The Art & Science of Practice:

Academia-Industry Interfacing in Operations Research in Montreal

Laure Cabantous

Cass Business School, City University London, London, United Kingdom,
laure.cabantous.1@city.ac.uk

Gilbert Laporte

CIRRELT and Canada Research Chair in Distribution Management, HEC Montréal

Montréal, Canada, Gilbert.Laporte@cirrelt.ca

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Laure Cabantous
Cass Business School, City University London, London, United Kingdom
laure.cabantous.1@city.ac.uk

Gilbert Laporte
CIRRELT and Canada Research Chair in Distribution Management, HEC Montréal
Montréal, Canada, Gilbert.Laporte@cirrelt.ca

Abstract: This paper reports on the 40-year experience of academia-industry interfacing in the operations research (OR) field in Montreal. We focus on five spin-off companies that academic entrepreneurs from the CIRRELT and the GERAD created between 1976 and 2003: INRO Consultants, GIRO, AD OPT, Omega Optimisation/Planora, and ExPretio. The importance of university spin-offs for knowledge transfer is well documented in fields such as biology and nanotechnology; however, few papers have studied university spin-offs in OR. Yet, OR has an enormous impact on society, and university spin-off firms play a key role in the diffusion of research to the world of practitioners. In this paper, we tell the story of five companies created by academics from two world-renowned OR research centers based in Montreal, and we derive lessons about academia-industry interfacing in the OR field. By so doing, we hope to improve our understanding of the creation of fruitful relationships between academics and OR practitioners.

Key words: university; industry; spin-off; operations research.

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Many companies, particularly in the transportation and telecommunications sectors, depend on operations research (OR) for their operations and survival. The existence of journals such as *Interfaces*, which aims to publish "papers describing real-world problems and their practical solutions" (Bollapragada 2011), offers further evidence of the lasting interest of operations researchers in real applications. Most *Interfaces* papers describe successful OR implementations and report on the actual practice of OR and its impact on real organizations; however, relatively few have investigated the factors that make these implementations possible; see Miller (2010) for an exception. We therefore still know relatively little about how operations researchers manage the interface between academia and practice. An important factor that enables the successful application of OR techniques within organizations is the existence of collaborations between academics and practitioners, which sometimes take the form of spin-off companies. Management scholars have long studied the importance of university spin-offs in knowledge transfer (Vohora et al. 2004), but they have usually focused on fields such as biology or nanotechnology.

In this paper, we study the experience of academia-industry interfacing in OR in Montreal where two leading OR research centers are located: the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation (CIRRELT), formerly the Centre for Research in Transportation (CRT), and the Group for Research in Decision Analysis (GERAD). We focus on five spin-off companies, which CIRRELT and GERAD researchers created between the 1970s and the early 2000s: INRO Consultants (http://www.inrosoftware.com/), the Informatics and Operations Research Group (GIRO) (http://www.giro.ca/en/), AD OPT (http://www.ad-opt.com/), Omega Optimisation/Planora, now the research division of JDA

(http://www.jda.com), and ExPretio (http://www.expretio.com/). In reporting on the development of these spin-offs over the past 40 years, we provide insights into their contribution to knowledge development and transfer.

Operations Research in Montreal: 40 Years of Research Excellence

Teaching and research activities in the OR field in Montreal are spread among seven institutions: Concordia University, McGill University, Université de Montréal (UdeM), Université du Québec à Montréal (UQÀM), HEC Montréal, Polytechnique Montréal, and École de Technologie Supérieure. HEC, a business school, and Polytechnique, an engineering school, are affiliated schools of UdeM. Approximately 50 Montreal-based professors conduct research in OR. The exact number is difficult to ascertain because the frontiers between OR and related fields, such as computer science, mathematics, industrial engineering and operations management, are fuzzy.

The Montreal OR community is widely recognized as a world leader in OR, as evidenced by the number of prizes and honors awarded to its professors and graduate students, the number of publications in leading OR journals by these professors and students and citations to these publications, and the community's impact on practice. Two of the eleven awardees of the Robert Herman Lifetime Achievement Award (INFORMS Transportation Science and Logistics Section) and two Edelman finalists are part of the Montreal OR community. This community is very active and encompasses some of the most productive authors in the operation research and management science (OR/MS) field (Hsieh and Chang 2010). UdeM is the third most-featured organization in the four leading transportation journals, which are the main areas of expertise of the CIRRETL and GERAD. These journals are *Transportation Science*, *Transportation Research Part B: Methodological*, *Transportation Research Part C: Emerging Technologies*, and *Transportation Research Part E: Logistics and Transportation*. Between 1970 and 2015, these

journals published 193 articles from UdeM, 52 from HEC Montréal, and 49 from Polytechnique Montréal, a total of 294 articles (6.13 percent, n=4,796). This makes the Montreal OR community the second most-featured community in these journals; the University of California System, which comprises nine campuses, ranks first.

