&D-oriented roadmap is constructed, the final expected output is then achieved: an initial R&D project portfolio to start I-U collaboration. Once the R&DS layer was filled by university experts specialized in the most relevant competences to the industry's priority R&D strands (which, in turn, were originated from highly correlated PERFxCOMP clusters), the elements of this layer constitute an initial R&D portfolio that subsumes all the key aspects taken into consideration during the three-stage RSP methodology. Moreover, that is likely to be highly aligned to the individual research agenda of the researchers involved. Thus, this list of R&D projects plotted over time is a reasonable starting point for beginning an I-U collaboration.

5. Discussion

This study was aimed at devising an appropriate methodology for setting an R&D shared agenda between companies and academic institutions. According to the adopted perspective, an initial portfolio of R&D projects was set between a top-ranked Brazilian university and a local subsidiary of a large multinational automotive company. The three-stage RSP methodology was then derived from this experience based on intervention–reflection–adjusting loops.

The resultant methodology is intended to be applied to start I-U collaborations for technology-based innovation and is supported by two main pillars: (i) a co-constructed systematic view of innovation opportunities and (ii) a shared research agenda between partners. This approach intends to avoid some common barriers identified for this kind of cooperation:

(1) <u>A shared research agenda reduces differences in partners' expectations and the perceived importance of research opportunities</u>. Typically, there are significant differences in what is considered scientifically relevant for university and what is commercially attractive from the company's perspective (Barnes *et al.*, 2002; Debackere & Veugelers, 2005). This gap is often linked to stoppages in early efforts of I-U cooperation initiatives, once studies and inventions generated in the university may not adhere to industrial interests (the technology-push challenge) and, reversely, industry demands may not fit universities' scientific interests. Moreover, such demands usually emerge as unformatted needs typical of FFE (cf. Khurana & Rosenthal, 1998; Oliveira *et al.*, 2019), difficult to translate and diffuse in academic environments. Thus, conflicts associated with differences in expectations inherent to the institutional nature of each partner may be diminished if the ideas are shared and refined in the initial phases of innovation development, as proposed by the three-stage RSP methodology.

(2) <u>A common research agenda helps to adjust the pace of work</u>. The typical urgency of industrial problems often contrasts with the way that academic institutions deal with research work (Barnes *et al.*, 2002). The proposed methodology is focused on R&D opportunities, which, by nature, are not just better synchronized with the pace of academic work, but also better addressed by an innovation portfolio aimed at strategic and long-term impacts, assuring mutual interests and benefits (Barnes *et al.*, 2002; Oliveira *et al.*, 2019).

(3) <u>Mutual commitments get stronger in a gradual way and allow partners to better deal with projects' contractual issues</u>. The R&D portfolio in the proposed approach results from gradual convergence among people involved in both sides of the partnership. This approach potentially smooths the subsequent work to be done between universities' TTOs and industry's contractual/legal people – i.e. the contract signing that precedes the project execution, following Plewa *et al.* (2013) – contributing to reducing disparities in project scope and assignments, which is likely to impact bureaucratic work (Bagno, Salerno, Souza Junior, & O'Connor, 2020). In doing so, research trends and market needs are the predominant topics of the initial discussion, instead of an abrupt immersion in topics like intellectual property rights and financial division of royalties, for instance.

(4) <u>A shared work environment provides mutual benefits other than those associated with R&D outcomes</u>. Just like the roadmapping is often more important than the roadmap itself (Freitas *et al.*, 2019, 2020; Phaal *et al.*, 2010), as the three-stage RSP methodology steps are put into practice in a partnership context, mutual trust grows in each partner's team and tends to be a central element in the development of risky and uncertain projects that will come after (Melo *et al.*, 2020; Plewa *et al.*, 2013). Moreover, other kinds of valuable interaction tend to emerge, and some examples that resulted from the case were company's sponsorships and participation in academic events; participation of company's people in graduation and post-graduation courses; seminars to academic community conducted by company's people; more involvement and diffusion in trainee programs; university networking access by partner company; technical visits in the company for the academic community, etc. In other words, the three-stage RSP in practice fostered interactions of multiple natures and further R&D efforts of the company (Berbegal-Mirabent *et al.*, 2015; Scandura, 2016).

The proposition of a methodology to build an initial R&D portfolio contributes to "unfuzzying" the FFE of a company's innovation process (Bagno, Salerno *et al.*, 2020).

Moreover, it helps to consolidate organizational micro-processes that offer a structural basis for organizational objectives (e.g. the development of applied technologies) that often lack well-defined routines and a systemic approach (Bagno, Salerno, & Dias, 2017; Melo *et al.*, 2020).

This study enriches an open innovation practical approach by providing methodological support to (i) generating focused ideas, aligned with inputs from strategy and market; (ii) defining criteria for idea selection; and (iii) sequencing ideas in the early phases of the innovation process. It suggests a more iterative approach to the traditional "idea-prioritization" input phases of an innovation funnel (Bagno, Salerno, & Silva, 2017; Salerno *et al.*, 2015), resulting in a "prioritization-idea-prioritization" sequence to gain control over the process and better adherence to strategic guidelines. Once an "opportunity space" is previously defined and agreed upon in a partnership context, the preliminary opportunity identification suggested in the FFE is improved in its accuracy by using a systematic approach to collect and process data about customer, technology and competition (Oliveira *et al.*, 2019).

6. Conclusion
This study was based upon a "how question" concerning the building of an initial portfolio of R&D projects to start I-U collaboration. The answer was given through the proposition of a methodology intended to support companies and universities in the attempt to establish R&D partnerships. The way this work was conducted offers (at least) two prisms for analysis: an operational view, centered on how the methodology was built, how it should be applied and the insights that came from the interventional approach with the teams involved; and the managerial perspective, which raises the discussion on I-U collaboration and other related topics in innovation management.

Focusing on the first prism, the three-stage RSP methodology is a result of an effort to answer a real-world problem. Its basic general model serves as a guiding methodological reference, once adjustments, refinements or extensions may be made for another particular case. The original proposal, however, suggests its potential for businesses related to (i) products of complex structure (i.e. that result from the combination of several components and subsystems, which may be correlated to many possible performance aspects that have an impact on final customer satisfaction) and (ii) medium-high technology, concerning the scientific and technology trends that tend to propel important developments in the long term, and that are difficult to handle without a systematic approach. In part, these characteristics are associated with the combined concepts and assumptions behind QFD and roadmapping, the fundamental elements of the resultant methodology.

On the managerial discussion, this work tied some contemporary challenges of I-U cooperation to the problems related to the FFE of companies' innovation process, integrating the perspectives of R&D portfolio management and open innovation. The way the proposed three-stage RSP methodology seems to sew up these topics reinforces the need to view innovation management in a systemic perspective instead of focusing on small pieces of the organizational-related phenomenon.

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