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Analysis of knowledge flows in University-Industry collaboration: a materials innovation case

Florianópolis
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RESUMO

Materiais avançados são fundamentais para a inovação, pois desempenham um papel importante no desenvolvimento de todos os tipos de novos produtos e processos. Materiais avançados, entretanto, apresentam vários desafios devido à sua posição a montante na cadeia de valor. O desenvolvimento de materiais requer longos períodos de desenvolvimento e altos investimentos antes de obter os primeiros feedbacks dos clientes, aumentando assim os riscos de investimento. Portanto, a cooperação universidade-indústria (CUI), apoiada por políticas científicas nacionais e programas de fomento, desempenha um papel importante no apoio ao desenvolvimento de materiais avançados e na construção de vantagem competitiva no mercado. Na CUI, o compartilhamento de conhecimento é um dos principais objetivos, portanto, o gerenciamento dos fluxos de conhecimento (FC) entre a universidade e a indústria com práticas de gestão do conhecimento (GC) é uma questão importante para a eficácia da colaboração. A maioria dos estudos anteriores avalia a CUI e o fluxo de conhecimento no nível organizacional, deixando o nível de equipe (nível micro) desses construtos obscuros. O objetivo deste trabalho qualitativo foi analisar, usando uma abordagem de método misto, como o conhecimento flui em uma colaboração universidade-indústria para a inovação de materiais, a fim de propor uma estrutura de análise e um conjunto de práticas para melhorar a colaboração. A caracterização do fluxo de conhecimento mostra redes distintas de conhecimento técnico, gerencial e de mercado, nós principais espalhados pelas redes e uma série de práticas de gestão do conhecimento. Os resultados evidenciaram a relação entre o fluxo de conhecimento, CUI e fatores de influência, mas a relação quantitativa entre o desempenho da CUI e as práticas de GC não pôde ser identificada com os instrumentos empregados. A estrutura de análise sugere investigar FC pela rede, densidade, atividade do intermediador, capacidade absortiva e práticas; resultados da CUI, por seus principais produtos como tecnologias, componentes, publicações, patentes, pessoas treinadas, ganhos técnicos e econômicos e continuidade de parcerias; e fatores de influência, por setor, área de conhecimento, nível de maturidade tecnológica, posição da cadeia de valor, sobreposição de conhecimento e velocidade das mudanças. Os resultados podem ser gerados mapeando a rede usando a técnica da bola de neve e entrevistando os principais participantes da colaboração. A avaliação de nível micro forneceu informações da gestão da colaboração de nível operacional que permitiu uma visão mais profunda da colaboração e, portanto, a proposição da estrutura de análise e práticas para ajudar no sucesso da CUI. A partir dos fatores influenciadores encontrados neste trabalho, duas práticas foram concebidas e ainda não testadas: (i) implementar uma estrutura de encontros periódicos para conectar pesquisadores de todas as áreas; e (ii) dividir a colaboração em projetos de curto e longo prazo.

Palavras-chave: Materiais avançados; Pesquisa e Desenvolvimento (P&D); Cooperação Universidade-Indústria; Fluxo de conhecimento; Compartilhamento de conhecimento; Práticas de gestão do conhecimento.

RESUMO EXPANDIDO

Introdução

Materiais são um dos principais pilares da sociedade moderna. A inovação em produtos e processos não pode acontecer sem novos materiais desempenhando novas funções com propriedades especificamente projetadas. Em todas as áreas, cientistas e engenheiros desenvolvem materiais para serem mais inteligentes, ecologicamente corretos, mais leves, mais fortes, duradouros, eficientes e baratos. Além disso, nas últimas décadas, influenciados pela intensa competição e dinâmica de mercado, os materiais estão mudando de um uso clássico para um design de funções múltiplas, integrando recursos mecânicos, elétricos, ópticos, químicos e outros. Esses novos materiais com altos níveis de conhecimentos incorporados são chamados de materiais avançados. O desenvolvimento dos materiais avançados é um processo complexo, longo e caro, que exige o gerenciamento de altos níveis de incertezas tecnológicas e de mercado. Parcerias e financiamentos são essenciais para sustentar o desenvolvimento de materiais avançados até que eles criem e capturem valor em suas aplicações no mercado. Isso explica por que, no setor de materiais avançados, as tecnologias são normalmente projetadas em colaborações universidade-indústria apoiadas por políticas científicas nacionais. Empresas e universidades buscam cada vez mais essas parcerias, sendo estimuladas pelos sistemas de inovação que beneficiam ambas as partes. Na colaboração universidade-indústria, novas tecnologias são desenvolvidas através da criação, transferência e aplicação de conhecimento entre parceiros, tornando a gestão do conhecimento um assunto importante para o sucesso da colaboração. No processo de colaboração, muitas tecnologias e conhecimentos desenvolvidos nas universidades não são utilizados pelas empresas e não chegam ao mercado na forma de novos produtos e processos. Espera-se que melhorar os fluxos de conhecimento entre universidades e empresas reduza essa lacuna, embora o compartilhamento de conhecimento por si só não seja suficiente. Para isso é importante compreender a dinâmica no nível dos indivíduos (nível micro), pois são estes os responsáveis finais pela criação e compartilhamento do conhecimento, especialmente quando o conhecimento tácito está envolvido. A maioria das pesquisas em colaboração universidade-indústria e fluxo de conhecimento, no entanto, concentram-se apenas no nível organizacional, deixando a perspectiva de nível micro obscura. Investigar o comportamento entre os indivíduos nos fluxos de conhecimento para o desenvolvimento de materiais fornece insights valiosos para pesquisadores e gestores, que buscam implementar práticas para gerar mais valor destas parcerias.

Objetivos

O objetivo desta pesquisa é analisar como o conhecimento flui para atingir os objetivos de uma colaboração universidade-indústria para a inovação em materiais. A pesquisa avalia como os aspectos do fluxo de conhecimento e os fatores de influência afetam os resultados da colaboração em uma perspectiva de nível micro. A pesquisa se desdobra em três objetivos específicos: (i) propor uma estrutura de análise para a relação entre o fluxo de conhecimento, os resultados da colaboração universidade-indústria e os fatores de influência; (ii) identificar, caracterizar e analisar os fluxos de conhecimento dentro desta colaboração universidade-indústria para a inovação em

materiais; e (iii) propor um conjunto de práticas para estimular os fluxos de conhecimento e contribuir para os resultados da colaboração universidade-indústria.

Metodologia

Uma estrutura de análise é proposta para investigar a relação entre o fluxo de conhecimento, os resultados da colaboração universidade-indústria e os fatores de influência, que é apoiada por análises quantitativas e qualitativas. Este trabalho usa uma abordagem de método misto chamada design explanatório, um design sequencial de duas fases, em que a análise quantitativa é seguida pela análise qualitativa para aplicar e desenvolver o framework em uma colaboração para inovação de materiais. O método misto é empregado para fornecer uma compreensão mais profunda dos fenômenos estudados; para produzir resultados que se corroboram; explicar os achados da fase quantitativa; para explicar resultados inesperados; e para melhorar a utilidade dos resultados combinando duas abordagens. No design explanatório, os resultados obtidos na fase quantitativa, como resultados significativos e resultados não significativos, são explicados na fase qualitativa. A fase quantitativa deste trabalho mapeia o fluxo de conhecimento com ferramentas de análise de rede social; identifica padrões de redes sociais; e identifica as relações entre o fluxo de conhecimento e o desempenho da colaboração universidade-indústria. A fase qualitativa investiga e tenta explicar padrões e evidências por meio de entrevistas semiestruturadas. A aplicação do framework compreende sete etapas principais: (i) análise documental; (ii) coleta de dados quantitativos por meio de questionário; (iii) análise de dados com ferramentas de análise de redes sociais, equações estruturais e análise de variância; (iv) seleção dos principais participantes a entrevistar; (v) entrevistas semiestruturadas com nós-chave selecionados na etapa anterior; (vi) análise temática de dados qualitativos; (vii) integração dos dados quantitativos e qualitativos para fornecer uma melhor compreensão dos resultados.

Resultados e Discussão

A análise da colaboração universidade-indústria analisada mostra a inovação em materiais como parte de uma estratégia de inovação da empresa para diferenciar seus produtos, sustentando assim a competitividade. Dentro dessa estratégia, a empresa e a universidade colaboram para, entre outros benefícios, reduzir custos e acelerar o tempo de lançamento no mercado de desenvolvimento de materiais avançados. Nesta colaboração, os pesquisadores operam em uma complexa rede de fluxo de conhecimento multidisciplinar, que engloba diferentes áreas para atingir os objetivos planejados. Gerenciar fluxos de conhecimento em inovação de materiais é um fator importante para o sucesso da colaboração, que envolve aspectos como tipo de conhecimento, atores, grupos e atividades. Três fluxos de conhecimento foram investigados nesta pesquisa, fluxo de conhecimento técnico, de conhecimento gerencial e de mercado. A rede de conhecimento técnico é a mais conectada, enquanto as redes de conhecimento gerencial e de mercado são menos conectadas e mais fragmentadas em componentes, portanto mais dependentes de intermediadores. A análise mostra que diferentes fluxos de conhecimento coexistem na colaboração, com diferentes dinâmicas e efeitos no sucesso da colaboração. Os atores desses fluxos de conhecimento são professores, doutores, mestres, alunos de graduação, gestores de empresas e especialistas que participam do processo de desenvolvimento de novos conhecimentos e tecnologias. Os professores são mais centrais e intermediários, mas outras funções apresentam níveis de centralidade e intermediação semelhantes. Centralidade e intermediação, portanto, não parecem estar vinculadas a papéis formais. Os resultados mostram que essas posições mudam de acordo com o tipo de conhecimento. Os nós principais espalhados em cada rede devem ser considerados ao projetar estratégias para influenciar o fluxo de conhecimento. Em relação à avaliação em nível micro, o estudo investigou a colaboração universidade-indústria não apenas sob a ótica da alta administração, mas desde alunos de graduação até professores e pesquisadores de empresas. Os resultados mostram que a visão das pessoas nas diferentes camadas de gestão pode ser diferente e os instrumentos devem considerar isso para produzir resultados consistentes. Os instrumentos utilizados na avaliação das práticas de gestão do conhecimento e do desempenho da colaboração mostraram-se inadequados para esta avaliação em nível micro. A análise em nível micro, no entanto, contribuiu para um entendimento mais profundo do funcionamento da colaboração analisada. Um resultado intrigante do trabalho diz respeito a uma relação não significativa entre os indicadores de desempenho da colaboração universidade-indústria e as práticas de gestão do conhecimento, evidenciada pela modelagem de equações estruturais. A modelagem confirmou relação significativa entre os indicadores de desempenho da colaboração e entre os indicadores das práticas de gestão do conhecimento, mas não foi encontrada relação significativa entre os dois construtos. Pelo menos cinco razões podem explicar o resultado inesperado: (i) variáveis intermediárias, (ii) perspectiva da universidade, (iii) ajuste do instrumento, (iv) nível de avaliação (micro e macro) e (v) intervalo de tempo. Com base nos resultados, é proposta uma estrutura de análise entre fluxo de conhecimento, resultados da colaboração universidade-indústria e fatores de influência. Nesta estrutura o fluxo de conhecimento é caracterizado por sua rede, densidade, atividade de intermediadores, capacidade absortiva e práticas de gestão. Os resultados da colaboração são caracterizados por conhecimento, tecnologias, componentes, publicações, patentes, pessoas treinadas, ganhos técnicos e econômicos e continuidade da parceria. Já os principais fatores que influenciam o fluxo de conhecimento incluem indústria, campo de conhecimento, nível de maturidade tecnológica, posição da cadeia de valor, sobreposição de conhecimento e velocidade das mudanças. Os resultados podem ser obtidos identificando a rede com a técnica da bola de neve e entrevistando os principais participantes da colaboração. Com base nos fatores que influenciam a cooperação para a inovação em materiais identificados neste estudo, duas práticas foram concebidas para facilitar o fluxo de conhecimento. A primeira sugere a criação de uma estrutura de encontros periódicos para conectar pesquisadores e áreas dentro e entre universidade e empresa. A segunda sugere dividir o portfólio da colaboração em projetos de curto e longo prazo. Espera-se que essas duas práticas aumentem as chances de sucesso de colaboração e inovação de materiais, promovendo o compartilhamento de conhecimento em uma estrutura formal de reuniões e gerenciando as expectativas dos pesquisadores da universidade e da empresa. Mais pesquisas ainda devem ser realizadas a fim de testar o modelo.

Considerações Finais

A principal contribuição deste trabalho é uma estrutura de análise para o fluxo de conhecimento em colaborações universidade-indústria em uma perspectiva de nível micro, que foi usada para caracterizar os fluxos de conhecimento dentro de uma

colaboração formal para inovação de materiais. A estrutura foi desenvolvida a partir da revisão da literatura e usou uma abordagem de método misto, incluindo abordagens quantitativas e qualitativas para avaliar os construtos. Os resultados quantitativos caracterizaram redes de fluxo de conhecimento, práticas de gestão do conhecimento e indicadores desempenho da colaboração universidade-indústria. Os resultados forneceram informações relevantes sobre cada construto isoladamente, porém a relação entre as práticas de gestão do conhecimento e indicadores desempenho da colaboração não pôde ser evidenciada com os instrumentos empregados. Os resultados qualitativos descreveram os processos de fluxo de conhecimento, colaboração e inovação na empresa. Os resultados apresentam algumas evidências sobre a influência do fluxo de conhecimento na colaboração, como tamanho e densidade da rede, atividade do intermediador, capacidade absortiva e práticas. Fatores que influenciam o fluxo de conhecimento e a colaboração incluem indústria, campo de conhecimento, nível de preparação da tecnologia, posição da cadeia de valor, sobreposição de conhecimento e velocidade das mudanças. Com base nos fatores de influência identificados, duas práticas foram propostas para ajudar o fluxo de conhecimento e, assim, o sucesso da colaboração: (i) implementar uma estrutura de reuniões periódicas para conectar pesquisadores de todas as áreas; e (ii) dividir a colaboração em projetos de curto e longo prazo. Ao analisar a colaboração ao nível micro, este trabalho proporcionou uma visão aprofundada da colaboração, o que permitiu caracterizar os fluxos de conhecimento dentro da colaboração, desenvolver uma estrutura de análise e propor um conjunto de práticas. Os insights ajudam a avançar a linha de pesquisa em nível micro dos construtos envolvidos. Este trabalho confirma a colaboração universidade-indústria para a inovação em materiais como um empreendimento multidisciplinar, na base da cadeia de valor, que apresenta redes distintas de conhecimento técnico, gerencial e de mercado. As características desta área de conhecimento parecem influenciar a dinâmica dos fluxos de conhecimento na colaboração. Como o conhecimento é um recurso importante da colaboração, compreender e gerenciar a dinâmica dos fluxos de conhecimento é um assunto relevante para seu sucesso. Este trabalho contribui para melhorar a gestão da colaboração universidade-indústria no nível micro.

Palavras-chave: Materiais avançados; Pesquisa e Desenvolvimento (P&D); Cooperação Universidade-Indústria; Fluxo de conhecimento; Compartilhamento de conhecimento; Práticas de gestão do conhecimento.

ABSTRACT

Advanced materials are fundamental for innovation as they play a major role in all sorts of new products and processes development. Advanced materials however present several challenges due to its upstream position in the value chain. Materials development requires long periods of development and high investments before getting the first customers' feedbacks, thus increasing investment risks. Therefore, university-industry cooperation (UIC) supported by national science policies and granting programs plays an important role supporting the development of advanced materials and building market competitive advantage. In UIC, knowledge sharing is one of the main objectives, thus managing knowledge flows (KF) between university and industry with knowledge management (KM) practices is an important issue for collaboration effectiveness. Most of previous studies assess UIC and knowledge flow at organizational-level, leaving team-level (micro-level) of these constructs unclear. The objective of this qualitative work was to analyze, using a mixed method approach, how knowledge flows in a university-industry collaboration for materials innovation, in order to propose a framework of analysis and a set of practices to improve collaboration. Knowledge flow characterization show distinct networks of technical, managerial and market knowledge, key nodes scattered across the networks and a series of knowledge management practices. Results evidenced the relationship between knowledge flow, UIC and influencing factors, but the quantitative relationship between UIC performance and KM practices couldn't be identified with the instruments employed. The framework of analysis suggests investigating KF by its network, density, broker activity, absorptive capacity and practices; UIC outcomes, by its main outputs such as technologies, components, publications, patents, people trained, technical and economic gains and partnership continuity; and influencing factors, by industry, knowledge field, technology readiness level, value chain position, knowledge overlap and speed of changes. Results can be generated by mapping the network using the snowball technique and interviewing key participants of the collaboration. Micro-level assessment provided information from bottom-level collaboration management that allowed a deeper view of the collaboration and thus the proposition of the framework of analysis and practices to help UIC success. Based on influencing factors found in this work, two practices were conceived and not tested: (i) implement a structure of periodic meetings to connect researchers across areas; and (ii) split collaboration in short-term and long-term projects.

Keywords: Advanced materials; Research and Development (R&D); University-Industry Cooperation; Knowledge flow; Knowledge sharing; Knowledge management practices.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AKS	Actionable Knowledge Support
ANOVA	Analysis of Variance
AVE	Average Variance Extracted
HTMT	Heterotrait-Monotrait
ICT	Information and Communication Technology
IPR	Intellectual Property Rights
KC	Knowledge Creation
KF	Knowledge Flow
KM	Knowledge Management
KN	Knowledge Node
KPI	Key Performance Indicators
KR	Knowledge Retention
KS	Knowledge Sharing
KTO	Knowledge Transfer Offices
Lab	Laboratory
Org	Organization
PLS	Partial Least Squares
R&D	Research and Development
SEM	Structural Equation Modelling
SNA	Social Network Analysis
SRMR	Standardized Root Mean Square Residual
TRL	Technology Readiness Level
TTO	Technology Transfer Offices
UIC	University-Industry Cooperation
UITT	University-Industry Technology Transfer
VIF	Variance Inflation Factors

CONTENTS

1 INTRODUCTION

Materials are one of the major pillars of the modern society. Innovation in products and processes cannot happen without new materials performing new functions with specifically designed properties. In all areas such as automotive, aerospace, chemical, energy, refrigeration and electronics, scientists and engineers develop materials to be smarter, eco-friendly, lighter, stronger, long-lasting, efficient and cheaper. These new materials with high embedded knowledge are called advanced materials.

In the past decades, influenced by intense competition and market dynamics, advanced materials are shifting from a classical use to a multiple function design, integrating mechanical, electrical, optical, chemical and other features (BAYKARA; ÖZBEK; CERANOⅡLU, 2015). Materials became part of the complex and dynamic innovation process with great challenges which require advanced strategies.

From a technological management perspective, advanced materials are viewed as generic, radical and upstream technologies (EAGAR, 1998; MAINE; ASHBY, 2002; MAINE; GARNSEY, 2006). Generic technologies are those that span over to a large range of market applications, thus impacting a series of economic fields (NIOSI, 1993). Techniques used to produce nanomaterials are examples of generic technology, since they are applied in all sorts of industries and applications such as mechanical, electrical, thermal and biological. Radical technologies, in its turn, are those that dramatically impact product or process performance (MAINE; GARNSEY, 2006) and increase competitive advantage by imposing entrance barriers to competitors, or changing the dynamics of an existing market allowing new entrants. One example of radical technology is semiconductor technology, which revolutionized the entire electronic industry. Generic and radical technologies are highly desired by government and firms for their potential of value creation which promotes competitiveness and sustainable performance (MAINE; GARNSEY, 2006). Thus, advanced materials as generic and radical technologies represent a potential for major economic and social shifts, but which comes with a cost. Materials occupy an upstream position in the value chain (MAINE; SEEGOPAUL, 2016). The long distance until materials arrive in the hands of final consumers imposes an unique combination of high technological and market risks (MAINE; GARNSEY, 2006). Being at an upstream position, a series of technologies, products, processes and manufacturing lines might be modified to accommodate new technologies. Some of these processes and technologies may not exist and even if exist the capacity to absorb and apply the new knowledge – called absorptive capacity (COHEN; LEVINTHAL, 1990) – influence technology implementation (SJÖDIN D.R., 2015). Moreover, in advanced materials field, many technologies are born at basic science level, which can result in radical innovation, though it also means that there is a long and expensive path from first concept tests to final products, requiring process innovation, prototype development, specialized equipment, expert professionals, pilot plants etc. Additionally, since new product development follows a roadmap and development cycles, missing a window (i.e. delivery date) may also jeopardize the entire development effort, increasing technological risks. Regarding market uncertainties, distance from customers leads to other challenges. Develop the right applications is a hard task since it is difficult to gather market and customer feedback. Besides taking a long time to get feedback, those feedbacks might not be effective, once customers experience product functionalities, rather than materials' added value. Materials' upstream position combined with a generic characteristic hinders one to determine which technological application streams to follow. If firms pursue multiple markets, they can be exposed to higher levels of risk, emerging from regulations, new trends, changes in industry dynamics etc. (LUBIK; GARNSEY, 2016; MAINE; GARNSEY, 2006).

Developing advanced materials, though, is a complex, long and expensive process, that requires managing high levels of technological and market uncertainties. Effective partnerships and funding are key to sustain advanced materials development until it creates and captures value throughout market applications (MAINE; GARNSEY, 2006). This explains why in the advanced materials sector, technologies are typically designed in university-industry collaborations (UIC) (BABA, Yasunori; SHICHIJO; SEDITA, 2009; NIOSI, 1993), supported by national science policies and granting programs (MAINE; GARNSEY, 2006). Companies and universities have been increasingly searching for these partnerships, being stimulated by innovation systems which benefit both parties. Companies have access to knowledge, laboratory infrastructure (e.g. state-of-art equipment), risk reduction by non-reimbursable funding and attraction of highly skilled professionals. Universities benefit from larger funding contracts between university, industry and government, acquisition of market knowledge which increases probability of delivering technologies to products and professionals trained with wider competencies due to market collaboration (BODAS FREITAS; VERSPAGEN, 2017).

In UIC, new technologies are developed by creating, transferring and applying knowledge between partners, thus making knowledge management an important subject for collaboration success. In the collaboration process, many technologies and knowledge developed in universities are not used by companies (i.e. knowledge internalization rate) and do not reach market in the form of new products and processes. Improving knowledge flows (KF) between universities and firms is expected to close this gap (RYBNICEK; KÖNIGSGRUBER, 2019), although knowledge sharing alone may not increase knowledge and technology application (YOUNG CHOI; LEE; YOO, 2010).

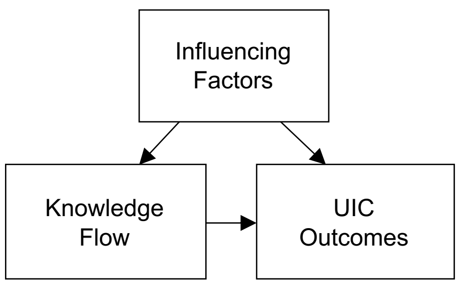
Moreover, most researches in university-industry collaboration and knowledge flow conduct only at the organizational level, leaving the micro-level (i.e. team-level) perspective unclear (LINDSAY *et al.*, 2003; SKUTE *et al.*, 2019; WU, 2017). Understanding the dynamics at the micro-level is important because individuals in organizations are ultimately responsible for knowledge creation and sharing, especially when tacit knowledge is involved. Individuals influence the dynamics in a series of ways such as with trust, open and informal relationships, absorptive capacity (VOLBERDA; FOSS; LYLES, 2010), ego defense mechanisms, jealousies and territorial protection (LINDSAY *et al.*, 2003). Investigating the behavior among individuals can evidence patterns not visible while assessing only the organizational level, that can used to better understand knowledge flows in university-industry collaboration.

The objective of this research is to analyze how knowledge flows in order to meet objectives of a university-industry collaboration for materials innovation. The research evaluates how aspects of knowledge flow and influencing factors affect UIC outcomes at a micro-level perspective. The research unfolds in three specific objectives:

- Propose a framework of analysis for the relationship between knowledge flow, university-industry collaboration outcomes and influencing factors;
- Identify, characterize and analyze knowledge flows within this university-industry collaboration; and
- Propose a set of practices to stimulate knowledge flows and contribute to university-industry collaboration outcomes.

This analysis of knowledge flow in UIC develops and tests a framework which addresses the relationship between knowledge flow, influencing factors and UIC outcomes, as depicted in the conceptual framework of Figure 1. The framework is developed with quantitative and qualitative approaches at micro-level. A formal agreement of cooperative research for materials innovation between universities and industry is used to apply and develop the framework of analysis. The quantitative analysis uses instruments found in the literature to gather information on UIC indicators and knowledge flow parameters. Relationships between constructs are assessed with analysis of variance and structural equation modelling. Based on quantitative results, interviewees are selected for the qualitative analysis which uses in-depth semi-structured interviews that provide a deeper understanding of knowledge flows within the investigated university-industry collaboration. With these results, the framework is revised and practices are suggested to facilitate knowledge flows and contribute to UIC success.

Figure 1: A conceptual framework of analysis for the relationship between knowledge flow network, influence factors and UIC outcomes



Source: Prepared by the author

Results contribute to the micro-level (team-level perspective) avenue of research in knowledge flow within formal university-industry collaboration by an in-depth quantitative and qualitative assessment of the partnership. A framework of analysis is proposed and used to generate insights about the dynamics of KF in these partnerships. Insights are valuable for researchers and managers looking towards the implementation of practices in their university-industry partnerships for materials innovation, in order to generate more value from these endeavors.

This work presents limitations that include results restricted to only one case of UIC and responses collected majorly from the university side of the partnership. The analysis also did not use a longitudinal approach thus not showing the progress of the studied collaboration. The quantitative instruments applied also require further development in order to be used in this application case. These facts limit the possibility to use results without further research.

This document is organized as follows, first university-industry cooperation and knowledge flow are reviewed in detail. Literature review provides the basis for proposing the framework to analyze knowledge flow in UIC. After presenting the framework, framework application procedures introduce the mixed method approach comprised of a quantitative analysis followed by qualitative analysis. Results are organized in quantitative and qualitative analysis and then discussed. Considerations are made on the proposed framework, resulting in a revised framework. For practical application, based on results and insights, two practices are proposed to stimulate knowledge flows and contribute to university-industry collaboration for innovation. Conclusions summarizes findings, limitations of the research and suggestions for future research.

2 LITERATURE REVIEW

2.1 UNIVERSITY-INDUSTRY COLLABORATION

2.1.1 A brief history of UIC

University-industry collaboration is considered the engagement of university and industry motivated by the desire to exchange knowledge and technology (SIEGEL *et al.*, 2003), where basic and applied research connects (MARÍA; VALENTÍN, 2002). Despite university is viewed nowadays as key for industry's economic growth, during most of 20th century, universities and companies had very clear separate paths. While universities were concerned in creating basic science and companies in developing new products, applied research was seen as an outrageous by conservative researchers. Even with great scientific achievements there wasn't much knowledge available to be readily applied into business (CHESBROUGH, 2003).

Around the 1970's a shift towards a new model began in the United States, as universities started to be criticized for creating new technologies rather than transferring to real world applications (SIEGEL *et al.*, 2003). Alongside with changes in government R&D funding and patent policies, these pressures started to change the structure of the higher educational system. These shifts resulted on university interest in managing patents and licensing, thus creating technology transfer offices (TTOs) (MOWERY, 2005).

Considered an important mark in this structural shift is the "University and Small Business Patent Procedures Act", a set of amendments in United States' patents and trademarks law approved in 1980 that became widely known as the "Bayh-Dole Act", named after senators Bayh and Dole who introduced the bill. Politicians proclaimed that the gap between universities and companies was seriously jeopardizing competitiveness of firms and hence economic performance. Before the act, all inventions made with federal research funding had to be assigned to federal government. The act allowed companies and universities to own inventions made with federal funding, in preference to the government, thus facilitating university-industry technology transfer (UITT) through legislation (SIEGEL *et al.*, 2003).

Legislators expected that by institutionalizing and legally supporting university ownership and management of intellectual property would accelerate the commercialization of new technologies and promote economic development and entrepreneurial activity. Rather Bayh-Dole is the cause, or the consequence, late 1970’s and early 1980’s saw considerable increase in patenting and licensing activity (MOWERY, 2005; SIEGEL *et al.*, 2003). By the time, United States government invested more than US$75 billion a year and accumulated 28,000 patents, of which less than 5% were commercially licensed. After Bayh-Dole, universities’ TTOs, increased the number of patents granted to universities from 300 in 1980 to more than 3700 in 2000. Along with the increase of patents granted the revenue from the licenses raised from less than US$160 million in 1980, to more than US$860 million in 2000 (SIEGEL *et al.*, 2003). Bayh-Dole act marks a shift towards an innovation model where technologies are not confined to business boundaries, but spans to different sectors and applications.

In Brazil, a similar initiative to stimulate innovation was signed twenty years later in 2004, which became known as the Technological Innovation Law (*Lei de Inovação Tecnológica*: Lei 10.973/2004 - Decreto 5563/2005)[1]. This measure promoted innovation through scientific and technological research in collaboration among universities, research centers, companies and independent inventors. The law made clear that the infrastructure and the resources in public universities and research centers could be used by the Brazilian private sector to foster technological innovation through research and development activities. The bill also included funding programs supported by public agencies to promote the university-industry collaboration, especially for micro and small companies. However, in order to operate this new model public universities and research centers would create TTOs to handle their intellectual property (IP), a measure that granted autonomy to fill IP applications and negotiate technology transfer, consulting services and licensing contracts over patents they own. In fact, most of the 157 TTOs mapped across the country in 2010 were created after 2005 (DOS SANTOS; TORKOMIAN, 2013). Similarly to what happen in USA, the participation of academic institutions in patent activity increased as a result of pressure imposed to universities engage in the innovation process. The signature of the innovation law marked a significantly increase on patent activity. From 2000 to 2004,

[1] Recently in 2016, another amendment regarding innovation incentives was signed, which has been called as Science, Technology and Innovation Regulation Mark (*Marco Legal da Ciência, Tecnologia e Inovação*: Lei 13.243/2016 - Decreto 9.283/2018).

47 academic institutions were responsible for 784 patent applications, while 323 applications were submitted just in 2005, the year after the innovation law.

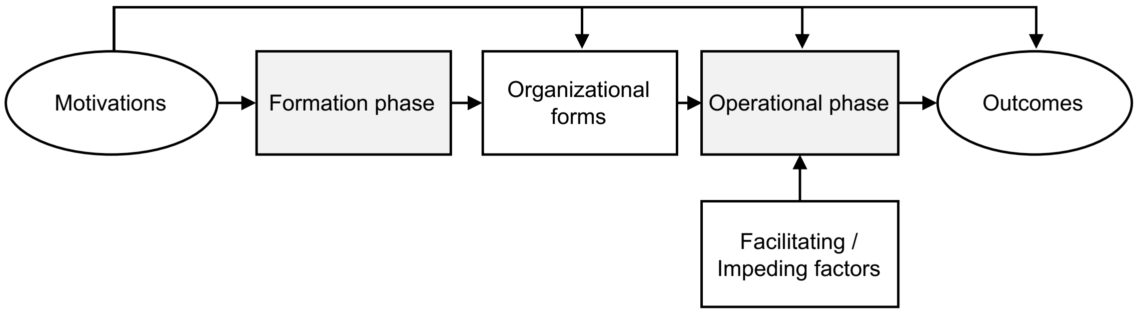
Yet, simply patenting inventions is not enough to ensure that technologies and knowledge are converted to technological innovation. Patenting and licensing is only one aspect of university-industry collaboration. In general, university revenue from licensing activity is small compared to university's budget for research. For instance, University of California – recognized university in Silicon Valley for transferring technology – earnings arising from royalties correspond to less than 0.5% of research investments realized in early 2000's (MARÍA; VALENTÍN, 2002). Brazil, on its turn, the increase in patent activity have not been accompanied by its commercial use. (DOS SANTOS; TORKOMIAN, 2013) show that the majority of TTOs still do not produce any revenue from licensing. The interaction between universities and industry is a much wider and complex system, which have been studied and organized by researchers in a series of frameworks.

2.1.2 Frameworks to analyze university-industry cooperation

Studies in this vast research field proposed many theoretical models, typologies and taxonomies to explain and discuss UIC, although it remains a difficult task due to system complexity (ANKRAH; AL-TABBAA, 2015; MARÍA; VALENTÍN, 2002; SKUTE *et al.*, 2019).

In recent work, (ANKRAH; AL-TABBAA, 2015) reviewed the literature and identified six dominating aspects on UIC: (a) motivations; (b) formation phase; (c) organizational forms; (d) operational phase; (e) facilitating and impeding factors; (f) outcomes, Figure 2. According to the authors, motivations are different reasons why university and industry enters a partnership, such as need for resources, knowledge and technology transfer, improve in corporate image, gains in competitiveness and so on. Formation phase consist on those activities performed to identify and contact partners, negotiate partnership, which depend on the collaboration sign agreement. Organizational formats refer to types of interaction that UIC can assume, such as personal informal relations between colleagues, student internships, consulting services, cooperation agreements, academic spin-offs, incubation centers of technology parks and many other formats (ANKRAH; AL-TABBAA, 2015; GEUNA; MUSCIO, 2009; MARÍA; VALENTÍN, 2002). Operational phase consists on activities during UIC that involve project planning and execution, communication, meetings, conferences, training, personnel exchange and even employment. Facilitating and impeding factors that influence UIC appear in most varied ways, for instance: organizational and individual level, related to political, legal, managerial, technological, cultural and resource issues. Finally, outcomes of UIC can be benefits, or even drawbacks of the relationship. Most benefits include new products and services, patents, new sources of revenue, cost savings, reduction of development cycles, knowledge creation and even gains in reputation. Drawbacks encompass threats to institutional mission of each partner, such as knowledge sharing for universities and profit and performance shrinkage for companies.

Figure 2: Conceptual process framework for UIC



Source: (ANKRAH; AL-TABBAA, 2015)

This work uses (ANKRAH; AL-TABBAA, 2015)'s complete and recent review on UIC as a framework to discuss UIC. Following sections review those six dominating aspects of UIC, from a perspective of knowledge flow between university and industry.

2.1.3 Motivations

Universities and industry have been experiencing an increasing pressure to transfer knowledge and despite many reasons to collaborate, these partnerships are majorly a resource-based relationship (CLOSS; FERREIRA, 2012), wherein each partner sees a different set of motivations.

2.1.3.1 University

Since society realized that universities should also work on converting knowledge and technologies into real applications, pressures on R&D policies reduced public funding availability, forcing universities to find new alternatives to fund their research activities (ANKRAH; AL-TABBAA, 2015). Economic resources, however, are not the only motivation to cooperate. Universities have access to other important resources, through deeper connection with firms. Close links with firms bring an indirect connection with market and managerial knowledge. This important source of knowledge helps researchers to develop their theories and develop research focused in real applications (ANKRAH; AL-TABBAA, 2015). The quality of research can also increase with knowledge transfers with industries (GEUNA; MUSCIO, 2009). Studies find that collaboration improves academic and commercial productivity (GERTNER; ROBERTS; CHARLES, 2011). Interaction also allows another type of knowledge transfer by social capital movement, as researchers access employment opportunities in firms. By operating in this new business model, universities may sustain its vanguard position, state-of-art knowledge development and also enhance university prestige (ANKRAH; AL-TABBAA, 2015).

2.1.3.2 Industry

Scientific knowledge in universities has experienced a fast growth since the last century (CHESBROUGH, 2003), but it also has been continuously evolving, reaching more real world applications. Universities have been increasingly performing applied research, rather than just basic research. In a scenario of increasing global competition and fast technological change, firms and government realized that scientific and technological knowledge in universities are extremely valuable to innovation (MAINE; GARNSEY, 2006).

Knowledge transfers started to be seen as a source of innovation and competitive advantage. Since governments realized that universities play an important role in the innovation systems, many policies have been proposed to increase knowledge transfers from universities to firms. The collaboration between government, firms and universities created an alternative revenue source to fund research activity. Government expect these policies to create wealth, international competitiveness, economic and social impact (ANKRAH; AL-TABBAA, 2015; GERTNER; ROBERTS; CHARLES, 2011; MARÍA; VALENTÍN, 2002). Firms find in knowledge transfers a source of state-of-art knowledge and technologies, a way to improve its capabilities, reduce product development cycle and access public funding that reduces costs and investment risks (ANKRAH; AL-TABBAA, 2015; PIVA; ROSSI-LAMASTRA, 2013). The interaction also improves firm reputation and access to academic network (ANKRAH; AL-TABBAA, 2015; PIVA; ROSSI-LAMASTRA, 2013). Some researchers even state that the interaction with academic inventors contributes to the speed of product commercialization (GEUNA; MUSCIO, 2009).

Universities have not only accumulated knowledge, but also social capital, as a result of the growing attraction of the high educational systems combined with the demand for specialized workforce (GEUNA; MUSCIO, 2009). Besides technical knowledge, social networks built during researchers' careers are also valuable (GEUNA; MUSCIO, 2009). Through interaction firms have access to academic network (PIVA; ROSSI-LAMASTRA, 2013), which enhances the possibility of knowledge transfers and hiring (ANKRAH; AL-TABBAA, 2015). Table 1 based on (ANKRAH; AL-TABBAA, 2015)'s work summarizes the motivations to cooperate from both universities and industry perspectives, in six groups: (1) Policies, (2) Economic, (3) Competitiveness / Leading edge position, (4) Image, (5) Reciprocal / Mutual benefits and (6) Control. As previously described, government policies, new sources of revenue, the increase of competitiveness and building or sustaining an organizational image motivates universities and firms to exchange knowledge. As discussed, there are differences why universities and firms engage in these collaborations. Thus, understanding mutual benefits and asymmetries in cooperation is important.

