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**A INDÚSTRIA 4.0 NO BRASIL: UM ESTUDO  
DOS BENEFÍCIOS ESPERADOS E TECNOLOGIAS  
HABILITADORAS**

Porto Alegre

2018

Lucas Santos Dalenogare

**A Indústria 4.0 no Brasil: um estudo dos benefícios esperados e tecnologias  
habilitadoras**

Dissertação submetida ao Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul como requisito parcial à obtenção do título de Mestre em Engenharia de Produção, modalidade Acadêmica, na área de concentração em Sistemas de Produção.

Orientador: Alejandro Germán Frank, Dr.

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habilitadoras**

Esta dissertação foi julgada adequada para a obtenção do título de Mestre em Engenharia de Produção na modalidade Acadêmica e aprovada em sua forma final pelo Orientador e pela Banca Examinadora designada pelo Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul.

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*“We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology.” (Carl Sagan)*

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## CRÉDITOS

A pesquisa apresentada nesta dissertação foi desenvolvida no Núcleo de Engenharia Organizacional da Universidade Federal do Rio Grande do Sul (NEO/UFRGS), como parte integrante do Programa de Pós-graduação em Engenharia de Produção da mesma universidade (PPGEP/UFRGS).

A presente pesquisa forma parte do projeto “*Gerenciamento de stakeholders para implementação da Indústria 4.0 em empresas gaúchas: uma análise focada na transformação dos modelos de negócios industriais*” financiado pela Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul mediante o edital FAPERGS/Pq-G 2017.

O desenvolvimento da dissertação também foi possível graças à bolsa de mestrado que o candidato recebeu da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) do Ministério de Educação – Governo Federal do Brasil.

Parte da coleta de dados foi possível graças à parceria do NEO/UFRGS com a Associação Brasileira da Indústria de Máquinas e Equipamentos (ABIMAQ), Regional Sul, mediante o projeto de pesquisa industrial intitulado “*Mapeamento das demandas e ofertas tecnológicas da ABIMAQ-RS para a Indústria 4.0*”.

## RESUMO

A Indústria 4.0 surge com o objetivo de desenvolver fábricas inteligentes, com alto grau de autonomia e flexibilidade, através da adoção de tecnologias digitais de forma integrada nas empresas e suas cadeias de valor. Ao mesmo tempo, a Indústria 4.0 promove benefícios que vão além da performance operacional, como o desenvolvimento de novas ofertas e novos modelos de negócios para as empresas. A Indústria 4.0 é originada na Alemanha, país com alta performance tecnológica, e rapidamente inspira outras iniciativas no mundo inteiro, inclusive em países emergentes como o Brasil. Estes países possuem maiores barreiras para a adoção das tecnologias relacionadas ao conceito, principalmente devido à atual situação tecnológica dos seus parques industriais. Embora a Indústria 4.0 seja um tema crescente na literatura, ainda existem grandes lacunas de estudo sobre a adoção de tecnologias relacionadas ao conceito no contexto de países emergentes, principalmente por se tratar de uma iniciativa recente. Logo, o objetivo desta dissertação é estudar o conceito da Indústria 4.0 no Brasil, de forma a entender quais são os benefícios do conceito para a performance industrial e as tecnologias habilitadoras. O trabalho tem uma abordagem quantitativa, com análises estatísticas aplicadas em dados de pesquisas *surveys* conduzidas em nível nacional. Os principais resultados obtidos foram: (i) identificação da relação entre as tecnologias e os benefícios esperados do conceito, (ii) identificação de disparidades entre a percepção industrial brasileira e a literatura sobre os benefícios da Indústria 4.0, (iii) identificação da abrangência do conceito da Indústria 4.0, compreendendo elementos que transcendem a manufatura avançada, e (iv) identificação de tecnologias habilitadoras para a implantação do conceito. Sob a perspectiva acadêmica, esta dissertação traz importantes contribuições para o entendimento do conceito e das tecnologias da Indústria 4.0, assim como o impacto destas na performance industrial. Do ponto de vista prático, os resultados auxiliam na compreensão de um tema de alta relevância empresarial, contribuindo com perspectivas para a diretriz estratégica das empresas à Indústria 4.0.

**Palavras Chaves:** Indústria 4.0, quarta revolução industrial, adoção de tecnologias, performance industrial,.

## **ABSTRACT**

Industry 4.0 arises with the goal to develop smart factories, with advanced autonomy and flexibility, through the adoption of digital technologies in an integrated manner in companies and in their value chains. The Industry 4.0 enables benefits beyond operational performance, as the development of new offerings and new business models for companies. Industry 4.0 was developed in Germany, a country with high technological performance, and quickly inspires other initiatives in the whole world, in developed and emergent countries such as Brazil. These countries face major barriers for the adoption of technologies related to the concept, mainly due to the current technological level of their industrial sites. Even though Industry 4.0 is a growing field in literature, there are still considerable gaps of studies about the adoption of technologies related to the concept in the context of emergent countries, mostly due to its novelty. Therefore, this dissertation aims to study the concept of Industry 4.0 in Brazil, in order to understand its benefits for industrial performance and its enabling technologies. This study has a quantitative approach, with statistical analysis of data from national surveys. The main outcomes obtained were: (i) the identification of a relation between technologies and the expected benefits of the concept, (ii) the identification of disparities between Brazilian industrial perception and the literature about Industry 4.0 benefits, (iii) the identification of a wide scope of Industry 4.0 concept, comprising elements that transcends smart manufacturing, and (iv) the identification of enabling technologies for the implementation of the concept. Under academic perspective, this dissertation brings important contributions to understand the Industry 4.0 concept and technologies, and its impact on industrial performance. As practical contributions, the results contribute for the understandings of a high relevant theme for companies, contributing with perspectives for their strategical orientation towards Industry 4.0.

**Key words:** Industry 4.0, fourth industrial revolution, adoption of technologies, industrial performance.



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# 1 INTRODUÇÃO

## 1.1 Contexto da pesquisa

A Indústria 4.0 começou como uma iniciativa do governo alemão para desenvolver o conceito de fábricas inteligentes – fábricas com alto grau de autonomia e flexibilidade, integradas em toda a cadeia de valor e no ciclo de vida do produto (WANG et al., 2016; TAO et al., 2018) –, visando a maior produtividade e eficiência do setor industrial do país e novas oportunidades de mercados. A iniciativa conta com uma parceria com universidade e empresas, de forma a desenvolver as competências necessárias e difundir as tecnologias que possibilitam as fábricas inteligentes (KAGERMANN et al., 2013).

O objetivo da Indústria 4.0 deveria ser alcançado com a adoção de tecnologias digitais em dimensões operacionais e administrativas, de forma integrada (ADOLPHS et al., 2015; GILCHRIST; 2016). Mesmo que algumas tecnologias compreendidas pelo conceito já estão sendo implementadas em âmbito industrial, suas aplicações têm alcance limitado, geralmente dando suporte apenas às atividades específicas e isoladamente nas funções de uma empresa, enquanto o conceito ideal visa a uma aplicação integrada em toda a empresa e na cadeia de valor em que esta está situada (LU; WENG, 2018; KAGERMANN et al., 2013; JESCHKE et al., 2017). A aplicação integrada implica em uma grande mudança de paradigma no funcionamento dos novos sistemas produtivos, que poderão responder às flutuações de demandas de consumidores, incluindo a produção de produtos customizados em larga-escala, com maior agilidade (BRETTEL et al., 2014).

As tecnologias consideradas no conceito da Indústria 4.0 também habilitam o desenvolvimento de novos produtos com maior valor agregado (KAGERMANN et al., 2013). Estes produtos possuem capacidades digitais que comportam serviços complementares à oferta do produto, que também pode ser oferecido como um serviço através de product-service systems (PSS), resultando em novos modelos de negócio para as empresas (PORTER; HEPPELMANN, 2015; ZHONG et al., 2017).