The Montreal OR community has also had a major impact on organizational practices, as evidenced by its rankings in the Rothkopf rankings, which rank academic institutions according to their contributions to the INFORMS practice literature. In the 1999 edition of the ranking, UdeM ranked fifth and HEC Montréal ranked eighth. Polytechnique Montréal ranked eleventh and sixth in the 2004 and 2007 editions, respectively (Rothkopf 1999, Rothkopf 2004, Rothkopf 2007). Our search, using the Web of Science database, shows that three Montreal-based universities are at the top of the list of the organizations featured in the articles published in *Interfaces* between 2000 and 2015. The impact of the Montreal OR community on the region is also visible through the creation of five university spin-offs since the late 1970s. These spin-offs have contributed to the worldwide dissemination of research results (i.e., commercial products) in companies and public organizations. Locally, they have generated more than 600 jobs.

The Role of Interuniversity Research Centers in Research Excellence

Research excellence in OR in Montreal is facilitated by two research centers, the CIRRELT and the GERAD, which carry out fundamental algorithmic and applied research in transportation network planning, scheduling, location, energy planning, combinatorial optimization, mathematical programming, and related fields. These multiple-university research centers help create an OR community that spans the universities. They also facilitate cooperation between their members, help generate funding, and increase the visibility of Montreal-based OR research worldwide.

The CRT, the first OR research center in Montreal, was formed in 1971 with a seed grant from the Ford Foundation to conduct interdisciplinary research activities in the field of transportation planning; OR was the main discipline. In 2006, the CRT merged with several OR groups from Montreal to become the CIRRELT. The main objectives of the CIRRELT are to carry out research, train students, transfer knowledge, and support policy and decision making). The GERAD was founded in 1979 to conduct research in quantitative decision making, with a strong slant toward transportation.

The main research activities of the CIRRELT and the GERAD are financed primarily by their supporting institutions (e.g., HEC Montréal, Polytechnique Montréal, UdeM) and by federal and provincial granting agencies, such as the National Science and Engineering Research Council Canada (NSERC) and the Fonds de Recherche du Québec (FQRNT). Only a few research contracts are exclusively funded by industrial partners; however, some government grants, such as the grants from the MITACS (a Canadian not-for-profit organization), require a partnership with industrial partners and play an important role in supporting the research carried out at the CIRRELT and GERAD. In addition, the federal and provincial governments provide fiscal incentives to promote university-enterprise collaborations. Finally, the host universities, which view the emergence of spin-offs favorably, conclude agreements with the companies regarding royalties, and welcome research partnerships with their spin-offs through collaborative university-industry research contracts.

Successful Examples of Academia-Industry Interfacing: Montreal's University Spin-Offs

A spin-off company is "a new venture that is dependent upon licensing or assignment of the institution's intellectual property for initiation" (Lockett and Wright 2005, p. 1044). This

definition, however, excludes companies founded by graduates or university researchers who are not linked to the university through a license or an intellectual property (IP) contract. In this paper, we retain a broader definition of spin-off; we include companies founded by university researchers or students, whatever the type of initial contract they had with the university. We focus on five spin-offs, created by CIRRELT and GERAD researchers, which have reached a sustainable stage: INRO, GIRO, AD OPT Technology, Omega Optimisation/Planora, and ExPretio Technologies. Table 1 provides an overview of these five spin-offs.

INSERT TABLE 1 ABOUT HERE

Below, we report on the creation, growth, and development of these spin-offs from their date of creation until 2012. To this end, we collected data in 11 face-to-face interviews with the founders of the companies and some of their colleagues (Table 2). We then complemented these interviews with publicly available information and documentation that the interviewees provided.

INSERT TABLE 2 ABOUT HERE

First Experiences of Academia-Industry Interfacing: INRO Consultants and GIRO

INRO Consultants is a privately held company created in 1976 by Michael Florian, an OR professor from UdeM, who specializes in traffic control and transport planning. In the late 1970s, valorization of research was not yet a priority at UdeM. Professor Florian, who was the first director of the CRT, acted as a pioneer when he decided to create INRO Consultants to help CRT

researchers commercialize their innovations. INRO's first success occurred in the mid-1980s with the commercialization of EMME/2, traffic-assignment and demand-forecasting software that was linked directly to the research conducted by the founder of INRO and his colleagues (Florian 1977, Florian and Nguyen 1978, Florian and Spiess 1983). Since then, INRO has developed two other core products, STAN, a strategic freight-planning software package, and DYNAMEC, a dynamic-traffic-assignment software package. Similar to EMME/2, these products build on research carried out on transportation-network models, which the INRO founder and his colleagues conducted.