Universities and firms share three main mutual benefits of interaction. The first is sharing complementary expertise, as previously stated different types of knowledge flows in both directions, enhancing partners' performance. Second, both parties may benefit from equipment available in each other's facilities. Third, there is a continuously personnel mobility from universities to companies, as universities supplies university graduates, while firms hires specialized workforce (ANKRAH; AL-TABBAA, 2015).

Regarding the asymmetric perspective of the partnership, control is one characteristic of UIC that exists for companies and not in universities. Firms are interested in generating the maximum amount of profit and creating barriers for new entrants. Therefore, they may desire to exert control over universities by directing university research and controlling knowledge transfers to other partners. This may be a drawback for UIC, as will be described latter.

Understanding motivations is important because they influence the entire process of collaboration, until benefits are realized.

Table 1: Motivations to transfer knowledge within UIC

	University	Industry
Policies		
The organizations often establish linkages with each other in order to meet necessary legal or regulatory requirements	— Responsiveness to government policy — Strategic institutional policy	— Responsiveness to government initiatives/policy — Strategic Institutional policy
Economic		
University-industry relationships are often based on pecuniary motivations	— Access funding for research (Government grant for research & Industrial funding for research assistance, lab equipment etc.) — Business opportunity, e.g. exploitation of research capabilities and results or deployment of IPR to obtain patents and licenses — Personal financial gain for academics	— Commercialize university-based technologies for financial gain — Benefit financially from serendipitous research results — Cost savings (easier and cheaper than to obtain a license to exploit foreign technology) — National incentives for developing such relations such as tax exemptions and grants — Enhance the technological capacity and economic competitiveness of firms — Shortening product life cycle — Human capital development
Competitiveness / Leading edge position		
Relationship provides organizations with competitive advantage which allows them to reach better results	— Shift in knowledge based economy (growth in new knowledge) — Discover new knowledge and test application of theory	— Shift in knowledge based economy (growth in new knowledge) — Business growth — Access new knowledge, cutting-edge technology, state-of-the art expertise/research facilities and complementary know-how

	University	Industry
	— Obtain better insights into curricula development — Expose students and faculty to practical problems/ applied technologies — Publication of papers	— Multidisciplinary character of leading edge technologies — Access to research networks or pre-cursor to other collaborations — Solutions to specific problems — Subcontract R&D (for example due to lack of inhouse R&D) — Risk reduction or sharing
Image		
The image of organizations is an important aspect that makes them pursuit activities that support their legitimacy	— Societal pressure — Service to the industrial community/society — Promote innovation (through technology exchange) — Contribute to regional or national economy — Academics' quest for recognition or achieve eminence	— Enhancement of corporate image
Reciprocal / Mutual benefits		
Relationships occur for the purpose of pursuing common or mutually beneficial goals or interests	— Access complementary expertise — State-of-the-art equipment and facilities — Employment opportunities for university graduates (i.e. personnel mobility)	— Access complementary expertise — State-of-the-art equipment and facilities — Access to students for summer internship or hiring (i.e. personnel mobility)
Control		
Refers to relationships prompted by the potential to exercise power or control over		— Maintain control over proprietary technology

	University	Industry
another organization and its resources		

Source: (ANKRAH; AL-TABBAA, 2015)

2.1.4 Formation phase

Forming an UIC involves identifying partners to cooperate, make contacts with potential partners, discuss capabilities, propose business cases, negotiate terms of cooperation, goals, responsibilities and sign a final contract (ANKRAH; AL-TABBAA, 2015). This process is a wide field in UIC with several issues and challenges which are not discussed in this work, such as the negotiation between the university TTO, the firm and in public funding agencies.

2.1.5 Organizational forms

The exchange of knowledge and technology can occur in different ways with distinct characteristics. Interactions can be grounded, for instance, in personal informal relations between colleagues, student internships, consulting services, cooperation agreements, academic spin-offs, incubation centers of technology parks and many other formats (ANKRAH; AL-TABBAA, 2015; GEUNA; MUSCIO, 2009; MARÍA; VALENTÍN, 2002).

This work focuses on formal agreements of cooperative research projects between universities and industry. Instead of emphasizing patent and licensing activity as measures of knowledge transfer like most studies in this research stream (GEUNA; MUSCIO, 2009), this work addresses knowledge transfers at micro-level (team-level), to further understand the interactions within teams and individuals of this alliances.

This formal agreement for UIC characterized in this work present at least some of the following characteristics: (i) a pre-defined organizational network arising from the contracts, even though the links between researchers spans over any formal structure; (ii) somewhat clear pre-determined objectives aligned with industry expectations; (iii) funding, in some cases with public funding agencies participation; (iv) formal contract with clauses that determines processes, intellectual property rights, length of the agreement etc.; (v) institutionalized interaction with organizational resources involved; (vi) partners may be willing to build a trust-based relationship, if it is not yet stablished; (vii) bi-directional knowledge transfers; and (viii) as a research cooperation it creates new knowledge and technologies, unlike in consulting services and training services.

2.1.6 Operational phase

Operational phase succeeds formation phase and includes those UIC activities to achieve collaboration objectives. (ANKRAH; AL-TABBAA, 2015) divided activities in six relevant themes: (1) Meetings & Networking; (2) Communication; (3) Training; (4) Personnel Mobility; (5) Employment and (6) Other Activities, Table 2. The framework, however, focuses in knowledge sharing activities which leaves out operational matters of cooperation such as generating the required deliverables, administration, invoicing, purchase of materials and recruitment (PHILBIN, 2008). (PRABHU, 1999) provides a wider view of the relationship process between university and industry, Figure 3. During project implementation, work is developed in the company, in the university and jointly. Knowledge transfer is one of the knowledge processes involved. Literature, however, presents few studies describing technology development within UIC and its activities. Rather most articles focus on typologies, factors that influence success, models and frameworks, steps, collaboration issues, knowledge transfer and ways to improve the process of collaboration. Most of them describe macro issues of collaboration and provide less focus on operational issues. Operational issues might be related to specific matters of each project, though while developing technology good practices might help the interaction between company and university.

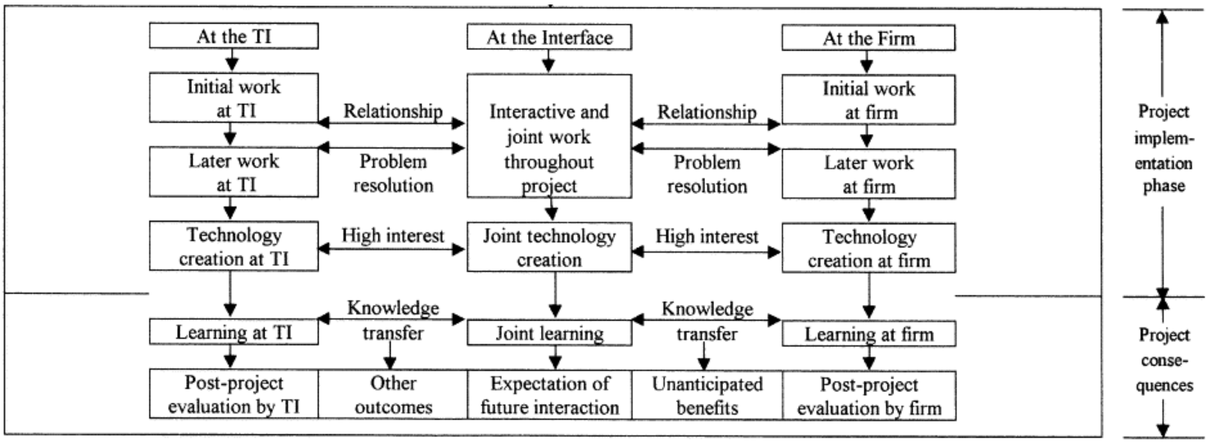
This work, though, do not intend to develop this operational agenda and focus on knowledge flow within those partnerships. Knowledge sharing which is a popular theme in the UIC research field is reviewed in the knowledge flow section.

Table 2: Activities during operational phase of UIC

Activities	Examples
Meetings & Networking	— Meetings (often in a formal way) — Conferences/Workshops/Seminars/Symposia/Forums — Expositions, Trade Shows/Fairs/Exhibitions — Informal social gatherings (e.g. U-I get-togethers, breakfast meetings) — Networking activities (the process of contacting and being contacted and maintaining these relationships/links)
Communication	— Communications by voice/mail/email/conference calls (formal or informal) — Publications or co-publications of research papers, reports, newsletters, booklets, bulletins, pamphlets
Training	— Tailored educational programmes for industrial personnel — Internships in company for students — Students' involvement in industrial projects — Joint supervision of masters' degree dissertations and PhD thesis by academic and industry personnel — Industrial fellowships for students and faculty — Industry involvement in curriculum development
Personnel Mobility	— Exchange of personnel to work at one another's research facilities — Lectures by industry members at universities and vice versa
Employment	— Employment of university researchers in the business sector — Employment of graduates particularly those related to the project — Representation on Industry Boards or University Committees
Other Activities	

Source: (ANKRAH; AL-TABBAA, 2015)

Figure 3: Map of the joint product innovation between technology institution (TI) and firm



Source: (PRABHU, 1999)

2.1.7 Influencing factors: barriers and facilitators

In the past few years, literature observed an increase in the number of papers interested in factors influencing UIC, such as commitment, trust, researchers' previous experience, reputation, cooperation formalization and geographic location (MARÍA; VALENTÍN, 2002). Alongside with this increase in scientific production, some researchers have been making valuable contribution by reviewing the literature and proposing frameworks to organize and explain the factors influencing UIC. As said before, this is a difficult task because each framework makes its own contribution to understand UIC from a different perspective.

(ANKRAH; AL-TABBAA, 2015) organized influencing factors (i.e. barriers and facilitators) into seven groups, namely: (i) capacity and resources; (ii) legal issues, institutional polices and contractual mechanisms; (iii) management and organizational issues; (iv) issues relating to the knowledge or technology; (v) political issues; (vi) social issues; and (vii) other issues, which are presented in Table 3. Drawing from the examples of Table 3, some observations can be made. For instance, the same motivations that influences universities and firms to transfer knowledge are also factors of influence. Policies, funding and contractual terms, which are closely related, can inhibit or stimulate knowledge transfer. Even knowledge content itself can influence knowledge transfers. Especially in UIC research projects, tacit knowledge content is very high and tacit knowledge is sticky, being difficult to transfer (SZULANSKI, 1996). Knowledge's perceived value positively influences knowledge transfers, for example the higher the complementarity of academic and industrial research more easily knowledge is transferred. On the other hand, cultural differences between universities and firms represent a major barrier to transfer knowledge, which can be decreased with trust, mostly built on researchers' previous experience. Trust is also developed with close collaborations, which helps overcome uncertainties in research projects and sometimes include personnel mobility. The geographic localization of partners also seems to influence knowledge transfers, partly justified by knowledge spillovers (GEUNA; MUSCIO, 2009).

These factors show that by managing UIC organizations may collect more benefits of partnerships. In the other hand, if mismanaged or neglected some factors may jeopardize one or both organizations. Acknowledging these factors is key to understand bottle necks in cooperation.

Table 3: Influencing factors of UIC

Influencing factors	
Capacity and resources	— Adequate resources (funding, human and facilities) — Incentive structures for university researchers — Recruitment and training of technology transfer staff — Capacity constraints of SMEs
Legal issues and contractual mechanisms	— Inflexible university policies including intellectual property rights (IPR), patents and licenses and contractual mechanisms — Treatment of confidential and proprietary information moral responsibility versus legal restrictions (e.g. research on humans)

Influencing factors	
Management and organization issues	— Leadership/Top management commitment and support — Collaboration champion — Teamwork and flexibility to adapt — Communication — Mutual trust and commitment (and personal relationships) — Corporate stability — Project management — Organization culture (cultural differences between the world of academia and of industry) — Organization structure (university administrative structure and firm structure) — Firm size (size of organization) — Absorptive capacity — Skill and role of both university and industry boundary spanners — Human capital mobility/personnel exchange
Issues relating to the knowledge or technology	— Nature of the technology/knowledge to be transferred (tacit or explicit; generic or specialized; academic rigor or industrial relevance)
Political issues	— Policy/legislation/regulation to guide/support/encourage UIC (support such as tax credits, information networks and direct advisory assistance to industry)
Social issues	— Enhancement in reputation/prestige
Other issues	— Low level of awareness of university research capabilities — Use of intermediary (third party) — Risk of research — Cross-sector differences/similarities — Geographic proximity

Source: (ANKRAH; AL-TABBAA, 2015)

2.1.8 Outcomes

Universities and firms are motivated to collaborate in order to achieve benefits that they would not accomplish separately. UIC outcomes, however, include either benefits as drawbacks. Benefits are directly linked to UIC motivations and Table 4 presents (ANKRAH; AL-TABBAA, 2015)'s summary on UIC benefits. Drawbacks, in its turn, are not desired and may endanger the success of collaborations.

Since universities and firms have essentially different purposes, one of the main drawbacks is the interference in each other interests. Firms are particularly interested in a collaboration with more applied research and profitable results, which may compromise basic research and the culture of open-science. Pre-competitive research and dissemination of knowledge may be reduced due to firms' private interests (GEUNA; MUSCIO, 2009).

On the other hand, productivity and quality of results may be reduced once universities may be pushing towards more theoretical rigorous scientific criteria, while firms may be pushing towards agility and short-term results. Studies in this matter are mixed though, some find negative impacts, others do not find negative impacts at all (THUNE, 2009), showing that more effort should be spent regarding UIC drawbacks.

According to (ANKRAH; AL-TABBAA, 2015), university drawbacks receive more attention in literature, what can be explained by the asymmetry in motivations to collaborate. Firms may exert control, to generate the maximum amount of profit and universities may be in a more vulnerable position because companies control economic resources.

(ANKRAH; AL-TABBAA, 2015) summarizes drawbacks in four categories: (i) Deviation from mission or objective; (ii) Quality issues; (iii) Conflicts; and (iv) Risks, presented in Table 5. Essentially drawbacks derive from two organizations interacting with different objectives and cultures and besides benefits, drawbacks must also be addressed by managers. Just as motivations, drawbacks can influence how members behave in collaboration.

Table 4: Benefits of university and company to engage in UIC

Benefits	University	Industry
Economic-related	— Source of revenue (both public and private) — Patents/IPRs/licensing income — Additional income or financial benefit to researchers — Create business opportunities — Contribution to local/regional economic development	— New products and/or processes — Improved products and/or processes — Patents, prototypes, generate IPRs, etc. — More cost-effective than similar research in-house — Improved competitiveness — Access public grants — Promote economic growth/enhancement of wealth creation
Institutional-related	— Exposure of students and faculty to practical problems/new ideas and/or to state-of-the-art technology, with positive effects on the curriculum — Provide a 'test bed' for feedback on research ideas, results/interpretations for the refinement of academic ideas/theories — Stimulate technological advancement and/or research activities in certain key areas — Acquisition of or access to up-to-date equipment — Training and employment opportunities for students — Build credibility and trust for the academic researcher among practitioners — Stimulate the development of spin-offs (or spin-off companies) — Provide opportunity for companies to influence and encourage the	— Improved innovative ability and capacity/ Keep up to date with major technological developments — Advance new technologies — Accelerates commercialization of technologies/Increases speed of innovation to market — No inter-firm conflicts of interest — Provide much needed legitimacy for industry products (e.g. software programme) — Access to new knowledge and leading edge technologies and/or a wide variety of multidisciplinary research expertise and research infrastructure — Influence university research directions and new programs for industry good — Access to specialized consultancy/Identify relevant

Benefits	University	Industry
	development of particular lines of university research — Joint publications with industry — Publication of papers by academics	problems/Solve specific technical problems — Product testing with independent credibility in testing — Training/continued professional development — Opportunity to access a wider international network of expertise — Act as a catalyst that leads to other collaborative ventures — Joint publications — Hiring of talent graduates
Social-related	— Service to the community — Enhancement of university's reputation	— Enhance reputation by becoming more social responsible business

Source: (ANKRAH; AL-TABBAA, 2015)

Table 5: Drawbacks in UIC

Drawbacks	University	Industry
Deviation from mission or objective (core ethic)	— Threats to research autonomy or integrity for commercial advantage that may have a negative impact on culture of open science and affect university mission — Confidentiality agreements may block the dissemination of knowledge — Could result in the abandonment of long-term basic research in favor of results-oriented, short term, applied research and technology transfer — Concern that the end result of collaboration could be short-term contracts in which industry would	— Slow academic bureaucracies may stifle technology commercialization, depress the firm's performance and delay the fulfillment of the firm's objectives — Diversion away from the 'bottom-line' issues of industry like return on capital investment — Collaboration may be costly due to increase in administrative overheads, as industry may have to develop specific managerial and administrative

Drawbacks	University	Industry
	require 'quick and dirty' solutions to problems, with university departments acting as extensions to the research activities of firms	competencies, which may be a time-consuming process
Quality issues	— Potential diversion of energy and commitment of individual staff who are involved in interaction with industry, away from core educational activities — Could affect types of research questions addressed and reduce the quantity and quality of basic research	— Low intellectual level of some contract work — Results in theoretical and impracticable solutions since university staff are too theoretical and not very practical whereas industry's focus is much more problem centered on critical situations requiring immediate attention
Conflicts	— Conflicts between researchers and company over the release of adverse results/damage in professional relationships among the researchers — Biased reporting by researchers sponsored by companies in favor of positive experimental results relating to company products	— Disharmony and discord during R&D development — Intellectual property disputes and patenting disagreement
Risks	— Dilemma of either publishing results for short term revenue and academic recognition or withholding until they are patented, with the risk of the technology becoming obsolete — Risks that academic—industry relationships pose to human subjects of research and to the integrity of academic investigation	— Diminished control or leakage of proprietary information — High failure rate of collaborations — Financial risk to industry — Risk of incomplete transfer or nonperformance of technology — Market risk where there is uncertainty of the success of the product launched in the market

Source: (ANKRAH; AL-TABBAA, 2015)

2.1.9 UIC indicators

On another important line of investigation, researchers have been studying forms of measuring UIC performance and success. Most of the studies assess UIC by its outcomes and at a macro-level perspective like patenting and licensing activity. Few approach UIC indicators from the perspective of participants and teams of the collaboration (micro-level). One of the few studies to address both issues is (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s work. Researchers reviewed the literature on UIC indicators and based on (BROWN, M. G.; SVENSON, 1998)'s work proposed four groups of key performance indicators (KPI): (i) inputs, (ii) in-process activities, (iii) outputs and (iv) impact. Using a qualitative approach, they interviewed members of many UIC projects and found a set of common micro level KPIs that evidence university-industry collaboration efficiency and effectiveness, which are presented in Table 6 and used in this work.

Regarding indicators of knowledge sharing within collaboration, most studies only assess UIC outcomes, such as patents and academic publications, which may not characterize the full picture of collaborations (PERKMANN; NEELY; WALSH, 2011). Activities during the operational phase are partly responsible for outcomes and performance of knowledge transfer collaborations. Yet, there are few performance indicators of knowledge transfers in this UIC phase (PIVA; ROSSI-LAMASTRA, 2013). Knowledge transferred in UIC is strongly based in tacit content (PIVA; ROSSI-LAMASTRA, 2013), which might be viewed more as a process of learning that generates further intangible benefits, rather than explicit knowledge transfer, which can be easily evaluated by quantitative measures (GERTNER; ROBERTS; CHARLES, 2011). Consequently, the lack of indicators difficult managers' job to take actions to enhance cooperation's performance. (PERKMANN; NEELY; WALSH, 2011) proposed a success map that addresses these issues in UIC performance measurement. Concerning knowledge transfer, they state that the level of interaction between partners while defining project's objectives and throughout the entire research is a main predictor of success. Intense and frequent collaboration impacts training and learning opportunities and facilitates tacit knowledge transfer. In this line, measures proposed to assess the level of interactions include: frequency of meetings for intermediate reviews; qualitative judgement of representatives on the quality and intensity of the interactions (PERKMANN; NEELY; WALSH, 2011); members' satisfaction; and partnership continuity measured by time (PIVA; ROSSI-LAMASTRA, 2013), which are in line with a micro-level approach used in this work.

With indicators, UIC managers may evaluate the impact of initiatives tailored to enhance performance. Since a plenty of factors influence UIC and knowledge flows, discovering which influence the most allows managers to invest on those that requires least resources but generates greatest amount of benefits. Those factors that influence UIC and knowledge sharing are referred as barriers, or facilitators, which were discussed in the previous section. The process of knowledge sharing is further examined within the review of knowledge flow in the following sections.

Table 6: UIC key performance indicators from micro-level perspective

Indicators	
Inputs	— Amount of resources allocated by partners to collaboration— illustrate partners commitment (PERKMANN; NEELY; WALSH, 2011)
In-process activities	— Project management: Collaboration projects are managed actively throughout their life cycle (KAUPPILA *et al.*, 2015; ROHRBECK; ARNOLD, 2006) — Clearly defined roles: Roles and responsibilities are clearly defined and communicated (BARBOLLA; CORREDERA, 2009; ROHRBECK; ARNOLD, 2006)
Outputs	— Number of new (improved) products, services, technologies developed by the company (university) per year thanks to UIC against total number of new ones developed (AL-ASHAAB *et al.*, 2011)
Impact	— Number of new R&D projects planned or initiated informed by alliance (PERKMANN; NEELY; WALSH, 2011) — Change/renewal of business revenue structure—through application of results achieved jointly (VUOLLE; LÖNNQVIST; SCHIUMA, 2014)

Source: (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)

2.1.10 University-industry collaboration & Materials innovation

Previous sections presented an overview on UIC organized in six aspects: motivations, formation phase, organizational formats, operational phase, outcomes and influencing factors. This section reviews the literature on university-industry collaboration within the field of materials innovation using this same framework. Only formal collaborations for R&D on materials innovation were included. Findings evidenced common characteristics of UIC across fields and specific characteristics of materials innovation which are related to generic, radical and upstream technologies, that encompass high levels of technological and market uncertainties.

Findings are distributed across motivations, outcomes and factors. Focusing on those characteristics of the materials innovation field, motivations encompass the potential for a large set of applications (ALBUQUERQUE *et al.*, 2015; HUANG *et al.*, 2015) and a potential of technology exploitation (PEREZ VICO; HALLONSTEN, 2019), Table 7. Regarding outcomes, Table 8, findings show an industry that looks for developing its own expertise and finds the university as a source to build this knowledge base (MINGUILLO; THELWALL, 2013). This show that UIC contributes not only with new knowledge and technologies applied to new products and services, but also to develop company's capabilities (PEREZ VICO; HALLONSTEN, 2019). At university side, papers show that university researchers that cooperates with companies make more contribution than those focused in pure science in this field (SHICHIJO; SEDITA; BABA, 2015). University researchers show a strongly interested in continuing the interaction (HEIDRICK; KRAMERS; GODIN, 2005). Besides benefits, drawbacks were also identified. Companies argue that collaboration does not attend industry needs, with few products and business opportunities (PEREZ VICO; HALLONSTEN, 2019). On university's behalf collaboration seems to be related to a low citation impact, even though this indicator might not be a good indicator to assess academic researchers (MINGUILLO; THELWALL, 2013). Regarding factors, Table 9, a two-way interaction between company and university researchers based not only on formal, but also informal networks seem important for materials innovation. In this way, a person in charge of network articulation facilitates the process. In materials field suppliers works as diffusers of knowledge and innovation, which influences UIC and might be related to the upstream position of materials in the value chain.

The analysis of materials innovation presents some particular characteristics that must be addressed while managing these partnerships, which is supported by studies that show industry knowledge base as an influencing factor of UIC (BABA, Yasunori; SHICHIJO; SEDITA, 2009; TAMADA *et al.*, 2006).

Table 7: Motivations of UIC in materials innovation

Motivations	
Efficiency	— Funding (HUANG *et al.*, 2015; PEREZ VICO; HALLONSTEN, 2019)
	— Not R&D but solution of technical problems, testing services, trials, characterizations and certification (SCUR; GARCIA; CASTRO ARAUJO, 2015)
Stability	— Broad applications (ALBUQUERQUE *et al.*, 2015; HUANG *et al.*, 2015)
	— Great potential of materials science to be industrially exploited and commercialized (PEREZ VICO; HALLONSTEN, 2019)
	— Joint knowledge development (PEREZ VICO; HALLONSTEN, 2019)
	— Data for scientific articles (PEREZ VICO; HALLONSTEN, 2019)
	— Access new knowledge (ALBUQUERQUE *et al.*, 2015)

Source: Prepared by the author

Table 8: Outcomes of UIC in materials innovation

Outcomes	
Benefits - Economic	— Successful domain in bridging the U-I gap and represents an attractive market niche, because industry needs to develop their own expertise (MINGUILLO; THELWALL, 2013)
Benefits - Institutional	— Significant academic knowledge development (PEREZ VICO; HALLONSTEN, 2019)
	— Entrepreneurial scientists make a relatively large contribution to furthering the scientific frontier (SHICHIJO; SEDITA; BABA, 2015)
	— Bring advanced scientific knowledge into the firm (BABA, Yasunori; YARIME; SHICHIJO, 2010)
	— Increased absorptive capacity (PEREZ VICO; HALLONSTEN, 2019)
	— Large number of PhDs employed by industry (PEREZ VICO; HALLONSTEN, 2019)
	— Strong interest and willingness to be involved in such projects again in the future (HEIDRICK; KRAMERS; GODIN, 2005)
Drawbacks - Risks	— Few innovation, new products and startups (PEREZ VICO; HALLONSTEN, 2019)
	— Research was not enough to industry’s needs (PEREZ VICO; HALLONSTEN, 2019)
	— Low citation impact, citations may not be the best indicator to assess academic researchers (MINGUILLO; THELWALL, 2013)

Source: Prepared by the author

Table 9: Influencing factors of UIC in materials innovation

Factors	
Management and organization issues	— Management approaches (PEREZ VICO; HALLONSTEN, 2019) — Setting goals for industrial involvement and investments (PEREZ VICO; HALLONSTEN, 2019) — Representation on boards (PEREZ VICO; HALLONSTEN, 2019) — Stimulating discussions (PEREZ VICO; HALLONSTEN, 2019) — Regular seminars (PEREZ VICO; HALLONSTEN, 2019) — Newsletters (PEREZ VICO; HALLONSTEN, 2019) — Personnel exchange (PEREZ VICO; HALLONSTEN, 2019) — Mutual understanding and trust (PEREZ VICO; HALLONSTEN, 2019) — Absorptive capacity (BABA, Yasunori; SHICHIJO; SEDITA, 2009) — Academy ability to listen to the problems from the factory (SCUR; GARCIA; CASTRO ARAUJO, 2015) — Firm fails to innovate without having researchers who exploit the knowledge (BABA, Yasunori; YARIME; SHICHIJO, 2010) — A person in charge of industry networking (PEREZ VICO; HALLONSTEN, 2019) — Two-way knowledge interaction between Pasteur scientists and right type (entrepreneurship) of corporate researchers (BABA, Yasunori; SHICHIJO; SEDITA, 2009; BABA, Yasunori; YARIME; SHICHIJO, 2010) — Informal personal networks (PEREZ VICO; HALLONSTEN, 2019) — Official channels play a limited role in the flow of knowledge between universities and industries (BABA, Yasunori; SHICHIJO; SEDITA, 2009) — “Pasteur scientists” increases firms’ R&D productivity (boundary spanners) (BABA, Yasunori; SHICHIJO; SEDITA, 2009) — Common language and mutual understanding (BABA, Yasunori; SHICHIJO; SEDITA, 2009)
Issues relating to the technology	— Dependent by the industry knowledge base (BABA, Yasunori; SHICHIJO; SEDITA, 2009; TAMADA *et al.*, 2006) — Suppliers as a diffusers of knowledge and innovation (SCUR; GARCIA; CASTRO ARAUJO, 2015)
Other issues	— Seek industrial relevance sometimes formed a barrier to the formulation of new research questions (PEREZ VICO; HALLONSTEN, 2019) — Cost inefficiency in the production of the material (PEREZ VICO; HALLONSTEN, 2019) — Geographical proximity (SCUR; GARCIA; CASTRO ARAUJO, 2015) — Firm size (BABA, Yasunori; SHICHIJO; SEDITA, 2009)

Source: Prepared by the author

Literature review on UIC provided instruments and a framework to be used in UIC characterization. Even though this work is interested in UIC outcomes, addressing UIC context helps understanding outcomes with more detail. Reviewing UIC reinforces the idea that knowledge is a major aspect of these collaborations. Managing knowledge flow between university and industry thus might play an important role for the success of those partnerships. By understanding the complexity of knowledge flows within the university-industry environment, one can conceive more effective knowledge management models and discuss issues that hinders value creation. The next section reviews knowledge flow modelling, starting with concepts of knowledge and knowledge management.

2.2 KNOWLEDGE FLOW

2.2.1 A brief introduction on the knowledge management discipline

In the past decades, especially with the advent of the internet, industrial era has been replaced by a knowledge age. Society is living in a high-tech interconnected world with a diminished influence of the manufacturing sector, where industry has been shifting from limited-resource to knowledge-intensive firms. Knowledge became the basis for companies to sustain competitive advantage (DALKIR, 2005).

The dynamics of knowledge shows some differences from other resources. Unlike limited-resources, knowledge is not consumable and the sender does not lose it when transferring to a partner. Knowledge is not a finite resource, but a result of human cognitive activity. Managing this valuable resource, however, is a challenging activity, much of the organizations' knowledge exist in their employees and the ability to extract benefits from it is demanding (DALKIR, 2005). Therefore, the need for processes to create, share, capture, distribute, acquire, use and reuse knowledge within a systematic approach resulted in the knowledge management discipline.

Specialists, however, do not agree in a single knowledge management definition. In an informal survey (DALKIR, 2005) found more than seventy-two good definitions for knowledge management, based on different perspectives, e.g. business, cognitive science, process and technology, showing that knowledge management has an intrinsic multidisciplinary nature and its definition depends on the domain of study.

This work uses the definition of knowledge management used in the Department of Knowledge Engineering and Management of the Federal University of Santa Catarina. Knowledge management is defined as "management of activities and processes that promote organizational knowledge to enhance competitiveness by the best use of and the creation of sources of individual and group knowledge". Alongside with knowledge management, knowledge itself also does not converge to a single definition. One way to describe knowledge is using the data-information-knowledge hierarchy: data can be viewed as content that is directly observable or verifiable; information can be viewed as content that represents analyzed data; and knowledge is a more subjective way of knowing, which is typically based on experiential or individual values, perceptions and experience. An example to distinguish data, information and knowledge is presented in Table 10.

Table 10: Data, information and knowledge hierarchy

	Distinctions	Example
Data	A set of discrete, objective facts about events.	Listings of the times and locations of all movies being shown today. "I download the listings".
Information	A message, usually in the form of a document or an audible or visible communication.	"I can't leave before 5 so I will go to the 7:00 P.M. show at the cinema near my office."
Knowledge	A fluid mix of framed experiences, values, contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories but also in organizational routines, processes, practices and norms.	"At that time of day, it will be impossible to find parking. I remember the last time I took the car I was so frustrated and stressed because I thought I would miss the opening credits. I'll therefore take the commuter train. But first I'll check with Al. I usually love all the movies he hates so I want to make sure it's worth seeing!"

Source: (DALKIR, 2005)

Knowledge, sometimes, is usually confounded with information. Some researchers say that knowledge is information with semantic, i.e. meaning. However, knowledge differentiates from information as knowledge can be expressed in two natures: tacit and explicit. In his seminal work, (POLANYI, 1966) coined the term tacit knowledge (i.e. implicit knowledge) in contrast to explicit knowledge. He argued that tacit knowledge is intangible, difficult to explain into words, text, or drawings. Tacit knowledge resides within the knower's head, thus a property of the knower. Explicit knowledge in turn is tangible and can be captured in any form of concrete media. Typically, the more tacit knowledge is, the more valuable it tends to be (DALKIR, 2005).

The knowledge nature gives an indicative of how knowledge management differ from information management. Instead of focusing in acquiring and sharing content, knowledge management includes more complex relationships. For instance, the use of information management systems (i.e. information and communication technologies) is not the most important issue in knowledge management (ALAVI; LEIDNER, 2001). The relationships between people are one of the most important issues in knowledge management. The culture and the organization strategy – for instance – are one of the most used knowledge management practices (KIANTO; ANDREEVA, 2014).

Knowledge management intends to systematically improve management to enhance the benefits of potential knowledge (HEISIG, 2009), or minimize the risks of mismanaged resources (DALKIR, 2005). This can be achieved by facilitating collaboration, helping knowledge workers connect and find experts and helping the organization to learn and make decisions based on complete, valid and well interpreted data, information and knowledge. Therefore, in order to manage knowledge effectively, researchers propose models and frameworks to describe the knowledge management phenomena (HEISIG, 2009).

2.2.2 Knowledge management frameworks

Frameworks are commonly used across disciplines to organize concepts, elements, instruments, constructs and provide a common base for researchers to advance the research agenda.

Literature on knowledge management has experienced a continuous increase in the number of KM frameworks since mid-90's (HEISIG, 2009). Each of these frameworks propose means to describe, explain and assess KM from different perspectives and contexts allowing organizations to systematically plan and implement knowledge management throughout organizational processes and practices (DALKIR, 2005; HEISIG, 2009).

(HEISIG, 2009) provided a deep review on KM frameworks and discovered three main categories addressed by frameworks: definition of knowledge, KM activities and critical success factors of KM. This study is particularly interested in mapping KM activities, or processes within knowledge flow in UIC. According to (HEISIG, 2009)'s review, frameworks include five central activities: sharing, creating, using, storing and identifying.

Following activity identification, measuring intensity is also important. (Singh, 2014) reviewed the literature and interviewed information technology professionals to develop a scale of four dimensions: knowledge creation, sharing, retention and actionable knowledge support. This instrument also managed to address knowledge management at team-level (micro-level) which is the focus of this work. Instead of capturing managers perspective, the instrument is designed to approach team members.

This work focuses on knowledge flow, whose frameworks is a sub-set of KM frameworks. Even though knowledge flow extensively discusses knowledge sharing, the other activities also participate in the process and must be considered, thus a short note on KM frameworks was necessary. The next section will review how the knowledge flows are modelled.

2.2.3 Modelling knowledge flows

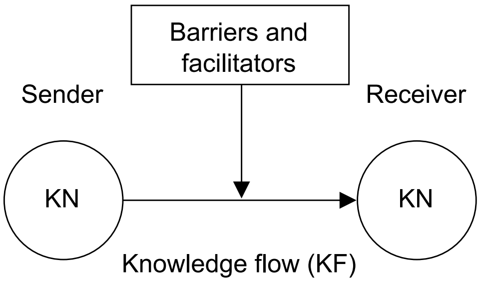
Knowledge flow (KF) is a dynamic process between people or knowledge processing mechanisms in certain context where relevant knowledge is created, transformed, propagated and applied (GUO; WANG, 2008; ZHUGE, 2002a). The objective of knowledge flow management is to improve the efficiency and efficacy of cooperation efforts of knowledge teams (ZHUGE; GUO; LI, 2007), working on facilitators and barriers, such as knowledge tacitness, ambiguity, motivational dispositions, absorptive capacity and other factors (DYER; NOBEOKA, 2000; GUPTA; GOVINDARAJAN, 2000). Modelling knowledge flow allows managers to assess how knowledge is propagated within and across organizations and propose actions to enhance its overall effectiveness and efficiency.

A visual model of the knowledge flow network can be produced quite easily with few graphic elements, as depicted in Figure 4. A knowledge node (KN) corresponds to a team member, role, group, or organization, which is connected to other nodes until the entire network of analysis is complete. A line is used to denote the connection between nodes and an arrow shows the direction of knowledge flow, determining the sender and the receiver (ZHUGE, 2002a). In those ties where knowledge flows in both directions a bi-directional arrow is used.

Modelling knowledge flows, however, encompasses a series of other elements, making it a more complex task. Knowledge content flowing between the nodes can be significantly different (e.g. type, level and location) (ZHUGE, 2002a), the intensities can vary, value may be perceived in different ways, depending on nodes, context, previous knowledge etc. There may be internal (intra) and external (inter) organizational knowledge flows, at all levels: individual, group, organizational and inter-organizational. The content is carried through different channels of communications, such as internet or local networks (ZHUGE, 2002a), depending on the content, network, technologies available etc. Nevertheless, many factors may moderate knowledge flows within the networks, acting as barriers and facilitators of knowledge flow.

Researchers propose a series of models and frameworks to assess knowledge flows and its elements. This work reviews the literature and organizes it into eight groups hereafter described: (i) content; (ii) network; (iii) intensity; (iv) value; (v) activities; (vi) communication channels and ICTs; (vii) multi-level knowledge flow; (viii) influencing factors, Figure 5.

Figure 4: A simple visual model for knowledge flow



Source: Prepared by the author

Figure 5: Framework to assess knowledge flow

Knowledge flow assessment framework
1. Content 2. Network 3. Intensity 4. Value 5. Activities 6. Communication channels and ICT 7. Multi-level knowledge flow 8. Influencing factors

Source: Prepared by the author

2.2.3.1 Content

Knowledge flow content can be specified in many ways. Perhaps, one of the major classifications is to distinguish the knowledge nature as tacit and explicit (HONG, 2008; KESSLER, 2003; POLANYI, 1966; XU *et al.*, 2014). Tacit and explicit knowledge present different inner structures and features requiring their own transfer paths and institutional conditions (XU *et al.*, 2014), for example (SZULANSKI, 2003) says that tacitness gives knowledge a sticky quality. Similar to the tacit-explicit dichotomy, (GUPTA; GOVINDARAJAN, 2000) performed a study of knowledge flows in inter-organizational environment that distinguished procedural knowledge or “know-how” (e.g., product designs, distribution know-how etc.) from declarative or “operational information” (e.g., monthly financial data). Specific domain, e.g. materials engineering, biotechnology, construction, extractive industries, information and communication, is also used to divide knowledge by productive sectors, in order to find innovative capabilities at national and regional levels (DEL-VECCHIO; BRITTO; DE OLIVEIRA, 2014).