Rapidamente, a iniciativa da Indústria 4.0 tem chamado atenção de grandes empresas de consultoria, que enxergam grandes oportunidades de negócios e um forte impacto econômico em nível global com a adoção das tecnologias habilitadoras do conceito (RÜßMANN et al., 2015; WEE et al., 2015; BERGER, 2014; SNIDERMAN et al., 2016). Ainda, o impacto dessa adoção é corroborado com o desenvolvimento de iniciativas por outros países com objetivos semelhantes aos da Indústria 4.0, como a parceria *Advanced Manufacturing* nos Estados Unidos e a iniciativa *La Nouvelle France Industrielle* na França (LIAO et al., 2017). Com a Indústria 4.0 como base, iniciativas foram desenvolvidas também em países emergentes, como o *Made in China 2025*, na China (LU, 2017), e o Rumo à Indústria 4.0, no Brasil (ABDI, 2017).

Desta forma, a Indústria 4.0 é considerada como o início da quarta revolução industrial, na qual pesquisadores, agências governamentais e empresas preveem grandes alterações de paradigmas que vão além da tecnologia empregada na manufatura, envolvendo também alterações nas abordagens de gestão, características mercadológicas e capital humano, conforme percebido nas três revoluções anteriores (YIN et al., 2018; DRATH; HORCH, 2014; STOCK et al., 2018).

## **1.2 Problema de pesquisa, tema e objetivos**

### **1.2.1 Problema de pesquisa**

A Indústria 4.0 surge com o objetivo de desenvolver fábricas inteligentes, que visam a solucionar problemas enfrentados pelo setor industrial e trazer novos benefícios que vão além da maior produtividade das fábricas (KAGERMANN et al., 2013; LU, 2017). Este objetivo será realizado através da adoção de tecnologias digitais nas empresas, cuja implementação holística em um sistema produtivo ainda é objeto de estudos para a sua viabilização, uma vez que é caracterizada por alta complexidade (LEE et al., 2015; ZHONG et al., 2017; GILCHRIST, 2016). Porém, algumas aplicações das fábricas inteligentes já são possíveis, as quais algumas empresas já se beneficiam com a adoção destas tecnologias, principalmente em países desenvolvidos.

Países desenvolvidos como a Alemanha e EUA efetivamente desenvolveram parques industriais sobre o preceito da automação da terceira revolução industrial, que serve como base para as fábricas inteligentes da quarta revolução industrial (KAGERMANN et al., 2013). Enquanto isso, em países emergentes como o Brasil, alguns setores industriais ainda estão no processo de automação, tornando estes países menos preparados para a Indústria 4.0 (CNI, 2016). Ainda, considerando o alto grau de inovação tecnológica do conceito, a disparidade entre países desenvolvidos e emergentes é acentuada, uma vez que países desenvolvidos realizam maiores investimentos em pesquisa e desenvolvimento (GUAN et al., 2006).

Considerando que o conceito da Indústria 4.0 é caracterizado por alta inovação tecnológica e por uma abrangência que transcende a manufatura, existem muitas lacunas sobre as tecnologias habilitadoras, assim como o impacto destas na competitividade das empresas. Por se tratar de um conceito muito recente, os primeiros estudos provêm de áreas de consultoria ou pesquisas industriais (e.g. RÜßMANN et al., 2015; WEE et al., 2015; BERGER, 2014). As principais pesquisas acadêmicas em periódicos científicos de alto fator impacto têm aparecido somente a partir de 2017 (e.g. SANTOS et al., 2017; QUEZADA et al., 2017; BOKRANTZ et al., 2017), destacando-se as edições especiais de periódicos tais como o *International Journal of Production Economics*. Contudo, a maior parte desses estudos tratam aspectos específicos da implementação de algumas tecnologias da Indústria 4.0, sem avaliar esta como um conceito abrangente com suas implicações para a gestão de operações. Nesse sentido, um dos problemas que se destacam é a ausência de evidências empíricas sobre os impactos que as tecnologias da Indústria 4.0 podem trazer sobre o desempenho operacional das empresas. Ao invés desta nova tendência ser aceita como um dogma, é necessário comprovar empiricamente os seus efeitos nas empresas. Isto torna-se mais necessário quando considerado o contexto específico do Brasil como um país emergente, o qual enfrenta diversas dificuldades estruturais para a implantação de inovações tecnológicas, tal como já o apontou no passado uma pesquisa de larga escala conduzida por Frank et al. (2016). Portanto, propõe-se a seguinte questão de pesquisa: *Existem benefícios para a performance industrial vindos da implementação da Indústria 4.0 no Brasil? No caso afirmativo, quais esses benefícios e de quais tecnologias que compõem esse grande*

*conceito eles provêm? E, além disso, como essas tecnologias são e podem ser implantadas para obter os benefícios esperados?*

### **1.2.2 Tema e objetivos**

O tema desta dissertação é a adoção de tecnologias digitais difundidas pelo conceito da Indústria 4.0 em países emergentes, considerando o impacto destas na performance industrial.

O *objetivo geral* deste trabalho consiste em estudar o conceito da Indústria 4.0 no contexto do Brasil, de forma a entender quais são os benefícios da Indústria 4.0 e as tecnologias habilitadoras.

O objetivo geral pode ser desdobrado nos seguintes *objetivos específicos*:

- (i) Entender os benefícios esperados com o conceito da Indústria 4.0 na indústria brasileira.
- (ii) Estudar quais tecnologias relacionadas ao conceito de Indústria 4.0 permitem tais benefícios; e
- (iii) Definir o(s) padrão(es) de adoção de tecnologias da Indústria 4.0 no contexto das empresas brasileiras.

## **1.3 Justificativa do tema e dos objetivos**

A Indústria 4.0 surgiu como conceito de um novo estágio industrial em que empresas manufatureiras precisam se adaptar para se manterem competitivas, afetando também outros setores da economia (CNI, 2016). Este estágio é caracterizado pela adoção de tecnologias digitais avançadas, de forma integrada (LU, 2017; SCHUH et al., 2017; GILCHRIST, 2016). Ainda que alguns estudos cite as tecnologias necessárias para a Indústria 4.0 (ZHONG et al., 2017; LU, 2017), existem lacunas sobre os benefícios promovidos pela adoção e a implementação destas em um sistema produtivo (STOCK et al., 2018). Estas lacunas trazem desafios para outras dimensões além da tecnológica: desenvolvimento do capital humano multidisciplinar, cadeias produtivas,

infraestrutura e regulação (STOCK et al., 2018). De modo a contornar estes desafios, o governo brasileiro lançou uma iniciativa em cooperação com agentes governamentais, academia e empresas, de forma similar a outros países mais avançados no conceito. Porém, conforme estudos conduzidos pela CNI, existe um grande desconhecimento do conceito pelo setor industrial brasileiro, no qual mais da metade das empresas desconhecem as tecnologias compreendidas pela Indústria 4.0. Ainda, considerando a heterogeneidade tecnológica no setor industrial brasileiro, o *roadmap* para a implantação da Indústria 4.0 no país deve considerar a disparidade entre os diferentes setores, aumentando as dificuldades para adaptação do país ao conceito, de forma geral (CNI, 2016). Logo, de forma a orientar a adoção das tecnologias da Indústria 4.0 pelas empresas brasileiras, torna-se necessário identificar qual a infraestrutura tecnológica mínima para a Indústria 4.0, de forma a preparar as empresas para a disrupção final do conceito. Ainda, tendo em vista que as tecnologias 4.0 permitem diferentes aplicações e benefícios, tal relação deve ser entendida considerando as diferentes dimensões de performance industrial no contexto brasileiro. Dessa maneira, destaca-se a importância do tema para os propósitos práticos da sua implantação nas empresas.