INRO products are used by thousands of transportation planners in more than 2,500 cities and 80 countries. Thanks to the reputation of its products, INRO has been involved in many important projects, such as the road investment project for the Vancouver 2010 Olympics. Cities such as London and Hong Kong use its software to manage their congestion-pricing and transit fares. INRO is still based in Montreal and its 35 employees contribute to the development and commercialization of its products, and to the facilitation of a community of users worldwide.

GIRO was created in 1979 by Jean-Marc Rousseau, who was then the director of the CRT, and by one of his doctoral students. The two researchers created GIRO to commercialize a vehicle and operator-scheduling system, HASTUS, which they had developed in partnership with the Montreal Transit Company (Roy and Filion 2005).

The GIRO founders published several academic papers based on their research (Blais et al. 1990) and received an award from the Canadian Operations Research Society for the development of HASTUS (Blais and Rousseau 1982); they also created a sustainable company. More than 35 years after its development, HASTUS remains GIRO's core product; the firm also commercializes two other products: GeoRoute, routing and scheduling-management software for

services such as postal operations and waste collection, and GIRO/ACCESS, a paratransit and transit of disabled-person scheduling software. The company sells its products to more than 200 organizations in 25 countries worldwide (e.g., Long Island Railroad in New York City, SBS Transit in Singapore, the Victoria Department of Transport in Melbourne, Skyss in Bergen, Norway). It has approximately 300 employees and 12 shareholders, and generated a turnover of CAD$56 million in 2013-2014 (Proulx 2015).

The Second Wave of Academia-Industry Interfacing: AD OPT

AD OPT was founded in 1987 by François Soumis, an OR professor from Polytechnique Montréal and member of the GERAD, who specializes in air transportation problems, two MSc students, and two colleagues from the CRT. In the late 1970s, these researchers developed a new optimization strategy, GENCOL for column generation, which allows a huge number of variables to be considered in solving large-scale integer linear programs (Desaulniers et al. 2005, Desrochers and Soumis 1989, Desrosiers et al. 2000, Desrosiers 2001, Lacroix and Desrosiers 2004). The GENCOL technology quickly became successful, and its inventors received awards from the European Association of Operational Research in 1983 and from the Operations Research Society of America in 1986 (Roy and Filion 2004a, 2004b).

Through a partnership with Air France and GIRO, the designers of GENCOL were able to move from a prototype to a commercial product. In 1987, they created AD OPT to sell their product to clients, such as Air Transat and UPS. Whereas the GENCOL technology was initially developed for the mining sector (Desrosiers 2010), the founders of AD OPT concentrated on the airline industry. Over time, AD OPT has developed a suite of crew-planning and scheduling solutions customized for this industry; these solutions include Altitude Pairing, a software

optimizer for crew-member pairing problems, Altitude PBS, a software optimizer for monthly crew blocks, and Altitude VBS, a bidding system that creates crew vacation timetables.

The founders of AD OPT originally adopted an organic growth strategy. In the mid-1990s, however, they turned to venture capitalists to acquire Carmen Systems, a division of Volvo. After being incorporated in 1994 and listed on the Toronto Stock Exchange in 1999, AD OPT launched in a series of acquisitions (e.g., Totalcare of Kelown in 2001, Mercury Scheduling of Vancouver in 2003). But, in 2004, KRONOS Inc, a U.S. software company acquired AD OPT for $68,200,000. At that time, the AD OPT turnover was approximately CAD$300,000 per year. AD OPT has since become the airline crew-planning division of Kronos. It is still based in Montreal, and its founders estimate that it has generated approximately 200 full-time jobs since its creation (Interview #5). Despite this acquisition, Kronos has kept the AD OPT name because of its excellent reputation among corporate clients.

Academia-Industry Renewal: Omega Optimization/Planora (2002) and ExPretio (2007)

Omega Optimization/Planora is a workforce optimization company that develops and sells optimization software for personnel scheduling in a wide range of market segments (e.g., hospitals, retail stores). When the company was created in 2001-2002, its two founders, Louis-Martin Rousseau and a fellow student, were both PhD students in OR at UdeM. Rousseau was experiencing delays in his doctoral research because he had to wait for some license renewals; he decided to use this free time to apply his skills in constraint programming to personnel rostering problems. Because he was convinced that his research had some commercial opportunities, he enlisted another PhD student in his project. Together, they enhanced the prototype and launched Omega Optimization. Omega Optimization's core product, originally called OpTime*,* is thus closely associated with the research of its founders (Rousseau et al. 2002, Côté et al. 2103).