From an integrated business perspective, knowledge can be categorized in technological, market and managerial, which is constantly flowing between production, R&D, sales and marketing organizational functions (ALBERTI; PIZZURNO, 2015; SAMMARRA; BIGGIERO, 2008). (SAMMARRA; BIGGIERO, 2008) argues that the consideration of these different types of knowledge in the context of inter-firm innovation collaboration has not received proper elaboration. There is a gap in innovation management concerning the links between technological development, marketing and organizational processes that should be strengthen. Each type of knowledge present different structural characteristics, thus requiring knowledge-specific exchange processes. From a research perspective, knowledge depends on the research field, on the technological maturity and it could be basic, mixed, or applied. These and other factors influence the way knowledge flows between institutions (D'AMORE *et al.*, 2013).

Knowledge content can be viewed in countless perspectives, thus researchers propose frameworks and models to organize knowledge and study knowledge flows. (ZHUGE, 2002b) proposes a knowledge space that arranges knowledge in three dimensions: category, level and location, in order to organize knowledge for problem-solving and other applications. In another context-based study, (GUO; WANG, 2008) proposed a "TPK" context model comprising task, process and knowledge spaces, in order to better understand knowledge flow and its application in practice. They argue that context is indispensable for representing knowledge flow.

Knowledge content can significantly influence the dynamics of knowledge flows, thus understanding its characteristics and the factors influencing the process is important to effectively manage knowledge. Organizing knowledge by types and introducing frameworks helps to accomplish this task.

2.2.3.2 Network

One of the first steps when studying knowledge flows is to discover the network by mapping all the nodes within the scope of analysis. Discovering the network provides the ground base for studying patterns and aspects of knowledge flows.

A knowledge flow network is a complex system of interconnected nodes with different characteristics and distinct roles sharing knowledge in multiple directions (DYER; NOBEOKA, 2000), understanding network is important because it directly impacts KF. By understanding patterns managers can propose strategies in order to extract more benefits from knowledge.

In a multi-national corporation network, for example, there is usually a centralized pattern with two major types of connections: connections between the centralized headquarter and its subsidiaries; and connections between subsidiaries. In each of these connections there are two streams: knowledge flowing inwards and outwards of each organization. Besides, headquarters and subsidiaries are different organizations which present distinct behaviors while exchanging knowledge. These aspects of knowledge flow evidence how complex are the interactions between partners and why different knowledge management strategies are required for knowledge to flow effectively (GUPTA; GOVINDARAJAN, 2000).

In more decentralized networks, on the other hand, different significant patterns start to emerge. Aside from central points, nodes called as brokers or gatekeepers are responsible for bridging the network. These nodes are important, because they connect different parts of the network, overcoming the lack of common knowledge, cognitive distance, shared vision, trust, complexity, or ambiguity and act as bridging ties between knowledge sources and knowledge seekers (YE; KANKANHALLI, 2013). These networks are also composed of a series of strong and weak bonds between nodes, that exchange knowledge in different ways.

From another perspective, individuals are constantly exchanging knowledge throughout boundaries (i.e. inward and outward), between project partners, across departments, between organizations, within formal and informal relationships. Also called as inbound and outbound knowledge flows, this is a matter of study for many researchers (CLEVELAND, S; MITKOVA; GONCALVES, 2015). Some authors say that inbound and outbound are complementary in open innovation, though (CASSIMAN; VALENTINI, 2016) finds no empirically evidence of the interdependency, showing that there is no consensus in this subject. (KESSLER, 2003) on the other hand argues that both internal and external knowledge flows contribute to R&D activity and how organizations manage internal and external knowledge networks is directly connected to the R&D success. (SIEGEL *et al.*, 2003) corroborates this statement in university-industry collaboration, showing that by collaborating knowledge flows in both directions with different knowledge contents and intensities, benefiting both parties. While technology is transferred from universities to firms, academic scientists can conduct better basic research because of new ideas provided by industry scientists, as well as having access to better equipment and additional financial resources to conduct more experiments.

The study of inbound and outbound knowledge flows is closely related to the study of intra- and inter-organizational knowledge flows. For instance, researchers found that inter- and intra-organizational knowledge flows seems to be different processes, as knowledge flows easily within an organization than between organizations (KOGUT; ZANDER, 1992). Another behavior that also appear in inter- and intra-industry knowledge flows (SCHMIDT, 2010) is that knowledge is more likely to be transferred among individuals within the same geographical areas or the same technological fields (LIU, X. *et al.*, 2015; SINGH, J.; MARX, 2013). Nevertheless, there is a consensus that inter- and intra-organizational interactions are both crucial to facilitate the acquisition of heterogeneous knowledge from collaboration partners (SAMMARRA; BIGGIERO, 2008).

Understanding the network, the links between nodes and the direction of the knowledge flows, patterns of KF can be identified, such as: bottlenecks (e.g. brokers), central nodes (e.g. star scientists), knowledge paths within the organization and strategies can be proposed to enhance knowledge flows between researchers and organizations.

2.2.3.3 Intensity

Another important matter of interest when studying knowledge flows is the intensity of flow and the intensity of relationships. Knowledge flow intensity has been measured by a wide variety of forms.

Several proxies have been used to study knowledge flows, such as: co-authorship and citation network in patent databases (DECAROLIS; DEEDS, 1999; HONG, 2008; JAFFE; TRAJTENBERG; HANDERSON, 1993); co-authorship and citation network in scientific articles databases (D'AMORE *et al.*, 2013; DECAROLIS; DEEDS, 1999); R&D contracting, R&D consulting and licensing (CASSIMAN; VALENTINI, 2016); R&D intensity and the number of alliances (DECAROLIS; DEEDS, 1999); citations of universities and research institutes carried out by companies (DEL-VECCHIO; BRITTO; DE OLIVEIRA, 2014); intensity of interactions measured by frequency (number of interactions) and stability (D'AMORE *et al.*, 2013).

Besides proxies, questionnaires sent to specialists also have been largely used. Likert-type scales have been used in interviews and self-evaluation forms to retrieve managers and employees' opinion on: knowledge inflows and outflows (GUPTA; GOVINDARAJAN, 2000); tacit and explicit knowledge transfer (XU *et al.*, 2014); knowledge flow of marketing know-how, distribution know-how, packaging design/technology, product designs, process designs, purchasing know-how, management systems and practices (GUPTA; GOVINDARAJAN, 2000); and knowledge acquired from interfirm contacts or university-industry contacts (ØSTERGAARD, 2009).

Knowledge flow intensity can be investigated by qualitative and quantitative forms, by inferring data using proxies, or retrieving data from specialists. Regardless of the strategy, the objective of assessing knowledge flow intensities is to find patterns of high and low knowledge flows, to propose strategies and retrieve more benefits of organizational knowledge.

2.2.3.4 Value

The motivation to exchange knowledge is a factor that varies between individuals in the organizations. This motivation is partly responsible for network bonds and intensity of knowledge flows. Also called as value of knowledge, this is a perceived quality and may be influenced by aspects such as the quality of relationships, shared values, motivational disposition, richness of transmission channels and absorptive capacity (GUPTA; GOVINDARAJAN, 2000; LINDSAY *et al.*, 2003). Thus, the perceived value of the knowledge may vary depending on node's view (ØSTERGAARD, 2009; SAMMARRA; BIGGIERO, 2008). Knowledge value is closely related to absorptive capacity, which is defined as "ability to recognize the value of new external knowledge, assimilate it and apply it to commercial ends" (COHEN; LEVINTHAL, 1990). Absorptive capacity is a key element in this work and is reviewed separately in detail.

Assessing knowledge value may be a difficult task since knowledge can be explicit and tacit. Explicit knowledge is relatively easy to evaluate because it is codified and can be analyzed by experts or measured by proxies. For instance, some studies call previous knowledge as "knowledge stocks" and measure it as proxies such as number of products, number of patents, firm citations (DECAROLIS; DEEDS, 1999). On the other hand, the tacit form of knowledge is difficult to evaluate and mostly rely on expert judgement, questionnaires, self-evaluation, peer evaluation and achievement tests. These subjective evaluations made with human judgement may produce some inconsistencies in pairwise comparisons, especially when the team is large, though they present good approximation of the system (ZHUGE; GUO; LI, 2007). It is also relevant to note that in some cases, human capital (e.g. graduate human capital) is also assessed in knowledge flows, especially when surveying knowledge flows through employee migration (FAGGIAN; MCCANN, 2006).

Knowledge value shows that previous knowledge, context aspects and absorptive capacity influence the behavior how nodes exchange knowledge. Thus, understanding motivations to exchange knowledge is important while planning KF strategies in organizations.

2.2.3.5 Practices

Knowledge flow activities in this study are viewed as knowledge management practices, which are those activities that are aimed at supporting knowledge management in the firm (KIANTO; ANDREEVA, 2014). Organizations are interested in KM practices, because practices allow organizations to capture the benefits of knowledge, generate more value and provide a strategic advantage to the organization.

An unified accepted list of KM practices has not yet been reached (KIANTO; ANDREEVA, 2014), though researchers proposes convenient forms of displacing them. (HEISIG, 2009) based on the similarities have organized activities into five central KM groups: (i) use; (ii) identify; (iii) create; (iv) acquire; (v) share; and (vi) store, which serves as a ground base for a common understanding between many KM frameworks.

KM practices are assessed in a series of ways. Researchers have developed, tested and validated instruments according to studies' objectives and research fields. Few studies, however, address KM practices at micro-perspective. (SINGH, R. M.; GUPTA, 2014)'s work contributes to this matter, as they developed an instrument that measures KM practices at team level in four dimensions: (i) actionable knowledge support, (ii) knowledge retention, (iii) knowledge sharing and (iv) knowledge creation.

Although all activities play their role in knowledge flow, knowledge sharing within UIC represent a major subject and may be further addressed. Knowledge sharing is performed by formal and informal meetings; by communicating through e-mail, phone calls, reports etc.; by training efforts, formal and informal; and by personal exchange resulting in further employment or not. In UIC, sharing can take many forms such as: collaborative research, patent licensing, personnel mobility, attendance to conferences, communities of practice, consulting services and others (GEUNA; MUSCIO, 2009). Most studies in the field assess knowledge transfer by number of patents, licenses and spin-offs, as these records are usually easy to be retrieved in knowledge transfer offices (KTOs). Nevertheless, knowledge sharing measured in these explicit forms represent just a little fraction of all knowledge transferred between partners (GEUNA; MUSCIO, 2009). Understanding how codified and non-codified knowledge flows within the social relationships between researchers is important for the success of knowledge transfer partnerships, but few studies assess the process of transferring knowledge at this micro-level of interaction (GERTNER; ROBERTS; CHARLES, 2011; GEUNA; MUSCIO, 2009). At this micro-level, three roles participate in the process of transferring knowledge between universities and firms: the academic, the gatekeeper and the company partner. The academic is seen as the academic knowledge source and is usually a graduate student who is responsible for creating, transferring and developing knowledge ties between universities and firms (THUNE, 2009); the gatekeeper is a conduit of knowledge, that intensifies the knowledge flow; and the company partner is the source of market knowledge, the primary recipient of knowledge and who is usually interested in monitoring and controlling the project (GERTNER; ROBERTS; CHARLES, 2011). Therefore it is clear that in UIC, knowledge flows in both directions (GEUNA; MUSCIO, 2009) and all parties handle different knowledge contents, such as technical, managerial and market knowledge, besides their own domain areas. Activities show that knowledge can be transferred through formal (e.g. formal meetings, contacts, event participation, training) and informal meetings (e.g. occasionally meetings, informal social networking); transfer can be held by electronic means, or personally – especially if knowledge content is tacit; and they may rely on personnel mobility between organizations, which include employment of academics by firms.

The difference between practices and processes also deserves a quick note, because they are linked to the concept of activity. Process and practice are different organizational concepts that contribute in distinct ways. While process is defined as “a series of activities systematically performed directed to some objective” (GUIDE TO THE BUSINESS PROCESS MANAGEMENT COMMON BODY OF KNOWLEDGE: ABPMP BPM CBOK, 2009), practice is defined as “a frequently repeated act, habit or custom performed to a recognized level of skill" (LEE, 2005). Process refers to the way business routines are formally organized which can be associated to explicit knowledge, whereas practices are related to the way how job is really done within organizations – thus more associated with the tacit form of knowledge. Processes are important because they institutionalize a path, which ensure that the necessary activities are performed, requirements are met and objectives are secured. However, processes don't reflect exactly how everything is done by members in every situation. The capacity to complete a task usually relies on members and team practices besides organizations standardized procedures (BROWN, J. S.; DUGUID, 2000). Therefore, practices can be viewed as those activities that are performed and compose the standardized procedures (KIANTO; ANDREEVA, 2014), but also those that fall outside the scope of these business processes (LEE, 2005). It should be noted that organizations and managers should properly balance business process and practices, because if the organization leans towards processes it loses flexibility, innovation performance, etc. whereas leaning towards practices, the lack of structure may jeopardize objectives, efficiency and so on (BROWN, J. S.; DUGUID, 2000). Processes and practices are complementary elements in the operationalization of knowledge management (DALKIR, 2005; HEISIG, 2009).

2.2.3.6 Communication channels and ICT

In a review on communication theory (KRONE; JABLIN; PUTNAM, 1987) found that most researchers agree on eight basic elements of any two-person communication: (i) a message, (ii) a sender, (iii) a coding scheme, (iv) a channel, (v) transmission through the channel, (vi) a decoding scheme, (vii) a receiver and (viii) the assignment of meaning to the decoded message. In a study of knowledge flows of internationalization of service firms (LINDSAY *et al.*, 2003), among other findings, concludes that communication channels are transmission channels for knowledge flows; the effectiveness of these channels depend on the perceived value of knowledge and the motivation to receive and share; the establishment of these channels is related of the quality of the relationship between individuals; informal and open relationships enrich the channels; and the role of individuals in maintain and create relationships is crucial to sustain these channels. These examples show that studies on communication channels addresses the aspects of knowledge flows that have been previously reviewed, such as knowledge content, knowledge flow networks, motivations to exchange knowledge, knowledge sharing activities etc. Thus, a study proposed to model and investigate knowledge flows must also identify the communication channels in place.

Communications channels used to share knowledge can be analyzed from different aspects, such as: formality (i.e. formal and informal contacts) (ØSTERGAARD, 2009); internet attributes (e.g. e-mail, discussion groups, chat, voip, video conference, remote access, libraries, file transfer protocol, world wide web) (KESSLER, 2003); face-to-face interactions (JOSHI; SARKER; SARKER, 2004); and cross-functional communications (DAGHFOUS, 2004; SCHMIDT, 2010). This study assumes that a person is not a communication channel.

By the previous examples, one should note that information and communication technologies (ICT) play a major role in communications channels. In the context of knowledge management, information and communication technologies are found to support the processes of acquisition, dissemination and exploitation of knowledge (CLEVELAND, Simon, 2014). The application of ICT and other technologies in industrial research and new product development is being called e-R&D and aims to improve organizations and teams' value-creating activities. These internet-driven e-R&D networking are valuable tools for facilitating internal, external and memory-related knowledge flows by overcoming traditional barriers of learning, promoting openness and teamwork, decentralizing knowledge flows, stimulating new links and improving quality of communications (KESSLER, 2003). Though, appropriate implementation of organizational structures and processes are necessary for ICT-based tools to be efficient (GRESSGÅRD *et al.*, 2014).

2.2.3.7 Multi-level knowledge flow

As previously reviewed in knowledge flow networks, the analysis of knowledge flows can be performed at different organizational levels, such as between individuals, groups or organizations. Furthermore, the role of the individual is key while studying the dynamics of knowledge flows because it is his the ultimately responsibility in company's knowledge creating and sharing, especially when tacit knowledge is involved. Individuals are responsible for maintaining the transmission channels effective with trust, open and informal relationships. The capacity to absorb knowledge is also influenced by how individuals interact, where shared knowledge facilitates the relationships (VOLBERDA; FOSS; LYLES, 2010). Individuals' personalities may also negatively affect knowledge flows with ego defense mechanisms, jealousies and territorial protection (LINDSAY *et al.*, 2003).

Regardless the importance of the individual for knowledge flows, most of the studies until 1990s have focused only in the organization level, leaving this subject mostly neglected (LINDSAY *et al.*, 2003). According to the resource-based view, most studies address knowledge as a resource embedded in the firm, though this largely overlooks the fact that knowledge ultimately resides in individuals. For instance, personnel mobility plays major influence on the way knowledge is used and how it flows within organizations.

The multi-level assessment is an important matter to understand the dynamics behind knowledge flows. Understanding the behavior between individuals may evidence patterns not visible while assessing only the organizational level. However, since the whole is more than the sum of its parts, an understanding of the multiple levels is required. In their work on multi-level perspective of knowledge transfer, (ZHAO; ANAND, 2009) distinguish individual-level and collective-level constructs. Individual-level is defined as the sum of the individual counterparts, while collective-level describes the interrelatedness among members or the global properties of the entire organization. In other words, the organizational phenomena is not a result of the simple collection of individuals' attributes, but flourishes from the overall structure and interrelation patterns occurring within the organization as a whole (KOGUT; ZANDER, 1992).

2.2.3.8 Influencing factors

Studies show that a series of factors influence knowledge flows, acting as moderators (i.e. barriers or facilitators), such as: trust, geographic distance, institutional distance, cognitive and social distance, the role of brokers between nodes, the capacity of organizations to internalize knowledge as a function of absorptive capacity, shared knowledge, reputation, centrality, social capital, transferring costs and social networks. (GUPTA; GOVINDARAJAN, 2000) organize barriers or facilitators into five aspects, from a knowledge sharing perspective: (i) value of the source unit's knowledge stock, (ii) motivational disposition of the source unit, (iii) existence and richness of transmission channels, (iv) motivational disposition of the target unit and (v) absorptive capacity of the target unit. Barriers and facilitators that affects knowledge flows were reviewed using (GUPTA; GOVINDARAJAN, 2000)'s framework and are described hereafter. Studies are summarized in Table 11.

2.2.3.8.1 Value of the source unit's knowledge stock.

The value of knowledge as a resource is not an absolute measure, knowledge's value is perceived differently between individuals (i.e. knowledge's value is closely related to absorptive capacity (COHEN; LEVINTHAL, 1990)), influencing its attractiveness (GUPTA; GOVINDARAJAN, 2000). (ZHUGE; GUO; LI, 2007) calls this knowledge value as knowledge energy and argues that knowledge stocks, same knowledge space and common interests facilitate knowledge flows (ZHUGE, 2002a). On the contrary, lack of knowledge and out-of-date knowledge are viewed as of low energy and low value making it difficult for knowledge to flow. The perception of knowledge value also comes along with the concept of costs. Knowledge flows are not cost free (TEECE, 1977) and for instance, "tacitness" or "causal ambiguity" may increase the process cost by acting as barriers to knowledge transfers (GUPTA; GOVINDARAJAN, 2000; ZANDER; KOGUT, 1995).

2.2.3.8.2 Motivational disposition of the source unit

To exchange knowledge, first the source unit must be willing to share. If knowledge is perceived as valuable resource, some nodes within the network may see valuable know-how as a way to retain power, thus the fear for loss of hegemony may represent a barrier in knowledge sharing. Thus, an inclination towards knowledge sharing may require rewards and incentives systems and to treat knowledge as a public resource.

2.2.3.8.3 Existence and richness of transmission channels

As previously reviewed, knowledge cannot flow without transmission channels. Their richness and bandwidth facilitate knowledge flows and are characterized by its formality, openness and density of communications. Socialization mechanisms play an important role in transmission channels, which incorporates organizational mechanisms and build interpersonal familiarity, personal affinity and convergence in shared mental models among individuals (GUPTA; GOVINDARAJAN, 2000).

2.2.3.9 Motivational disposition of the target unit

If the source unit must be willing to share, the target unit must also be willing to receive knowledge. As an opposite effect of power and loss of hegemony observed in the source unit, a “not-invented-here” syndrome may be observed in the target unit. This behavior is motivated by managers blocking inward knowledge flows afraid that others may be gaining importance and power within the organization, resulting in a major barrier for knowledge inflows. Strategies, however, can mitigate the negative effects of this behavior, such as creating incentives to learn from others, diminishing the perceived value of knowledge stocks within the network and deliberately applying high-management pressures (GUPTA; GOVINDARAJAN, 2000).

2.2.3.9.1 Absorptive capacity of the target unit

Even the most valuable knowledge may not be perceived if individuals, or organizations, in other words they may not have the ability to recognize its value. Absorptive capacity is responsible for allowing individuals and firms to recognize knowledge’s value, internalize, assimilate, transform and exploit it (COHEN; LEVINTHAL, 1990). Factors that composes absorptive capacity are therefore facilitators and barriers of knowledge flow, such as prior knowledge, homophily and limitations in the abilities to assimilate and apply knowledge (GUPTA; GOVINDARAJAN, 2000).

By reviewing factors that act as barriers and facilitators of knowledge flows, it can be seen that they are related to the knowledge management practices established within the organizations to maximize the benefits obtained from knowledge. By working on strategies that minimize barriers and promote facilitators, more efficient knowledge flows can be expected.

Table 11: Summary of influencing factors of knowledge flow

Facilitators	Barriers
(i) Value of the source unit's knowledge stock	
— Value (BARNEY, 1991; GUPTA; GOVINDARAJAN, 2000) — Knowledge energy (ZHUGE; GUO; LI, 2007) — Same knowledge space (peer-to-peer collaboration) (ZHUGE, 2002a) — Common interests (i.e. affinity) (ZHUGE, 2002a)	— Cost (GUPTA; GOVINDARAJAN, 2000; TEECE, 1977) — Tacitness (GUPTA; GOVINDARAJAN, 2000; ZANDER; KOGUT, 1995) — Causal ambiguity (GUPTA; GOVINDARAJAN, 2000; SHIN; HOLDEN; SCHMIDT, 2001; SZULANSKI, 1996) — Immobility (tacitness) of knowledge (SHIN; HOLDEN; SCHMIDT, 2001) — No information on knowledge existence or limitations in pre-existing knowledge (COHEN; LEVINTHAL, 1990; SHIN; HOLDEN; SCHMIDT, 2001) — Lack of up-to-date knowledge (SHIN; HOLDEN; SCHMIDT, 2001)
(ii) Motivational disposition of the source unit	
— Rewards; reciprocal relationships; organizational climates; social ties; trust; norm of reciprocity; shared language; shared vision; supervisory control; reputation; centrality; experience (HE; WEI, 2009) — Rewards and incentives systems (SUNDARESAN; ZUOPENG ZHANG, 2004) — Manage knowledge as a public good (MCLURE WASKO; FARAJ, 2000)	— Power (GUPTA; GOVINDARAJAN, 2000) — Fear for loss of hegemony (SHIN; HOLDEN; SCHMIDT, 2001; SZULANSKI, 1996) — Lack of commitment or negligence (SHIN; HOLDEN; SCHMIDT, 2001)

Facilitators	Barriers
(iii) Existence and richness of transmission channels	
— Informality, openness and density of communications (GUPTA; GOVINDARAJAN, 1991, 2000) — Information technology (SUNDARESAN; ZUOPENG ZHANG, 2004) — Electronic communities of practice (MCLURE WASKO; FARAJ, 2000) — Geographic located knowledge flows (JAFFE; TRAJTENBERG; HANDERSON, 1993) — Human interaction and communication (LINDSAY *et al.*, 2003)	— Weak co-location (GUPTA; GOVINDARAJAN, 1991; SHIN; HOLDEN; SCHMIDT, 2001) — Unfriendly relationships between source and recipient (SHIN; HOLDEN; SCHMIDT, 2001) — Limitations in individuals' network of knowledge or doubt about the network (SHIN; HOLDEN; SCHMIDT, 2001)
(iv) Motivational disposition of the target unit	
— Collaborative norms; perceived usefulness; seeker knowledge growth; self-efficacy; resource facilitating conditions; learning orientation; intellectual demands; perceived output quality; resource availability; incentive availability (HE; WEI, 2009) — Collaborative norms (BOCK; KANKANHALLI; SHARMA, 2006)	— Not invented here syndrome (GUPTA; GOVINDARAJAN, 2000; SHIN; HOLDEN; SCHMIDT, 2001) — Ego-defense mechanisms (GUPTA; GOVINDARAJAN, 2000; SHERIF; CANTRIL, 1947) — Power struggles within organizations (GUPTA; GOVINDARAJAN, 2000)
(v) Absorptive capacity of the target unit	
— Prior related knowledge (COHEN; LEVINTHAL, 1990) — Homophily (i.e., "the degree to which two or more individuals who interact are similar in certain attributes, such as beliefs, education, social status and the like" (GUPTA; GOVINDARAJAN, 2000; ROGERS, 1995)	— Limitation in interpretative ability (SHIN; HOLDEN; SCHMIDT, 2001) — Limited knowledge processing capacity - Knowledge location (SHIN; HOLDEN; SCHMIDT, 2001) — Limitations in the capacity to institutionalize new knowledge application (SHIN; HOLDEN; SCHMIDT, 2001; SZULANSKI, 1996)

Source: Prepared by the author

2.2.4 Social network analysis

Network analysis, as reviewed in previous sections, plays an important role in the investigation of knowledge flows. In this way, social network analysis (SNA) appears as an interesting set of tools to characterize knowledge flow networks. SNA is a multidisciplinary field of research that seeks to investigate the relationship between structures of social entities – such as people, groups, or organizations and other social phenomena (BUTTS, 2008). Social networks are the essential structures that connects members and are the base for formal and informal communication and knowledge transfer (ALLEN; JAMES; GAMLEN, 2007a; OTTE; ROUSSEAU, 2002). Although the concepts of social networks have been addressed since the 1950's it was only about 1980's that SNA started its history, which is mainly explained by availability of basic textbooks, computer software and especially the internet advent (BUTTS, 2008; OTTE; ROUSSEAU, 2002). Since then, SNA is a growing topic especially in social sciences, but other areas of research have been particularly interested, such as market economy, geography, transport networks, medicine and war (BUTTS, 2008; OTTE; ROUSSEAU, 2002).

By using a broad set of strategies (OTTE; ROUSSEAU, 2002), SNA is capable of mapping, measuring, analyzing and visualizing the ties between those social entities and the flows of information and knowledge (DALKIR, 2005). Through mathematical (i.e. graph theory) and visual analysis SNA can identify patterns of internal structures, roles, key positions (e.g. central nodes, remote nodes, gatekeepers) and behaviors in complex human systems (DALKIR, 2005).

SNA is a valuable and powerful set of tools (BUTTS, 2008) for managers, because they show invisible patterns of individual ties within the organization, which are not shown in organizational charts and strategies. Managers usually work on the formal social networks to enhance knowledge creating, sharing and problem-solving capacity, though they typically disregard those ungoverned, organic and invisible connections, which are intrinsic in human complex interaction (ALLEN; JAMES; GAMLEN, 2007a; CROSS; BORGATTI; PARKER, 2002; DALKIR, 2005). Although they remain slightly understood by managers, informal social networks play a major role in the way work is done within organizations (CROSS; BORGATTI; PARKER, 2002). These networks connect individuals and groups which are presumably disconnected and are invisible paths that individuals use to access information and knowledge to complete their tasks. In other words, diagraming organizational charts is not enough to improve effective collaboration within knowledge-intensive companies (CROSS; BORGATTI; PARKER, 2002).

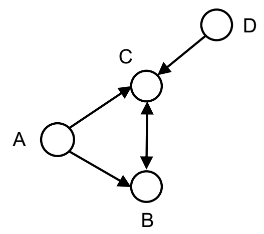
SNA is helping researchers to better understand the dynamics in R&D organizations and tailor specific and more effective initiatives to develop the organizational fabric that connects R&D teams and members. Within scientific and technical work, team members are far more prone to retrieve knowledge and information from colleagues rather than digital or physical repositories. Thus, by identifying “star” nodes, gatekeepers, boundary-spanning individuals and bottlenecks knowledge transfer can be encouraged, what contributes to company’s innovation capacity (ALLEN; JAMES; GAMLEN, 2007a).

Studying social networks basically consists of addressing two types of data: attribute and relational data. The first comprises the entities themselves and their properties, whilst the second encompasses the relations, together with its characteristics, between those entities. Typically, the SNA research field is more focused in structural characteristics of networks, individual properties although necessary to understand the social phenomena are secondary (OTTE; ROUSSEAU, 2002)). However, several studies use SNA as a toolbox where both types of data are equally relevant, this study is included in this group. Therefore, SNA is quantitative, but also qualitative. The analysis of attribute and relational data produce quantitative results, which can be evaluated by conventional statistics tests, while the patterns identified allows further qualitative investigation to clarify the phenomena, especially when studies are still in exploratory stages. The following sections are dedicated to providing an overall understanding of SNA by addressing its basic concepts.

2.2.4.1 Graph theory and representation

The analysis of social networks is based on a mathematics field called graph theory which provides a formal language for describing networks and their features (BUTTS, 2008; SCOTT, 2000). Graphs used in graph theory are distinct from those used to plot variables in statistical analysis or in other branches of quantitative mathematics. While more familiar graphs such as frequency data plots variables on orthogonal axes, the graphs in graph theory express the qualitative patterns of connection among points. Graph theory concerns are sets of elements and the relations among these. Figure 6 illustrates a simple sociogram (i.e. social graph), where each entity is noted by a geometric shape – referred to as a node and the relationships are represented by lines. In graph theory, the pattern of connections is the most important, rather than the actual positioning of the points in the page. In other words, there is no interest in the relative position of two points on the page, the lengths of the lines, or the size of character used to indicate the points. Graph theory does involve concepts of length and location, but these do not correspond to those concepts of physical length (SCOTT, 2000).

Figure 6: Simple four-point sociogram with directed lines



Source: Prepared by the author

Although sociograms are very helpful to understand patterns of networks, graph theory is much more than the simple visualization of nodes and relationships. Graph theory is a quantitative analysis to investigate the relationship between social characteristics and network patterns. Thus, graph diagrams themselves are of secondary importance in graph theory. Although the example in depicted Figure 6 is quite simple and easy to draw, in graph visualization drawing a clear and comprehensible diagram for large sets of points with complex patterns of connections is a challenge. Therefore, by expressing the properties of the graph in a more abstract mathematical form, there is no need to draw a sociogram, what makes it easier to manipulate very large graphs.

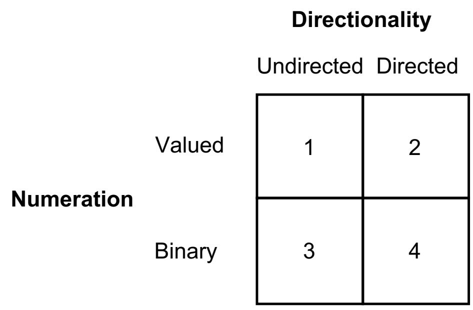
2.2.4.2 Social network data

In social network analysis, a graph is comprised of two sets of data: attribute and relational data. Attribute data refers to the quantifiable attributes of a particular entity, whether it is an individual, or a group and includes attitudes, opinions, behavior, properties, qualities and characteristics. This type of data is the primary source of information in sciences studies which is collected through questionnaires and interviews to be further analyzed by a variety of statistical procedures.

Besides the attributes of the nodes, social network analysis is particularly interested in the relationships between them. Relational data is the information about how the nodes are connected, it comprises the connections and its characteristics. Information on relationships is a matter of system of agents and thus cannot be reduced to properties of the agents themselves. Relational data is gathered in the same way as attribute data, by questionnaires, interviews, participant observation or documentary sources and both types of data can be collected at the same time (SCOTT, 2000).

Measurement in relational data can be classified in two main dimensions (i.e. directionality, numeration), resulting in four groups, Figure 7. Graphs can be directed or undirected. In directed graphs, relations are directed from one agent to another and the graph is represented with arrows, whose direction indicates the direction of the relation. Directed graphs can also be bidirectional, such as the link between nodes B and C in Figure 6. On the other hand, in undirected graph direction is not relevant and graph is represented with simple lines. Then, there are binary and valued graphs. Binary graphs are the most straightforward way of addressing relationships, that is there is or there isn’t a link. In valued graphs though intensity of the relations is important which can be represented by a numerical value. In some cases, a numbered relationship can be positive or negative. Thus, as depicted in Figure 7, the simplest form of relationship is that undirected and binary (type 1), whereas the most complex is directed and valued (type 4), which carries more information.

Figure 7: Classification of relational data in social network analysis (SCOTT, 2000)



Source: Prepared by the author.

As reviewed so far, SNA data is collected at the individual level, but the assessment is realized at the structural level. Even when a group is defined as entity, a member of the organization is responsible to provide its opinion. The following topics provide a short description of the most used concepts, patterns and measurements in SNA.

2.2.4.3 Degree

Nodes that are directly connected by a single line are said to be adjacent to each other, whereas the set of all adjacent nodes of one point (i.e. ego) is said to be its neighbors or alters. Then the size of the neighborhood (i.e. the total number of neighbors) is called degree. In a directed graph where there are inward and outward connections the concept of in-degree and out-degree emerges (BUTTS, 2008; HAWE; WEBSTER; SHIELL, 2004; SCOTT, 2000).

2.2.4.4 Path and distance

Apart from its neighbors, nodes are indirectly connected to other points by a series of lines. A simple set of connected lines is called a walk, while each different set of lines that connect two points is called a path. Consequently, the distance – also termed as geodesic distance – between two nodes is the length (i.e. number of lines) of the shortest path that separates them. In directed graphs, the direction of the lines must be considered to determine the walks, paths and distances (BUTTS, 2008; SCOTT, 2000).

2.2.4.5 Positions, roles and clusters

Based on the points and its ties, SNA is particularly interested in the patterns of social relations, as they can be related to social behaviors independently from the points involved. For instance, the relationship between mother, father and children might present the similar characteristics independently from the families. This concept is called social positions, or roles. Social position is defined as nodes that are substitutable one for another, relying on its ties, rather than its own characteristics. In an organization, for example, with institutionalized roles, standardized culture and procedures agents may act in compliance with these norms. Besides individuals, this concept is also applicable to groups (SCOTT, 2000).

2.2.4.6 Equivalence

Equivalence is a formal way to define roles. If nodes present similar relational characteristics, i.e. they are connected to a wide number of same nodes, they are said to be equivalent. There are different ways to find equivalent nodes, though in general they try to group nodes that present similar connections. Algorithms helps researchers to group nodes by iteratively comparing nodes relations. REGE algorithm calculates the number of equal connections each node has and present nodes at levels of equivalence. The higher the level, the higher equivalence, while the lower the number of equivalent nodes. Equivalence is pertinent because structural similar nodes may be similar (BORGATTI; EVERETT; JOHNSON, 2013).

2.2.4.7 Centrality and centralization

One of the key roles pursued by SNA is the concept of “star”, those nodes that are central to the network. The concept of centrality is usually related to nodes that are the most relevant, play a major strategic importance in the network structure, are the most “popular” and who gather important competences, knowledge and experience. Centrality is assessed locally and globally by distinct methods. Locally centrality uses the concept of degree, which measures the number of adjacent nodes. Globally centrality is evaluated by the distance from the other points of the network. In other words, a globally central node is one that can easily (i.e. in short distances) reach many of the other points in the structure. The notion of centrality also applies to directed graphs, which can be split in in-centrality and out-centrality. As a consequence of defining centrality, the concept of more peripheral points is likewise addressed (BUTTS, 2008; HAWE; WEBSTER; SHIELL, 2004; SCOTT, 2000).

2.2.4.8 Betweenness

Another key position in a network sought by SNA is one that links parts of the network that wouldn't be connected without them, this notion is referred by betweenness. This parameter measures how a node acts as a broker or gatekeeper, by quantifying how many times a node lies in the shortest paths between various other points (BUTTS, 2008; HAWE; WEBSTER; SHIELL, 2004). There are many forms to measure betweenness, which is considered one of the most complex measures to calculate (SCOTT, 2000). The nodes that occupies these positions – which are also termed "structural holes" – may exert control over the network, even presenting a relatively low degree compared to the overall structure (SCOTT, 2000).

2.2.4.9 Components, cores and cliques

Sub-groups are another matter of interest in SNA, though dividing the network in smaller parts involves many methods. Thus, the resulting sub-groups are referred by many different terms, such as cliques, clusters, components, cores, circles etc. and misuse of terminology is frequently found in the literature (SCOTT, 2000). A component, for instance, is the maximum set of interconnected nodes, thus disconnected nodes do not belong to components. Clique, in turn, is a sub-set of nodes that are all directly connected to one another and a clique must not be part of another clique (SCOTT, 2000). Clique is one of the most used methods to encounter densification (i.e. strongly connected sub-groups) within the network structures (HAWE; WEBSTER; SHIELL, 2004). Other definitions on sub-groups can be found in SNA handbooks, such as (SCOTT, 2000), that reviews different methods of network partitioning and specifically discusses many of its aspects.

2.2.4.10 Density

The concept of density is perhaps one of the most used to compare graphs and sub-graphs. Density is measured as the ratio between the number of connections and the total possible number of connections. In an undirected graph, it is t ties divided by n(n-1)/2, where n is the total number of points. This concept is closely related to the degree of its points and the network "inclusiveness". Since some points may not be connected to any other points and to the network, inclusiveness is the parameter that measures to the number of points which are connected to the network, defined by the ratio between the number of connected points and the total number of points (BUTTS, 2008; HAWE; WEBSTER; SHIELL, 2004; SCOTT, 2000).