Por outro lado, do ponto de vista acadêmico, a Figura 1 apresenta o relatório do Web of Science ® de uma própria pesquisa realizada em 31/08/2018 sobre artigos em periódicos científicos internacionais com os tópicos “Industry 4.0” ou “Industrie 4.0”. Observa-se que somente a partir de 2015 o tema começou a surgir e seu crescimento tende a ser crescente (observa-se que 2018 apresenta resultados só até agosto e estes já ultrapassaram o total do ano anterior), marcando uma destacada importância acadêmica para o assunto. Além disso, recentemente os principais periódicos científicos da área de gestão de operações têm realizado chamadas especiais para publicações de edições específicas sobre o tema, dentre eles destacam-se: “Industry 4.0 and Production Economics” (*I.J. of Production Economics*, 2019), “Operational Excellence towards Sustainable Development Goals through Industry 4.0” (*I.J. of Production Economics*, 2017), “Industry 4.0 and Smart Manufacturing” (*Manufacturing Letters*, 2018), “Industry 4.0 – Smart production systems, environmental protection and process safety” (Process Safety and Environmental Protection, 2018), “Implementation and acceleration of Industry 4.0” (*J.of Manufacturing Technology Management*, 2019), entre outros. A novidade do tema faz com que existam ainda diversas lacunas na literatura que precisem



de uma melhor e maior compreensão, dentre elas as apontadas na problemática da presente dissertação.

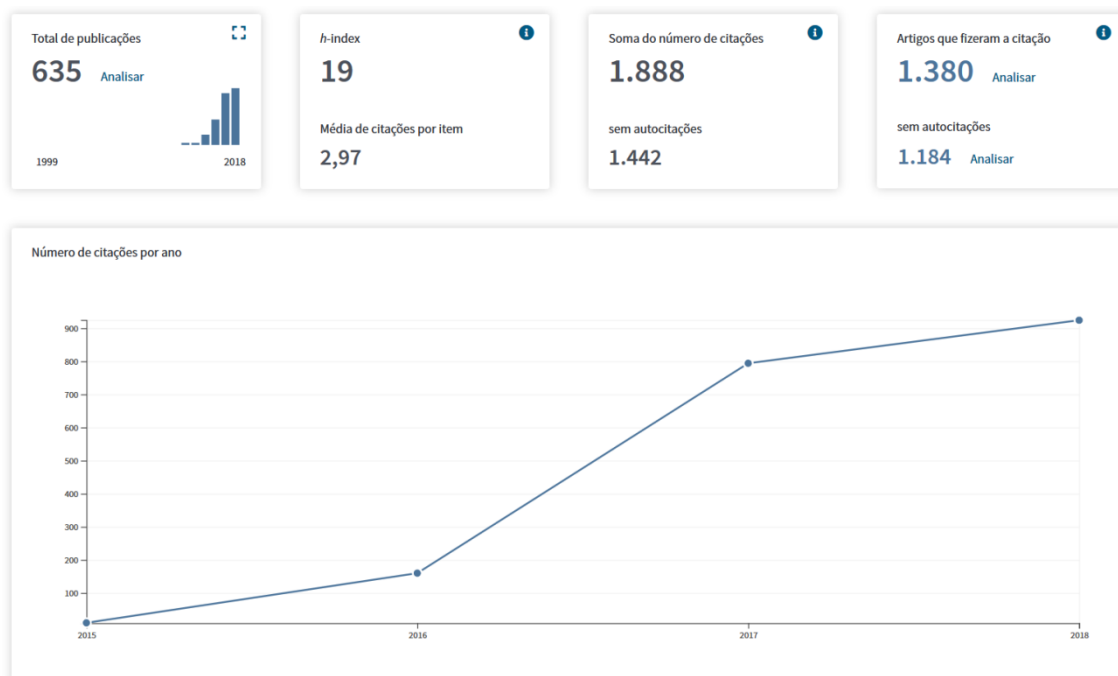


Figura 1 – Relatório de citações do Web of Science ® para os tópicos “*Industry 4.0*” OR “*Industrie 4.0*” realizado em 31/08/2018.

## 1.4 Método

De acordo com as definições de projetos de pesquisa de Gil (2002), este trabalho é preponderantemente de natureza aplicada, pois visa gerar conhecimentos específicos sobre aplicações práticas, envolvendo problemas indústrias reais e atuais. A pesquisa é caracterizada com uma abordagem quantitativa, pois são utilizados métodos estatísticos para analisar dados de amostras de empresas, buscando identificar padrões explicativos para o fenômeno estudado. Referente aos objetivos, o trabalho pode ser classificado como explicativo e em parte exploratório, pois busca entender relações entre variáveis (tipos de tecnologias e desempenho) e entender padrões de adoção tecnológica, através da análise de dados coletados. Por fim, uma vez que se trata de um fenômeno já iniciado, mas ainda em desenvolvimento e com alto grau de inovação, diversos procedimentos foram utilizados a fim de analisá-lo com o maior detalhamento possível. Os métodos são detalhados na Figura 2 e explicados a seguir.

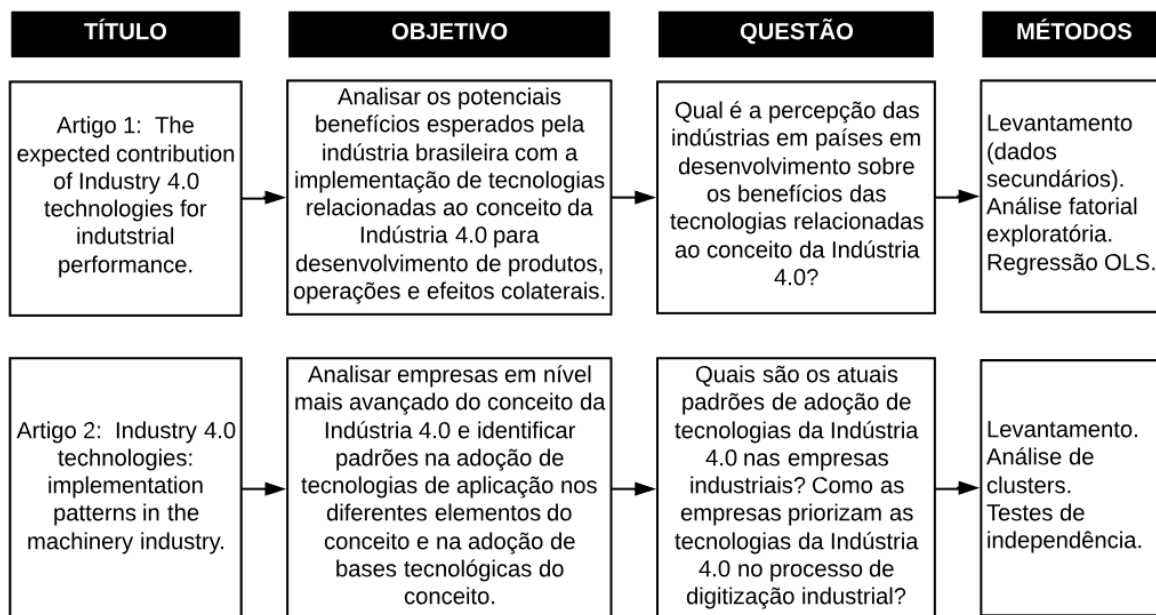


Figura 2 - Divisão da estrutura do trabalho segundo os objetivos específicos.