Omega Optimization initially worked in partnership with a software company responsible for developing and maintaining the interface, doing market research, and managing the relationship with Omega Optimization's clients. As a result of this partnership, Omega acquired its first clients, two hospitals from the Montreal area and the Labatt brewery in Montreal (Interviews #8 and #9). Between 2002 and 2007, the company experienced slow but steady growth with more employees and larger contracts from clients in Quebec, such as the Federation of Milk Producers and Dairy Farms. In 2009, two years after Omega Optimization ended its partnership with the software company, it benefited from a massive injection of funds and commercialized its new product, Planora™. Between 2010 and 2014, many changes occurred. In 2010, it turned to an investment fund to gain access to capital and grow further (e.g., its shareholder number grew from three in 2007 to six in 2010); in 2011, it was renamed Planora. In July 2012, RedPrairie, a large U.S. company specializing in supply chain management solutions acquired Planora, just before RedPrairie merged with JDA in late 2012. Since then, Planora, which employs approximately 40 persons, has been the research lab of JDA.

ExPretio is a privately owned company headquartered in Montreal and specializing in revenue-optimization and pricing solutions in the airline and railway industries. It was founded in 2003 by a group of four OR academics from Canada, France, and Belgium specializing in bilevel optimization algorithms in the transport sector: Gilles Savard (CIRRELT, Polytechnique Montréal), Patrice Marcotte (DIRO, UdeM), and two European colleagues. The idea of creating a company to commercialize the new algorithm that the researchers had codeveloped came in the late 1990s, after the four researchers coauthored a paper in *Management Science* (Labbé et al. 1998) and another one in *Transportation Science* (Brotcorne et al. 2000). ExPretio's core product is thus directly based on the output of this research. The four academics founded ExPretio in

2003 with the help of a UdeM graduate and former AD OPT vice president, who provided funds and became ExPretio's CEO. A former PhD student of one of the lead academics joined as chief technology officer. The French national railway company, SNCF, which had an interest in the technology since its beginning, joined the venture as one of its subsidiary companies (Interviews #10 and #11).

ExPretio was located initially at Polytechnique Montréal, but it left the university premises in 2007. It currently employs 35 persons and has seven shareholders. Its core product, APPIA, is sold worldwide to rail industry clients, such as the SNCF, Thalys, Renfe, and NTV.

Overcoming Critical Junctures: A Comparison of the Five Montreal Spin-offs

The growth trajectory of university spin-offs is usually not linear. Moving from one stage (e.g., opportunity recognition) to another (e.g., commercialization) is critical to the survival of the venture (Vohora et al. 2004). Although such moves enable new ventures to grow, they put them at risk because a new configuration of resources, capabilities, and network ties are required (Wright et al. 2004, p. 289). Below, we compare the ways in which the five Montreal spin-offs have overcome a series of critical junctures and have become sustainable.

First Critical Juncture: Opportunity Recognition

Most university spin-offs face an opportunity-recognition critical juncture when academic entrepreneurs who are convinced of the value of their research must identify whether a market opportunity exists (Vohora et al. 2004). Academic entrepreneurs have to find a way to match their discoveries with an "unfulfilled market need and a solution that satisfies the need" (Vohora et al. 2004, p. 160). In many cases, this match is not easy to find, because academic

entrepreneurs usually have limited knowledge of market needs and cannot easily evaluate the potential commercial value of their research.

For the Montreal spin-offs, this market-knowledge barrier was lower because the academic entrepreneurs had developed partnerships with industry partners, through personal contact or during conferences (Interview #4), before launching their new venture. In some of the cases that we study, the industry partnership was a requirement of the government, which was financing the research through a specific type of grant that required the spin-off to have industry partners (Interview #5). This type of partnership enables researchers to gather some knowledge of industry needs and helps them to move from a prototype to a commercial product. The cases of INRO, GIRO, and ExPretio illustrate how the lead researchers developed knowledge of market needs through industry partnerships. In the case of INRO, the research was initially financially supported by the Transport Canada central research and development branch. The lead researcher quickly became aware that no one in Canada had ever developed the model his research team was developing. He also realized that to further develop the technology, his team would need to create its own software package, because no existing software could integrate the powerful algorithm the team it had developed (Interview #1). He thus decided to work closely with potential users, such as the city of Winnipeg, to develop a prototype. Eventually, as some partners asked how much the software would cost, he realized that a market opportunity existed for the technology:

> "And then people started to ask 'How much does it cost?' Then we did two pilot implementations: one in Stockholm where we had very good collaborators, and one in Portland, Oregon in the United States. We then did another pilot implementation

in Ottawa for public transit. We then realized that there was a market and we decided to negotiate the distribution rights with the university […]" (Interview #1).