2.2.4.11 Social network measurements used to assess knowledge flow in UIC

The previous topics provided a quick review on the main concepts used to characterize networks in SNA. In addition, a literature review on social network analysis applied to knowledge flows in UIC was performed to identify SNA measures, attribute and relational data used to investigate the interactions among actors. Table 12 summarizes the information.

Many studies use attribute and relational data from patent and articles database, mainly because of its availability in public or private databases. Other studies collect data with a more direct approach by sending questionnaires to managers or interviewing employees to gather more detailed information. A wide range of SNA measures was observed by all approaches. This review provides a set of social network measurement used to characterize networks and knowledge flow.

Table 12: Social network analysis data and measurements used for knowledge flow studies in university-industry collaboration

Paper	Attribute data	Relational data	SNA measures
(LIU, L.; YU, 2015)	— Scientist name — Organization name	— Patent co-authorship — Number of citations	— Degree centrality — Bonacich power — Structural holes — Betweenness centrality — Eigenvector centrality — Reach centrality — Average reciprocal distance

Paper	Attribute data	Relational data	SNA measures
(CHEN; GUAN, 2016)	— Patent number — Patent granted year — Country from patent file inventor	— Citations network — Number of citations	— Q-measures
(VAN EGERAAT; CURRAN, 2013)	— Companies — Directors — Researchers — Patents — Type of knowledge traded	— Co-inventorship — Co-directorships	— Density — Total no. of ties — Average no. of ties — Cluster coefficient — Random cluster coefficient — Average path length among those connected — Random average path length
(MARTIN; MOODYSSON, 2011)	— Organization — Part of the interviewed group — Spatial dimension (regional, national or international)	— Bilateral exchange of knowledge	— Indegree centrality — Number of nodes — Number (%) of links
(ZAPPA, 2011)	— Physicians — Experience — Publications — Hierarchical position — External communication — Affiliation — Specialty — Prominence	— Knowledge sharing (undirected colleague network)	— Density — Degree range — Isolates — Components — Alternating k-stars — Alternating k-triangles — Alternating independent two-paths
(SAMMARRA; BIGGIERO, 2008)	— Firm — Size — Turnover — R&D investment	— Knowledge exchanged through dyadic relationships with partners	— Sum of degrees — Density — Connectivity

Paper	Attribute data	Relational data	SNA measures
		— Amount and type of knowledge exchanged	

Source: Prepared by the author

2.2.4.12 Sampling techniques

Collecting data for social network analysis is usually performed by one or a combination of these three approaches: “positional”, “reputational” and “affiliation”. The positional method is used when there is available information that determines members and roles of interest (SCOTT, 2000). For instance, an organization may be interested in how employees interact each other beyond the formal hierarchy or project teams. Hence, formal structures are used to define the sample for investigation (ALLEN; JAMES; GAMLEN, 2007a; CROSS; BORGATTI; PARKER, 2002). The reputational approach is used when previous information is not available, thus relying on knowledge of researchers and network agents themselves. In this method, the researcher may ask informants for a list of nominees – those that are supposed to be members of the target population – to perform the investigation. A particular and widely used strategy in reputational approach is the “snowballing” technique. By this method, a small list of nominees is gathered with key informants, then each nominee is asked to indicate members who they relate with, creating a “snowball” effect. There are two main methods to retrieve ego’s alters, the first is to ask members to provide their contact’s name, the second is to present a list and ask them to point their contacts. The second alternative is useful when samples are quite large, but less than fifty members. After this threshold the method starts to be cumbersome (BUTTS, 2008). As the snowball technique progresses the number of additional nominees tend to decrease. The last method “affiliation” is similar to the positional approach, though, in this case, research is focused in networks formed by particular events (i.e. affiliations). For instance, networks established by people participating in communities of practice outside their organizational boundaries (SCOTT, 2000).

When collecting data from members, however, it is important to note that research is exposed to non-response and measurement error. For example, links might be omitted, or relationships might be reported by just one node of the pair. Causes of these inconsistencies can be explained either by a result of the measurement configuration or a measurement error.

Another important matter regarding SNA sampling is the definition of boundaries. If boundaries are poorly defined, important nodes and ties might not be included in the study, thus key patterns are not identified. Therefore, consistent methodology and criteria is critical to include and exclude nodes and ties. There are three ways of defining network boundaries (BUTTS, 2008). The first is called "exogenously defined boundary" when there is an external factor that clearly indicates which nodes to include. Most studies that use this approach are of small groups or intra-organizational studies. The second method called "relationally defined boundary" retrieves key-information within the sample or endogenously, wherein one premise is that those points chosen can be analyzed apart from the entire set. For instance, a researcher may choose a seed sample of organizations and evaluate only other organizations that are directly linked to them. The third method is called "methodologically defined boundary", which uses parameters to determine if a node is included or excluded. Parameters may include communication channel, institutionalized role etc. (BUTTS, 2008). In all methods, however, researchers must be careful to ensure if the methodology is appropriate to investigate the object of study.

2.2.4.13 SNA Software

A number of Social Network Analysis software is available to study large networks. This study uses a software called Ucinet, due to its wide use, free license for students and a user-friendly interface. The software produces the numerical analysis and graph visualization and manipulation. Manipulation of data and graphs. From the raw results. Such as groupings, statistical tools.

In order to study knowledge flows at team level, SNA provides a series of tools to characterize networks, groups, actors and roles. Results of social network analyses can be useful to identify bottlenecks and to improve information and knowledge flows within and across organizational frontiers (DALKIR, 2005). This study does not intend to deepen the analysis of social networks, rather it proposes the use of SNA tools to characterize and identify patterns of knowledge flows across addressed networks. This way, SNA also provides means to select key nodes to interview, contributing to a better understanding of studied phenomena.

2.2.5 Knowledge flow & Materials innovation

Literature review on knowledge flow provided an eight aspect framework to assess knowledge flow which includes: content, network, intensity, value, activities, communication channels and technologies, multi-level knowledge flow and influencing factors. This section focuses on knowledge flow within materials innovation. By reviewing studies that evidenced aspects of knowledge flow in materials innovation, findings appear in four categories: content, network, practices and influencing factors.

Studies commenting on knowledge content in materials innovation, Table 13, refers to knowledge as tacit and explicit; technical, managerial and market; and basic and applied. Knowledge is embodied in machinery, equipment, components and intermediate goods within the supply chain (PARK; LEE; PARK, 2009). Articles found emphasizes market knowledge, those related to user needs which travels a long path along the supply chain (LUBIK; GARNSEY, 2016; MAINE; LUBIK; GARNSEY, 2012). Regarding basic and applied knowledge, materials knowledge provides a wide set of basic knowledge background that allows new possibilities (BABA, Y *et al.*, 2004; EAGAR, 1998; MAINE; GARNSEY, 2006; NIOSI, 1993; PAVITT, 1998; SALTER *et al.*, 2000). In this sense, advanced materials knowledge, as enablers of radical technologies can change paradigms and thus market dynamics (MAINE; GARNSEY, 2006). When it comes to networks, Table 14, knowledge flows between a series of organizations such as universities, government laboratories, firms' laboratories, service providers and suppliers (BABA, Y *et al.*, 2004; EAGAR, 1998; MAINE; GARNSEY, 2006; NIOSI, 1993). Studies evidence the importance of expert members that facilitates knowledge transfers (DEZFOULIAN; AFRAZEH; KARIMI, 2017; MAINE; ASHBY, 2002) and also the importance of informal (CASAS; DE GORTARI; SANTOS, 2000) and bilateral (two-way) knowledge links (MEHTA, 2002; MEYER-KRAHMER; SCHMOCH, 1998). An author (SONG, 2013) also suggests that knowledge flow in materials innovation can be traced by following materials supply chain. Identified practices concentrate on sharing, Table 15, a complex activity wherein simply licensing technology is not enough to guarantee technology absorption and close collaboration is said to facilitate (BAYKARA; ÖZBEK; CERANO⊥LU, 2015). The analysis of influencing factors, using (GUPTA; GOVINDARAJAN, 2000)'s framework, Table 16, shows that most factors are related to the character of researchers involved, their interactions, their willingness to interact and their capacity to absorb knowledge. University researchers that develops basic research based on market needs are said to contribute to firm's R&D (BABA, Yasunori; SHICHIJO; SEDITA, 2009; BABA, Yasunori; YARIME; SHICHIJO, 2010), whereas researchers recognized by a high publishing activity exert little impact on innovation (BABA, Yasunori; SHICHIJO; SEDITA, 2009). On company's side, expert researchers are necessary in a two-way close interaction with university researchers for an effective knowledge sharing (BABA, Yasunori; SHICHIJO; SEDITA, 2009; BABA, Yasunori; YARIME; SHICHIJO, 2010; DEZFOULIAN; AFRAZEH; KARIMI, 2017). Researchers involved in papers and patents with entrepreneurial experience act as boundary spanners in knowledge flow (BABA, Yasunori; YARIME; SHICHIJO, 2010). Company researchers' capacity to absorb knowledge influences the innovation performance of the firm (BABA, Yasunori; SHICHIJO; SEDITA, 2009; DEZFOULIAN; AFRAZEH; KARIMI, 2017). Still, regarding interaction, among other factors, informal channels seems to play an important role for knowledge to flow (BABA, Yasunori; SHICHIJO; SEDITA, 2009; CASAS; DE GORTARI; SANTOS, 2000; COHEN *et al.*, 2002). Finally, according to (SONG, 2013) one could use material supply chain management as a groundwork to understand and manage factors that influence knowledge flows.

In summary, the dynamics of knowledge flow within materials innovation show that researchers' profile, type of research, market awareness, close two-way interaction between university and company and informal networks are key to knowledge flow.

Table 13: Content in knowledge flow within materials innovation

Content	
Tacit & Explicit	— Embodied (machinery, equipment and components) and disembodied knowledge (human mobility and research spillovers) (PARK; LEE; PARK, 2009) — Firms commercializing advanced materials technology produce an intermediate good (MAINE; GARNSEY, 2006; WILLIAMS, 1993)

Content	
Technical, Managerial & Market	— Knowledge of user needs in order to carry on R&D activities in the advanced materials sector (MAINE; GARNSEY, 2006) — These ventures often need complementary market knowledge, scale-up facilities and distribution channels, which they generally seek from commercial partners (LUBIK; GARNSEY, 2016; MAINE; LUBIK; GARNSEY, 2012)
Basic & Applied	— Basic and applied research (BABA, Y *et al.*, 2004; EAGAR, 1998; MAINE; GARNSEY, 2006; NIOSI, 1993) — Strong support of basic research (CASAS; DE GORTARI; SANTOS, 2000) — Background knowledge enables to find analogies for new problems and to support a viable search for possible solutions (PAVITT, 1998; SALTER *et al.*, 2000) — Advanced materials overturn current technological knowledge and enable new possibilities which changes paradigms (MAINE; GARNSEY, 2006)

Source: Prepared by the author

Table 14: Network in knowledge flow within materials innovation

Network	
Nodes & Roles	— Radical advanced materials innovation commercializes knowledge generated by basic and applied research, created in universities, government laboratories and the R&D laboratories of large firms (BABA, Y *et al.*, 2004; HOWSAWI; EAGER; BAGIA, 2011; MAINE; GARNSEY, 2006; NIOSI, 1993) — Actors include: universities; service providing small companies; sub-contracting companies; in-house testing service and design providers; supplier companies; designer and software development companies (BAYKARA; ÖZBEK; CERANO⊥LU, 2015) — Expert members accelerate knowledge transfers (DEZFOULIAN; AFRAZEH; KARIMI, 2017) — Expert members make cross-boundary connections acting as a key decision maker (MAINE; ASHBY, 2002)
Links & Direction	— Collaborative networking emerges as a new paradigm for advanced materials (BAYKARA; ÖZBEK; CERANO⊥LU, 2015; VAN DER VALK; CHAPPIN; GIJSBERS, 2011) — U–I collaborations in advanced materials are bilateral, a 'two-way' interaction (MEHTA, 2002; MEYER-KRAHMER; SCHMOCH, 1998) — Material supply chain management (SONG, 2013)

Network	
Inter & Intra Knowledge Flow	— In materials science, the prevailing pattern is intranational knowledge flows (Mexico) (CASAS; DE GORTARI; SANTOS, 2000)
Formal & Informal	— Networking experiences are based on spontaneous and informal relationships (CASAS; DE GORTARI; SANTOS, 2000)

Source: Prepared by the author

Table 15: Practices in knowledge flow within materials innovation

Practices	
Share	— Technology transfer is a complex task, technology licensing is not sufficient for technology absorption (BAYKARA; ÖZBEK; CERANO⊥LU, 2015) — Close collaboration results in better and faster achievements (BAYKARA; ÖZBEK; CERANO⊥LU, 2015)

Source: Prepared by the author

Table 16: Influencing factors in knowledge flow within materials innovation

Influencing factors	
Value of the source unit's knowledge stock	— Tacit knowledge embodied in corporate researchers appears crucial for the identification of potential users' needs (BABA, Yasunori; SHICHIJO; SEDITA, 2009; MAINE; GARNSEY, 2006; NIOSI, 1993) — "Star scientists" (i.e. researcher with high publishing activity) exert little impact in innovative output (BABA, Yasunori; SHICHIJO; SEDITA, 2009) — "Pasteur scientists" (i.e. researcher recognized by use-inspired basic research) increases firms' R&D productivity (BABA, Yasunori; SHICHIJO; SEDITA, 2009; BABA, Yasunori; YARIME; SHICHIJO, 2010)

Influencing factors	
Existence and richness of transmission channels	— Researchers involved in scientific papers and many patents act as boundary spanners between science and technology, pushing R&D towards commercialization (BABA, Yasunori; YARIME; SHICHIJO, 2010) — Two-way knowledge interaction between "Pasteur scientists" and corporate researchers (BABA, Yasunori; SHICHIJO; SEDITA, 2009; BABA, Yasunori; YARIME; SHICHIJO, 2010) — Expert members accelerate knowledge transfers (DEZFOULIAN; AFRAZEH; KARIMI, 2017) — Entrepreneurial experience of management, presence of a visionary deal-maker, flexibility of the organization, effective knowledge acquisition and management and operational efficiency (MAINE; ASHBY, 2002) — Official channels play a limited role in the flow of knowledge between universities and industries, while informal channels play a critical role in knowledge transfer (BABA, Yasunori; SHICHIJO; SEDITA, 2009; CASAS; DE GORTARI; SANTOS, 2000; COHEN *et al.*, 2002) — Strentghning the relationship reduce costs of knowledge transfer (DEZFOULIAN; AFRAZEH; KARIMI, 2017) — Common language, mutual understanding, formal agreements, informal commitment, friendship and reciprocal trust (BABA, Yasunori; YARIME; SHICHIJO, 2010) — Larger partnerships experience more difficulties, with larger transaction costs (NIOSI, 1993) — Firm size affect tasks within innovation strategy (MAINE; ASHBY, 2002)
Motivational disposition of the target unit	— Little interest of industry in acquiring frontier knowledge and willingness to transfer mostly mature technologies (SONG, 2013; TAGSCHERER; KROLL; LUO, 2012) — Close tie and coordination, understanding of end-user needs, understanding of maximum value-added, information feedback and effectiveness, feel the system and shared benefits (SONG, 2013) — Government incentives (SONG, 2013)
Absorptive capacity of the target unit	— Absorptive capacity affect firm's innovation performance (BABA, Yasunori; SHICHIJO; SEDITA, 2009) — Absorptive capacity reduce time on knowledge transfer (DEZFOULIAN; AFRAZEH; KARIMI, 2017)

Source: Prepared by the author

Literature review on knowledge flow provided a framework and techniques to characterize and analyze knowledge flows in UIC. With knowledge flow and UIC indicators the relationship between knowledge flow and UIC can be assessed. Next section reviews a quantitative method to investigate this relationship.

2.3 ANALYSIS OF VARIABLES RELATIONSHIP

Relationships between variables can be evaluated with a series of approaches depending on research purposes. Structural Equation Modelling (SEM) is one these approaches used in quantitative analysis. This technique allows researchers to evaluate multiple relationships between variables (HENSELER; RINGLE; SARSTEDT, 2014) by testing significance and influence between them. Unlike factorial analysis, multiple regression and other techniques that address one relation at a time, SEM is a statistical technique that can handle multiple inter-related questions simultaneously (HAIR, Joseph F *et al.*, 2006). Questions such as “which variables influence project performance” and “how do they interact with each other”? This possibility to test and develop theories is one of the main reasons to use SEM, especially in business and marketing research (HAIR, Joe F.; RINGLE; SARSTEDT, 2011; HENSELER; RINGLE; SINKOVICS, 2009; STEENKAMP; BAUMGARTNER, 2000).

Partial least squares (PLS) is a variance-based approach of SEM that has been widely used in information system, strategic management, marketing, business and other fields of research (HENSELER; RINGLE; SARSTEDT, 2014) especially because it handles factor and composites variables simultaneously (HENSELER; RINGLE; SARSTEDT, 2014), works with smaller sample sizes compared to covariance-based SEM (CBS-SEM) (CHIN, 1998; HENSELER; HUBONA; RAY, 2016) and does not require a normal distribution dataset (FORNELL; BOOKSTEIN, 1982; HAND, 2012; ZACK; MCKEEN; SINGH, 2009). PLS is also preferred in exploratory studies and theory development when construct relationship is not widely investigated (CHIN, 1998) and for success factor studies (HENSELER; RINGLE; SARSTEDT, 2014).

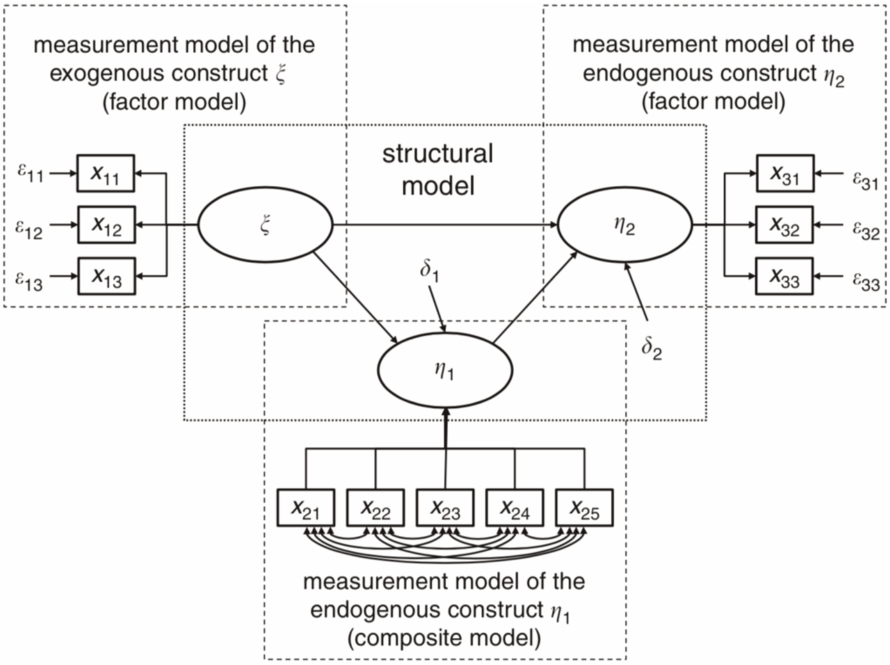
A PLS-SEM model is essentially comprised by two components: a measurement model and a structural model. Measurement model refers to how variables are measured by indicators, while structural model refers to the relationships between variables. These two models form each a linear equations system (HENSELER; RINGLE; SARSTEDT, 2014).

Presenting SEM models in mathematical notation can be complex though. Thus, researchers usually display these models in a visual form called path diagram, Figure 8, (HAIR, Joseph F *et al.*, 2006). A path diagram handles a lot of information in a simple and pretty straightforward picture containing variables, indicators and dependence paths depicted as circles, squares and arrows respectively. With these elements measurement and structural models are created.

Measurement model is responsible to specify relationships between latent variables and observable indicators (HENSELER; RINGLE; SARSTEDT, 2014). Variables can be modelled as factor (i.e. reflective) or composite (i.e. formative). If indicators reflect changes in the associated variable, i.e. variance of indicators explains the existence of an unobservable variable, the variable is modeled as factor. In factor variables, indicators are expected to have high inter-relations. If indicators form the concept of the associated variable, i.e. indicators are proxies of the construct, the variable is modeled as composite. In composite variables, indicators are not expected to correlate.

Structural model is responsible to specify relationships between variables (HENSELER; RINGLE; SARSTEDT, 2014). Variables, thus, can be endogenous and exogenous. Variables are endogenous if their variances are explained within the model by other variables. Variables are exogenous if their variances are explained outside the model.

Figure 8: Visual representation of structural equation modelling



Source: (HAIR, Joseph F *et al.*, 2006)

One should note though, conceiving models is a theory-based activity. Researchers may be interested either in using existing theory to model the study or develop new instruments for research. In either, existing literature is required to create these models.

Within a SEM study, researchers create and assess models. Using the conceived model, empirical data collected throughout measurement instruments and a PLS software. Model assessment produce validity measures, desired significance and effect of one variable on another. This process encompasses analysis of overall model, measurement model and structural model, Table 17 (HENSELER; RINGLE; SARSTEDT, 2014).

2.3.1 Overall model assessment

Assessment starts addressing how good is the overall model. Goodness of fit evaluates how empirical data fits the proposed model. In PLS-SEM researchers use standardized root mean square residual (SRMR) to measure how good is the model (HU; BENTLER, 1998). Authors say that SRMR under 0,08 is a reasonably good fit.

2.3.2 Measurement model assessment

Process moves to analyze measurement model validity which encompasses four steps: (i) indicator reliability, (ii) internal consistency, (iii) convergent reliability and (iv) discriminant validity (or vertical collinearity).

Indicator reliability analyzes how each indicator correlates with the associated variable. Indicators' loadings must be significant to a determined value so the model can be considered valid. This lower threshold spans in literature from 0,5 (HAIR, Joseph F *et al.*, 2006) up to 0,7 (HULLAND, 1999). Since this study is exploratory, a value of 0,5 is acceptable.

Internal consistency evaluates construct reliability, which means if all indicators consistently represent constructs. This consistency is measured by indicators variance, in the form of rho A (DIJKSTRA; HENSELER, 2015) and CR (HENSELER; HUBONA; RAY, 2016). In either case, values of reliability must be over 0,7 (BAGOZZI; YI, 1991; NUNNALLY; BERNSTEIN, 1994).

Convergent reliability measures how much a variable represents its indicators variance. 50% is considered a sufficient degree of convergence. Convergent validity is measured by Average Variance Extracted (AVE) which varies from 0 to 1 (BAGOZZI; YI, 1991; FORNELL; LARCKER, 1981).

Discriminant validity shows how independent each indicator is from other variables, that is to what extent each indicator represents only one construct or how each construct is different from others. Discriminant validity is assessed by Fornell and Larcker Criterion (FORNELL; LARCKER, 1981) and Heterotrait-Monotrait Ratio (HTMT) (HENSELER; RINGLE; SARSTEDT, 2014). In Fornell and Larcker Criterion, AVE of each latent variable must be higher than squared correlations between the latent variable and all other variables (CHIN, 2010; FORNELL; LARCKER, 1981). In Heterotrait-Monotrait Ratio, acceptable values of HTMT must be under 0,85 for each construct (KLINE, 2011).

2.3.3 Structural model assessment

Assessing structural model in its turn includes three main steps: collinearity issues (CASSEL; HACKL; WESTLUND, 1999), level of R^2 (CHIN, 1998) and effect sizes f^2 (COHEN J., 1988). This step provides significance and effect size of one variable in another which is what the study is interested in. It evidences significant relationship between constructs which shows researchers how results relate to theory.

Assessing collinearity, like in measurement model assessment, investigates how constructs are independent from each other and its indicators. To assess collinearity tolerance and Variance Inflation Factors (VIF) need to be applied. VIF values must be under 5 (CASSEL; HACKL; WESTLUND, 1999), once values of VIF much higher than one may indicate multicollinearity.

R-Square or Coefficient of Determination measures proportion of variance in a latent endogenous variable that is explained by the other exogenous expressed as a percentage (Chin, 1988). R-Square Ajusted differentiates from R-Square, because it also accounts for model complexity and sample size, what is useful to compare models and explanatory power across samples (HENSELER; HUBONA; RAY, 2016). Literature shows that R^2 might be more than 0,2 and ideally more than 0,3 (LOWRY; GASKIN, 2014).

Effect sizes shows the influence of independent variable on dependent variable, when all other independent variables are kept the same. Effect size is considered weak when $f^2 \approx 0{,}02$, moderate when $f^2 \approx 0{,}15$ and strong when $f^2 \approx 0{,}35$ (COHEN J., 1988; HENSELER; HUBONA; RAY, 2016).

Table 17: Summary of SEM assessment: overall model, measurement model and structural model

Assessment	Criterion
Overall model	
1. Test of model fit	Standardized root mean square residual (SRMR) < 0,08 (HENSELER; HUBONA; RAY, 2016)
Measurement model	
1. Indicator reliability	Indicator loading > 0,5 (HAIR, Joseph F *et al.*, 2006; HULLAND, 1999)
2. Internal consistency	Rho A > 0,7 (NUNNALLY; BERNSTEIN, 1994) CR > 0,7 (GEFEN; STRAUB; BOUDREAU, 2000)
3. Convergent reliability	Average Variance Extracted (AVE) > 0,5 (BAGOZZI; YI, 1991; FORNELL; LARCKER, 1981)
4. Discriminant validity	Fornell and Larcker Criterion: AVE of each latent variable > Squared correlations between the latent variable and all other variables (CHIN, 2010; FORNELL; LARCKER, 1981)
	Heterotrait-Monotrait Ratio (HTMT) < 0,85 (KLINE, 2011)
Structural model	
1. Assess structural model for collinearity issues;	Variance Inflation Factors (VIF) < 5 (CASSEL; HACKL; WESTLUND, 1999)
2. Endogenous variables (Assess the level of R2)	R^2 > 0,2 (LOWRY; GASKIN, 2014)
3. Effects (Assess the effect sizes f2)	Significance (p-value, confidence interval) Effect size

Source: Prepared by the author

2.3.4 PLS-SEM Software

The increase on PLS-SEM use is accompanied by a number of software available to perform this analysis. This study uses SmartPLS (RINGLE; WENDE; WILL, 2005) and Adanco (HENSELER; HUBONA; RAY, 2016) for their wide use, free licenses and user-friendly interface which includes graphical results visualization.

This review on structural equation modelling provides a technique to evaluate relationships between variables from quantitative perspective. The next section provides chapter considerations about the review on UIC and knowledge flow.

2.4 CHAPTER CONSIDERATIONS

Literature review shows UIC as an important strategy for firm's innovation, as a means of developing new products and processes, especially in those areas with high technological and market risks. UIC is a vast research field, wherein many frameworks and instruments are proposed by researchers to study each aspect of UIC. Some of these frameworks provide an overarching overview of collaborations, which are useful to characterize the UIC context and to connect to other instruments. In a recent work, (ANKRAH; AL-TABBAA, 2015) proposed a framework of analysis with six dominating aspects: (i) motivations; (ii) formation phase; (iii) organizational forms; (iv) operational phase; (v) facilitating and impeding factors; and (vi) outcomes. This framework allows assessing performance and success of UIC from a qualitative perspective, though it does not present a quantitative instrument. Many studies in this area of UIC performance and success assessment evaluates UIC outcomes with patenting, licensing, published articles and people trained. Few studies measure partial outcomes and intermediate performance, especially at team-level (micro-level). In other words, operational level studies on UIC progress are still limited in literature. One of the few studies that address this issue is (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s work. The researchers reviewed the literature on UIC indicators and based on (BROWN, M. G.; SVENSON, 1998)'s work, they proposed four groups of key performance indicators (KPI): (i) inputs, (ii) in-process activities, (iii) outputs and (iv) impact, that evidence university-industry collaboration efficiency and effectiveness. Therefore, the combination of (ANKRAH; AL-TABBAA, 2015)'s UIC framework and (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s UIC KPIs forms an interesting instrument to characterize and analyze UIC progress.

By reviewing UIC, it can be seen that knowledge is a major aspect of these collaborations. Knowledge appears in all aspects of UIC, including knowledge transfer as one of collaboration objectives. Managing knowledge flow between university and industry thus play an important role for the success of these partnerships. By understanding knowledge flows within the university-industry environment, issues that hinders collaboration effectiveness and efficiency can be discussed and knowledge management models can be conceived. Knowledge flow, comparable to UIC, is a wide field of research which presents many frameworks and instruments to analyze flows. On contrary of UIC, it was not found a framework providing a wide view of the concept. Instead, a framework was developed with the main concepts of knowledge flow encountered in literature, which includes content, network, intensity, value, activities and practices, communication channels, multi-level and influencing factors. Besides this framework, SNA appeared as a suitable set of techniques to map and characterize knowledge flows. SNA provides tools to collect data and quantify network patterns such as networks, groups, actors and roles. Patterns evidenced by SNA tools can be useful to identify bottlenecks and to improve information and knowledge flows within and across organizational frontiers.

Literature review on UIC and knowledge flow shows that the operational and individual perspectives of these constructs are still limited in the literature. Most researchers focus on the final outcomes of UIC at the organizational-level, which may not characterize the full picture of collaborations (LINDSAY *et al.*, 2003; PERKMANN; NEELY; WALSH, 2011). A few researchers, however, started to investigate the operational and micro levels of the constructs, thus providing frameworks and instruments to analyze knowledge flow on UIC from individuals' perspectives. For instance, (SINGH, R. M.; GUPTA, 2014) and (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018) provided micro-level instruments to investigate knowledge management practices and UIC KPIs, respectively, instruments that can be combined to address the influence of KM practices on UIC performance. Gathering information with the frameworks, instruments and techniques reviewed directly from researchers involved at the operational level of collaborations thus will help better understand the phenomena.

Moreover, the analysis of this relationship is not complete if influencing factors are not included. (ANKRAH; AL-TABBAA, 2015) lists UIC influencing factors in seven groups: (i) capacity and resources, (ii) legal issues and contractual mechanisms, (iii) management and organization issues, (iv) issues relating to the knowledge or technology, (v) political issues, (vi) social issues and (vii) other issues. In knowledge flow field, (GUPTA; GOVINDARAJAN, 2000) proposed organizing knowledge flow influencing factors in five categories: (i) value of the source unit's knowledge stock, (ii) motivational disposition of the source unit, (iii) existence and richness of transmission channels, (iv) motivational disposition of the target unit and (v) absorptive capacity of the target unit. Considering these factors is important to understand the whole picture.

By this literature review, a framework of analysis can be created to investigate the dynamics of knowledge flows within UIC and the influencing factors involved from both quantitative and qualitative perspectives, at the micro-level. Understanding the relationship between the constructs and elements is valuable for working on strategies that minimize barriers and promote facilitators thus enabling efficient knowledge flows and guaranteeing the success of these partnerships for innovation.

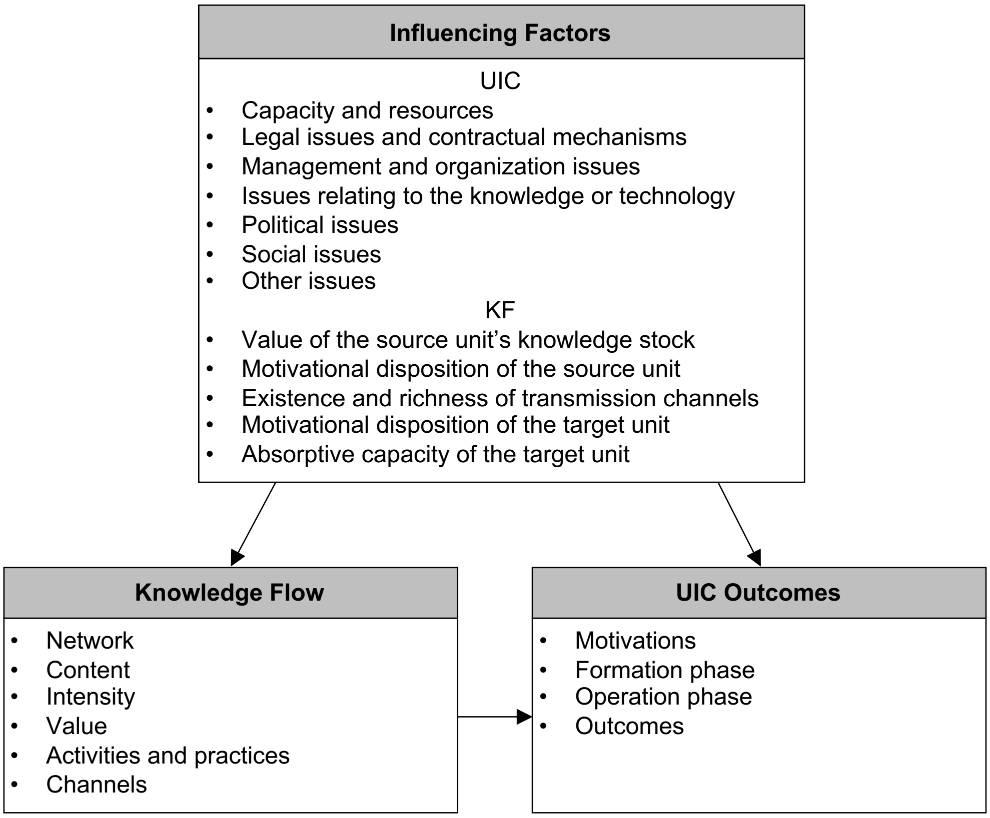
3 FRAMEWORK OF ANALYSIS

With concepts, frameworks and instruments reviewed on literature, a framework of analysis for knowledge flow in UIC is proposed hereafter. As outlined in the introduction, this framework intends analyze the relationships between knowledge flow, UIC outcomes and influencing factors in UIC for materials innovation, supported by quantitative and qualitative approaches. This framework is expected to contribute to the analysis of knowledge flows in UIC and provide insights to design better knowledge flows.

Departing from the conceptual model depicted in introduction and developed with elements found in literature, the resulting framework is presented in Figure 9. The framework is composed by three elements: knowledge flow, UIC outcomes and influencing factors. To characterize knowledge flow, the framework uses the aspects reviewed in literature of KF: network, content, intensity, value, activities and practices and channels. To characterize UIC, the framework uses four elements of (ANKRAH; AL-TABBAA, 2015)'s framework: motivations, formation and operation phases and outcomes. Although this work is interested in UIC outcomes, understanding motivations, formation and operation phases of UIC contributes to a better understanding of the phenomena. Since this work is focused on formal agreements of cooperative research, other formats of UIC are not considered. To characterize influencing factors, the framework uses groups of factors proposed by (ANKRAH; AL-TABBAA, 2015) and (GUPTA; GOVINDARAJAN, 2000) for UIC and knowledge flow respectively.

Next sections present the quantitative and qualitative approaches of the framework, the elements involved and the employed instruments.

Figure 9: Framework of analysis to knowledge flow in UIC



Source: Prepared by the author

3.1 QUANTITATIVE ANALYSIS

Using instruments found in literature, a three-parts questionnaire was developed to analyze knowledge flow and UIC performance.

Part one of the questionnaire concerns mapping knowledge flows, Table 18. The wording of the question leads to map knowledge that is relevant to collaboration outcomes and was developed after (OJO; RAMAN, 2015)'s instrument that investigates team-level capacity to "identify partner's knowledge with the most significant value to the project performance". The question aims to map only the five most relevant people who the person share knowledge to achieve project objectives. Only five nodes are asked for each respondent to limit questionnaire response duration and produce homogeneity in responses. Respondents also lists nodes that share knowledge in order of knowledge value regarding how relevant knowledge is to achieve collaboration objectives. Knowledge is labeled into technical, managerial and market categories following (ALBERTI; PIZZURNO, 2015; SAMMARRA; BIGGIERO, 2008) classification. Classifying knowledge in these three groups allows the investigation of the different knowledge flow networks by knowledge type. Classification is also interesting because it also simplifies the analysis of knowledge content once it becomes unnecessary to interpret knowledge that respondents share. This way, respondents are responsible for knowledge classification. The questionnaire also evaluates knowledge flow direction, if inwards or outwards, as proposed by (GUO; WANG, 2008; ZHUGE, 2002a). This information is relevant for creating a directional network, thus allowing the analysis of network parameters such as inflow or outflow centrality. For instance, nodes that are central in sending knowledge might not be central in receiving knowledge, therefore representing different roles within the network. Finally, knowledge flow intensity is also examined as frequency of knowledge sharing according to (KESSEL; KRATZER; SCHULTZ, 2012)'s instrument that measures interaction in never, less than a month, monthly and weekly. Intensity is important to create valued networks. As directed networks provide important information on knowledge flow dynamics, intensity can also provide valuable insights. By mapping knowledge flow and using SNA techniques, network parameters can be generated so networks, groups and nodes are characterized. Examples of network parameters include density, centrality, in-betweenness, roles and cliques. These parameters can then be assessed regarding relationship with other variables such as practices in knowledge flow and UIC parameters, both described next.

Table 18: Questionnaire part 1: network and knowledge flow

In order to accomplish the activities of the university-industry cooperation project in which you participate, think on 5 people who possess the most relevant knowledge to achieve the objectives of the project. These people can be members of the same project or from other projects or organizations. In the next fields, list these people in order, starting with the person who has the most relevant knowledge.

If necessary, refer to the list of project members. Note that the person with who you share knowledge may not be listed.