No Artigo 1 – “The expected contribution of Industry 4.0 technologies for industrial performance” – foi utilizada uma base de dados secundários levantada a partir de uma pesquisa de levantamento (*survey*) conduzida pela Confederação Nacional da Indústria (CNI) no Brasil, sobre Indústria 4.0. O objetivo desse artigo é identificar quais os benefícios esperados pelas empresas brasileiras do setor industrial com a adoção de tecnologias específicas do conceito da Indústria 4.0, relacionando os achados com a literatura. Para tanto, utilizou-se um método de regressão linear simples para avaliar a relação entre as tecnologias e os benefícios esperados. O método utilizado tem objetivo explicativo, pois identifica os fatores que determinam a ocorrência de fenômenos, neste caso, quais tecnologias devem ser empregadas para determinados benefícios. O procedimento realizado é do tipo *expost-facto*, pois através de regressão linear, analisa a existência de relações entre variáveis independentes e dependentes, sem ter o controle sobre as variáveis.

No Artigo 2 – “*Industry 4.0 technologies: implementation patterns in the machinery industry*” – foi conduzida uma pesquisa de levantamento (*survey*) em empresas nacionais do setor de máquinas e equipamentos industriais. A partir dos resultados, foi realizada uma análise de cluster e testes de independência, de forma a identificar grupos com diferentes maturidades no conceito da Indústria 4.0 e, no grupo com maior maturidade, identificar padrões de adoção das tecnologias do conceito – tecnologias de

aplicação e tecnologias habilitadoras. O método utilizado tem objetivo exploratório, no qual após levantamento, foi realizada uma análise de cluster para identificar empresas com maior maturidade no conceito e realizados testes de independência para maior compreensão da adoção de tecnologias da Indústria 4.0 nestas empresas.

## **1.5 Delimitações do trabalho**

A maior limitação desta pesquisa é a sua contextualização em países em emergentes, uma vez que o conceito analisado está em um estágio mais avançado em países em desenvolvimento, embora existam iniciativas e empresas mais avançadas no conceito em países em desenvolvimento.

Embora sejam consideradas algumas limitações técnicas referentes as tecnologias em estudo, estas limitações não são estudadas com profundidade neste trabalho, considerando o foco principal de performance industrial.

Outra limitação é que as tecnologias estudadas no Artigo 1 não são completamente correspondentes às tecnologias da Indústria 4.0 utilizadas no Artigo 2. Isso se deve ao fato que os pesquisadores não tiveram controle sobre a condução da primeira pesquisa, sendo esta de dados secundários. Nessa pesquisa, a CNI optou por considerar algumas tecnologias tradicionais da indústria dentro do conceito de Indústria 4.0 (por exemplo CAD/CAE). Por outro lado, na segunda pesquisa (Artigo 2), conduzida pelo pesquisador e colaboradores, optou-se por priorizar as tecnologias consagradas na literatura acadêmica recente sobre o tema, de maneira que haja uma maior ênfase em conceitos emergentes (por ex. inteligência artificial e realidade aumentada). Contudo, os conceitos e entendimentos trazidos por ambos os artigos continuam sendo complementares.

Outras limitações específicas de cada um dos artigos abordados são tratados diretamente nos mesmos, visando facilitar a compreensão do leitor enquanto se acompanham os resultados.

## 1.6 Estrutura do trabalho

Esta dissertação está estruturada em quatro capítulos. Neste primeiro capítulo introdutório foi apresentado o problema de pesquisa, a justificativa e métodos utilizados. O Capítulo 2 consiste no primeiro artigo da dissertação, voltado aos objetivos específicos (i) e (ii). O Capítulo 3 apresenta o segundo artigo da dissertação, busca atender o objetivo específico (iii). Por fim, no Capítulo 4 são apresentadas as conclusões do trabalho e sugestões de trabalhos futuros.

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## 2 ARTIGO 1 – THE EXPECTED CONTRIBUTION OF INDUSTRY 4.0 TECHNOLOGIES FOR INDUSTRIAL PERFORMANCE\*

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### Abstract

Industry 4.0 is considered a new industrial stage in which vertical and horizontal manufacturing processes integration and product connectivity can help companies to achieve higher industrial performance. However, little is known about how industries see the potential contribution of the Industry 4.0 related technologies for industrial performance, especially in emerging countries. Based on the use of secondary data from a large-scale survey of 27 industrial sectors representing 2,225 companies of the Brazilian industry, we studied how the adoption of different Industry 4.0 technologies is associated with expected benefits for product, operations and side-effects aspects. Using regression analysis, we show that some of the Industry 4.0 technologies are seen as promising for industrial performance while some of the emerging technologies are not, which contraries the conventional wisdom. We discuss the contextual conditions of the Brazilian industry that may require a partial implementation of the Industry 4.0 concepts created in developed countries. We summarize our findings in a framework, that shows the perception of Brazilian industries of Industry 4.0 technologies and their relations with the expected benefits. Thus, this work contributes by discussing the real expectations on the future performance of the industry when implementing new technologies, providing a background to advance in the research on real benefits of the Industry 4.0.

**Keywords:** Industry 4.0; digitization; advanced manufacturing; industrial performance; emerging countries.

## 2.1 Introduction

Industry 4.0 is understood as a new industrial stage in which there is an integration between manufacturing operations systems and information and communication technologies (ICT) – especially the Internet of Things (IoT) – forming the so-called Cyber-Physical Systems (CPS) (JESCHKE et al., 2017; WANG; TÖRNGREN; ONORI, 2015). This new industrial stage is affecting competition rules, the structure of industry and customers' demands (BARTODZIEJ, 2017; GILCHRIST, 2016). It is changing competition rules because companies business models are being reframed by the adoption of IoT concepts and digitization of factories (DREGGER et al., 2016; LASI et al., 2014; WANG; TÖRNGREN; ONORI, 2015). From the market point of view, digital technologies allow companies to offer new digital solutions for customers, such as internet-based services embedded in products (AYALA et al., 2017; COREYNEN; MATTHYSENS; VAN BOCKHAVEN, 2017). From the operational perspective, digital technologies, such as CPS, are proposed to reduce set-up times, labor and material costs and processing times, resulting in higher productivity of production processes (Brettel et al., 2014; Jeschke et al., 2017).

Several countries have recently created local programs to enhance the development and adoption of Industry 4.0 technologies. In Germany – where this concept was born – this program was called “High-Tech Strategy 2020”, in the United States was established the “Advanced Manufacturing Partnership”, in China the “Made in China 2025” and in France the “*La Nouvelle France Industrielle*” (KAGERMANN et al., 2013; RAFAEL et al., 2014; WAHLSTER, 2013; ZHOU, 2017; CNI, 2013; LIAO et al., 2017). In Brazil, the program called “Towards Industry 4.0” (*Rumo à Indústria 4.0*) was created by the Brazilian Agency for Industrial Development (ABDI – *Agência Brasileira de Desenvolvimento Industrial*) together with other initiatives of the Ministry of Industry, Foreign Trade and Services (MDIC – *Ministério da Indústria, Comércio Exterior e Serviços*) (ABDI, 2017). All these programs, in both developed and emerging countries aim to disseminate the Industry 4.0 concepts and technologies in local firms.

Nevertheless, it is well-known that the adoption of advanced technologies can be more challenging for emerging countries (HALL; MAFFIOLI, 2008; KUMAR; SIDDHARTHAN, 2013). Since the economies of emerging countries have been

historically more focused on the extraction and commercialization of commodities, companies in these countries are frequently behind in terms of technology adoption, when compared to their counterparts in developed countries (CASTELLACCI, 2008). Other factors such as ICT infrastructure, culture, level of education and economic and political instability can also interfere in the value perception and in the consequent level of investments in advanced technologies (FRANK et al., 2016). Thus, even when the Industry 4.0 related technologies are presented by the literature as beneficial for firms, given the particular characteristics of developing economies, an important question emerges: *what is the perception of industries in developing countries about the benefits of Industry 4.0 related-technologies for industrial performance?*

We aim to answer this question by analyzing the potential benefits for product development, operations and side-effects aspects expected by the Brazilian industry when implementing the Industry 4.0 related technologies. We analyze secondary data from a large survey recently applied in Brazil by the National Confederation of the Industries (*Confederação Nacional das Indústrias – CNI*), which comprises a sample of 2,225 companies from different industrial segments of this emerging country. Our findings indicate that only some of the Industry 4.0 related technologies are expected as beneficial by the Brazilian industry and that it depends on the focus of the industrial sectors, i.e. focus in differentiation or cost. We also discuss some unanticipated findings regarding advance technologies with negative expected results on industrial performance.