A similar story of collaborative research with industry partners developed through the personal contacts of GIRO's founders. The creators of HASTUS did not initially think about creating a spin-off, but wanted to conduct relevant research:

"The creation of GIRO is the result of several unpredictable events […]. The idea of developing a piece of software emerged when I joined the university in 1973. My first MSc student worked in the computer science department of the Montreal transit company. I asked him to see whether he could identify an interesting operations research problem within the company. He came back with a driver-scheduling problem, which was rather complicated because of all kinds of complex collective agreement rules" (Interview #4).

Three years after the development of the first version of HASTUS, the Montreal transit company signed a contract with the designers of HASTUS and asked them for an updated version of the software. It renewed its contract for HASTUS in 1978 and, when the researchers proved to the transit company that it could save 3 percent of its labor cost by using HASTUS, it decided to finance a larger research project with the support of the Quebec Ministry of Transport. The designers of HASTUS then realized that other companies might be interested in their software and they established GIRO (Roy and Filion 2005).

The case of ExPretio differs slightly. The academic entrepreneurs were quickly convinced of the potential commercial value of their research; however, they decided to wait until they had found an industry partner committed to support them financially. This opportunity occurred four years after they first had the idea to establish a venture:

> "As far as I am concerned, we had decided in 1999 to start a company. Our business plan was 'Let's go ahead when we have a customer.' Because we did not want to rely only on consulting activities, we had to have a product. So we waited until we had our first customer who was willing to invest in the development of the product" (Interview #11).

Another reason that the Montreal academic entrepreneurs successfully overcame the opportunity-recognition critical juncture was because their innovations were not disruptive; they were sustaining innovations—innovations that substantially improve the existing technology and provide better value in an existing market. In all five cases, as a result of the high level and robustness of the academic research that supported them, the technologies were far more advanced than those incorporated in the software available in the market. The value of these technologies thus was not because they solved new problems, but because the research teams had developed better techniques to solve existing optimization problems. A technology's nature can make a significant difference: identifying market opportunities for sustaining innovations is easier than for disruptive innovations, because the market already exists and the new product can be benchmarked against existing products.

Second Critical Juncture: Entrepreneurial Commitment

Recognizing a market opportunity is important; however, taking an idea forward and creating a company that commercializes this opportunity is also necessary. The academic entrepreneurs must have persistence, take actions, and show commitment. Entrepreneurial commitment is thus the second critical juncture that academic entrepreneurs face. Academics who have identified a market opportunity have to firmly commit to creating a spin-off; in doing so, they usually face a series of challenges. They must deal with the operational, managerial, and financial aspects of

the project. They also must accept risks, overcome their lack of prior business experience, and attract competent managers (Vohora et al. 2004). They may also have to deal with reluctance from within their academic environment. All these elements put at risk their willingness to commit to the commercialization project.

The academic entrepreneurs who established the Montreal spin-offs operated in a professional environment in which their colleagues were relatively supportive of their projects to develop ventures. In the late 1970s, when GIRO and INRO were established, UdeM and Polytechnique Montréal did not have a policy that addressed how academics could commercialize their research output; however, the climate was favorable. The two academics who founded GIRO and INRO had high-level positions in their universities, and they were directors of the CRT. In 1987, when AD OPT was created, UdeM and Polytechnique Montréal were encouraging collaborations with industry partners. In 1982-1983, UdeM launched a funding campaign directed toward large companies (Roy and Filion 2004b). Moreover, the Canadian government was providing incentives to academics to collaborate with industry, through specific grant programs that required industry partners. Finally, in the cases of Omega Optimization/Planora and ExPretio, both created in the early 2000s, the institutional environment was even more supportive. In 1998, UdeM and Polytechnique had created a university-transfer organization, Polyvalor (renamed Univalor in 2001), whose mission was to help academics manage the challenges associated with creating new ventures. Univalor relies on standard mechanisms of technology transfer, such as the compensation of researchers who develop an intellectual property, through sharing royalties, equity participation in academic start-ups, and licensing to established firms. With respect to the royalty-sharing rule, Univalor adopted a formula in which royalties are shared equally between the researchers who have contributed to

the development of the intellectual property and the university (Savary et al. 2002). Over time, Polytechnique Montréal and UdeM have become more involved in technological transfer, as the director of research and innovation at Polytechnique Montreal (and cofounder of ExPretio) explains:

> "The technological transfer mission [of Polytechnique Montréal] is relatively recent […] but linkages with companies started 30 years ago. It took time to understand this equilibrium between fundamental research and research for common good and companies. There are people who […] distinguish between the common good and the good of companies, but […] companies are part of society […], so for us there is no opposition. We are here for the good of society and since we are engineers, it is for the good of companies, among others. This is how it goes. Today, this is well accepted at Polytechnique but it took 15 years" (Interview #11).