Refer to the following definitions of knowledge:

- Technical knowledge: competencies and know-how necessary to realize processes and product and process development;
- Managerial knowledge: competencies and know-how necessary to efficiently and effectively coordinate and supervise resources and organizational processes;
- Market knowledge: competencies and know-how centered in characteristics, preferences and needs of clients, which companies must satisfy.

Observation: In case there are not 5 people, fill the most you can and in further sections write “non/available” in the fields “Name” and “Organization” and mark “Never” for all alternatives.

Name:
Organization:

	Never	Less than once a month	Monthly	Weekly
I SEND TECHNICAL knowledge for this person	○	○	○	○
I RECEIVE TECHNICAL knowledge from this person				
I SEND MANAGERIAL knowledge for this person	○	○	○	○
I RECEIVE MANAGERIAL knowledge from this person	○	○	○	○
I SEND MARKET knowledge for this person	○	○	○	○
I RECEIVE MARKET knowledge from this person	○	○	○	○

Source: Prepared by the author

Part two of the questionnaire concerns knowledge management practices at team level. Practices are investigated with (SINGH, R. M.; GUPTA, 2014)'s instrument composed of four groups of practices, twenty-seven items and a five-point Likert-type scale. Groups of practices are actionable knowledge support, knowledge retention, knowledge sharing and knowledge creation. (SINGH, R. M.; GUPTA, 2014)'s instrument was used because is one of few instruments that investigates practices at team-level and also gives evidence on factors that might be related to the knowledge network and UIC performance. Investigating practices may indicate groups of nodes within the network presenting higher levels of UIC performance for instance, which can be further analyzed. By performing analysis of variance and a SEM analysis of these quantitative variables addressed in this questionnaire, results may evidence relationships between variables.

Table 19: Questionnaire part 2: knowledge management practices at team level

Actionable knowledge support (km_aks)
— (km_aks1) Experts in my team give valuable suggestions when approached
— (km_aks2) Experts in my team are open to new ideas proposed even by a novice
— (km_aks3) When I seek knowledge, team members encourage me
— (km_aks4) New ways of solving problems are enthusiastically accepted in my team
— (km_aks5) My team members do not hesitate in seeking help from experts in other teams
Knowledge retention (km_kr)
— (km_kr1) My team members regularly update information on the intranet (share drive, knowledge portals)
— (km_kr2) My team members regularly use information from the intranet (share drive, knowledge portals)
— (km_kr3) Information available on intranet (share drive, knowledge portals) is well organized
— (km_kr4) Knowledge of my team processes is known to many team members
— (km_kr5) If a person of my team leaves, knowledge of my team processes is not lost

Knowledge sharing (km_ks)

- (km_ks1) When a team member develops some know-how, it is shared in the team
- (km_ks2) My team members willingly share knowledge
- (km_ks3) My team members do not hide knowledge to themselves
- (km_ks4) My team members share information on problem-solving strategies that have worked well
- (km_ks5) My team helps me understand knowledge embedded in work processes
- (km_ks6) The team clearly discusses the project details when a new project is initiated
- (km_ks7) My team is able to optimally utilize competencies of its individual members
- (km_ks8) We have regular meetings where people share their knowledge

Knowledge creation (km_kc)

- (km_kc1) My team members take initiative to develop new knowledge
- (km_kc2) My team actively spends resources (time, effort) in acquiring new knowledge
- (km_kc3) My team members are aware of latest developments in their field
- (km_kc4) My team implements best practices adopted from outside the team
- (km_kc5) My team members develop knowledge keeping in mind a long-term perspective
- (km_kc6) My team continuously rethinks about its work processes
- (km_kc7) My superiors are appreciative of my team members' effort to create new knowledge
- (km_kc8) My team members show interest in solving challenging problems
- (km_kc9) My team members search outside the team (Internet, books, friends, etc.) for efficient work processes

Five-point Likert-type scale: (1) Strongly disagree, (2) Disagree, (3) Neither agree nor disagree, (4) Agree and (5) Strongly agree

Source: Prepared by the author

Part three of the questionnaire concerns UIC key performance indicators. UIC is investigated with (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s instrument. The researchers identified common performance indicators across different UIC projects and divided them into four phases of the project lifecycle: input, in-process, output and impact. The instrument uses a five-point Likert-type scale. (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s instrument was chosen because it analyzes the different moments of cooperation lifecycle aligned with (ANKRAH; AL-TABBAA, 2015)'s framework and it is also one of few instruments that assesses UIC at micro-level. By investigating all steps of the collaboration, factors influencing UIC outcomes, and UIC partial outcomes can be better analyzed.

Table 20: Questionnaire part 3: UIC key performance indicators.

Inputs (uic_input)

- (uic_input1) Cooperation partners invest a sufficient amount of financial resources in the project in which I participate
- (uic_input2) Cooperation partners invest a sufficient amount of time in the project in which I participate

In-process activities (uic_progress)

- (uic_progress1) The project that I participate in is actively managed throughout their life cycle, both at the university and at the company
- (uic_progress2) Roles and responsibilities are clearly defined and communicated between members of the project in which I participate

Outputs (uic_output)

- (uic_output1) Of the products and services developed by the company, a relevant amount is the result of the project in which I participate when compared to other university-industry partnership projects
- (uic_output2) Of the processes developed by the company, a relevant amount is the result of the project in which I participate when compared to other university-industry partnership projects
- (uic_output3) Of the technologies and methods developed by the company, a relevant amount is the result of the project in which I participate when compared to other university-industry partnership projects

Impact (uic_impact)

- (uic_impact1) A relevant number of new R&D projects are planned or have been initiated from the project in which I participate
- (uic_impact2) The application of the results achieved jointly in the project in which I participate resulted in changes on the company's revenue structure

Five-point Likert-type scale: (1) Strongly disagree, (2) Disagree, (3) Neither agree nor disagree, (4) Agree and (5) Strongly agree

Source: Prepared by the author

By using micro-level quantitative instruments, this three-part questionnaire helps characterize KF network, KF practices and UIC indicators at the team level and understand the relationship between each variable. Thus, this quantitative part of the framework provides a view of knowledge flow and UIC and relevant aspects to be further investigated in the following qualitative analysis.

3.2 QUALITATIVE ANALYSIS

Using frameworks and elements found in literature a semi-structured interviews guide was developed. The interviews guide consists of two parts, one for exploring UIC and other for knowledge flow.

The first part of the guide is based on (ANKRAH; AL-TABBAA, 2015)'s framework and aims understanding UIC motivations, formation and operation phases, outcomes and influencing factors. The guide investigates the role of UIC in innovation process and characteristics of this collaborative materials development.

The second part of the guide addresses knowledge flow is based on the framework develop in literature review. The guide addresses how knowledge flows within the UIC, key nodes, types of knowledge, influencing factors, how knowledge is managed and specific characteristics in materials innovation.

With this two-parts interview, knowledge flow within UIC will be characterized, influencing factors will be identified and the relationship between these elements investigated. Patterns and aspects identified in the quantitative phase are investigated within the semi-structured interviews.

Table 21: Interview's guide

Part (i) – UIC
Without entering the specificities, in your opinion, what are the objectives of this university-industry cooperation project? What are university objectives? And company's? Are they the same? If not, why? What are project success criteria? Need came from company, or ideas came from university?
About innovation process involving university and company, what were the main stages involved? Since identified need, or opportunity until product, or process placed in market. Where it started and were it finished? How is project formation phase? How is project operation phase? Who absorbs company in the company? What roles are involved in the process? Who are those more critical, in the university and in the company?

What are the main barriers of the process? Barriers to incorporate developed materials in products that arrive market. Why what is developed in university doesn't arrive market?

In your vision, how process is managed? Who are key actors?

What are specific characteristics to materials development? Are they different from development in other knowledge areas?

Part (ii) – Knowledge Flow

In this cooperation project, how knowledge flowed to meet project objectives? How knowledge was created, shared, retained (stored) in the process? How was it regarding technical knowledge? How was it regarding market knowledge? Dynamic of both are the same? What are the differences?

What are the differences between knowledge flow within organization and between organizations? What are contact points between company and university? Are they few, many, enough? Why?

What are the main barriers to knowledge reach people who need it? Such as for technical, as for market knowledge.

In your vision, how knowledge is managed? Who are key actors?

What are specific characteristics to materials development? Are they different from development in other knowledge areas?

Source: Prepared by the author

This chapter presented a framework of analysis that comprises quantitative and qualitative approaches to investigate knowledge flow, UIC and influencing factors. Next chapter presents procedures for framework application which will be applied to test the framework in a collaboration for materials innovation.

4 PROCEDURES FOR FRAMEWORK APPLICATION

As previously outlined a framework of analysis is proposed to investigate the relationship between knowledge flow, university-industry collaboration outcomes and influencing factors, which is supported by quantitative and qualitative analysis. Therefore, this work uses a mixed method approach called explanatory design, a two-phase sequential design, wherein quantitative analysis is followed by qualitative analysis to apply and develop the framework in a collaboration for materials innovation. This mixed method is used to provide a deeper understanding of the studied phenomena; to produce results that corroborates each other (i.e. provide greater validity); to explain findings identified in the quantitative phase; to explain unexpected results; and to improve the usefulness of findings to practitioners by combining two approaches (BRYMAN, 2006; CRESWELL; CLARK, 2011). In explanatory design, results obtained in the quantitative phase, such as significant results and non-significant results are explained in the qualitative phase (CRESWELL; CLARK, 2011).

The quantitative phase of this work maps knowledge flow with SNA tools; identifies patterns of social networks; and identifies relationships between knowledge flow (i.e. key nodes and groups, such as star, gatekeeper and periphery points) and UIC performance. The qualitative phase investigates and tries to explain patterns and evidence throughout semi-structured interviews.

The application of the framework comprises seven main steps: (1) document analysis; (2) collect quantitative data by sending a questionnaire to all UIC members; (3) analyze data with social network analysis tools, SEM and analysis of variance; (4) create a list of key participants to interview based on results of step 3; (5) perform semi-structured interviews with key nodes selected in step 4; (6) assess qualitative data thematic analysis; (7) integrate quantitative and qualitative data to provide a better understanding of the results. Phases are described in the following sections and summarized in Table 22.

Table 22: Summary of procedures for framework application: an explanatory mixed-method design, comprised of 7 phases

Phase	Procedure	Product
1. Document analysis	Perform document analysis	Organizational and individual-level data for research control
2. Quantitative data collection	Send questionnaire to all members of the UIC. Identify additional participants through the snowball technique	Quantitative data: Social network; knowledge network, knowledge management practices, UIC performance
3. Quantitative data analysis	Perform SNA, SEM and analysis of covariance	Patterns of social network; significant correlations between constructs
4. Case selection	Choose 10 participants by social patterns and constructs covariance	List of participants
5. Qualitative data collection	Perform face-to-face semi-structured interviews. Gather additional documentation	Interview transcripts; additional documentation
6. Qualitative data analysis	Perform coding and thematic analysis	Codes and themes
7. Interpretation and integration of the quantitative and qualitative results	Interpret and explain quantitative and qualitative results	Results; discussions; conclusions; future research avenues

Source: Prepared by the author

Phase 1: Data for research control at organizational and individual levels

First step is to acquire data for research control before collecting data from the individuals. Data from university and company involved in the UIC formal agreement is gathered by document analysis. Collaboration was investigated regarding history of collaboration, the partners, formal participants and scope. History on collaboration included information from news and previous contracts. Information about both partners was collected from publicly information available in websites and news. Information about the university laboratory was also gathered in organizational documentation. Collaboration scope (i.e. objectives) was assessed in the contract (i.e. portfolio), programs and projects charters. The list of participants formally involved in the UIC was collected in the collaboration management system, which included: names; roles; program and project participation; and contact information. This step requires interaction with managers to collect information.

Phase 2: Quantitative data collection

Quantitative data is gathered by sending a questionnaire, described in the framework of analysis, to all members of the formal collaboration. In summary, this questionnaire intends to (i) map and characterize knowledge flows, (ii) evaluate knowledge management practices within knowledge flows and (iii) assess UIC performance. Results provide information on distinct knowledge flow networks, significant nodes, clustering of practices and UIC performance and relationship between practices and UIC performance, which will all be further investigated in the qualitative phase of the study.

Phase 3: Quantitative data analysis

Based on responses and using social network analysis, relevant positions such as gatekeepers, "star" scientists, distant and isolated edges, groups and deviations between formal and informal structures in knowledge sharing emerge. Network visualization is used to produce a diagram, showing all nodes and connections, thus facilitating the comprehension of network patterns. Moreover, statistical methods such as: analysis of variance, analysis of correlation and structural equation modeling (SEM) are used to evidence significant relationships between constructs. This phase is designed to produced insights to be analyzed, to clarify unexpected results and understand social patterns.

Phase 4: Case selection

Before performing the quantitative phase, participants to be interviewed were selected based on their social positions, unexpected results or behaviors and dissonant relationship between constructs. Ten participants were interviewed with semi-structured interview's guide. Interviews last about one hour. The semi-structured interview guide was developed after Phase 3 which is divided in two parts: (i) UIC for innovation; and (2) knowledge flow. Part (i) investigates interviewee’s point of view about collaborative innovation process between company and university, cooperation’s objectives, success criteria, steps and factors of influence. Part (ii) investigates knowledge flows, activities, influencing factors, key actors and management.

Phase 5: Qualitative data collection

Using protocols developed in previous phases interviewed participants clarified and provided a deeper understanding of social phenomena. All interviews were recorded and team members’ opinion was collected regarding UIC performance for innovation, knowledge flow and influencing factors.

Phase 6: Qualitative data analysis

The qualitative data analysis provides a deeper understanding and complementary insights which are used to explain and clarify results of quantitative phase. Interviews are recorded, transcribed and then assessed with thematic analysis (BRAUN; CLARKE, 2006).

Phase 7: Interpretation and integration of the quantitative and qualitative results

The last phase of the study is interpretation and integration of quantitative and qualitative results which summarizes relevant findings. After interpreting and discussing results, the framework of analysis is reviewed with two additional interviews with researchers that participate in another university-industry collaboration for materials innovation. One researcher from university and one researcher from company are interviewed using the reviewed framework of analysis to refine the framework. Based on results practices are proposed to facilitate knowledge flows and UIC performance, thus providing practitioners a set of insights to generate more value from the technologies developed in those partnerships.

In order to verify the applicability of the framework, a university-industry collaboration for materials innovation is analyzed with the framework and following the steps presented in this procedure. Next section presents results produced by the framework application.

5 RESULTS

Results of the framework application are organized in three sections: (i) document analysis, (ii) quantitative analysis and (iii) qualitative analysis.

5.1 DOCUMENT ANALYSIS

This research investigates a formal agreement for research and development of advanced materials between a federal university and a large company located in south of Brazil. The agreement is a three-year R$ 25 million contract signed in 2014 to develop metallic materials to allow sustainable increase of energetic efficiency in mechanical devices. The agreement is part of an enduring partnership between university and industry, that develops technologies in advanced materials in collaboration for almost thirty years. The contract is organized in seven programs (i.e. goals) and more than thirty projects distributed in these programs. The contract also holds the mark of largest formal agreement for research cooperation in university's history, at the time of this research. The contract is funded by the company and a funding agency.

At university's side, the endeavor is carried out by a five-laboratory association leaded by a materials laboratory that develops advanced materials, particularly in the areas of powder metallurgy, plasma, tribology, polymers, corrosion and nanomaterials, with a multidisciplinary approach. These researchers are professors, post-graduate, graduate and undergraduate students, which are assigned as team members of the university-industry cooperation projects, besides their academic obligations. Researchers from different academic backgrounds are found within the team, such as: physicist, materials engineering, mechanical engineering, electrical engineering, production engineering, chemical engineering and others. Regarding management aspects, professors and post-graduate students are responsible to manage the collaboration agreement, including the interface with the company. In a daily base, professors are seen as advisors with their expert judgement, while post-graduate, graduate and undergraduate students have some autonomy over their activities.

The company is a large Brazilian multinational, with R$ 1,28 billion in revenue and 10.000 employees, that allocates to R&D about 3% of its revenue and 300 researchers. The company was awarded many times as one of the most innovative company in Brazil, including by agencies that funds scientific, technological and innovation projects. The company also held world’s largest market share within its segment.

Document analysis identified 116 researchers directly involved in the contract, mostly in the university. The study departed from this list to send the questionnaire and gather quantitative data.

5.2 QUANTITATIVE ANALYSIS

The quantitative exploratory study is presented into five parts: (i) respondent characterization, (ii) whole network characterization, (iii) node characterization, (iv) group characterization and (v) relationship between KF practices and UIC KPIs. Results were obtained after applying the quantitative part of the framework of analysis. Data was analyzed by social network analysis (SNA), analysis of variance (ANOVA) and structural equation modelling (PLS-SEM).

5.2.1 Respondent characterization

After examining project documentation, 162 researchers directly and indirectly involved in the university and the company were identified to whom the questionnaire was sent. 73 responses were gathered yielding 45% of response rate. Table 23 and Table 24 classify respondents per organization and hierarchic position. Regarding organizations within the university, 9 different laboratories were identified. Laboratory is referred as autonomous research groups led by a coordinator professor, which work on one or more research fields. Different laboratories engage in collaborative R&D contracts, each with their own expertise and roll of researchers.

The main laboratory involved in this project accounts for more than 50% of total responses. Most responses are from doctorate students (36%), followed by undergraduate students (31%). There was only one response from the company, Table 24, corresponding to 1% of the entire sample, while responses from the university accounts for the other 99%. Thus, this part of the study represents mostly the point of view of the university.

Table 23: Respondent count from university classified by laboratory and hierarchic position

Org	Professor	Post-doctorate	Doctorate	Master	Undergraduate	Technician	Total	Total (%)
Lab A		1					1	1%
Lab B	3		1	1			5	7%
Lab C	4		14	7	21	1	47	65%
Lab D	2		3		1		6	8%
Lab E	1						1	1%
Lab F	1		3				4	6%
Lab G	1		2				3	4%
Lab H				1			1	1%
Lab I			3	1			4	6%
Total	12	1	26	10	22	1	72	100%
Total (%)	17%	1%	36%	14%	31%	1%	100%	

Source: Prepared by the author

Table 24: Respondent count from company classified by company and hierarchic position

Org	Specialist	Total	Total (%)
Company A	1	1	100%
Total	1	1	100%
Total (%)	100%	100%	

Source: Prepared by the author

Project members were asked to indicate other people with whom they exchange important knowledge to achieve project objectives. The list of project participants was sent with the questionnaire. Respondents indicated: (i) other respondents, (ii) people who were not in the list and (iii) people who were not involved directly in project activities. A total number of 129 nodes were identified, 108 from university – Table 25 – and 21 from companies – Table 26. Most nodes – 67% – identified in this study belongs to the same laboratory, which is almost the same ratio found in the number of respondents – 65%. Two laboratories – J and L – of the same university but outside formal project boundaries were identified. One laboratory outside the country – K – was mentioned. Three other companies were identified by project member responses, though most nodes are from the project partner company. Again, most nodes are doctorate students, followed by undergraduates. This shows how project knowledge network spams from formal organograms.

Table 25: Node count from university classified by laboratory and hierarchic position

Org	Professor	Post-doctorate	Doctorate	Master	Undergraduate	Technician	Total	Total (%)
Lab A	1	1	1				3	3%
Lab C	4		1	1			6	6%
Lab J			1				1	1%
Lab K	1						1	1%
Lab C	7	4	19	9	31	2	72	67%
Lab D	2		3		1		6	6%
Lab L			1				1	1%
Lab E	2						2	2%
Lab F	1		3	1			5	5%
Lab G	1		2				3	3%
Lab H				1			1	1%
Lab I	1		4	1		1	7	6%
Total	20	5	35	13	32	3	108	100%
Total (%)	19%	5%	32%	12%	30%	3%	100%	

Source: Prepared by the author

Table 26: Node count from companies classified by company and hierarchic position

Org	Specialist	Total	Total (%)
Company A	18	18	86%
Company B	1	1	5%
Company C	1	1	5%
Company D	1	1	5%
Total	21	21	100%
Total (%)	100%	100%	

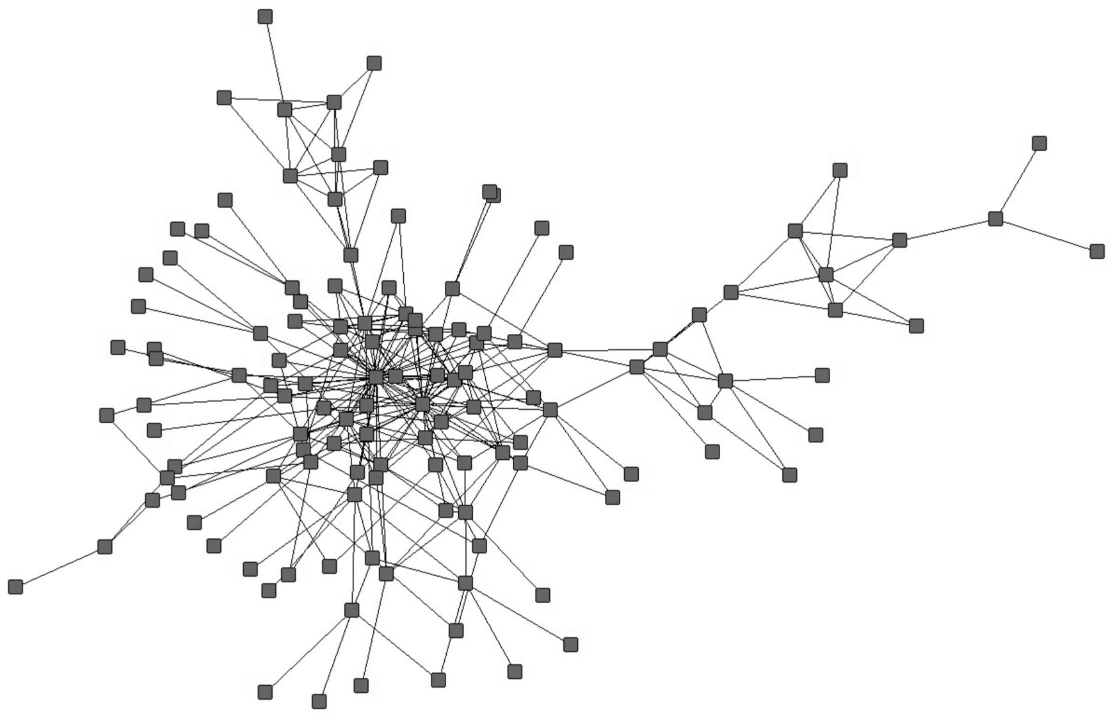
Source: Prepared by the author

5.2.2 Whole network characterization

The networks of technical, managerial and market knowledge are characterized as whole networks to investigate differences among them and provide an overview of the entire network.

The entire knowledge network is composed by 129 nodes that are connected by 316 links that transfer all three types of knowledge – technical, managerial and market – in both directions – send and receive. Figure 10 depicts the whole network, all 129 nodes and all 316 links regardless link direction.

Figure 10: Network visualization



Source: Prepared by the author

Regarding type of knowledge flow, of all 316 connections, all connections exchange (i.e. send, or receive) technical knowledge, a smaller number of connections exchange managerial knowledge and fewer exchange market knowledge, Table 27. Figure 11 shows number of connections by type of knowledge and overlap between types. All connections between nodes share technical knowledge in either direction. Some of these connections also share managerial or market knowledge and a small group of connections share all three types of knowledge. Technical knowledge appears to be the foundation of the knowledge network, while managerial and market knowledge are built on top.

Regarding direction of knowledge flow, most connections are bidirectional, i.e. pairs of nodes send and receive technical, managerial or market knowledge. A smaller number of connections only receive that knowledge and only a few just send knowledge, Figure 12. Thus, the number of paths directed towards nodes (i.e. inflow or receiving knowledge) are higher than those directed from nodes (i.e. outflow sending knowledge).

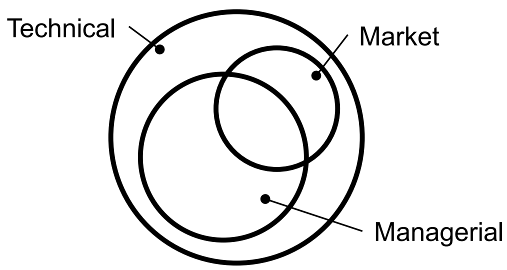
Analyzing flow direction and type of knowledge together, 83% of technical connections share knowledge in both directions, 15% only receive and 2% only send knowledge. On managerial knowledge flow, compared to technical knowledge, there is a decrease on bidirectional links and an increase on the links that only receive. This behavior seams to increase in market knowledge. Market knowledge is the type of knowledge least shared in both ways, most of the connections only receive this type of knowledge. Managerial and market knowledge present a higher inflow rate, i.e. more people seem to only receive this type of knowledge. Managerial and market networks are smaller than technical network and a considerable part of knowledge flow seems to propagate in one direction (i.e. inwards)._For all three types of knowledge few very few people answered that they only send knowledge.

Table 27: Number of connections between nodes by type of knowledge and direction

	Technical	Managerial	Market
Total of connections	316 (100%)	238 (100%)	204 (100%)
Send and receive knowledge	263 (83%)	152 (64%)	93 (45%)
Only receive knowledge	47 (15%)	82 (34%)	102 (50%)
Only send knowledge	6 (2%)	4 (2%)	9 (4%)

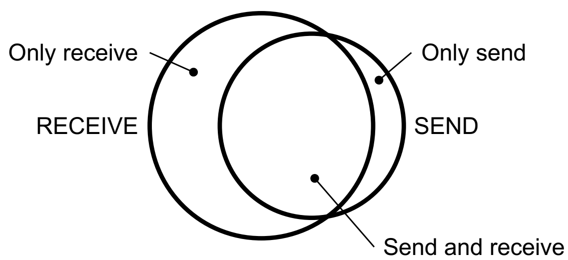
Source: Prepared by the author

Figure 11: Number of connections by type of knowledge



Source: Prepared by the author

Figure 12: Comparison between number of nodes that receive and send knowledge



Source: Prepared by the author

One should note though, that responses are not symmetrical. For instance, the number of only receive and only send knowledge does not match. This happens because the network is constructed based on the responses of each respondent about up to 5 people who they exchange knowledge, responses from sender and receiver don't necessarily match. There are at least 3 reasons for this outcome: (1) a respondent that is mentioned by another respondent may not include the last in his response, which was particularly observed in relationships between star nodes and its adjacencies. Due to the limitation of five knowledge partners asked in the survey a star node will point those that they exchange the most valuable knowledge to meet project objectives and do not identify a wide number of nodes which they are also connected. (2) Two respondents that mentioned each other, may not give a symmetrical response (e.g. one node says that he sends and receives knowledge from the other node and that node in its turn says that he only sends knowledge). (3) And there are people identified by respondents to whom the questionnaire was not sent.

Since asymmetry may represent a methodological issue, from this point, connections are treated as undirected. This measure avoids asymmetry and simplifies the study, with minor losses to analysis, as a minor number of connections only send knowledge compared to the total number of connections and yet all those links were analyzed.

Disregarding direction of knowledge flows, three new networks are formed, one for each type of knowledge. Networks by knowledge type are characterized by network parameters and presented in Table 28. Technical, managerial and market knowledge networks are statistically different from each other, as confirmed by a network analysis test, where a thousand sub samples were randomly generated for each network and compared, Table 29.

Technical knowledge network is the largest and most connected network, as evidenced by density, degree and connectedness. It also shows the highest degree of centralization and the lowest average distance between nodes. Since not all nodes are connected in managerial and market knowledge networks, these networks present more than one component, most of them are single nodes that are not connected to the main component. Technical knowledge flow is the most cohesive, while managerial and market are fragmented, which may indicate an obstacle to knowledge flow.

Table 28: Network characterization by knowledge type

	Technical knowledge	Managerial knowledge	Market knowledge
Density	0,04	0,03	0,02
Average Degree	4,57	3,46	2,99
Degree Centralization	0,34	0,30	0,25
Components	1	16	26
Connectedness	1,00	0,77	0,62
Average Distance	3,75	3,80	4,21

Source: Prepared by the author

Table 29: Network density by knowledge type

Density difference between networks	t-test
Technological and managerial knowledge	6,8418
Technological and market knowledge	7,5220
Managerial and market knowledge	4,6662

T-test for 1000 degrees of freedom and 0,05 confidence interval: 1,9623

Source: Prepared by the author

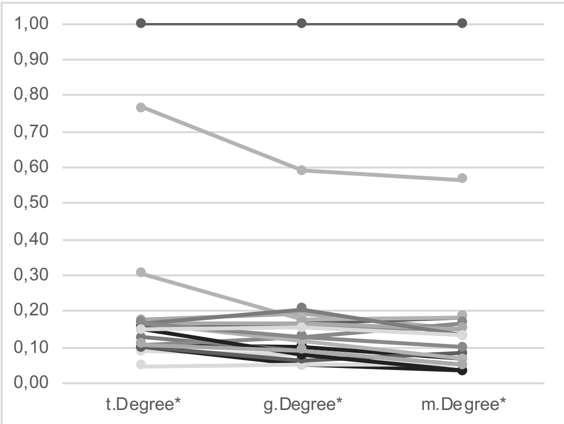
5.2.3 Node characterization

Nodes were characterized for each knowledge network by network parameters degree and betweenness, in order to identify different roles within networks. 20 nodes that scored higher in degree and betweenness were set aside to compare nodes' position alongside networks, to verify if nodes that occupy a central or broker position in one network remains in the same position in other networks. Degree and betweenness were normalized based on the highest value of each parameter.

5.2.3.1 Degree

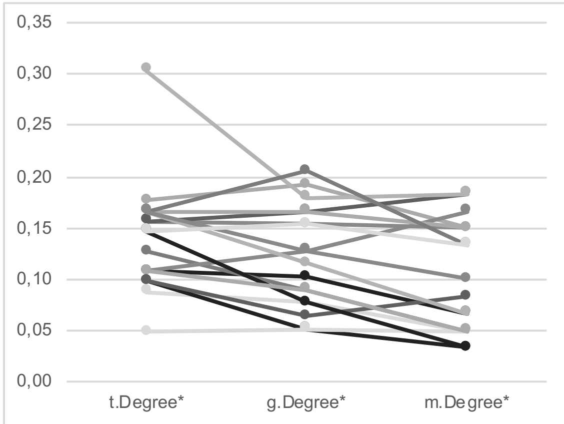
Figure 13 shows how degree of the top-20 nodes, sorted by the technical network, varies for each network. Node A is the most central node in all networks. Node B is the second most central node in all networks, but its degree decreases for managerial and market knowledge. The other 18 nodes present lower and closer levels of degree, thus a better view of the same graph is presented in Figure 14 where node's degree is displayed up to 0,35. This top-20 degree graph shows that nodes may be more or less central depending on type of knowledge.

Figure 13: Degree distribution of nodes that ranked top-20 in technical network



Source: Prepared by the author

Figure 14: Zoom-in in degree distribution of nodes that ranked top-20 in technical network after removing top 2 nodes

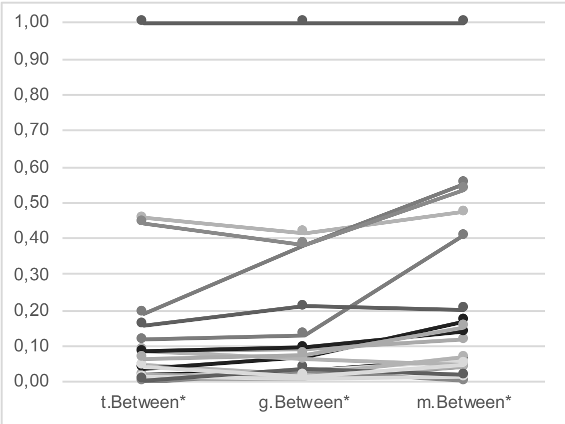


Source: Prepared by the author

5.2.3.2 Betweenness

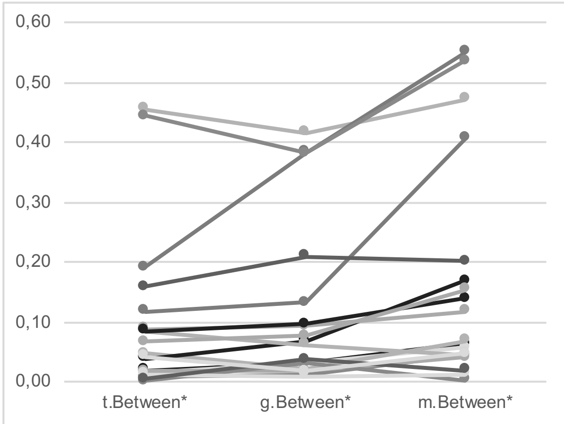
Figure 15 shows how betweenness of the top-20 nodes, sorted by the technical network, varies for each network. Node A is the most in-between node in all networks. The other nodes present lower and closer levels of betweenness, thus a better view of the same graph is presented in Figure 16 where node's betweenness is displayed up to 0,60. This top-20 betweenness graph also show that nodes may connect more or less portions of the network. Top-20 in-between nodes seem to be higher in the market knowledge network, probably associated with the fact that this network has more components and is less connected. These nodes may play an important role in knowledge flow.

Figure 15: Betweenness distribution of nodes that ranked top-20 in technical network



Source: Prepared by the author

Figure 16: Zoom-in in betweenness distribution of nodes that ranked top-20 in technical network after removing top 1 node



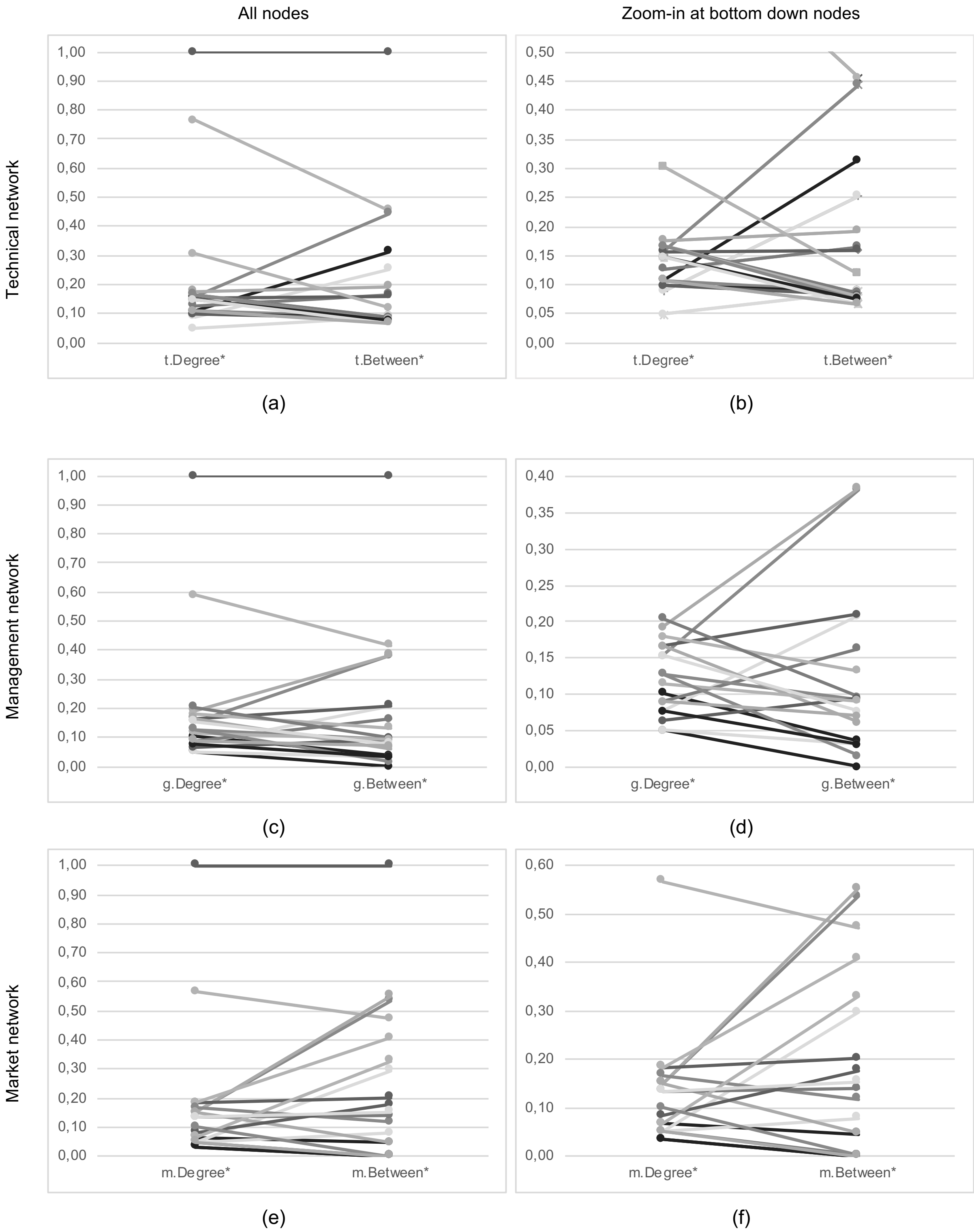
Source: Prepared by the author

These results show that centralization and brokering present different behaviors and nodes may act as different roles for each type of knowledge. Centralizing knowledge is different from brokering knowledge.

5.2.3.3 Degree versus Betweenness

In order to compare degree and betweenness for each knowledge network, Figure 17 presents degree and betweenness of the top-20 nodes, sorted by the technical network. Figures on the left present the full range of the graph, while figures on the right provides closer look in a narrow section containing most of the nodes. It can be seen that most nodes present different scores in normalized degree and betweenness, thus nodes may play different roles in knowledge flow.