The remaining sections of this paper are structured as follows. In Section 2, we provide the theoretical background for Industry 4.0 technologies and the expected benefits of their implementation, as well as their usefulness in emerging countries. Section 3 introduces the research method where we discuss the secondary data source and our methodological procedures for the data treatment and analysis. The results are presented in Section 4, followed by the discussions of the findings in Section 5 and the conclusions in Section 6.



## **2.2 Theoretical background**

### **2.2.1 Industry 4.0 and the international technology diffusion-adoption theories**

Some scholars and practitioners have considered four main industry changes throughout the history, while the Industry 4.0 is the last one and an ongoing industry transformation (QIN; LIU; GROSVENOR, 2016). The steam machine – between 1760 and 1840 – characterized the first industry revolution; the second was defined by the utilization of electricity in industrial processes in the end of the XIX century; the third revolution started in the decade of 1960 with the use of ICT and industrial automation. The fourth industrial revolution – or Industry 4.0 – emerged from several developed countries and it was consolidated in a German public-private initiative to build smart factories by the integration of physical objects with digital technologies (BRETTEL et al., 2014; HERMANN; PENTEK; OTTO, 2016). The key element that characterizes this new industrial stage is the deep change in the manufacturing systems connectivity due to the integration of ICT, IoT and machines in cyber-physical systems (CPS) (KAGERMANN; WAHLSTER; HELBIG, 2013; SCHWAB, 2016). As a result, the Industry 4.0 can be considered nowadays as a new industrial age based on the connectivity platforms used in the industry (LASI et al., 2014; PARLANTI, 2017; REISCHAUER, 2018). It considers the integration of several different dimensions of the business, with a main concern on manufacturing issues, based on advance manufacturing technologies (SALDIVAR et al., 2015; FATORACHIAN and Kazemi, 2018). In such a sense, Industry 4.0 can be understood as a result of the growing digitization of companies, especially regarding to manufacturing processes (KAGERMANN, 2015; SCHUMACHER; EROL; SIHN, 2016).

Following this concept, Industry 4.0 can be seen as a matter of technology diffusion and adoption. Emerging technologies of this new industrial age have been conceived in developed countries such as Germany, which is nowadays leading the diffusion of the concept to other countries interested in its adoption (ARBIX et al., 2017; BERNAT; KARABAG, 2018). However, the diffusion-adoption process tends to be slow and it usually flows from developed countries to developing countries (COMIN; HOBIJN, 2004; EATON; KORTUM, 1999; PHILLIPS; CALANTONE;

LEE, 1994). Therefore, different behavior patterns could be seen when analyzing digital technologies in an emerging country such as Brazil comparing to the leading countries on this issue such as Germany. According to the diffusion-adoption theories, different aspects can produce such gaps between economies. Barriers to the diffusion and adoption are frequently present (PARENTE; PRESCOTT, 1994) and the competitive environment of both the supplier side and the adopter industry also create differences (ROBERTSON; GATIGNON, 1986). As a consequence, emerging countries can have a different value perception of the diffused technologies (ALEKSEEV et al., 2018; LUTHRA; MANGLA, 2018) which may be based on different needs compared to developed countries (KAGERMANN, 2015).

Our study is based on the fact that the perceived value of technologies can be different in emerging countries, which can also change their adoption of these technologies (CASTELLACCI, 2008; CASTELLACCI; NATERA, 2013). Instead of studying the technology diffusion-adoption flow, as previously done by several other scholars (e.g. PHILLIPS et al., 1994; COMIN and HOBIJN, 2004), we focus on the current adoption and its expected benefits in the Brazilian industry. We first address the general benefits proposed by those enthusiastic on Industry 4.0. Second, we consider the Brazilian industrial context and the possible difficulties for the implementation of Industry 4.0 concepts. Then, we use empirical data to investigate the adoption levels and the expected benefits. We use the diffusion-adoption theory in order to understand better our findings.

### **2.2.2 Industry 4.0 and its expected benefits**

The Industry 4.0 concepts are proposed to enable companies to have flexible manufacturing processes and to analyze large amounts of data in real time, improving strategic and operational decision-making (KAGERMANN; WAHLSTER; HELBIG, 2013; PORTER; HEPPELMANN, 2014; SCHWAB, 2016). This new industrial stage has been possible due to the use of ICTs in industrial environments (KAGERMANN; WAHLSTER; HELBIG, 2013) and due to the cheapening of sensors, increasing their installation in physical objects (BANGEMANN et al., 2016; BRETTEL et al., 2014; PORTER; HEPPELMANN, 2014). The advancements in these technologies allowed the

development of embedded and connected systems (BRETTEL et al., 2014; JAZDI, 2014; KAGERMANN; WAHLSTER; HELBIG, 2013). These systems aim to monitor and control the equipment, conveyors and products through a cycle of feedbacks that collect a great quantity of data (big data) and update the virtual models with the information of the physical processes, resulting in a smart factory (GILCHRIST, 2016; WANG; TÖRNGREN; ONORI, 2015; WANG et al., 2016a). Therefore, since the development of digital manufacturing in the 1980s, different technologies have emerged and have been applied in production systems, such as cloud computing for on-demand manufacturing services (YU; XU; LU, 2015), simulation for commissioning (SALDIVAR et al., 2015), additive manufacturing for flexible manufacturing systems (KAGERMANN; WAHLSTER; HELBIG, 2013; WANG et al., 2016a), among others. Table 1 presents a list of ten types of technologies frequently associated to the Industry 4.0 concept (CNI, 2016; GILCHRIST, 2016; JESCHKE et al., 2017).

The technologies presented in Table 1 support the three main advantages that characterize Industry 4.0: vertical integration, horizontal integration and end-to-end engineering (KAGERMANN; WAHLSTER; HELBIG, 2013; WANG; TÖRNGREN; ONORI, 2015). The vertical integration refers to the integration of ICT systems in different hierarchical levels of an organization, representing the integration between the production and the management levels in a factory (KAGERMANN; WAHLSTER; HELBIG, 2013). On the other hand, the horizontal integration consists in the collaboration between enterprises inside a supply chain, with resource and real time information exchange (BRETTEL et al., 2014). End-to-end engineering is the integration of engineering in the whole value chain of a product, from its development until after-sales (BRETTEL et al., 2014; GILCHRIST, 2016; KAGERMANN; WAHLSTER; HELBIG, 2013).