The supportive institutional climate, however, does not mean that academic entrepreneurs do not have to engage in intense negotiation with their universities for intellectual property rights (Roy and Filion 2004a, 2004b). The GIRO entrepreneur team negotiated retroactive rights in the mid-1980s, because when GIRO was created, the university did not have a formal intellectual property policy (Roy and Filion 2005). GIRO eventually obtained the right to commercialize the GENCOL technology after a long series of discussions with the university:

> "There was not really a model here. It was not common to see companies emerge from research activities. It took a long time before we started negotiating formal agreements with the university. Then, we negotiated for a long time […]. The university did not know how to handle this. We did not know either. We told the

university: we will negotiate something that will be retroactive. Finally we arrived at an agreement in 1987" (Roy and Filion 2005, p. 6).

In the case of AD OPT, complex intellectual property-rights negotiations with the university occurred in two steps. In the mid-1980s, the founders of AD OPT first negotiated the right to commercialize the software they had developed for the mining sector. They then concluded an agreement for the rights to GENCOL in the early 1990s, when they expanded the company's activity to include the airline sector. This second round of negotiations proved more challenging because more organizations (e.g., HEC Montréal, Polytechnique Montréal, UdeM) were involved, and GIRO's founders had already negotiated the right to commercialize the GENCOL technology in the public transit sector (Gratton et al. 2007). The Omega Optimization/Planora and ExPretio situations are different, because a formal intellectual property policy was in place when these companies were established.

Academic entrepreneurs also face a challenge in transitioning to managerial roles. The academic entrepreneurs we study resolved this challenge in different ways. In three cases (Ad OPT, Omega Optimization/Planora, and ExPretio), they did not leave their universities to manage their ventures; they relied on surrogate entrepreneurs. Various reasons explain their choices. First, these academics were truly committed to their academic projects, and one of their primary motivations for creating the ventures was to secure external sources of funding so that they could pursue their research:

"Why commercialize to start with? I must admit, the objective was to help finance our research activities. Initially, our research group was made up of about 25 students, research assistants, and postdocs. To finance all these people, we had to repeatedly apply for grants. So this helped. Second, there was the relevance of our

research. Even if we carry out fundamental research, it must someday be relevant. Third, there is the question of finding openings for our graduates. Fourth, this type of spin-off and university cooperation attracts students who are interested in industry. Let's not hide it; only 20 to 25 percent of our graduates go into academia. So we have to prepare them" (Interview #11).

Second, these academics did not necessarily have any interest in taking on managerial roles, such as CEO. As one of our interviewees said: "I am an academic, and I also am an entrepreneur, but there is a huge difference between being an entrepreneur and being a manager" (Interview #8). They were also usually convinced that they would be more effective in their academic roles than in managerial positions: when the lead academic becomes a manager, he (she) has less time to dedicate to his (her) research activities, which deprives the spin-off of one of its best resources (Interview # 5). Third, the policy adopted by UdeM and Polytechnique does not allow academic entrepreneurs to take on managerial roles if they want to keep their university positions (Savary et al. 2002).

In the case of GIRO and INRO, the two academic entrepreneurs eventually took a managerial role in their companies and left their university jobs. The founder of GIRO quit his position as professor at UdeM 10 years after GIRO was established to become the company's vice president. The INRO founder stayed as a professor at UdeM for more than 30 years, and became CEO of INRO when he left the university in 2004.

Third Critical Juncture: Market Credibility

The third critical juncture, market credibility, refers to the "entrepreneur's ability to gain access to and acquire an initial stock of resources, which are required for the business to begin to function" (Vohara et al. 2004, p. 164). The commercial exploitation of a research team's

technological assets usually requires funding. In the cases we study, the seed funding was limited, especially when compared to that required to launch biotechnological ventures. This explains why none of the spin-offs sought access to venture capital to launch a venture.