Figure 17: Degree and betweenness distribution of nodes that ranked top-20 in technical network, by knowledge network



Source: Prepared by the author.

5.2.4 Group characterization

Nodes were grouped by their characteristics such as organization, role, program involved and by two network grouping techniques: cliques and equivalence. Then Analysis of Variance were performed to discover if difference in group's means are significantly different concerning knowledge management practices, university-industry cooperation indicators and network parameters. Analysis were performed at 5% of confidence interval and results are presented by each attribute. Analysis provide significant differences of means and point if group characteristics may be related to KM practices, UIC performance and SNA indicators.

5.2.4.1 By organization

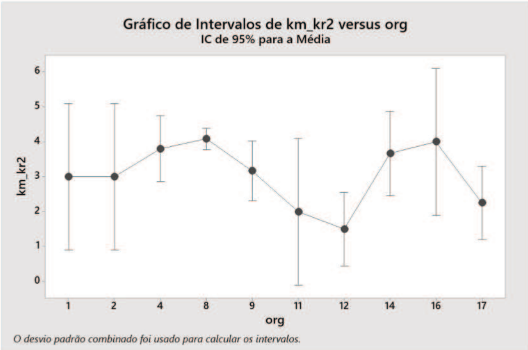
Organizations are those laboratories within the university and the companies involved in the contract. Analysis of variance showed significant influence of organization on knowledge retention, sharing and creation, university-industry input and progress indicators. Table 30 presents those parameters that showed significant difference in means and respective p-values. Interval graphs in Figure 18, in turn, show how parameters' means varied according to each organization. Laboratories 11 and 12 scored lower for some knowledge management practices, while company and laboratory 17 scored lower for project progress. Organization appears to have some influence on some KM practices and UIC indicators.

Table 30: Analysis of variance of KM practices and UIC performance by respondent organizations at 5% of confidence interval

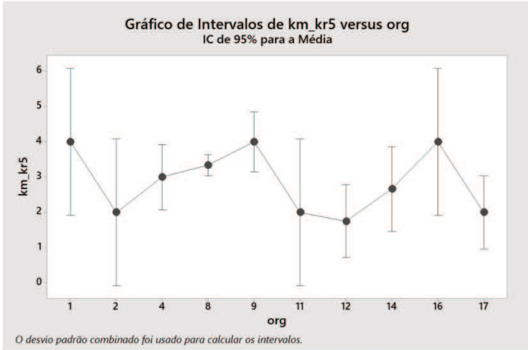
Attribute	Indicator		p-value
Knowledge retention	km_kr2	My team members regularly use information from the intranet (share drive, knowledge portals)	< 0,001
	km_kr5	If a person of my team leaves, knowledge of my team processes is not lost	0,017
Knowledge sharing	km_ks1	When a team member develops some know-how, it is shared in the team	0,044
	km_ks4	My team members share information on problem-solving strategies that have worked well	0,008
Knowledge creation	km_kc7	My superiors are appreciative of my team members' effort to create new knowledge	0,003
UIC input	uic_input2	Cooperation partners invest a sufficient amount of time in the project in which I participate	0,043
UIC progress	uic_progress1	The project that I participate in is actively managed throughout their life cycle, both at the university and at the company	0,002
	uic_progress2	Roles and responsibilities are clearly defined and communicated between members of the project in which I participate	0,037

Source: Prepared by the author

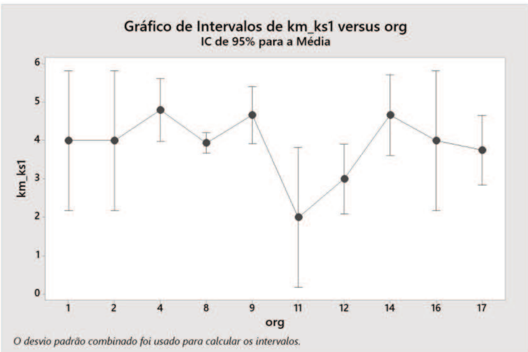
Figure 18: Mean distribution of indicators across organizations that showed significant difference in means, at indicated p-value. Respondent organizations: 2 – Company; 1, 4, 8, 9, 11, 12, 14, 16, 17 – Laboratories within university.



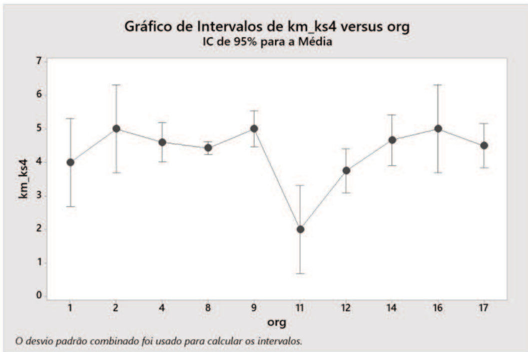
(a) km_kr2



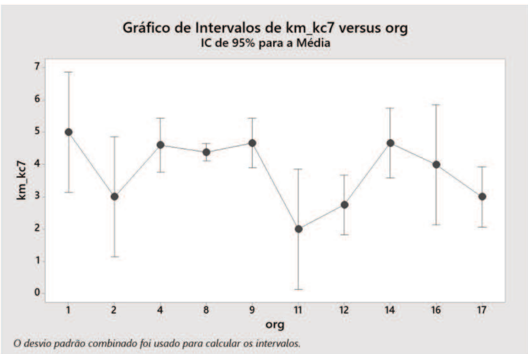
(b) km_kr5



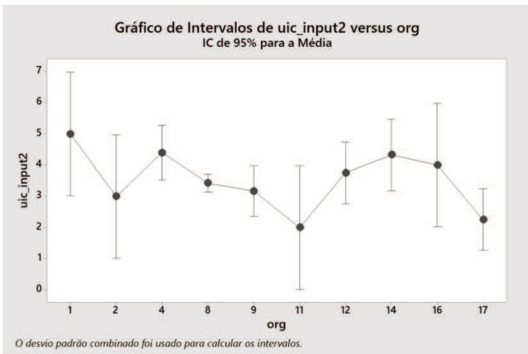
(c) km_ks1



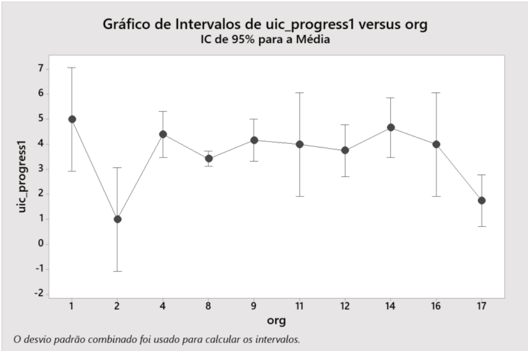
(d) km_ks4



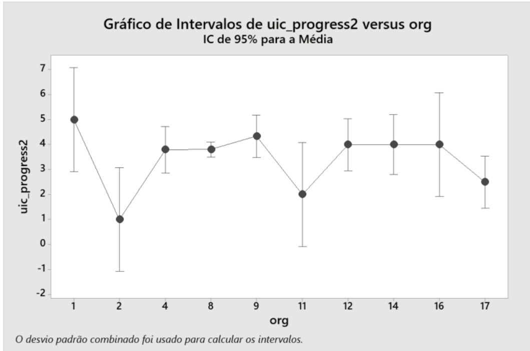
(e) km_kc7



(f) uic_input2



(g) uic_progress1



(h) uic_progress2

Source: Prepared by the author.

5.2.4.2 By role

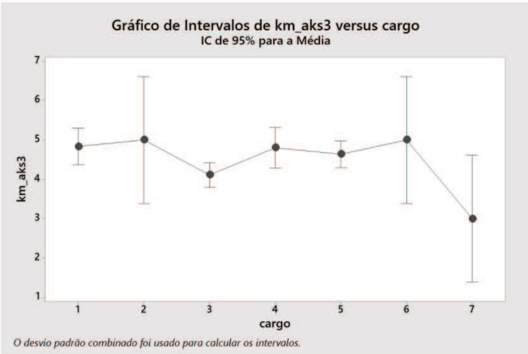
Role is the hierarchic position within the university or the company. Identified roles are: professor, post-doctorate, doctorate, master and undergraduate students, technician and specialist. Analysis of variance showed significant influence of role on actionable knowledge support, knowledge creation, university-industry cooperation input and progress, degree on technical, managerial and market knowledge networks and betweenness in market knowledge network. Table 31 presents those parameters that showed significant difference in means and respective p-values. Interval graphs in Figure 19, in turn, show how parameters' means varied according to each role. Specialist's view of project progress is lower than laboratory partners regarding both UIC project progress indicators. Professors shows evidence position in all three knowledge networks regarding degree. Professors and company specialist occupy central and brokering positions regarding market knowledge network. Role seems to be related to network indicators.

Table 31: Analysis of variance of KM practices, UIC performance and network parameters by respondent roles at 5% of confidence interval

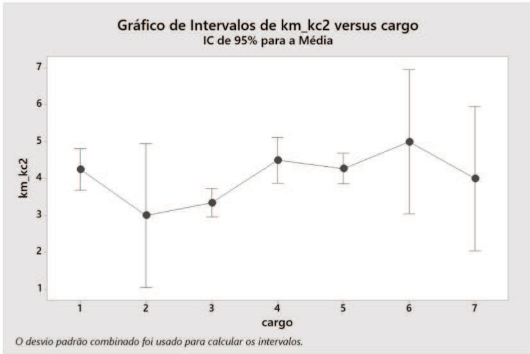
Attribute	Indicator		p-value
Actionable knowledge support	km_aks3	When I seek knowledge, team members encourage me	0,040
Knowledge creation	km_kc2	My team actively spends resources (time, effort) in acquiring new knowledge	0,009
	km_kc8	My team members show interest in solving challenging problems	0,021
UIC inputs	uic_input2	Cooperation partners invest a sufficient amount of time in the project in which I participate	0,036
UIC progress	uic_progress1	The project that I participate in is actively managed throughout their life cycle, both at the university and at the company	< 0,001
	uic_progress2	Roles and responsibilities are clearly defined and communicated between members of the project in which I participate	0,016
Technical network	t.Degree	Node degree in technical knowledge network	0,006
Managerial network	g.Degree	Node degree in managerial knowledge network	0,046
Market network	m.Degree	Node degree in market knowledge network	0,033
	m.Between	Node in-betweenness in market knowledge network	0,015

Source: Prepared by the author

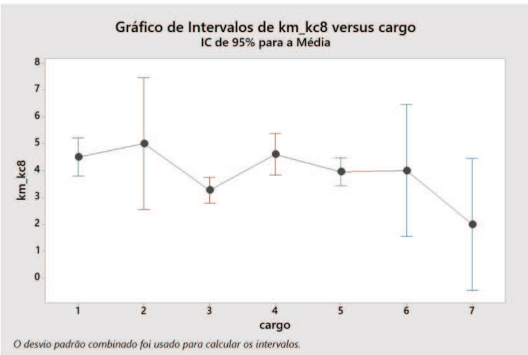
Figure 19: Mean distribution of indicators across roles that showed significant difference in means, at indicated p-value. Respondent roles: 1 – Professor; 2 – Post-doctorate; 3 – Doctorate student; 4 – Master student; 5 – Undergraduate student; 6 – Technician; 7 – Specialist.



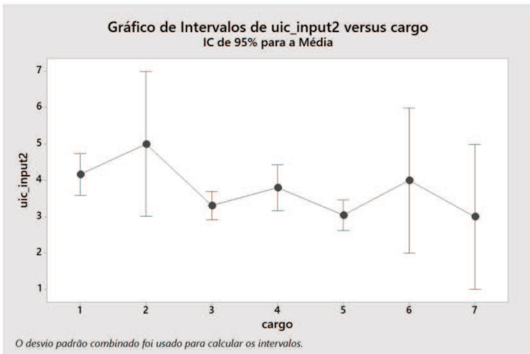
(a) km_aks3



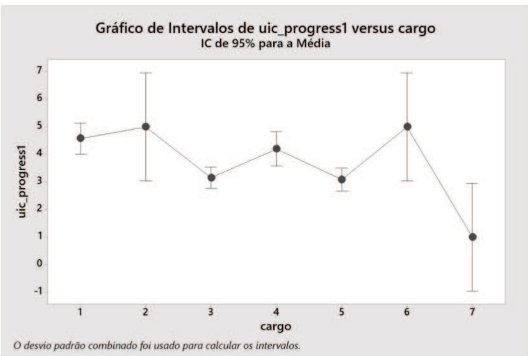
(b) km_kc2



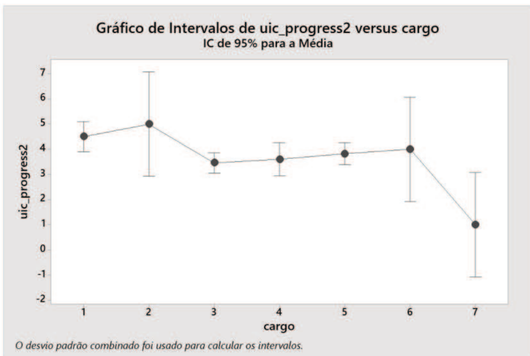
(c) km_kc8



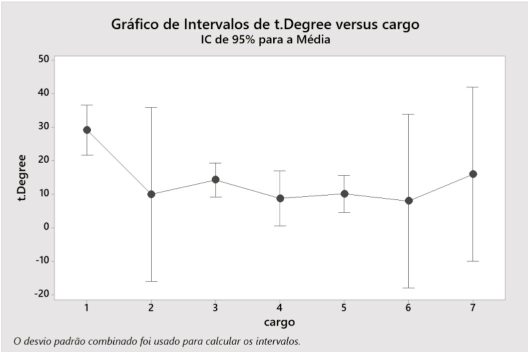
(d) uic_input2



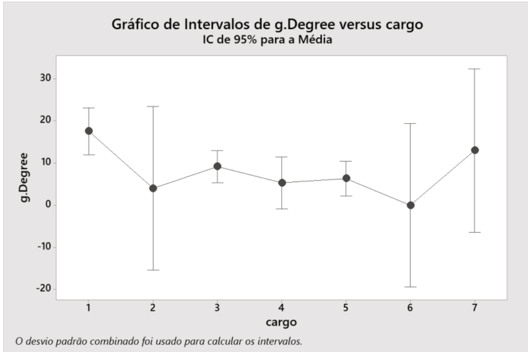
(e) uic_progress1



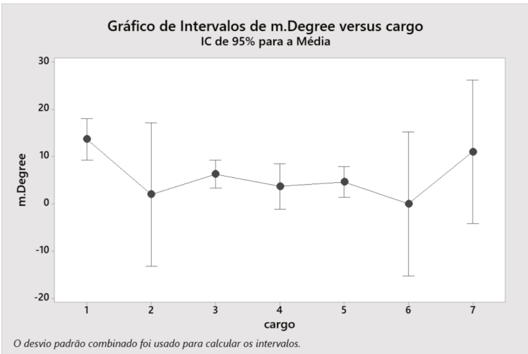
(f) uic_progress2



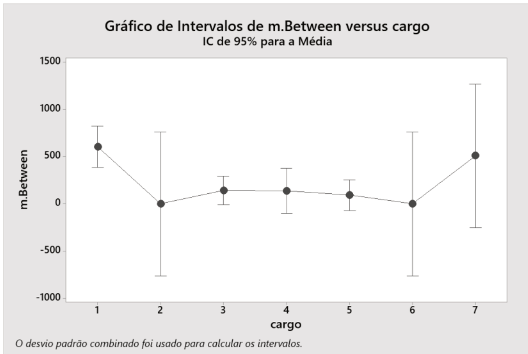
(g) t.Degree



(h) g.Degree



(i) m.Degree



(j) m.Between

Source: Prepared by the author

5.2.4.3 By program

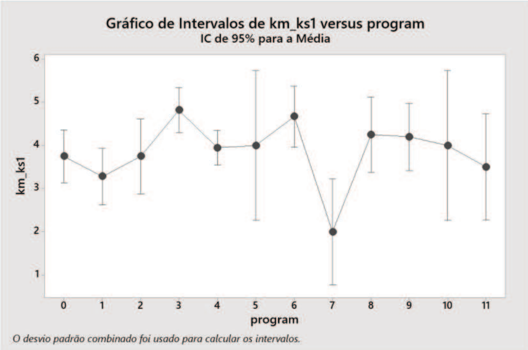
Program is a subset of the R&D contract determined by specific objectives, that is related to research fields and thus laboratories involved. Laboratories engage in one or more programs, while the managing laboratory is involved in all programs. Analysis of variance showed significant influence of program on knowledge sharing, knowledge creation, university-industry cooperation progress, output and impact, degree and betweenness in technical, managerial and market knowledge networks. Table 32 presents those parameters that showed significant difference in means and respective p-values. Interval graphs in Figure 20, in turn, show how parameters' means varied according to each program. Members of program 5 seems scored lower in project progress, output and impact, while program 7 scored lower in knowledge sharing and creation. Members that participated in all programs were coded 11 and presented significant relationship with network parameters degree and betweenness, as one would expect. Program, which is related to project teams, appears to be related to KM practices and perception of UIC performance indicators, while participation in many programs is related to network parameters.

Table 32: Analysis of variance of KM practices, UIC performance and network parameters by respondent programs at 5% of confidence interval

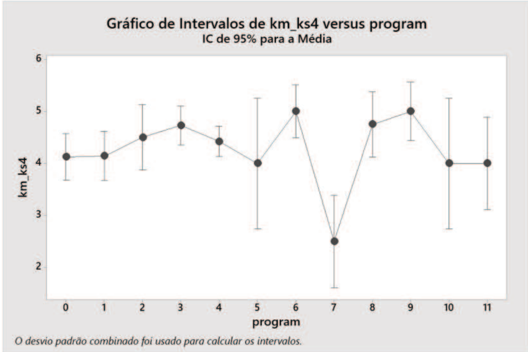
Attribute	Indicator		p-value
Knowledge sharing	km_ks1	When a team member develops some know-how, it is shared in the team	0,005
	km_ks4	My team members share information on problem-solving strategies that have worked well	0,001
	km_ks7	My team is able to optimally utilize competencies of its individual members	0,016
Knowledge creation	km_kc3	My team members are aware of latest developments in their field	0,041
	km_kc7	My superiors are appreciative of my team members' effort to create new knowledge	0,011
UIC progress	uic_progress1	The project that I participate in is actively managed throughout their life cycle, both at the university and at the company	0,023
UIC output	uic_output1	Of the products and services developed by the company, a relevant amount is the result of the project in which I participate when compared to other university-industry partnership projects	0,014
	uic_output2	Of the processes developed by the company, a relevant amount is the result of the project in which I participate when compared to other university-industry partnership projects	0,004
UIC impact	uic_impact2	The application of the results achieved jointly in the project in which I participate resulted in changes on the company's revenue structure	0,002
Technical network	t.Degree	Node degree in technical knowledge network	< 0,001
	t.Between	Node in-betweenness in technical knowledge network	< 0,001
Managerial network	g.Degree	Node degree in managerial knowledge network	< 0,001
	g.Between	Node in-betweenness in managerial knowledge network	< 0,001
Market network	m.Degree	Node degree in market knowledge network	< 0,001
	m.Between	Node in-betweenness in market knowledge network	< 0,001

Source: Prepared by the author

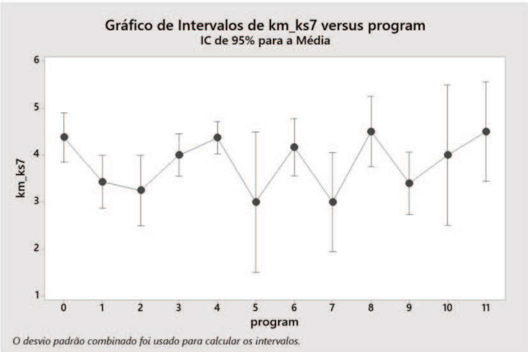
Figure 20: Mean distribution of indicators across programs that showed significant difference in means, at indicated p-value. Respondent program: 0 – Respondents not formally allocated to a program; 1-10 – Programs each addressed one collaboration objective; 11 – Respondents that participated on all programs.



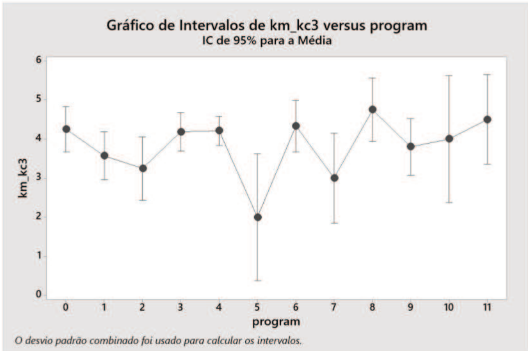
(a) km_ks1



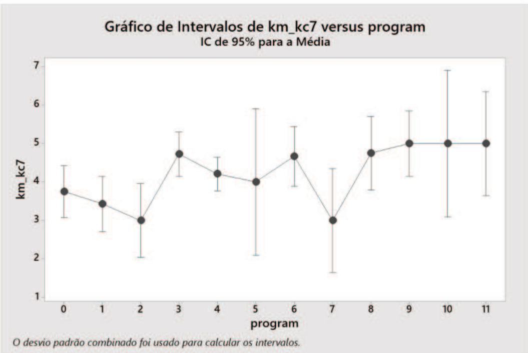
(b) km_ks4



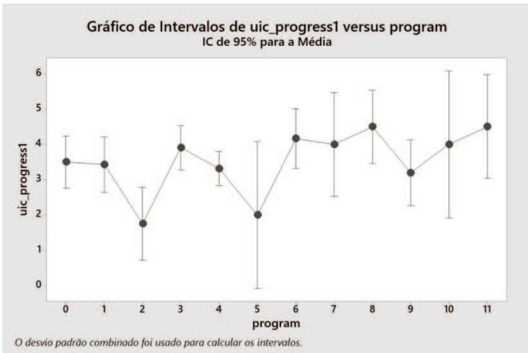
(c) km_ks7



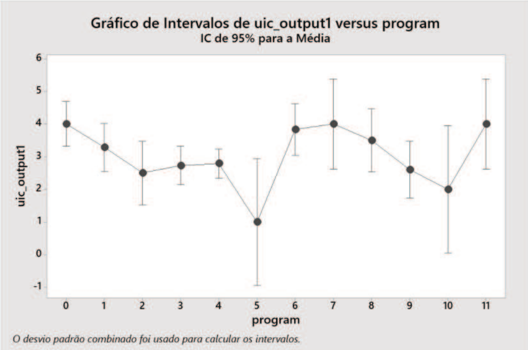
(d) km_kc3



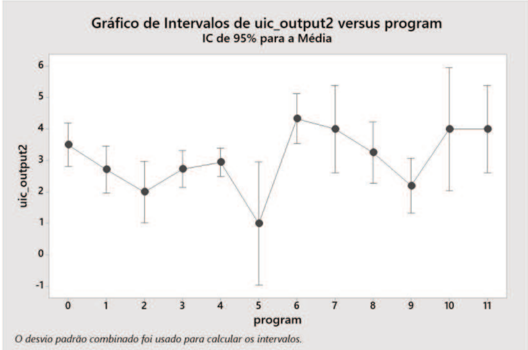
(e) km_kc7



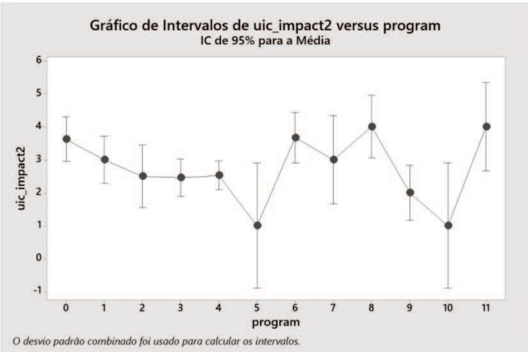
(f) uic_progress1



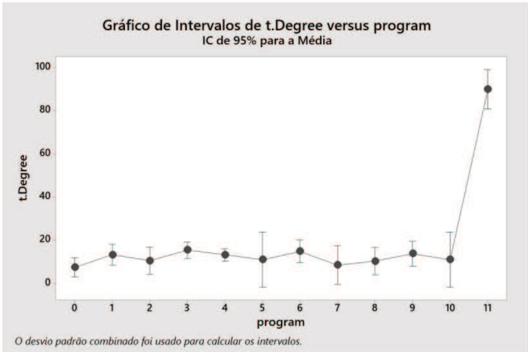
(g) uic_output1



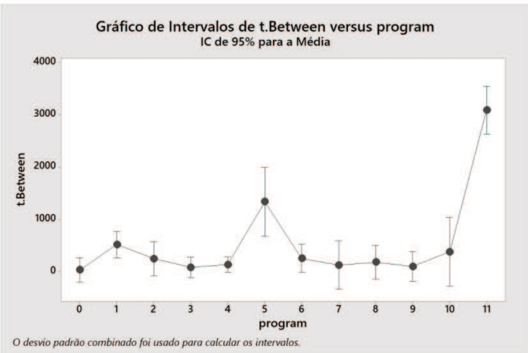
(h) uic_output2



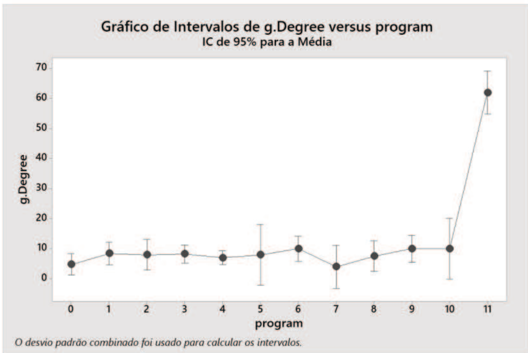
(i) uic_impact2



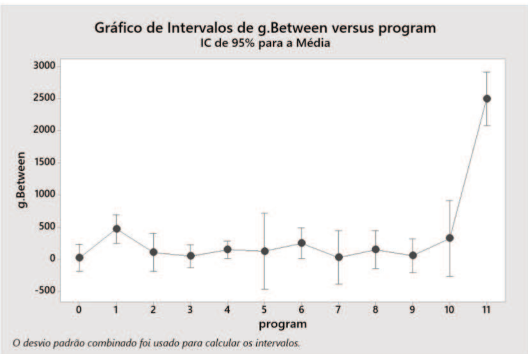
(j) t.Degree



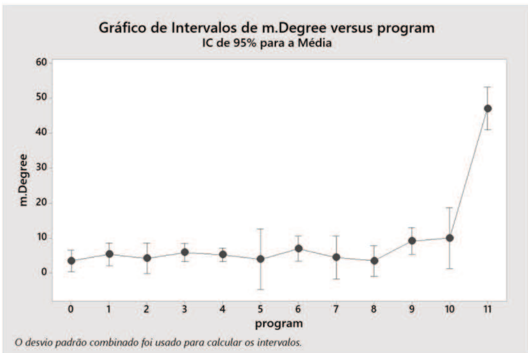
(k) t.Between



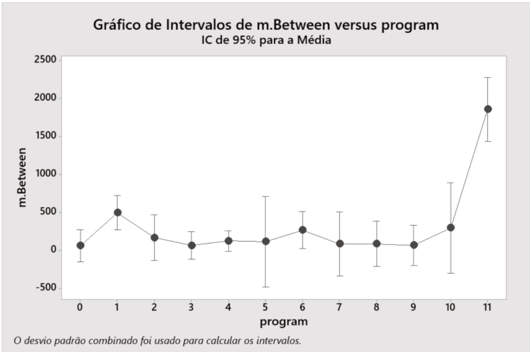
(l) g.Degree



(m) g.Between



(n) m.Degree



(o) m.Between

Source: Prepared by the author

5.2.4.4 By clique

Nodes were grouped by cliques as described in social network analysis section according to its knowledge network and by a minimum set size. Departing from the minimum set size of 3, set size was increased until it reaches a reasonable number of cliques to be further investigated, Table 33. Seven cliques of size 5 were found in the technical network. Managerial and market networks presented only 2 groups of 5 members and were not addressed. Then an ANOVA test was performed to find significant differences between means. ANOVA test showed only a significant difference in a UIC input indicator. Table 34 displays the resulting p-value, while Figure 21 displays interval graph of UIC input for each clique. The clique which showed a smaller mean is a group formed mostly by project members of one laboratory, though this laboratory did not present a smaller mean when the ANOVA test was performed with organizations. Only this group of members within the laboratory showed this difference. It was not found any pattern within this group, thus this grouping technique didn't seem to be valuable for this research.

Table 33: Number of cliques found in each knowledge network and as a function of the minimum set size

Minimum Set Size	t	g	m
3	83	65	48
4	46	23	15
5	7	2	2

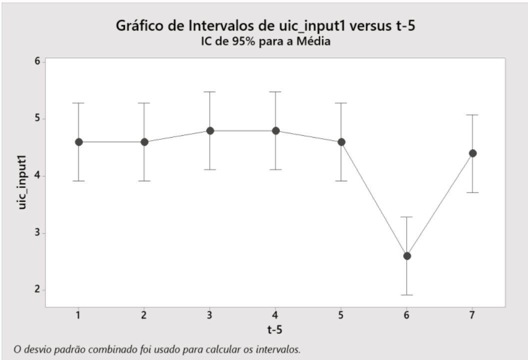
Source: Prepared by the author

Table 34: Analysis of variance of UIC performance by clique at 5% of confidence interval

Attribute	Indicator		p-value
UIC input	uic_input1	Cooperation partners invest a sufficient amount of financial resources in the project in which I participate	0,001

Source: Prepared by the author

Figure 21: Mean distribution of indicators across cliques that showed significant difference in means, at indicated p-value



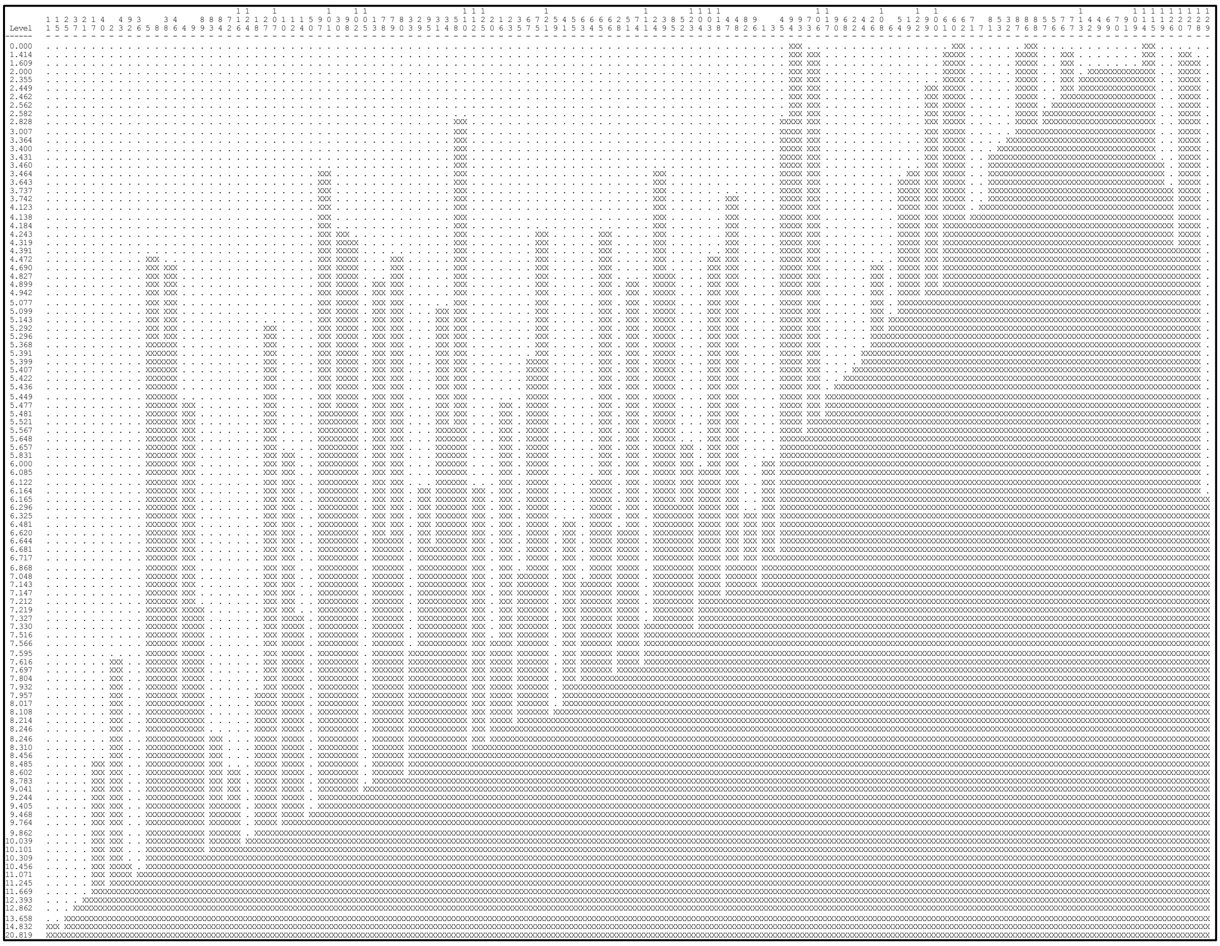
uic_input1, p-value: 0,001

Source: Prepared by the author.

5.2.4.5 By equivalence

Nodes were grouped by equivalence, a node characterizing technique based on network positions. Nodes are organized by level sets of equivalence, as depicted in Figure 22. Equivalence is organized by the number of same direct ties that nodes are connected to. Departing from the minimum level set of 1, level set was increased until it reaches a reasonable number of equivalent nodes to be further investigated. Eight groups of equivalent nodes were found in the technical network with 31 nodes. Only 3 of these nodes answered the questionnaire though, thus making unfeasible to perform an ANOVA test. The grouping technique equivalence, like the clique technique, wasn't able to identify any pattern, therefore it didn't seem to be valuable for this research.

Figure 22: Visual representation of node equivalence. Nodes at x-axis and level at y-axis



Source: Prepared by the author

In summary, social network analysis showed that technical, managerial and market knowledge flows are statistically different. Technical knowledge network connects all nodes (i.e. formed by only one component), while managerial and market knowledge are smaller and fragmented networks, which may be an obstacle to knowledge flow. Technical knowledge network seems to be the departing network, where managerial and market knowledge builds on it. Managerial and market knowledge also present higher inflow rates. Nodes, on its turn, play different roles in knowledge flow. Regarding centrality and in-betweenness nodes are more or less central depending on type of knowledge. Central nodes are not necessarily in-between and vice versa, thus centralizing knowledge is different from brokering knowledge. Particularly in market knowledge network, nodes present higher in-betweenness scores, probably associated with the fact that this network is less connected (i.e. has more components).

Analysis of variance evidenced potential relationships between indicators. Organization appears to be related to some KM practices and UIC indicators. Role seems to be related to network indicators. Program appears to be related to KM practices and perception of UIC performance indicators, while participation in many programs is related to network parameters. Grouping techniques clique and equivalence were not able to identify patterns for this research.

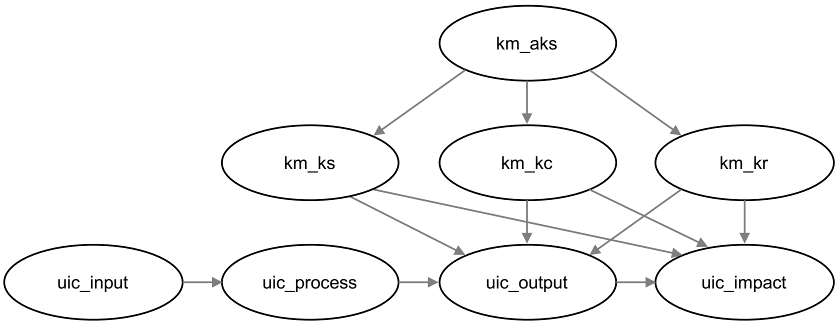
5.2.5 Relationship between KF practices and UIC KPIs

Partial least squares – structural equation modelling – was performed to investigate the relationship between knowledge flow practices and university-industry cooperation performance indicators. Models were developed and assessed until reaching reasonably validity measures (i.e. a good model fit).

5.2.5.1 Model 1

Analysis started with Model 1 depicted in Figure 23, where KM practices and UIC performance indicators are showed using codes presented in Table 19 and Table 20, respectively. Actionable knowledge support practices (km_aks) are assumed to influence knowledge sharing (km_ks), creation (km_kc) and retention (km_kr) which in turn influence project input (uic_input) and output (uic_output). Model 1 was assessed following the methodology previously presented in Table 17. Resulting goodness of model fit (SRMR) and indicator reliability (indicator loadings) are presented in Table 35 and Table 36 respectively. Model 1 showed a SRMR value of 0,10, slightly over a desired 0,08, while many indicator loadings were found to be under a desired 0,5. Model 1 was discarded.