Table 1: Technologies of the Industry 4.0

Technologies	Definition
Computer-Aided Design and Manufacturing [CAD/CAM]	Development of projects and work plans for product and manufacturing based on computerized systems (SCHEER, 1994).
Integrated engineering systems [ENG_SYS]	Integration of IT support systems for information exchange in product development and manufacturing (ABRAMOVICI, 2007; BRUUN et al., 2015; KAGERMANN; WAHLSTER; HELBIG, 2013).
Digital automation with sensors [SENSORING]	Automation systems with embedded sensor technology for monitoring through data gathering (SALDIVAR et al., 2015).
Flexible manufacturing lines [FLEXIBLE]	Digital automation with sensor technology in manufacturing processes (e.g. radio frequency identification – RFID – in product components and raw material), to promote Reconfigurable Manufacturing Systems (RMS) and to enable the integration and rearrangement of the product with the industrial environment in a cost-efficient way (ABELE et al., 2007; BRETTEL et al., 2014).
Manufacturing Execution Systems (MES) and Supervisory control and data acquisition (SCADA) [MES/SCADA]	Monitoring of shop floor with real time data collection using SCADA and remote control of production, transforming long-term scheduling in short term orders considering restrictions, with MES (JESCHKE et al., 2017).
Simulations/analysis of virtual models [VIRTUAL]	Finite Elements, Computational Fluid Dynamics, etc. for engineering projects and commissioning model-based design of systems, where synthesized models simulates properties of the implemented model (BABICEANU; SEKER, 2016; SALDIVAR et al., 2015).
Big data collection and analysis [BIG_DATA]	Correlation of great quantities of data for applications in predictive analytics, data mining, statistical analysis and others (GILCHRIST, 2016).
Digital Product-Service Systems [DIGITAL_SERV]	Incorporation of digital services in products based on IoT platforms, embedded sensors, processors, and software enabling new capabilities (PORTER; HEPPELMANN, 2014).
Additive manufacturing, fast prototyping or 3D impression [ADDITIVE]	Versatile manufacturing machines for flexible manufacturing systems (FMS), transforming digital 3D models into physical products (GARRETT, 2014; WELLER; KLEER; PILLER, 2015).
Cloud services for products [CLOUD]	Application of cloud computing in products, extending their capabilities and related services (PORTER; HEPPELMANN, 2014).

The extant literature has suggested that this integration achieved by digital technologies can promote several benefits to the industry (KAGERMANN; WAHLSTER; HELBIG, 2013). For business operations, the communication between machines and products enables reconfigurable and flexible lines for production of customized products, even for small batches (BRETTEL et al., 2014; WANG et al., 2016b). In addition, with the CPS for information processing, companies have more support for decision-making processes and have faster adaptation for several kinds of events, like production line breakdowns (SCHUH; ANDERI; GAUSEMEIER, 2017). Therefore, these systems can increase the productivity of the companies, with better efficiency of resources utilization, through the combination of production with smart grids for energy savings, for example (ALI; AZAD, 2013; JESCHKE et al., 2017). Industry 4.0 also has opportunities and benefits for business growth. Through the horizontal integration concept, collaborative networks among enterprises combine resources, divide risks and quickly adapt to changes in the market, seizing new opportunities (BRETTEL et al., 2014). Collaboration is extended to customers also, through digital channels and smart products that integrate the firm with the customers, allowing also the delivery of higher value to the latter (KIEL, D., ARNOLD, C., COLLISI, M., VOIGT et al., 2016; PORTER; HEPPELMANN, 2014). Using additive manufacturing technology, enterprises can co-design products with customers, resulting in highly customized products, increasing their perceived value (WELLER; KLEER; PILLER, 2015). Finally, with the service orientation of Industry 4.0 (GILCHRIST, 2016) and horizontal integration, new business models can be developed, with new ways to deliver and capture value from customers (CHRYSSOLOURIS et al., 2009; KAGERMANN; WAHLSTER; HELBIG, 2013).

From a socio-technical perspective (HENDRICK; KLEINER, 2001), it is acknowledged that the adoption of the aforementioned emerging technologies of the Industry 4.0 are not supported by themselves. There are at least three complementary socio-technical dimensions to the technological one to consider the digitization process towards the Industry 4.0 implementation (FRANK; RIBEIRO; ECHEVESTE, 2015): (i) organization of work - new technologies need to rethink how the organization will operate (BRETTEL et al., 2014); (ii) human factors – new technologies require new

competences and skills from the workers (RAS et al., 2017; WEI; SONG; WANG, 2017); and (iii) external environment – adoption of new technologies are dependent of the maturity where they are implemented (SCHUMACHER; EROL; SIHN, 2016). We focus on two of them, the *technological* opportunities and its relation with a specific *external environment* (i.e. an emerging country). Human factors and the organization of work can be enablers that potentialize the benefits of these technologies for business performance, as previously shown in the broader literature of technology management (WESTERMAN; BONNET; MCAFEE, 2014). Thus, we consider only the first step, which is to verify the expected contribution of the technologies for industrial performance, being aware that such technologies may need a complementation of these other dimensions in a specific context.

### **2.2.3 Industry 4.0 in the context of emerging countries**

As stated, Industry 4.0 was born in developed countries, where prior industrial stages are already mature regarding automation and ICT usage, two concepts of the third industrial revolution that converge in the Industry 4.0 (KAGERMANN; WAHLSTER; HELBIG, 2013). In this sense, emerging countries may face an important gap for the Industry 4.0 adoption due to the low maturity of prior industrial stages (GUAN et al., 2006; KRAWCZYŃSKI; CZYZEWSKI; BOCIAN, 2016). In the case of Brazil, the ICT adoption has significantly grown improving work productivity (CORTIMIGLIA; FRANK; MIORANDO, 2012; MENDONÇA; FREITAS; DE SOUZA, 2008). However, as shown in the findings of Frank et al. (2016) in a large-scale survey of Brazilian industry, the investments on software acquisition has not leaded to good results in terms of market benefits or internal manufacturing process improvement. The authors suggest that companies are investing in software acquisition simply to automatize their operational routines instead of seeking advanced ICT tools that could give them a real competitive advantage in innovation development (FRANK et al., 2016).

On the other hand, regarding manufacturing technologies, the same work of Frank et al. (2016) shows that machinery and equipment acquisition strategy resulted in poor results for innovation outcomes when compared to other innovation activities of

industries in Brazil. As argued by these authors, one of the reasons is that most of the companies do not acquire leading technologies – as those from the Industry 4.0 –, but only those basics to update old industrial equipment, which is also in line with other prior works in emerging markets (e.g. FRANCO; RAY; RAY, 2011; ZUNIGA; CRESPI, 2013). In this sense, the work of Nakata and Weidner (2012) showed that most population in emerging countries has lower incomes than in developed countries, what implies that the most consumed product are low cost, making lower price a more relevant factor in competitiveness than innovativeness. This market behavior can clearly influence technology investments. Usually, firms in developing countries are focused on making investments in well-established technologies for the increase of productivity than in advanced technologies for the differentiation of products, as evidenced in prior studies, cited above. Thus, the two main pillars of Industry 4.0 – processing technologies and ICT – still seems weak in order to advance toward the fourth industrial revolution.

In addition, there are structural challenges that emerging economies may face and that can be a barrier for the Industry 4.0 establishment. One of them is that emerging economies growth are based on the low-cost workforce, especially for manufacturing activities, and it can discourage or delay investments in automation and other technologies, which usually are more expensive in these countries (CASTELLACCI, 2008; RAMANI; THUTUPALLI; URIAS, 2017). The supply chain of the manufacturing industry may be another constraint, which tend to be less integrated when compared to developed countries (MARODIN et al., 2016, 2017b). Besides, the few investments in R&D (OLAVARRIETA; VILLENA, 2014), added to the economic and political instabilities and low quality of education and research institutions (CRISÓSTOMO; LÓPEZ-ITURRIAGA; VALLELADO, 2011; FRANK et al., 2016; HALL; MAFFIOLI, 2008), configure a hard scenario for the adoption of Industry 4.0 technologies.