Another important aspect of market credibility is the acquisition of key customers. In all five cases, the end users are companies, not individuals. Operating in the business-to-business market makes acquiring customers easier, because academic OR conferences often welcome representatives from industry and facilitate contacts between university researchers and potential users or industry partners (Interview #4). The specificities of the innovations developed in Montreal also explain why the market-credibility test was successful. Because these innovations were not disruptive innovations, a market already existed for the technologies. The innovators could thus show to potential clients that their technology performed better, or was better aligned with the customer's needs. The academic entrepreneurs in all five spin-offs were extremely clear about this specificity of their innovations and explained that they acquired market credibility by running their software using client data. They built their business cases by benchmarking their new software against the software that the client company was running:

> "[…] with a tactical product the client can construct his schedules with his old system, while you construct your schedules on your side. And, we put the two side by side. As he still has his old system, he quickly knows how much money he can save. This is benchmarking. The business decision is made on the business case, and when you develop a business case where people can save $25 million a year, they don't care who you are! This is how we have made our way into the market" (Interview #5).

Overall, the acquisition of customers relied heavily on reputation and word of mouth, but also on active market research, partnerships with other organizations (e.g., Omega Optimization/Planora), and acquisitions (e.g., AD OPT).

Fourth Critical Juncture: Attaining Sustainable Returns

The final critical juncture refers to the ability to continuously reconfigure existing resources, capabilities, and social capital with new information, knowledge, and resources to ensure sustainable returns, that is, "revenues from customers for services or product sold, milestone payments from collaborative agreements of investment from existing or new investors" (Vohara et al. 2004, p. 166).

The Montreal spin-off entrepreneurial teams had different approaches to reconfiguring their existing resources and capabilities to grow their companies. A sharp contrast exists between INRO and AD OPT. INRO is privately held, never relied on bank loans or venture capital, and opted for a pure organic growth (Interview #1); in contrast, AD OPT went public in the 1990s, and, in the 2000s, embarked on a series of acquisitions before Kronos acquired it. INRO's founder decided to grow the company by building internal capabilities; AD OPT grew by acquiring firms. The Omega Optimization/Planora case also differs, because this spin-off initially opted for slow, steady growth using local clients. But, in 2010, its founders radically changed their strategy: they turned to venture capital, and were later acquired by JDA, which turned the spin-off into its research lab.

Summary

Knowledge on efficiently managing the interface between academia and industry is crucial to maintaining the usefulness and relevance of OR. In this paper, we have reported on the cases of

five university spin-offs that academic entrepreneurs from the CIRRELT and GERAD established. These five ventures have distinct trajectories; however, all were created by OR academics who had developed innovative methods for solving complex scheduling problems.

We can learn three lessons from these cases. First, in this paper, we show that being an academic entrepreneur is both exciting and challenging. Designing an innovative OR technology that wins academic awards is only one element in the story. Once they have decided to commercialize their innovation, academic entrepreneurs must overcome a series of critical junctures, which necessitate that they acquire a new set of skills. Beyond adapting the technology to market needs, they must include many types of partners, such as banks and customers, in their projects (Akrich et al. 2002). They also must accept that technology is not the only element that matters: "Technology is one thing but value proposition and go to market strategy are also important. It is not because as scientists we can 'do' something useful, that a significant number of customers will be willing to pay for this service" (Interview #8).

Second, although we have focused on five spin-offs that commercialized sustaining innovations for which they needed no massive up-front capital, we showed that significant differences exist between these spin-offs. In all five cases, the acquisition of customers relied on benchmarking, reputation, and personal contacts. Yet, the trajectories of the spin-offs—in particular their approaches to dealing with their financial and managerial challenges—differed significantly: some founders decided to go public, and others preferred to grow their firms organically by developing internal resources and capacities.

Finally, our paper shows that industry partnerships and a favorable institutional environment play a key role in creating sustainable university spin-offs. Without assistance from industry partners, none of the academic entrepreneurs we studied would have been able to create

its company. The institutional climate within the Montreal universities also positively contributed to the successful development of these ventures. In return, these universities have benefited from many positive externalities. As one of the cofounders of AD OPT said, when we asked him to reflect on his insights for initiating and growing a start-up: “The creation of a spin-off has helped my team and me to further develop our research and to obtain external funding in order to conduct new research. It also helped us to create jobs for our students. Last, it is also a very lucrative venture, and a model for the next generation of OR researchers in Montreal” (Interview #5).

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Tables

Company [year founded]	**Opportunity**	**Technology**	**Main products**	**Current growth phase**	**Start-up investment**	**IP**	**Venture champion**
INRO Consultants [1976]	To design, develop, and commercialize transport planning solutions	Multimodal equilibrium	EMME/2 STAN Dynameq	Sustainable return phase International market Privately owned n=35	Only one funder, the lead academic. No partner involved	University: IP license negotiated in 1985	One academic entrepreneur
GIRO [1979]	To design, develop, and commercialize software solutions for managing urban transport related operations	Column generation (GENCOL)	HASTUS GIRO / ACCESS GeoRoute	Sustainable return phase* International market Privately owned n=240	No external funding in 1979. Early 1980s: research contracts and a CAD 400 000$ R&D loan from the Société Générale de Financement	University: retroactive IP license in 1987 after several years of negotiation	One academic entrepreneur One surrogate entrepreneur (full time from 1982)

*GIRO's turnover was CAD$30M in 2010; the company founders and the senior management hold GIRO shares.