Figure 23: PLS-SEM Model 1



Source: Prepared by the author

Table 35: Model 1, Overall model assessment: Goodness of model fit (SRMR)

SRMR	0,1085

Standardized root mean square residual (SRMR) < 0,08 (HENSELER; HUBONA; RAY, 2016)

Source: Prepared by the author

Table 36: Model 1, Measurement model assessment: Indicator reliability (Indicator loadings)

Indicator	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output	uic_impact
km_aks1	0,7905							
km_aks2	0,7667							
km_aks3	0,727							
km_aks4	0,6897							
km_aks5	0,6869							
km_kr1		0,8138						
km_kr2		0,7759						
km_kr3		0,6641						
km_kr4		0,4753						
km_kr5		0,6271						
km_ks1			0,638					
km_ks2			0,7594					
km_ks3			0,7429					
km_ks4			0,6544					
km_ks5			0,806					
km_ks6			0,5301					
km_ks7			0,5825					
km_ks8			0,3243					
km_kc1				0,6724				
km_kc2				0,4807				
km_kc3				0,7535				
km_kc4				0,6135				

Indicator	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output	uic_impact
km_kc5				0,7597				
km_kc6				0,6544				
km_kc7				0,6844				
km_kc8				0,4693				
km_kc9				0,5716				
uic_input1					0,5844			
uic_input2					0,9896			
uic_progress1						0,9326		
uic_progress2						0,7654		
uic_output1							0,9199	
uic_output2							0,9262	
uic_output3							0,9282	
uic_impact1								0,7351
uic_impact2								0,8812

Double underscore: indicator loading < 0,5; Underscore: 0,5 < indicator loading < 0,6

Indicator loading > 0,5 (HAIR, Joseph F *et al.*, 2006; HULLAND, 1999)

Source: Prepared by the author

5.2.5.2 Model 2

Model 2 was defined after Model 1 by removing indicators whose loadings scored under 0,5, while keeping the same structural model. Goodness of model fit (SRMR), indicator reliability (indicator loadings), indicator consistency (Rho A) and internal consistency (AVE) are presented in Table 37, Table 38 and Table 39, respectively. Model 2 also presented a SRMR over 0,08 with around 0,10 while all indicator loadings scored over 0,5. Concerning indicator consistency, uic_impact showed a Rho A under a desired 0,7, while for internal consistency km_ks and km_kc presented AVE slightly under a desired 0,5. Model 2 was discarded.

Table 37: Model, Overall model assessment: Goodness of model fit (SRMR)

SRMR	0,1088

Standardized root mean square residual (SRMR) < 0,08 (HENSELER; HUBONA; RAY, 2016)

Source: Prepared by the author

Table 38: Model 2, Measurement model assessment: Indicator reliability (Indicator loadings)

Indicator	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output	uic_impact
km_aks1	0,7929							
km_aks2	0,7611							
km_aks3	0,7244							
km_aks4	0,6932							
km_aks5	0,6893							
km_kr1		0,8507						
km_kr2		0,8292						
km_kr3		0,6914						
km_kr5		0,6125						
km_ks1			0,6491					
km_ks2			0,7541					
km_ks3			0,734					
km_ks4			0,6661					
km_ks5			0,8122					
km_ks6			0,5332					
km_ks7			0,5821					
km_kc1				0,6588				
km_kc3				0,7845				
km_kc4				0,6523				
km_kc5				0,7974				
km_kc6				0,6735				
km_kc7				0,6549				
km_kc9				0,5844				
uic_input1					0,5844			
uic_input2					0,9896			
uic_progress1						0,9326		
uic_progress2						0,7654		
uic_output1							0,9202	
uic_output2							0,926	
uic_output3							0,928	
uic_impact1								0,7494
uic_impact2								0,8709

Double underscore: indicator loading < 0,5; Underscore: 0,5 < indicator loading < 0,6

Indicator loading > 0,5 (HAIR, Joseph F *et al.*, 2006; HULLAND, 1999)

Source: Prepared by the author

Table 39: Model 2, Measurement model assessment: Indicator consistency (Rho A) and Internal consistency (AVE)

Construct	Dijkstra-Henseler's rho (ρA)	Average variance extracted (AVE)
km_aks	0,791	0,538
km_kr	0,735	0,566
km_ks	0,807	0,465
km_kc	0,820	0,476
uic_input	2,314	0,660
uic_progress	0,800	0,728
uic_output	0,929	0,855
uic_impact	0,521	0,660

Rho A > 0,7 (NUNNALLY; BERNSTEIN, 1994)

Average Variance Extracted (AVE) > 0,5 (BAGOZZI; YI, 1991; FORNELL; LARCKER, 1981)

Source: Prepared by the author

5.2.5.3 Model 3

Model 2 assessment indicated an issue of indicator consistency with uic_impact. Thus, by analyzing project output and project impact, one could say that both variables vary together, influencing each other. Both variables were then merged resulting in Model 3, depicted in Figure 24.

Regarding the overall model assessment. Model 3 presented a goodness of fit measured by SRMR at 0,11, Table 40, also above the recommended threshold of 0,08, which recommends further investigation and validation of the instrument. This work acknowledges the issue but it does not develop the instrument any further accepting a low overall model fit, since this is majorly a qualitative study, which uses quantitative instruments as base for deeper investigation performed by structured interviews.

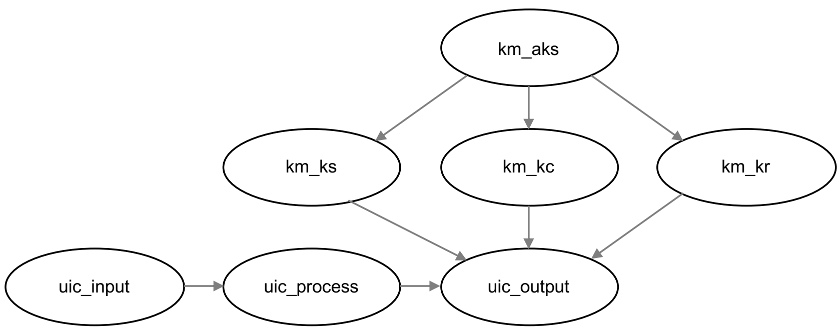
Regarding the measurement assessment. Indicator loadings, which measures indicator reliability, all scored over a desired 0,5, with few indicators scoring between 0,5 and 0,6, Table 41. Rho A, which measures indicators consistency, of all constructs scored above the desired 0,7 threshold, Table 42. In the same table, AVE, which measures internal consistency, showed two variables – km_ks and km_kc – slightly under a desired 0,5. These values would also require a deeper analysis, which won't be performed due to the nature of this study. Concerning discriminant validity, using Fornell and Larcker Criterion which measures vertical collinearity, all variables' AVE scored higher than the squared correlations between the latent variable and all other variables, Table 43. Still on discriminant validity, Heterotrait-Monotrait Ratio of Correlations (HTMT) showed all values under 0,85, as desired, Table 44.

Regarding the structural model assessment. Indicator multicollinearity measured by Variance Inflation Factors (VIF) all scored under 5, Table 45. All endogenous variables presented values of R-squared over 0,2, Table 46.

Model 3 is, therefore, accepted with observations after overall, structural and measurement model assessment.

Model 3 showed 5 significant direct effects between variables, shown in Table 47, at confidence levels under 0,01. Figure 25 depicts Model 3 with effect sizes at significance levels. It was found that actionable knowledge support practices are directly related to knowledge sharing, creation and retention practices. It was also found that uic_input is directly related to uic_process which in turn is directly related to uic_output. However, none of knowledge sharing, creation and retention practices were significantly related to uic_output.

Figure 24: PLS-SEM Model 3



Source: Prepared by the author

Table 40: Model 3, Overall model assessment: Goodness of model fit (SRMR)

SRMR	0,1100

Standardized root mean square residual (SRMR) < 0,08 (HENSELER; HUBONA; RAY, 2016)

Source: Prepared by the author

Table 41: Model 3, Measurement model assessment: Indicator reliability (Indicator loadings)

Indicator	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output
km_aks1	0,7937						
km_aks2	0,7616						
km_aks3	0,7252						
km_aks4	0,6924						
km_aks5	0,6877						
km_kr1		0,849					
km_kr2		0,8332					
km_kr3		0,693					
km_kr5		0,6104					
km_ks1			0,6643				
km_ks2			0,7679				
km_ks3			0,7394				
km_ks4			0,6819				
km_ks5			0,8081				
km_ks6			<u>0,5176</u>				
km_ks7			<u>0,5625</u>				
km_kc1				0,669			
km_kc3				0,7897			
km_kc4				0,6532			
km_kc5				0,7932			
km_kc6				0,6675			
km_kc7				0,6669			
km_kc9				<u>0,5673</u>			
uic_input1					<u>0,5867</u>		
uic_input2					0,9892		
uic_progress1						0,9238	
uic_progress2						0,7805	
uic_output1							0,88
uic_output2							0,8993
uic_output3							0,8587
uic_impact1							<u>0,5896</u>
uic_impact2							0,7355

<u>Double underscore</u>: indicator loading < 0,5; <u>Underscore</u>: 0,5 < indicator loading < 0,6

Indicator loading > 0,5 (HAIR, Joseph F *et al.*, 2006; HULLAND, 1999)

Source: Prepared by the author

Table 42: Model 3, Measurement model assessment: Indicator consistency (Rho A) and Internal consistency (AVE)

Construct	Dijkstra-Henseler's rho (ρA)	Average variance extracted (AVE)
km_aks	0,791	0,538
km_kr	0,733	0,567
km_ks	0,808	0,469
km_kc	0,820	0,477
uic_input	2,263	0,661
uic_progress	0,757	0,731
uic_output	0,904	0,642

Rho A > 0,7 (NUNNALLY; BERNSTEIN, 1994)

Average Variance Extracted (AVE) > 0,5 (BAGOZZI; YI, 1991; FORNELL; LARCKER, 1981)

Source: Prepared by the author

Table 43: Model 3, Measurement model assessment: Discriminant validity (vertical collinearity, Fornell and Larcker Criterion)

Construct	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output
km_aks	**0,538**						
km_kr	0,203	**0,567**					
km_ks	0,402	0,273	**0,469**				
km_kc	0,386	0,246	0,303	**0,477**			
uic_input	0,079	0,039	0,024	0,091	**0,661**		
uic_progress	0,176	0,201	0,178	0,172	0,299	**0,731**	
uic_output	0,024	0,033	0,024	0,102	0,064	0,167	**0,642**

AVE of each latent variable > Squared correlations between the latent variable and all other variables (CHIN, 2010; FORNELL; LARCKER, 1981)

Source: Prepared by the author

Table 44: Model 3, Measurement model assessment: Discriminant validity (Heterotrait-Monotrait Ratio of Correlations - HTMT)

Construct	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output
km_aks							
km_kr	0,571						
km_ks	0,777	0,671					
km_kc	0,772	0,616	0,679				
uic_input	0,351	0,234	0,143	0,327			
uic_progress	0,611	0,649	0,598	0,612	0,614		
uic_output	0,174	0,176	0,156	0,362	0,068	0,491	

Heterotrait-Monotrait Ratio (HTMT) < 0,85 (KLINE, 2011)

Source: Prepared by the author

Table 45: Model 3, Structural model assessment: Indicator Multicollinearity (Variance inflation factors - VIF)

Indicator	km_aks	km_kr	km_ks	km_kc	uic_input	uic_progress	uic_output
km_aks1	1,699						
km_aks2	1,6187						
km_aks3	1,4953						
km_aks4	1,4593						
km_aks5	1,4078						
km_kr1		3,5176					
km_kr2		3,4364					
km_kr3		1,4106					
km_kr5		1,0644					
km_ks1			2,1361				
km_ks2			2,6995				
km_ks3			2,2841				
km_ks4			2,2471				
km_ks5			2,0119				
km_ks6			1,2688				
km_ks7			1,2265				
km_kc1				1,6467			
km_kc3				1,9324			
km_kc4				1,4877			
km_kc5				1,9083			
km_kc6				1,5121			
km_kc7				1,4031			
km_kc9				1,3392			
uic_input1					1,2706		
uic_input2					1,2706		
uic_progress1						1,302	
uic_progress2						1,302	
uic_output1							3,9581
uic_output2							3,1515
uic_output3							3,7582
uic_impact1							1,2538
uic_impact2							1,7864

Variance Inflation Factors (VIF) < 5 (CASSEL; HACKL; WESTLUND, 1999)

Source: Prepared by the author

Table 46: Model 3, Structural model assessment: Endogenous variables (R-Squared)

Construct	Coefficient of determination (R2)	Adjusted R2
km_kr	0,2027	0,1915
km_ks	0,402	0,3935
km_kc	0,3863	0,3776
uic_progress	0,2987	0,2888
uic_output	0,2073	0,1607

R^2 > 0,2 (LOWRY; GASKIN, 2014)

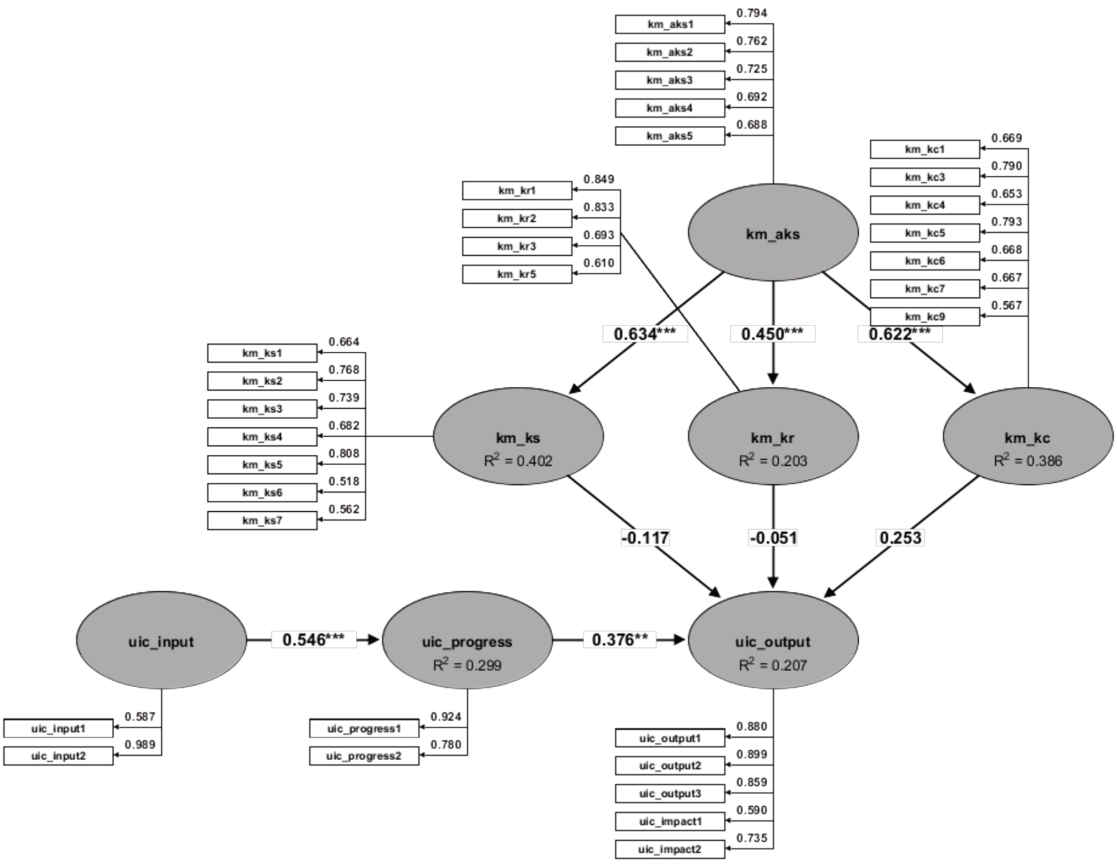
Source: Prepared by the author

Table 47: Model 3, Structural model assessment: Significant direct effects

Effect	Total effect	Significance (p-value)
km_aks -> km_kr	0,4503	< 0,001
km_aks -> km_ks	0,634	< 0,001
km_aks -> km_kc	0,6215	< 0,001
uic_input -> uic_progress	0,5465	< 0,001
uic_progress -> uic_output	0,3764	< 0,01

Source: Prepared by the author

Figure 25: Model 3, Effects (effect size at significance levels measured by p-value)



Source: Prepared by the author

This quantitative part of the study characterized knowledge flow throughout its nodes, links, types of knowledge, roles, groups and networks, while also evaluated correlations between indicators. This part also investigated correlation between KF practices and UIC indicators. Even though results show relationships between elements within each construct, no relevant relationship between knowledge flow and UIC was found using the instruments proposed in the framework of analysis.

The qualitative part of the study departs from these results to further investigate knowledge flow in university-industry cooperation. Semi-structured interviews provide a deeper understanding of the studied phenomenon. Next part investigates UIC within the innovation process of the firm, the knowledge flow within collaboration and specific characteristics on materials innovation.

5.2.6 Selecting project members to interview

Project members were selected for the qualitative part of this study after patterns evidenced in quantitative results, which includes:

- Organization: laboratories and company;
- Role: professor, graduate students, undergraduate students and specialists;
- Network position: centrality and betweenness.

Ten project members were selected to be interviewed, using the interview protocol presented in Table 21, and are summarized in Table 48 and Table 49.

Table 48: List of selected members to interview

Project member	Organization	Role	Network position
Professor A	Laboratory	Professor	Central
Doctorate student A	Laboratory	Doctorate student	Central
Master student A	Laboratory	Master student	Central
Professor B	Laboratory	Professor	Broker
Doctorate student B	Laboratory	Doctorate student	Broker
Specialist A	Company	Specialist	Central
Specialist B	Company	Specialist	Central
Specialist C	Company	Specialist	-
Specialist D	Company	Specialist	-
Specialist E	Company	Specialist	-

Source: Prepared by the author

Table 49: Summary of the interviewee by organization and role

University	**5**	**Company**	**5**
Professor	2	Specialist	5
Doctorate student	2		
Master student	1		

Source: Prepared by the author

5.3 QUALITATIVE ANALYSIS

Selected project members were interviewed according to the semi-structured interview guide, presented in Table 21. Interviews were recorded and transcribed. Transcriptions were then analyzed by thematic analysis. Themes were grouped and provided the results that are presented in this section. Results are organized in three main subsections, Figure 26. First, findings on UIC process are described starting with innovation frameworks used by researchers while explaining collaboration. Then, knowledge flow within the university-industry collaboration for materials innovation is addressed. Finally, materials innovation is described within the innovation process from firm's perspective.

Figure 26: Summary of qualitative results

Qualitative results organized into
1. University-industry collaboration 2. Knowledge flow within collaboration 3. Materials Innovation

Source: Prepared by the author

5.3.1 University-industry cooperation

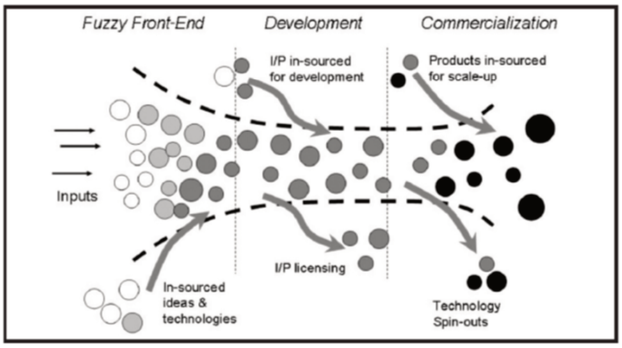
5.3.1.1 Innovation process

Researchers report that university-industry cooperation is part of a company's technological innovation strategy. Company searches differentiation in the market, being ahead of suppliers and traditional solutions. This strategy can also be a reaction to competitors that cause decrease on sales. Innovation, from company researchers' perspective, can be solutions to problems in product and process and also exploring new business. Moreover, a researcher points that the company seeks differentiation because company's market is under commoditization, which is referred to a process in which goods that have economic value and are distinguishable in terms of attributes (uniqueness or brand) end up becoming simple commodities in the eyes of the market or consumers. Company researchers comment that the company was once the market leader and saw decrease on sales and lost market share for its competitors in the past five years.

Following the innovation strategy, the company works on technology roadmaps that plan product and technology development. These development strategies consider short, mid and long terms, though connecting short to long term planning is reported to be a challenge. Another challenge is to envision products ten years ahead due to lack of market knowledge. Moreover, engaging people in the process of planning is also difficult.

Researchers use different frameworks to plan and explain technology development. The innovation funnel is an example, Figure 27. At the left-side of the funnel new ideas enter, while at the right-side mature products are delivered to the market. Ideas enter and exit the funnel all the time and at different levels of maturity. Ideas, or projects are also combined. This concept assumes that not all ideas are employed, or even developed. As ideas enter the funnel, some are dropped off the process and only a few reaches the end of the funnel. A company researcher reports that managers work to increase the number of ideas that reaches the end of the funnel, thus minimizing consumed resources and increasing efficiency of the innovation process.

Figure 27: Innovation funnel

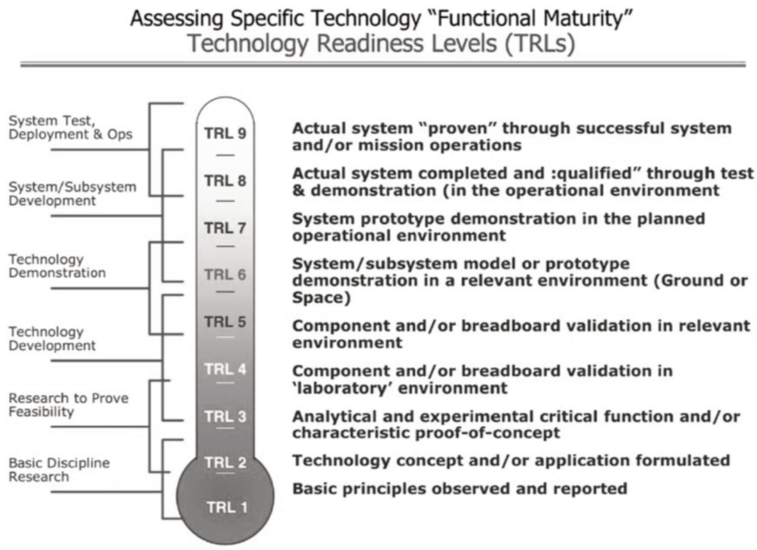


Source: (DU PREEZ; LOUW, 2008)

Related to the concept of the innovation funnel, researchers also referred to the use technology readiness level (TRL) framework, created by NASA to explain technology maturity management, Figure 28. In this framework technologies develop from level one to nine. In level one, basic principles are observed, while in level 9 technologies are commercialized (MANKINS, 2009). According to researchers, not all ideas reach the market and some take more, or less time to develop. Some development cycles take 2, 4 or 15 years to reach market. Development lifecycles comprise a series of steps: development in laboratory, prototype and industrial scales, testing and feasibility evaluation. Company researchers comment that market demands faster lifecycles (i.e. shorter lifecycles), which puts pressure on the innovation process.

Nevertheless, researchers note that risk is part of the process. Not all ideas, technologies, projects and resources allocated will be utilized by the firm, thus waste is part of the process. Exploratory projects at lower TRL (i.e. at the left side of the funnel) present more risk. Technology chaining is also a risk, since one premise can compromise the entire product, or process. Risk management is an issue in technology development, since shareholders are averse to risk.

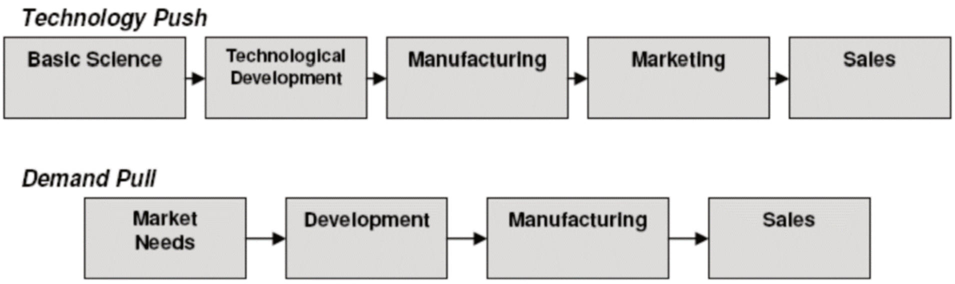
Figure 28: Technology Readiness Level Framework



Source: (MANKINS, 2009)

Another framework mentioned by researchers is the concept of technology push and market pull, Figure 29. This concept refers to the flow of information and knowledge in the process of innovation. Technologies are pushed when market need is defined after or during technology development. Meanwhile, in market pull, technologies are developed to meet market needs (VISHNEVSKIY; KARASEV; MEISSNER, 2016). The company uses both approaches within its innovation strategy. Researchers say that the company tend to market pull and short-term incremental innovation. However, they also say that strategy changes over time, especially with changes in management teams. For instance, researchers reported that the company shifted from a more technology push strategy towards a more market pull approach in the past five years.

Figure 29: Technology push – Market pull framework



Source: (DU PREEZ; LOUW, 2008)

Results on university-industry cooperation are presented throughout four steps: motivation, formation phase, operational phase and outcomes, following (ANKRAH; AL-TABBAA, 2015)'s framework. Results of interviews are described from the perspectives of the company and the university.

5.3.1.2 *Motivation*

Company's motivation to engage in a cooperation with the university described by interviewed members include (i) knowledge and technologies, (ii) new capacities, (iii) develop human resources, (iv) seek funding.

The company collaborates with the university to develop (i) knowledge and technologies and deliver products and processes in the market. By collaborating with the university, company expects to be ahead of the competition in terms of technology with more efficient and cheaper products, with less environmental impact and with less use of raw material. Nevertheless, researchers know that not all knowledge developed convert into products and also not expected knowledge is created.

Company also wants to develop (ii) new capacities alongside with the university such as: a long-term vision on innovation, see new things, or see things by other perspectives. The lack of these capacities impedes the company to work on projects or solve the problems.

The company is interested in developing knowledge, but also (iii) human resources. The company cannot attend some issues today because of the lack of human resources or knowledge. Thus, the company wants to develop human resources that can be hired.

Another motivation to engage with the university is the possibility to access (iv) public funding, which reduce risk and contributes to R&D investment. The studied project was conceived to meet a government notice. Project proposal was written to capture this opportunity.

University, on the other hand, sees the collaboration with the company as a way of (i) developing human resources, (ii) academic production, (iii) inspiration to new research fields, (iv) funding and (v) contribute with the society (societal pressure). Project activities help students to be developed and hired by companies or organizations. Related to the formation of human resources is academic production or knowledge creation such as papers, thesis, dissertation and other products delivered by students or researchers. Working with the company also helps to inspire new research fields, especially applied research. The company collaborates with important knowledge to research associated with the way it works, such as market and managerial knowledge. By working with the company, the university can also access funding, either from the company and from public funding programs that require company participation. This kind of funding notices provide larger amount of resources, compared to those that finance university alone projects. Resources are used to execute project activities, finance other research fields and expand or maintain laboratory's infrastructure. Finally, by working with the company, university works on applied knowledge that helps solving society problems. This way, university works to develop and apply new technologies and knowledge in the market. Working with the company helps to create a sense of purpose. Society demands more sense of market in the university. Thus, collaboration projects help to approximate university to market. This way, university works in basic and applied research. Table 50 summarizes company and university motivations.

Table 50: Company and university motivations to enter collaboration

Motivations of the company	Motivations of the university
— Knowledge and technologies	— Develop human resource
— Capacities	— Inspiration to applied research
— Develop human resource	— Funding
— Funding	— Academic production
	— Contribute with the society

Source: Prepared by the author

Besides company and university another stakeholder in collaboration are funding agencies which fund R&D initiatives with public resources. Those initiatives that companies would not invest on, due to high risks involved. Public notices are thematic and follow government public policies, thus funding agencies influence projects with requirements that project proposals must meet. The studied project is an example.

5.3.1.3 Formation phase

Formation phase comprises the search for competencies, project contracting, idea identification.

To start the cooperation project, the company seeks universities, laboratories and researchers who are recognized for skills that the company needs. The company and the university align expectations between company needs and university research fields and then sign a collaboration project.

During the formation phase, ideas of projects are conceived by the company, by company and university working together and by the university. Though, researchers from both company and university tend to agree that most of the ideas of projects are conceived in the company. Projects are created to solve company needs. Short, mid and long-term needs that come from problems the company faces, such as customer needs, regulation issues, day-by-day needs and research activities. Projects are also born from financial opportunities. Ideas for projects can also come from the strategic vision of the company, which is translated in a technological roadmap that considers market and technology trends. In this process, many areas of the company are consulted. Ideas for projects also come from consulting firms that are hired by the company to help identify opportunities. In the case of the project studied, this was performed before involving the university. Regarding company attitude on idea identification, researchers report that the company sometimes assumes a passive attitude, in which it waits for demands and sometimes an active attitude, when it seeks opportunities. Nevertheless, projects' cost must be adequate to market's disposition of paying for such solutions.

The company also works with the university to conceive projects in a collaboration manner. Company presents problems and university suggests solutions. In this process, gaps of knowledge required to achieve project objectives are identified. Some researchers report a 50-50 distribution of ideas for projects between company and university, though other researchers estimate about 80% for the company. Researchers commented that the ratio between ideas from company and university varies along time. In the past, the university used to help more with project identification and also participated in company's planning. As reported by a researcher, maybe the university now participates less with project identification due to increase of market speed, as university cannot match that speed.

Ideas for projects are also born from the vision of professors in the university. Ideas aim to investigate technological opportunities, beyond company needs. These ideas of basic research are not too connected with short-term needs of the company. Researchers report that the university has difficulty to understand the market of the company and university researchers aren't too interested in market knowledge. University researchers don't see company needs.

In addition, the project can also be born from a funding opportunity presented by a funding agency in the form of a public notice, which is the case of the project investigated. In any case, company and university work to aligning expectations.

A series of activities were identified in the process of ideation (i.e. finding opportunities), such as: brainstorming, need identification with company employees, project and technology maturity assessment, alignment of expectations, prior art search, simulation, preliminary study of potential solutions, cost analysis and analysis of empathy of the final customer. Ideas for projects are also identified during the execution of current endeavors.

Along with this activities, factors of influence were identified, Table 51. Factors include misalignment of expectations between project stakeholders, difficulty on transmitting project requirements, many voices telling different needs, difficulty on managing short- and long-term results, difficulty to follow high speed of changes in the market and long-term planning according to these fast changes. The identified facilitator was alignment of teams in the beginning of the project.

Table 51: Influencing factors of UIC

Influencing factors	
Alignment	— Misalignment of expectations
	— Short term vs. Long term expectations
	— Transmit requirements: many voices
	— Alignment in the beginning of the project
Speed of changes	— Fast changes
	— Difficulty to plan on long-term due to speed of change in the market

Source: Prepared by the author

5.3.1.4 Operational phase

During the operational phase, a series of short, mid and long-term projects are executed. Projects are reported to go through a series of phases, such as: planning, development, validation, feasibility assessment, transfer and incorporation, which are described hereafter.

5.3.1.4.1 Planning

Project planning succeeds idea identification. During planning, project scope is developed; interaction is planned; preliminary research and detailed research are described; deliverables and chronogram are elaborated. Project teams plan to advance on technology readiness levels and integrate multiple knowledge areas. In fact, project planning is based on knowledge sharing between partners. Difficulties found while planning include aligning objectives between company and university, forecasting deadlines and managing multiple organizations.

5.3.1.4.2 Development

After planning, according to interviewees, project is executed in the university, by students, while the company continuously review and manage the project. Throughout project execution university develops knowledge, technologies and solutions in different scales, such as laboratory and pilot-production scale. In the end, some of the technologies developed are transferred to the company, while others may require further steps of development. During execution, projects can also derive from initial objectives, problems may appear and new projects may be conceived. A series of barriers that affect project execution were reported, such as: different interests between company and university, as company is concerned in technological advantage, while university concerned with publications (i.e. objective divergence); short interaction between company and university; and university difficulty to follow company and market speed.

5.3.1.4.3 Validation and Feasibility

The next step after technologies and knowledge are created is to prove technologies, prove concepts, test in products, test in real conditions, confirm expected gains, assess application feasibility and approve technologies. This technology assessment is performed from various perspectives: technical, economic, financial, while different areas of the company are involved in this step. Projects must be attractive to proceed.

5.3.1.4.4 Knowledge and technology transfer

Knowledge and technology transfer are treated as a subsequent step of project execution. Knowledge and technology are transferred to the company in different ways, such as: hiring, visits to the company, work in collaboration with company specialists. This integration between university and company is required until the application of knowledge and technologies. A researcher reports that the lack of connection between university and company during development activities act as a barrier for knowledge transfer. Company's interest is another factor that affects knowledge transfer, technologies and knowledge that are not or become not interesting to the company stay in a buffer of solutions. Technologies and knowledge must meet development windows (i.e. attend development deadlines) within the company, otherwise other solutions may take their place in the technology roadmap. Thus, not all knowledge and technologies developed are transferred to the company.

5.3.1.4.5 Application

The process of applying knowledge in the firm is complex, involves different areas within the company and it usually takes time. The process requires modification of many processes of different areas, demanding a responsible for integrating those people. Barriers identified with interviewees are: knowledge and technology must be very attractive to a series of areas in the company; technological and economical factors may turn a technology unfeasible; missing windows of opportunity may block the use of knowledge; other technologies and knowledge may compete; changes in the company strategy due to change on management, economic scenario, market share; and employee's desire to implement consolidated solutions, with less risk. A facilitator of this process is the existence of a broker who is responsible for joining people in the company.

5.3.1.5 Outcomes

The definition of project success or benefits for company and university differ. On one hand, success for the company is delivering knowledge, technology, products and methods in the market, in other words, company wants to put knowledge in the final product. In this sense, success indicators are number of technologies developed, patents, components developed, number of hired personnel, interest of other areas in the knowledge created, technical and economic gains and cooperation continuity, because if projects add value, then companies continue to invest on them. However, a company researcher says that project success can also be responding questions and not necessarily implementing knowledge in products. Knowledge that proves things don't work is also a success criterion. Nevertheless, researchers comment that measuring success on university-industry cooperation projects is difficult.

On the other hand, university measure of success or benefit of projects are achieving company expectations, train people, filling patents, partnership continuity, solutions development, publication, impact index of articles and journals, development of laboratory infrastructure, curriculum development (also measured by research agencies indexes) and post-graduation program index improvement.

Table 52 summarizes results found in each aspect of the UIC framework: motivation, formation phase, operational phase and outcomes. In order to achieve project success, company and university follow-up projects, which is described in the next section as management activity.

Table 52: Summary of results of University-industry cooperation (UIC)

	Motivation	Formation phase	Operational phase	Outcomes
Company	— Strategic plan — Innovation and technology plan — Materials development — Collaboration	— Search of specialists — Contracting — Accessing funding — Ideation	— Planning — Development — Testing — Validation — Feasibility — Transfer — Incorporation	— Technologies — Patents — Components — Hired personnel — Interest of other areas within the company — Knowledge — Technical and economic gains — Cooperation continuity
University	— Human resources development — Resources — Publication — Applied research	— Ideation	— Planning — Development — Testing — Validation — Feasibility — Transfer	— Achieve company expectations — Train people — Fill patents — Partnership continuity — Solution development — Publication

	Motivation	Formation phase	Operational phase	Outcomes
				— Impact index of articles and journals — Development of laboratory infrastructure — Curriculum development — Post-graduation program index improvement

Source: Prepared by the author

5.3.1.6 Management

Company and university both participate in project management. They keep aligning objectives and expectations by periodically reviewing project scope, which is said to be positive for project and partnership success (i.e. continuity). Follow-up is important because, according to company specialists, projects if not supervised deviate from project scope and company needs change rapidly. The continuous follow-up is a process that brings university researchers close to the company, integrates university development and implementation in company, helps the company to assess project potential and helps saving time. This process, however, didn’t exist and was developed over time, according to a company researcher.

This process involves people in the company and in the university, whose managers present a technical profile. The managing group administer and define objectives from the project ideation until deliverables output. According to a company specialist management by more than a person generates credibility. This work involves brokers, that works to integrate areas and which is said to be a hard work. Those brokers work to manage expectations and involves knowledge of managing and integrating competencies.

In the company, management is performed by specialists, a cooperation manager and R&D manager. Directors are also involved in some moments. Managing in group is said to amplify vision and bring more people to participate, which helps to achieve company objectives. A specialist of each area is allocated to each area in the university, acting as a broker. Each specialist has a management profile. As reported by a specialist, a facilitator of the process is developing an interested person inside the company, which feels the importance of the partnership and solutions developed. On the other hand, the lack of these interlocutors is a barrier for the partnership. Another mentioned facilitator of the process is the presence of the university in the company routine in a day-to-day base, along with project execution.

In the university, management is performed by professors with support of post-graduation students. The university seems to be more horizontally organized and projects within the university seems to be less managed compared to the company. Management in the university depends on the profile and willingness of the researcher. Researchers are said to see more their deliverables and objectives rather than the company's. A reported barrier to manage projects in the university is the technical profile of the researchers, thus the presence of the university in the company routine is a facilitator. A challenge to manage projects is the integration of multiple laboratories, teams, profiles and fields of knowledge and laboratories that are not connected.

Regarding management models, a series of models were tested in the partnership. These models are usually related to those managers. Researchers say management models within the company and the groups in the university should be integrated, which is a challenge. Establishing a connection and managing people between groups is difficult. Managing the partnership is developed through time. Another challenge of managing partnerships is to conciliate activities, company and academic deliverables. According to a company researcher, within the partnership short, mid and long-term activities are performed and short term are important to keep company close and maintain communication.

Within these management models, meetings are frequently mentioned. Meetings are used to periodically review deliverables, to follow-up projects, mark project milestones and discuss results. Meetings address project communication, which can cause frustration in case of communication failure. Meetings are performed with members of the company, of the university and sometimes of the funding agency. A barrier identified for meetings is the time meetings consume and the lack of time availability of researchers from the company and from the university.

The series of factors that facilitate or difficult management activity are displaced in Table 53. Barriers to manage projects include lack of time to engage in management activities, which is related to the few people allocated; lack of management profile within project members, especially in the university; and lack of interaction between areas and between university and company. On the other hand, facilitators include geographical proximity, that contributes to a more frequent contact; presence of an interlocutor in the company (i.e. broker); previous experience of partners in cooperation; and trust between partners, which is reported to be acquired through time along years.