Finally, based on this prior research, it is clear that challenges for the adoption of Industry 4.0 technologies in emerging countries are different from those in developed countries, as it is proposed in the technology diffusion-adoption literature (PHILLIPS; CALANTONE; LEE, 1994). As the concept of Industry 4.0 is relatively new, there is a high uncertainty and lack of knowledge about the real impact and contribution of the

Industry 4.0 related technologies in the context of emerging countries in general. In order to fill this gap, our study focuses on the contribution of these technologies in the Brazilian industry, as one representative of the emergent economies which has significantly increased the industrial activities in the recent years (FRANK et al., 2016). Few studies have been conducted in this country on Industry 4.0 initiatives, while most of them come from consulting research and presents only descriptive information of this scenario. One of them is the survey conducted by Price Waterhouse Coopers (PWC) in 32 Brazilian industries (PWC, 2016), which shows a low level of digitization in several business processes. However, despite the low level of digitization, this survey shows that Brazilian enterprises expect bigger investments in digital technologies for the next years, with return in efficiency improvement, reduction of operational costs and additional business income (PWC, 2016). Other important source of information is the industrial survey conducted by the National Confederation of the Industry of Brazil (CNI, 2016), where a set of Industry 4.0 related technologies were considered and analyzed in the Brazilian industry. This survey shows that the level of implementation is still low, but that there are already some industrial sectors investing in these technologies and that an important part of the industry is concerned with this issue and is expecting new benefits from such investments. Following this last survey, we aim to deepen such analysis by investigating the association between the considered technologies and expected benefits in the CNI (2016) large-scale survey.

## **2.3 Research method**

### **2.3.1 Sampling and measures**

Our study focuses on a secondary data analysis of the dataset collected by the ‘Special survey on Industry 4.0 in Brazil’, conducted by the National Confederation of the Industries (CNI, 2016). CNI is an entity that represents the Brazilian industry and comprises 1,250 employers’ unions and almost 700,000 industrial businesses affiliated. CNI promotes the interests of the industry in Brazil and as well as research and



development studies<sup>1</sup>. This large-scale industrial survey had the purpose of obtaining a current technological overview on Industry 4.0 in Brazilian industry. CNI elaborated a questionnaire and sent it by e-mail to operations managers of 7,836 companies random selected from the population. The population of the survey is composed only by companies related to production activities (i.e. extractive and transformation sectors). The total amount of useful responses obtained was 2,225 which represents a response rate of 28.39% (CNI, 2016). The final sample represents 40,8% small, 36,6% medium and 22,6% large industrial companies from 27 sectors in Brazil (see demographic details in Table 2). Given the demographic distribution of the complete responses (questionnaires) regarding companies' size, the industrial sectors, and the regional distribution of the data collected (which included all the industrialized States of the country), we have no reasons to believe the existence of biased patterns when compared to the incomplete responses, which were not included in the final sample (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009, p.42-45). However, such level of details is not provided in the available secondary data from (CNI, 2016).

Table 2 : Demographic characteristics of the industrial sectors considered in the sample

Industrial sectors considered in the study	Mining	Rubber products
	Food products	Plastics products
	Beverages	Non-metallic mineral products
	Textiles products	Basic metals
	Wearing apparel	Metal products (not machinery and equipment)
	Leather and related products	Computers, electronics and opticals products
	Footwear and parts	Electrical equipment
	Wood products	Machinery and equipment
	Pulp and Paper	Motor vehicles, trailers and semi-trailers
	Printing and recorded media	Other transport equipment
	Coke and refined petroleum products	Furniture
	Chemicals	Repair and installation
	Soap and detergents	Other manufacturing
	Chemicals and pharmaceuticals	
Sample distribution	Total of companies in the 27 sectors: 2,225	Large companies: 500 (22.6%)
		Medium companies: 815 (36.6%)
		Small companies: 910 (40.8%)

The questionnaire used in the survey is composed by six group of main questions<sup>2</sup>: (i) *Key-technologies*: a list of 11 digital technologies related to the Industry

<sup>1</sup> Information source <http://www.portaldaindustria.com.br/cni/en/about/about-cni/>

<sup>2</sup> The complete questionnaire is available at <http://www.portaldaindustria.com.br/estatisticas/sondesp-66-industria-4-0/>

4.0 where the companies indicate the technologies that they consider the most potential to enhancing the competitiveness of the Brazilian industry in the next five years; (ii) *Adopted technologies*: the same list of technologies where the companies indicate those technologies they are already using (iii) *Expected benefits*: a list of benefits expected from digital technologies where the companies indicate up to five benefits they expect to obtain with the technologies adopted; (iv) *Internal barriers*: a list of internal barriers the companies face in order to acquire digital technologies; (v) *External barriers*: a list of external barriers the companies face in order to acquire digital technologies (vi) *Industrial policy*: a list of possible actions the government should make to accelerate the digital technologies adoption by the Brazilian industries. For the purpose of this paper, we used data from the questions (ii) and (iii) of this survey, i.e. the digital technologies adopted and the expected benefits. Question (ii) asks: “*Indicate the digital technologies that your company already uses*”. For this question, a list of 11 digital technologies are provided (see Section 3.2). Question (iii) asks “*Indicate the main benefits that your company expects to obtain by adopting digital technologies: (Indicate up to five items)*”. Here, a list of 14 benefits are provided (see Section 3.2). For both set of variables, the scale provided by the CNI database is in percentage (0% to 100%), representing the relative amount of companies of each industrial sector that have adopted a specific technology (Question ii) or that are expecting a specific benefit (Question iii).

### 2.3.2 Variables Selection

Since our main purpose is to understand the expected benefits of Industry 4.0 related technologies for industrial performance in Brazil, we defined as independent variables the technologies of Industry 4.0 adopted by the industrial sectors and as dependent variables the benefits expected by industrial sectors that are applying these technologies, which are both provided by the CNI (2016) survey. As presented in Table 2, the Industry 4.0 technologies are represented by 11 technologies and the expected benefits by 14 main benefits aligned with those highlighted in the literature. From the independent variables of our regression model, we did not include two technologies that are considered in the CNI survey. The first one was ‘digital automation without

sensors', that was excluded because it is exclusively related to the classic automation of the third Industrial Revolution. The second variable excluded was Simulation/virtual models [VIRTUAL], because it did not follow a normal distribution in the data, presenting a high value of Kurtosis (4.269) (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009), although it is directly related to the Industry 4.0 and was considered in Table 2. The data for the considered variables of our study are provided by CNI (2016) at an aggregate-level, as the percentage of companies in each industrial sector that indicated the adoption of a specific technology and the expectation for a specific benefit. Therefore, our study considers the analysis at the industrial sector level. Besides these variables, we also included two dummies as potential control variables in order to represent the three levels of technology intensity of the 27 industrial sectors under analysis (low, medium and high). These technological intensity levels are described in the CNI (2016) report. Table 3 summarizes the dependent and independent variables used in our regression model.

Table 3 : Technologies and expected benefits considered in the research model

<b>Technologies</b> <b>(Independent Variables)</b>	<b>Expected benefits</b> <b>(Dependent variables)</b>
Computer-Aided Design integrated with Computer-Aided Manufacturing [CAD/CAM] Integrated engineering systems [ENG_SYS] Digital automation with sensors [SENSORING] Flexible manufacturing lines [FLEXIBLE] MES and SCADA systems [MES/SCADA] Big data [BIG_DATA] Digital Product-Services [DIGITAL_SERV] Additive manufacturing [ADDITIVE] Cloud services [CLOUD]	Y1: Improvement of product customization Y2: Optimize automation processes <sup>1</sup> Y3: Increase energy efficiency <sup>1</sup> Y4: Improvement of product quality Y5: Improve decision-making process <sup>1</sup> Y6: Reduction of operational costs Y7: Increase productivity Y8: Increase worker safety <sup>1</sup> Y9: Create new business models <sup>1</sup> Y10: Reduction of product launch time Y11: Improving of sustainability Y12: Increase of processes visualization and control Y13: Reduce of labor claims Y14: Compensate for the lack of a skilled worker <sup>1</sup>

<sup>1</sup> These dependent variables were deleted from the model during the EFA procedure of variables reduction as explained in Section 3.3.