Table 1: For each spin-off company we discuss in this paper, we show information pertinent to the company.

Company [year]	**Opportunity**	**Technology**	**Main products**	**Current growth phase**	**Start-up investment**	**IP**	**Venture champion**
AD OPT [1987]	To design, develop, and commercialize crew planning optimization solutions for the airline industry	Column generation (GENCOL)	*iBid* *Altitude suite*	Sustainable return phase; international market* A division of Kronos since 2004 n=200	CAD$300 000 from two Canadian research funding bodies. Two companies gave CAD$150,000. Five entrepreneurs acted as guarantors and invested CAD$100 each.	University: IP license Two rounds of negotiation (1986 and 1992)	Academic entrepreneurs and surrogate entrepreneurs

*AD OPT turnover was CAD$25M in 2003 (Gratton et al. 2007)

Table 1 Cont'd

Company [year]	**Opportunity**	**Technology**	**Main products**	**Current growth phase**	**Start-up investment**	**IP**	**Venture champions**
Omega / Planora [2001]	To design, develop and commercialize optimal workforce management solutions and personal scheduling systems for complex cases across market segments	Constraint programming	*Planora* (formerly *OpTime*)	Growth phase International and regional markets Acquired by RedPrairie/JDA in 2012 n=20 (before acquisition by RedPrairie/JDA)	Two main sources of funding: Tax credit R&D (80%) Electronic trade credit (20%) Partnership with a web company previously funded by one of the lead funders of Omega	The company was created when the two funders were still PhD students. No IP right to negotiate	Two academic entrepreneurs, one surrogate entrepreneur (in 2007), and one industry partner

Table 1 Cont'd

Company [year]	**Opportunity**	**Technology**	**Main products**	**Current growth phase**	**Start-up investment**	**IP**	**Venture champions**
ExPretio [2003]	To design, develop and commercialize revenue management and pricing solutions for the rail and airlines industries	Bilevel mathematical programming	*APPIA* (formerly *NetPro*)	Growth phase International market Privately owned n=35	Four university professors were the main shareholders; they provided research time and expertise Research contracts from MITACS in collaboration with industry partners for CAD$ 400 000/year.	Discussions with the University led to the conclusion that there were no IP rights to negotiate.	Four academic entrepreneurs, two surrogate entrepreneurs, and one industry partner

Table 1 Cont'd

Firm	Interviewee	Role	Affiliation*	Education	Interview Date
INRO	1	INRO Consultants Founder, President Professor Emeritus, UdeM	CIRRELT	PhD, Operations Research, Columbia University, 1969	October 24, 2011
INRO	2	VP, Development and Solutions		MSc, Engineering Systems, Technology and Policy, MIT, 2004	October 24, 2011
INRO	3	VP, Marketing		PhD, Operations Research, UdM	October 24, 2011
GIRO	4	GIRO founder, VP (1979-2000) Former UdeM Professor Former CRT director	CRT	PhD, Operations Research, MIT, 1973	October 24, 2011 and October 26, 2011
AD OPT	5	AD OPT cofounder Professor, Polytechnique Montréal Former director of GERAD	GERAD	PhD, Informatics and OR, UdeM, 1979	October 14, 2011

Table 2: For each of the 11 interviewees, we show role at the spin-off, research center to which the interviewee was affiliated at the time the spin-off was established, education, and date of interview.

Table 2 Cont'd

Firm	Interviewee	Role	Affiliation	Education	Interview Date
AD OPT	6	Operations Research Architect at AD OPT, a division of Kronos	GERAD	PhD in Applied Mathematics & OR, Polytechnique Montréal, 1989	October 25, 2011
AD OPT	7	R&D team member at AD OPT, a division of Kronos	GERAD	PhD, Polytechnique Montréal, 2003	October 27, 2011
Omega	8	Omega cofounder Professor at Polytechnique Montréal	CIRRELT	PhD, UdeM, 2003	December 10, 2011
Omega	9	Omega Former president (Planora)			October 24, 2011
ExPretio	10	ExPretio cofounder	CIRRELT	PhD, Operations Research, UdeM, 1982	June 10, 2011
ExPretio	11	ExPretio cofounder	CIRRELT & GERAD	PhD Applied Mathematics & OR, Polytechnique Montréal, 1989	October 14, 2011