Table 53: Influencing factors of UIC management

Influencing factors	
Interaction	— Lack of interaction between areas and between university and company
	— Previous experience with cooperation
	— Trust between partners
	— Meetings
Availability	— Lack of time
	— Few people to manage projects in the company
	— Allocate management in the technical body in the university
Brokering	— Interlocutor in the company
Geography	— Geographical proximity

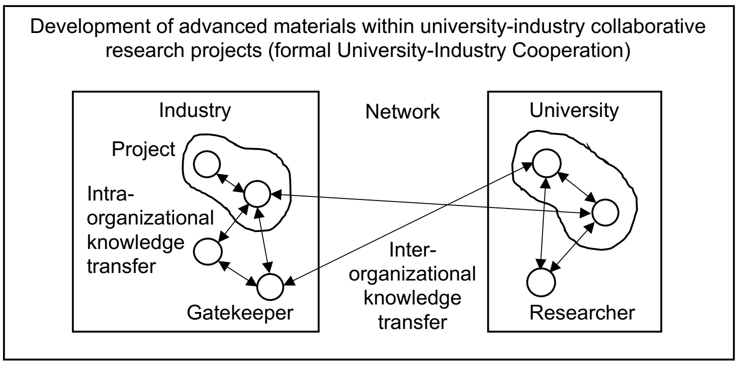
Source: Prepared by the author

The next section explores cooperation management, throughout the lens of knowledge management, addressing knowledge and technologies shared by areas and, between university and company, which is referred as knowledge flow.

5.3.2 Knowledge flow

In the second part of the semi-structured interviews, interviewees were asked to describe how knowledge flowed in order to achieve project objectives. Within the UIC, at industry side, specialists work to develop new products and processes to sustain competitive advantage of the firm. At university side, researchers work to create new knowledge and technologies. Each individual also plays a different role in the network, for instance gatekeepers may moderate knowledge flows between teams and organizations. For instance, on company's behalf, technology or product researchers act as brokers between the activities held in the university and the new product development process within the firm. Therefore, these researchers bridge the knowledge between product development team members in the firm and university researchers. Inside both organizations, individuals are grouped into teams with common goals. Knowledge flows as researchers share knowledge inside and outside project and organization boundaries, Figure 30.

Figure 30: Diagram of knowledge flow in a university-industry cooperation network

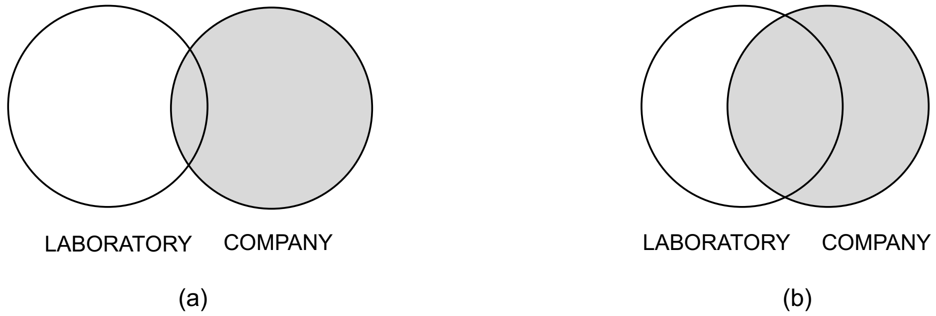


Source: Prepared by the author

Knowledge content that flows in this network of individuals, groups and organizations (i.e. intra and inter-organizational knowledge flow) differ in type (e.g. technological, market and managerial), intensities and directions. Project members listed many types, such as: applied knowledge, technical knowledge, technological maturity knowledge, market knowledge, technical assistance knowledge, marketing knowledge and managerial knowledge. Regarding managerial knowledge, a company researcher says that few university laboratories has some managerial knowledge. This same company researcher says that the company knows little about how knowledge flows within the university. Know-who and know-what were also mentioned by researchers. They referred to know-who as the right persons to talk to, while to know-what as to know what knowledge is available. Knowing what laboratories do, are opportunities of partnership.

Researchers commented that knowledge of different areas or domains are used in the process of materials development and that knowledge overlaps across areas. For instance, knowledge overlaps across company areas (e.g. sales, marketing, procurement); between value chain and business core domains; and between university and company domains. In this application case study, the main university laboratory involved in the cooperation project presents a moderate overlap of knowledge with the company. While the university laboratory works with materials development – at the beginning of value chain –, the company is focused in device development. In contrast, one of the university laboratories involved in the cooperation project presents a wider overlap in knowledge with the company. This difference in knowledge overlap evidences a distinct relationship between these laboratories and the company. Referring to (RAJALO; VADI, 2017)'s model, Figure 31 shows overlaps of these two laboratories and the company, which has managerial implications. Another important aspect of materials development concerns the application of technology, or knowledge developed by the cooperation. Many times, knowledge is applied in company's suppliers instead of company's own boundaries. These aspects possibly affect knowledge overlaps, knowledge flows, interaction dynamic and management models to be adopted in each case.

Figure 31: Concept of UIC overlap knowledge: (a) moderate knowledge overlap, (b) high knowledge overlap



Source: (RAJALO; VADI, 2017)

Regarding knowledge process, eight processes were identified: acquisition, creation, sharing, retention, loss, recover, apply and manage, Table 54, which are described as follows.

Table 54: Knowledge process identified in interviews

Knowledge processes	
— acquisition,	— loss,
— creation,	— recover,
— sharing,	— apply and
— retention,	— manage

Source: Prepared by the author

5.3.2.1 Acquisition

During knowledge acquisition, team members acquire knowledge by literature review, reading papers, thesis, dissertations, patents and benchmarking.

5.3.2.2 Creation

During knowledge creation, market knowledge is generated in the company, technical knowledge is created based on market knowledge, in the university and in the company. Knowledge creation happens during project activities, developing experimental apparatus, simulation models. Knowledge is created in discussion with the company and from the results of the project and the interaction between company and university during project execution.

5.3.2.3 Sharing

Knowledge sharing was the most commented knowledge process. University researcher commented that in the beginning of the project, knowledge flows from the company to the university. It is said that the knowledge flow between company and university helps to generate more results from the partnership, that working collectively with follow-up and communication generates more results.

Meetings is the most commented topic in knowledge sharing. There are technical meetings, formal and informal conversations of sharing. Tacit knowledge is said to be shared in meetings. During meetings knowledge is shared, but also created. During project execution, there are meetings between professors and students, between company and university, when groups of the university present results for the company, between university and funding agency, which are less frequent. There are meetings to follow-up project budget.

Some groups of the university go to the company and understand its reality and see company's objectives. People from company areas try to share knowledge concerning development. And company has knowledge areas, that interact with the university. A university researcher reported though that meetings are not enough for the university to understand the reality of the company.

Sharing include online communication channels, such as e-mail and phone calls and reports, though a company researcher says that in meetings sharing is more effective because both sender and receiver are in the same "page". Other ways of sharing include experimental apparatus, good practices, presentations, training, hiring people (i.e. personnel mobility), dissertations, thesis and papers.

Researchers mention the role of brokers in knowledge sharing. Brokers are focal points in communication, which are responsible for propagating knowledge. Brokers permeate organizations. There are brokers between areas, there are brokers in the company and in the university.

Identified factors that influence knowledge sharing are presented in Table 55, which are organized in (i) know-who and know-what, (ii) interaction, (iii) availability, (iv) brokering and (v) absorptive capacity.

Table 55: Influencing factors of knowledge flow identified in interviews

Influencing factors	
Know-who & know-what	— Don't know the people that has knowledge (know-who) — Don't know what knowledge is available — Don't know that knowledge sharing is needed — Don't know what other laboratories do
Interaction	— Little communication with the company — Punctual interaction between groups — Lack of open channel of communication — Groups don't have many projects in conjunct — Difficulty in interaction — Size of the team: bigger teams require structured meetings, communication in small teams is easier — Transparency and trust
Availability	— Knowledge sharing consumes time — Limited time to interact with other groups — Dispute time as a resource to follow-up project — Mobilize people to meetings — Overload of information and knowledge — Geographical distance
Brokering	— Broker doesn't give flow to knowledge — Communication centralization only in one person (broker) is prejudicial to knowledge flow as it restricts flow rate
Absorptive capacity	— Disinterest of the company — Company reality is not visible to university

Source: Prepared by the author

5.3.2.4 Retention

Knowledge retention is reported to be accomplished by expliciting knowledge in reports, in cloud platforms, documents, systems, centralized and decentralized repositories and experimental apparatus. Researchers say that knowledge explicitation is difficult, that some tacit knowledge can't be explicited, that few knowledge is explicited and it is sometimes performed in activities of sharing tacit knowledge. They say that the process of documenting knowledge consumes a lot of time and few people spend time documenting knowledge. Researchers say that most of the knowledge stays in the university, especially knowledge on what went wrong. It is said that the company does not present a structure to retain knowledge developed in the university which is not used in projects. Another reported form of knowledge retention is throughout projects.

5.3.2.5 Loss

Researchers reported that knowledge is lost when people change, when knowledge is not shared, if organizations that cooperate separate, if knowledge is not used and if there is no knowledge repository. If there is no knowledge repository, there is no recovery of previously created knowledge. Losing knowledge is said to result in repeating the same mistakes, which is waste.

5.3.2.6 Recovery

Researchers mention that there are tools to search knowledge and that documentation helps to recover knowledge. Communication is also a form of searching knowledge. Researchers say that retain knowledge is important, but recover knowledge is difficult, such as reading reports. Researchers are not used to recover knowledge that were not used in products and projects, which were created in the university. Though, researchers say documentation is important because it also helps to recover tacit knowledge.

5.3.2.7 Application

Knowledge develop in collaboration is applied in products, reports and manuals. While working in the company, researchers work by demand, using available knowledge. They decide whether or not use knowledge. There are responsible in the company for the internalization of knowledge. In the beginning of the project, there is no idea on how to apply knowledge.

5.3.2.8 Management

Researchers report that knowledge flow management is not structured, though it is a responsibility of the project leader and each team. Researchers say that periodic internal communication and synchronization of activities in the company and in the university facilitates knowledge flow.

5.3.3 Materials innovation

One of the areas or fields of research in the company's innovation process is new materials development, which is the object of this research. Researchers say although developing new materials is not company's core business, the company works with new materials to differentiate their products from competitors'. By using materials as a source of differentiation companies may access advantage.

As reported by company researchers, one of the benefits of developing materials in-house concerns the ability of competitors to copy solutions. Materials, unlike product design, may be difficult to copy, because processes used to manufacture components are not visible in final products. Competitors may assess materials composition, but not how they were obtained, or they may know that components are different but not how they were manufactured. By developing in-house, competitors cannot access these characteristics throughout suppliers and must develop their own solutions with or without suppliers in order to implement in their products. Materials technologies impose a barrier to copy.

Another benefit of developing materials is related to materials availability in countries. Materials may be more or less expensive, or even unavailable, which may influence price of final products and therefore competition dynamic.

Other characteristic of materials addressed by researchers and the literature review is its ability of being generic. Materials development delivers solutions to different components, systems, products and areas of the company. This may be attractive from a resource allocation perspective.

Materials are also mentioned as an upstream technology, i.e. in the beginning of the value chain. Interviewees reported that they perceive materials far from the final product and far from value perception. Materials researchers face more phases to implement technologies in products. Technologies are delivered in lower levels in the technology readiness level framework and take more time to be implemented. Changing materials may imply changes in the chain production, which involves high costs.

Thus, developing materials involves many areas in the firm. People and knowledge of many areas are required to implement technologies in products. The innovation process involves not only R&D personnel, but people from systems, legal, intellectual property, manufacturing, logistics, marketing, sales, procurement and foreign trade. Projects are multidisciplinary and simultaneously. This means that materials development teams work with many other areas within the company.

Within this innovation process, researchers evidence the complexity of developing solutions and address the need to collaborate with the university to meet company's objectives, especially regarding long term projects.

This qualitative part of the research described the materials innovation, UIC process and knowledge flow within firm's innovation process. UIC was described using (ANKRAH; AL-TABBAA, 2015)'s framework: motivation, formation phase, operational phase, influencing factors, outcomes and management, as an additional perspective. Building on UIC, knowledge flow was characterized by its knowledge processes, wherein knowledge sharing was the most discussed process by researchers, and its influencing factors.

Results present some evidence on the influence of knowledge flow in UIC, such as network size, network density by knowledge type, role of brokers bridging knowledge, absorptive capacity or knowledge value of participants and practices involved, especially knowledge sharing activity. Influencing factors identified that are related to knowledge flow and UIC identified include industry, knowledge field, technology readiness level, value chain position, knowledge overlap and speed of changes.

Next chapter discusses quantitative and qualitative results, reviews the proposed framework of analysis and suggest a set of practices to enhance knowledge flow within UIC.

6 DISCUSSION

This chapter discusses findings of the framework application. Considerations are made on the materials innovation case studied, on the framework of analysis and on the tested relationship between knowledge flow practices and UIC performance. Then, based on considerations, a revised framework of analysis and a set of practices are proposed.

6.1 MATERIALS INNOVATION

The analysis of this university-industry collaboration shows materials innovation as part of an innovation strategy of the firm to differentiate its products, thus sustaining competitiveness. Within this strategy, company and university collaborate to, among other benefits, reduce costs and accelerate time to market in advanced materials development. During formation and operation phases of collaboration researchers operate in a complex knowledge flow network to achieve collaboration objectives. Complexity arises from a series of factors intrinsic to materials innovation. Some seems to arise from the fact that materials suppliers are at an upper position within the supply chain (MAINE; SEEGOPAUL, 2016). The company in the studied collaboration, for instance, is recognized for using advanced materials in their mechanical devices, though materials development is not among company’s major competencies (i.e. knowledge fields). Thus, company and university show a moderate overlap concerning knowledge, which results in a limited ability to recognize knowledge’s value (i.e. absorptive capacity) and that compromises knowledge flows (GUPTA; GOVINDARAJAN, 2000). Interventions, thus, should be implemented to enhance absorptive capacity, especially at the firm, for achieving outcomes (RAJALO; VADI, 2017). Also, the upper position causes an indirect application of the knowledge developed in collaboration. Knowledge is not always implemented directly within the company that participates in the collaboration, but in company’s suppliers, which then delivers parts to company’s own products. Knowledge in this case travels longer paths which may encounter more obstacles. In addition, materials development is a multidisciplinary endeavor that encompasses researchers from different knowledge areas within company and university. In other words, more nodes in the network must be involved in the process, in order to achieve desired outcomes and benefits. Thus, managing knowledge flows in materials innovation is an important factor for collaboration success, as evidenced in this study, which involves aspects such as knowledge type, actors, groups and activities.

6.2 CONSIDERATIONS OF FRAMEWORK APPLICATION

Three types of knowledge were investigated in this research: technical, managerial and market knowledge. Technical knowledge was the most shared, as one would expect since access to technical knowledge is a motivation for UIC. Unlike technical knowledge network, managerial and market networks are less connected and fragmented in composites, thus more dependent on brokers for knowledge to flow. Additionally, most links that share technical knowledge are bi-directional, i.e. they send and receive knowledge, but for managerial and market knowledge, a large number of researchers say they only receive this type of knowledge, thus showing a limited flow and probably the need of a special attention. Different knowledge flows, thus, coexist in UIC, with different dynamics and effect in collaboration success. Therefore, increasing chances of collaboration success by managing knowledge flows requires knowledge flow segmentation and application of specific actions designed for each flow. Managerial and market knowledge flows, compared to technical knowledge, are moderate, hence their influence on collaboration success should be further investigated.

Actors in those knowledge flows are professors, doctorate, master, undergraduate students, company managers and specialists that participate in the process of developing new knowledge and technology. Professors are more central and in-between nodes, but other roles present similar centrality and in-betweenness scores. Centrality and in-betweenness therefore, don't seem to be linked to formal roles, as evidenced by (ALLEN; JAMES; GAMLEN, 2007b). Results show also that these positions also change according to type of knowledge. Key nodes scattered by each network, then, must be considered while designing strategies to influence knowledge flow and collaboration success.

Contrary to expectations, group characterization didn't show significant relationship between groups of nodes, network parameters, knowledge management practices and UIC performance, except for role that evidenced professors as more central and in-between nodes. Network parameters, especially centrality and in-betweenness also show no significant correlation with any indicator of UIC performance and KM practices. In other words, there wasn't found a group that significantly evidenced more or less knowledge management practices, or UIC performance. Segmentation by groups was inconclusive with adopted instruments and a specific investigation at nodes would contribute to this matter.

The analysis of knowledge flow evidenced the knowledge intensive activity that is UIC. Activities include acquisition, creation, sharing, retention, loss, recover, apply and manage, that occur along formation and operation phases of collaboration. Knowledge sharing was the most discussed activity by researchers and all barriers identified in this study concerns sharing. Many of those identified barriers refer to the existence and richness of transmission channels, in line with (DE WIT-DE VRIES *et al.*, 2019) that evidence the importance of communication practices for the quality of knowledge sharing. These identified barriers were used, in the end of this section, to propose two practices to enhance knowledge flow and UIC.

This work also provided insights on knowledge flow characterization and team-level analysis for this type of cooperation. Knowledge flow characterization, using a questionnaire, provided a good overview of project members, key nodes and network. This technique showed a good way to triangulate data and compare quantitative data with interviews. It was possible to map a wide number of collaboration members, including those that are not formally participating. SNA tools helped evidencing key nodes, roles and distinct knowledge networks. However, grouping techniques (i.e. clique and equivalence) didn't provide evidence on key groups, showing that they were not adequate to these research characteristics and objectives. The main contribution of SNA to this study concerns techniques of data collecting and network mapping. Regarding micro-level assessment, the study investigated UIC not only from top management perspective, but from undergraduate students up to professors and company researchers. Results provided information from undergraduate students who perform experiments in university laboratories, to company researchers who work to apply it in company R&D processes, thus showing operational issues, barriers and challenges in multiple management levels. Results show that the view of people on top and bottom management might be different, which impact instruments (i.e.

questionnaire and interview scripts) that must consider this to produce consistent results. Instruments proposed to assess KM practices and UIC performance were not adequate at a team-level assessment. A disadvantage of micro-level assessment includes more people to be interviewed, or to respond questionnaires, still, micro-level analysis contributed to a deeper understand of UIC operation.

6.3 KF PRACTICES AND UIC KPIS

An intriguing result concerns a non-significant relationship between UIC performance indicators and KM practices, evidenced by structural equation modelling. SEM confirmed expected relationship between UIC indicators inputs, in-process activities, outputs and impact and at the same time the relationship between KM practices actionable knowledge support, knowledge retention, sharing and retention. Though, there was not found significant relation between UIC performance indicators and KM practices. In other words, with the applied instruments it wasn’t possible to identify any relationship between UIC and knowledge management. At least five reasons might explain the unexpected result: (i) intermediate variables, (ii) university perspective, (iii) instrument fit, (iv) level of assessment (micro and macro) and (v) time spam, described hereafter.

(i) Intermediate variables. There might exist intermediate variables between UIC performance and KM practices, that moderate the influence. Although there is evidence that knowledge transfer is important for a successful collaboration (PHILBIN, 2008; RYBNICEK; KÖNIGSGRUBER, 2019), many situations may mediate knowledge sharing and application of knowledge in company products and processes, as measured by UIC output and impact indicators, such as capacity, or willingness of teams in the firm to apply knowledge developed within the university. Intermediate indicators might be used to assess UIC performance, on the way to implement knowledge. (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)’s UIC framework presents “in-process activities” indicators, though they are related to UIC management and not UIC partial deliverables, which will be assessed by the firm. Outputs in UIC performance indicators might be divided in two, outputs produced during UIC projects and outputs incorporated in products and processes. There is a gap between project deliverables and the application of those knowledge. For instance, meeting development lifecycles windows is important to knowledge and technology application, missing those windows may impede knowledge or technology application even if they are promising. Absorptive capacity is another important construct that counts when applying knowledge (GUPTA; GOVINDARAJAN, 2000).

(ii) University perspective. Practically all responses were collected from university researchers, professors to undergraduate students. Since university researchers may not be aware of activity within the firm, results may not provide a complete view of the application of knowledge developed in collaboration. More responses should be gathered from the company to provide a clear understanding of UIC performance.

(iii) Instrument fit. As discussed in items (i) and (ii), instruments might not be ideal to the purposes of this research, especially UIC performance. While “in-process activities” indicators are focused in UIC management, “outputs” and “impact” addresses the application of knowledge by the firm, which may be way ahead after handing over project deliverables. Partial results, especially regarding awareness and use of knowledge might be intermediate indicators to UIC success.

(iv) Level of assessment (i.e. micro and macro levels). Level of assessment might be playing influence in results. This study gathered responses from professors to undergraduate students. Maturity, awareness and wide view of cooperation landscape, project objectives, motivations, deliverables etc. might be very different. The view of professors managing UIC is very different from undergraduates. Responses thus may be limited by the view of respondents of the application of knowledge or technologies in the firm. Again, intermediate indicators might better fit the purposes of the study.

(v) Time spam. Respondents were asked about application of knowledge in the firm. Knowledge created in UIC projects are still to be analyzed, developed and used in products. Thus, application might be investigated again in the future, or it should have studied past projects that have already finished in the past years. University researcher’s turnover is high, since participation of undergraduate, master and doctorate students spam from 1 to 4 years. Respondents might not be aware of projects in the past and the application of knowledge developed in those projects.

Results show that these quantitative instruments cannot be used to assess the relationship between UIC performance and KM practices at micro level, without further development. Nevertheless, this study confirms (SINGH, R. M.; GUPTA, 2014)'s framework of KM practices and (ALBATS; FIEGENBAUM; CUNNINGHAM, 2018)'s UIC performance indicators separately.

6.4 REVISED FRAMEWORK

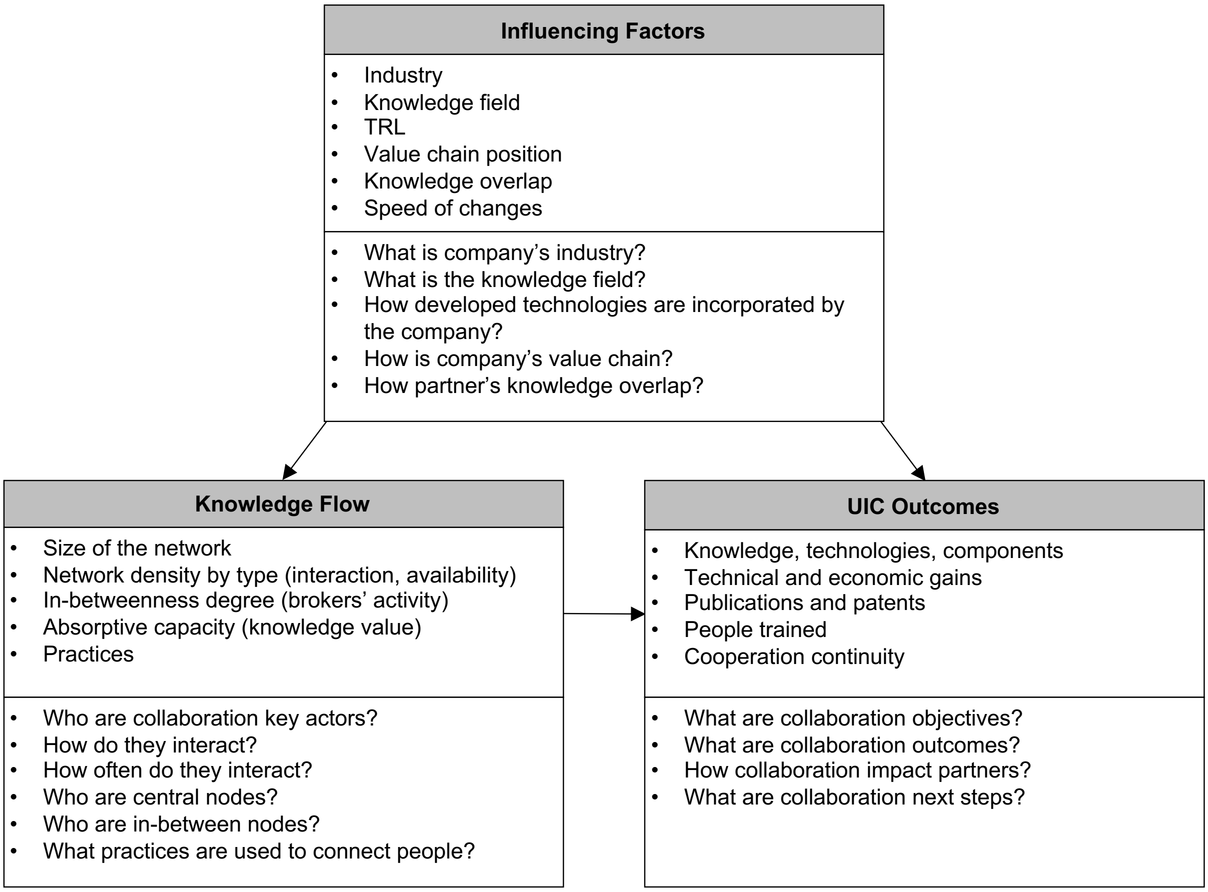
Based on results the framework of analysis of knowledge flow, UIC outcomes and influencing factors is revised and depicted in Figure 32. Each construct is presented with two boxes. The key elements to be analyzed are disposed in the upper box and the key questions to be used in semi-structured interviews, in the lower box.

The framework suggests investigating KF throughout its network, density, broker activity, absorptive capacity and practices. UIC outcomes are investigated by main outputs of UIC such as knowledge, technologies, components, publications, patents, people trained and UIC impact such as technical and economic gains and partnership continuity. Main influencing factors of knowledge flow within UIC include industry, knowledge field, TRL, value chain position, knowledge overlap and speed of changes. Results can be gathered by identifying the network using the snowball technique and interviewing key participants of the collaboration.

With this framework one could analyze, with latitudinal and longitudinal approaches, the impact of knowledge flow on UIC outcomes and advance on this research avenue. The framework also provide insights for managers to plan knowledge flows in order to maximize outcomes out of university-industry collaborations.

The revised framework was tested with two researchers from another small UIC for materials innovation, one researcher from university and other from company. The framework appears to be a consistent instrument to investigate the relationship between knowledge flows and UIC.

Figure 32: Revised framework of analysis to knowledge flow in UIC



Source: Prepared by the author

The next section proposes a set of practices to improve knowledge flow based on the influencing factors identified within this university-industry cooperation for materials innovation case.

6.5 PROPOSITION OF A SET OF PRACTICES TO IMPROVE COLLABORATION

Most factors influencing materials innovation cooperation success identified in this study concern knowledge sharing. Based on the characterization of materials innovation, UIC and knowledge flow, two practices were designed to address factors that hinder knowledge flow. The first suggest creating a structure of periodic meetings to connect researchers and areas within and between university and company. The second suggest splitting UIC portfolio in short-term and long-term projects. Table 56 shows these two practices and the factors each one address.

Table 56: Proposed solutions to improve collaboration and factors they address

Factors	Structure of periodic meetings between company and university researchers and areas	Split portfolio in short-term and long-term projects
Know-who & know-what	x	
Interaction	x	
Brokering	x	
Alignment	x	x
Absorptive capacity	x	x
Fast changes	x	x
Availability	x	x

Source: Prepared by the author

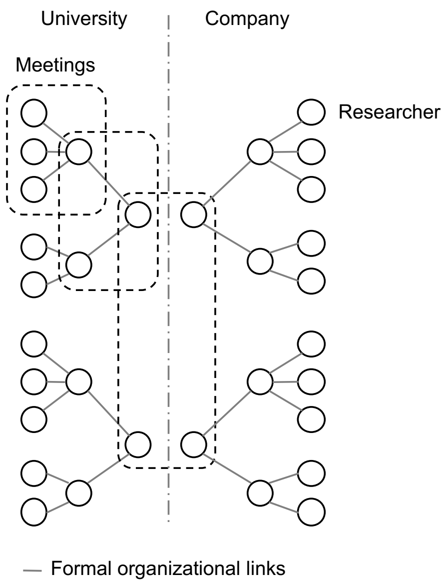
6.5.1 Periodic meetings

Since knowledge sharing knowledge is important to the success of UIC (DE WIT-DE VRIES *et al.*, 2019), this work suggests a structure of periodic meetings to connect researchers across areas in university and company. Improving knowledge sharing is expected to facilitate alignment of objectives and expectations, reduce project uncertainties, constantly assess project feasibility and take measures, meet requirements of multiple areas, share managerial and market knowledge and thus facilitate knowledge absorption in the firm.

Just increasing number of meetings though may not be enough to promote knowledge sharing, once lack of time is another identified barrier to get teams together. Thus, a structure of meetings is suggested to bring teams together without negatively impacting their time availability. The proposed solution is a structure of hierarchical and periodic meetings composed by representatives of each cooperation level and thus providing a better use of resources. In other words, the model proposes increasing the total number of meetings across the collaboration, without increasing the number of meetings individuals must attend. Periodicity might be defined by researchers, so that the right knowledge must reach the right people at the right time, in order to meet project objectives and expectations. Figure 33 shows the proposed structure of meetings, which reflects team organization. Each team or meeting has a leader responsible for calling and conducting meetings. Those leaders organize themselves in the next level of meetings with a new leader. This follows until reaching the interface with the company and vice versa. The model suggests that the last level should involve multiple areas of the university and of the company, instead of having only two brokers between both parties, i.e. one each side. Having only one path between university and company may restrict knowledge flow between partners, thus failing to meet requirements, expectations and compromise from areas that should be involved. In this model, leaders can be seen as gatekeepers of UIC levels. The structure may be used during project planning and execution. Meetings agenda may encompass project planning, follow-up, continuous feasibility investigation, requirement, continuous alignment, objective review and other activities required to guarantee project (i.e. collaboration) success. One should note that this practice is suited for large collaborations involving a series of researchers and areas in the university and in the company.

In summary, this structure aims to promote a minimal and constant flow of technical, managerial and market knowledge within and between organizations. With regular meetings this model intends to improve collaboration members interaction, create more knowledge brokers, promote continuous alignment between partners, improve absorptive capacity - i.e. knowledge awareness – and enhance the capacity to follow-up changes, while considering members availability. One should note though that the model does not intend to substitute other types of interaction between researchers, such as those to transfer technologies.

Figure 33: Illustration of proposed structure of meetings



Source: Prepared by the author

6.5.2 Portfolio split

During collaboration different knowledge flows coexist while working on collaboration objectives. University and company have distinct objectives which difficult the process of incorporating knowledge in new products, or processes (ANKRAH; AL-TABBAA, 2015). On one side, as company is interested in developing new products and processes as soon as possible, company researchers complain that university has difficulty on delivering in time or following changes at market speed. On the other, as university is interested in creating knowledge and developing human resources, university researchers complain on industry focus on short-term results. This problem might be greater in materials innovation, since materials development involves multiple areas, is at the base of the value chain and shows a smaller knowledge overlap.

By deliberately splitting UIC portfolio in short and long-term projects, Table 57, objectives may be managed accordingly, thus reducing divergence in expectations and better accommodating company and university interests. Short-term portfolio addresses company's interests, while long-term, university's ones. This way, university may commit with company's short-term outcomes, in exchange for long-term outcomes and vice-versa.

Short-term projects are oriented towards short-term deliverables, less risk, incremental innovation, market-pull oriented, agility to follow changes, attention to deadlines and development cycles and more frequent follow-up meetings to guarantee project outcomes. Short-term deliverables might involve market-oriented researchers, frequent interactions, intensive in market knowledge flow, attention to deadlines and being affected by faster changes.

Long-term projects, on its turn, are oriented towards long-term deliverables, more risk, radical innovation, freedom to push knowledge boundaries, technology-push oriented, less frequent follow-up meetings. Short-term deliverables might involve science-oriented researchers, less frequent university- company interaction, majorly technical knowledge flows, less pressure on meeting deadlines and being less affected by changes in scope.

In summary, this practice tries to improve the balance between company's and university's own interests while collaborating for mutual and also distinct objectives. By handling objectives apart, knowledge flow networks can be designed and managed with the appropriate nodes and interaction.

Table 57: Long-term and short-term portfolio orientation towards each criterion

Criteria	Long-term	Short-term
Focus	— University	— Company
Deliverables	— Long-term	— Short-term
Risk	— More	— Less
Innovation	— Radical	— Incremental
Push - Pull	— Technology-push oriented	— Market-pull oriented
Expectations	— Freedom to push knowledge boundaries	— Attention to deadlines and development cycles — Agility to follow changes
Follow-up	— Less frequent follow-up meetings	— More frequent follow-up meetings to guarantee project outcomes

Source: Prepared by the author

These two suggested practices are expected to increase the chances of collaboration success and materials innovation by promoting knowledge sharing throughout a formal structure of meetings and managing expectations of university and company researchers. Further research must still be conducted in order to test the model.

7 CONCLUSION

The objective of this research was to analyze how knowledge flows in order to meet objectives of a university-industry collaboration for materials innovation. The research proposes a framework of analysis for the relationship between knowledge flow, analyzes knowledge flows within a large university-industry collaboration for materials innovation and proposes two practices to stimulate knowledge flows in UIC thus promoting innovation.

The major contribution of this work is a framework of analysis for knowledge flow within UIC at a micro-level perspective, which was used to characterize knowledge flows within a formal collaboration for materials innovation. The framework was developed from the literature review and used a mixed method approach including both quantitative and qualitative approaches to assess the constructs. From the quantitative approach the framework used a three-part questionnaire elaborated with micro-level instruments found in literature which characterized SNA parameters, knowledge management practices and UIC key performance indicators. From the qualitative approach the framework used semi-structured interviews to assess knowledge flow and university-industry collaboration also based on the frameworks found in the literature.

Quantitative results characterized knowledge flow networks, knowledge management practices and UIC indicators. Results provided relevant information on each construct alone, however the relationship between constructs could not be evidenced with the employed instruments. This result may be explained by the use of non-adequate indicators at a micro-level assessment, the existence of intermediate variables, data being gathered only from the university and the need of a longitudinal study, thus requiring those instruments to be further developed, especially UIC outcome indicators that may be developed for short-term assessment. The instruments thus may not be used without further development for this application.

Qualitative results described the processes of knowledge flow, UIC and the innovation in the firm. Results present some evidence on the influence of knowledge flow in UIC, such as network size and density, broker activity, absorptive capacity and practices. Influencing factors impacting knowledge flow and UIC were also identified including industry, knowledge field, technology readiness level, value chain position, knowledge overlap and speed of changes.

With results the framework was revised and tested on another collaboration for materials innovation. The framework of analysis was able to characterize, from a qualitative perspective, the knowledge flow in the UIC and provided insights to design and improve knowledge flows in UIC for innovation.

Based on identified influencing factors, two practices were proposed to help knowledge flow and thus UIC success: (i) implement a structure of periodic meetings to connect researchers across areas; and (ii) split collaboration in short-term and long-term projects. These practices are still to be tested and confirmed.

By analyzing collaboration at a micro-level this work provided a deep view of the collaboration, which allowed to characterize knowledge flows within UIC, develop a framework of analysis and propose a set of practices. The insights help advance the micro-level research avenue of the constructs involved.

This work confirms materials innovation in UIC as a multidisciplinary endeavor, at the base of value chain, that presents distinct networks for technical, managerial and market knowledge, evidenced by whole network analysis, node centrality and in-betweenness. Specificities encountered in this knowledge area seems to influence dynamics of knowledge flows in collaboration.

As knowledge is an important resource of UIC, understanding and managing the dynamics of knowledge flows is a relevant subject for collaboration success. This work contributes to improve UIC management at the micro-level.

8 LIMITATIONS OF THE RESEARCH

This work presents limitations that impact internal and external validity and which may be considered when using results.

This application case study addressed one case of UIC involving multiple laboratories (i.e. units) within the university and multiple areas within the company. The study didn't use a longitudinal approach. These two facts limit the possibility to use results without further research.

This is a qualitative research that used quantitative tools such as correlation analysis, structural equation modelling and social network analysis to evidence patterns to be investigated in the semi-structured interviews. The number of respondents, though, is one limitation concerning internal validity. In this work, only 73 researchers answered to the questionnaire, of which only one respondent from the company, which provides a limited view of the company. Also, there were few respondents of some university laboratories, which may result in heterogeneous answers, considering that laboratories might show considerable differences among each other. This lack of respondents also impacts SNA. With the 73 answers, only 129 nodes were identified. The resulting network provides a quite reasonable representation of the collaboration network from university's perspective, though from company's point of view only 18 nodes were identified, which still represent a small piece of the entire knowledge network.

Still in the quantitative part of the research, when performing SEM analysis, the model used presented some issues regarding model fit in overall model assessment and internal consistency. The instruments might not be adequate for the study purposes and should be further developed.

As for those two suggested practices, they still must be tested and the benefits assessed and proved.

9 FUTURE RESEARCH

Some subjects for new studies are listed here which may help the success of university-industry collaborations for materials innovation.

Regarding micro-level studies, in order to advance on the operational level of collaborations, indicators must be developed to assess UIC performance. Top management view might be quite different from operational level, thus requiring adjust in those instruments. This will allow better quantitative studies in this research field. This may also consider instruments for university and company points of view. If instruments can be the same for each part.

This research provided a view of the university, but an extensive study within company boundaries is indeed needed. Most studies are still on the university side of the cooperation. Especially how the company absorbs knowledge from the university.

A longitudinal research of the collaboration would also help researchers to understand UIC performance, especially with some KM practices.

The overlap between company's and university's knowledge commented in this work is an aspect of collaboration that appears to influence UIC performance and success. A study on this subject would help to understand which management models or practices might be used in each case and how it impacts UIC.

The two suggested practices in this research must be tested and investigated if they produce desired results and outcomes.

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