### 2.3.3 Variables reduction for regression analysis

To understand how the different Industry 4.0 related technologies are seen as beneficial for the industrial performance, we kept all Industry 4.0 technologies (Table 2) as single variables (not constructs) in order to differentiate the association of each of them to the expected performance outputs. We tested multicollinearity using the Variance Inflator Factor (VIF) to avoid potential multicollinearity among these independent variables in the regression model. On the other hand, we synthesized the 14 expected benefits presented in Table 2 (i.e. industrial performance) into main categories using a Exploratory Factor Analysis (EFA)<sup>3</sup>. EFA technique allowed us to obtain broader performance metrics based on the partial contribution of different but correlated measures (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). Such a strategy was also used in other prior works in the operations management field (e.g. MARODIN et al., 2017a) and innovation field (e.g. FRANK et al., 2016). This helped us to study the potential contribution of the technologies for the benefits of overall performance metrics when strong correlated outputs are considered. Based on Hair et al. (2009), we divided this procedure in two steps, the validation of EFA adequacy to the sample and the reduction of variables by means of the EFA technique, as explained next.

We used three criteria to evaluate the adequacy of the data to the EFA technique: the Kaiser-Meyer-Olkin (KMO) test for measure of sampling adequacy, Bartlett's test of sphericity, and the measure of sampling adequacy (MSA)<sup>4</sup> (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). All these tests suggested that the dependent variables can be reduced using EFA, since the KMO test was 0.501 (i.e. it equals the threshold value recommended), while the Bartlett's test of sphericity presented a p-value < 0.001 (i.e. lower than the suggested p < 0.05 significance level)

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<sup>3</sup> EFA has been proposed as suitable also for small sample sizes (aggregated data, in our case), when the validation tests and the outputs are robust enough as those obtained in our results. For more details see MacCallum et al. (2001) and Dochtermann and Jenkins (2011).

<sup>4</sup> The statistical tests for both EFA and regression analysis were performed by using IBM® SPSS® Statistics version 20.

and the MSA test indicated that 75% of the variables had values higher than 0.5, as required by this test (Hair et al., 2009).

Then, we performed the EFA for the dependent variables (Table 4). We used a Varimax orthogonal rotation factor solution in order to reduce ambiguities often related to non-rotated analysis and achieve clearer and more meaningful factor solution from the EFA (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). We followed an iterative process to achieve the optimized solution where the optimal number of components were selected based on the eigenvalues, which should be higher than 1.0 (latent root criterion) and on the the percentage of variance criterion, which considers that the optimal number of components are those that exceed 60% of the total variance and ideally more than 70%; in our case we used the latter percentage (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). In the initial solution, 6 of the 14 output variables (Y2, Y3, Y5, Y8, Y9 and Y14) showed no relation to any principal components (these variables are indicated in Table 3). Therefore, they were deleted from the outputs. Then, the EFA with Varimax was performed again for the eight remaining dependent variables, which were represented in three components that explain 75.49% of the variance, as shown in Table 4. The three main components were defined according to the variables with high factor loading ( $>0.5$ ) represented in them. The factorial scores for these new three outputs were obtained by means of the Thurnstones' method. Table 3 also shows the reliability analysis of the three constructs using Cronbach's alpha, being all them above the threshold value of 0.7 (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). Hence, the final three factors are: Product expected benefits [PRODUCT], Operational expected benefits [OPERATION] and Side-effects expected benefits [SIDE-EFFECTS]. The first one (PRODUCT), includes all benefits regarding the product offered, measurement of customization, quality and launch time as dimensions of the product performance. The second construct (OPERATION) considers all the metrics regarding the internal industrial activity of the factory, including costs, productivity and process control of the factory.

Lastly, we called the third component as Side-effects expected benefits [SIDE-EFFECTS] because it considers the collateral effects related to the use of digital technologies of Industry 4.0. In this third component, two benefits are included: the improvement in sustainability (or reduction of externalities) and the reduction of labor

claims. Despite the main goal of Industry 4.0, which is to increase productivity, the initiative aims to reach this goal with more efficient resources utilization, possible by the use of technologies such as additive manufacturing (DE SOUSA JABBOUR et al., 2018b; KAGERMANN; WAHLSTER; HELBIG, 2013). In addition, labor claims can be reduced due to different reasons in this initiative, as this new paradigm relies less on the human force (i.e. fewer workers with potential claims) and also because some technologies aim to help workers to perform their tasks (i.e. workers more assisted to do their job), e.g. human-machine collaboration systems (GILCHRIST, 2016; WANG; TÖRNGREN; ONORI, 2015). Both benefits, improving sustainability and reducing labor claims, can be related into one component as they are usually not the primary objectives expected from industries when investing in digital technologies, so these benefits can be seen as derivative from the expected primary benefits from the Industry 4.0 (CNI, 2016). Table 5 presents the correlation matrix of the final set of variables used in our analysis. This table also shows the descriptive statistics such as mean, standard deviation and the skewness and kurtosis test to verify normality of the data.

Table 4: Rotated Factor-Loading Matrix from EFA procedure

List of expected benefits from the Industry 4.0	Factor loadings <sup>(a)</sup>			
	PRODUCT	OPERATIONAL	SIDE-EFFECTS	Communalities
Improvement of product customization	<b><u>0.797</u></b>	0.251	-0.171	0.727
Improvement of product quality	<b><u>0.766</u></b>	0.167	-0.309	0.711
Reduction of operational costs	0.306	<b><u>0.865</u></b>	0.026	0.843
Increase productivity	0.461	<b><u>0.609</u></b>	0.071	0.588
Reduction of product launch time	<b><u>0.868</u></b>	0.028	0.202	0.796
Improving of sustainability (externalities)	0.079	-0.076	<b><u>0.935</u></b>	0.886
Increase of processes visualization and control	-0.035	<b><u>0.818</u></b>	0.06	0.675
Reduce of labor claims (worker satisfaction)	-0.311	0.357	<b><u>0.767</u></b>	0.813
<b>Eigenvalue</b>	<b>2.986</b>	<b>1.919</b>	<b>1.135</b>	
<b>% of variance explained (cumulative)</b>	<b>37.32%</b>	<b>61.31%</b>	<b>75.49%</b>	
<b>Cronbach's alpha</b>	<b>0.807</b>	<b>0.750</b>	<b>0.720</b>	

<sup>(a)</sup> High factorial loadings (>0.5) are represented in bold and underlined

Table 5: Correlation matrix and descriptive analysis

	MEAN (%)	S.D.	Skweness	Kurtosis	1	2	3	4	5	6	7	8	9	10	11	12	13	14
<b>1 PRODUCT</b>	0.24	0.06	0.402	0.596	--													
<b>2 OPERATIONAL</b>	0.36	0.05	-0.639	-0.112	0.000	--												
<b>3 SIDE-EFFECTS</b>	0.07	0.02	-0.284	-0.328	0.000	0.000	--											
<b>4 CAD_CAM</b>	0.27	0.17	0.542	-0.771	0.648**	0.402*	0.080	--										
<b>5 ENG_SYS</b>	0.14	0.08	0.352	-0.683	0.597**	0.446*	0.215	0.749**	--									
<b>6 SENSORING</b>	0.20	0.09	-0.080	-0.400	-0.191	0.335	0.281	-0.157	0.229	--								
<b>7 FLEXIBLE</b>	0.06	0.04	0.343	-0.327	0.191	0.207	0.062	-0.069	0.303	0.699**	--							
<b>8 MES-SCADA</b>	0.05	0.03	0.347	-0.747	-0.305	0.297	0.234	-0.113	0.300	0.714**	0.505**	--						
<b>9 BIG_DATA</b>	0.07	0.04	0.795	0.970	-0.279	0.487*	0.187	0.045	0.246	0.256	0.109	0.516**	--					
<b>10 DIGITAL_SERV</b>	0.03	0.02	1.054	2.517	0.381	0.306	-0.104	0.226	0.363	-0.020	0.256	0.073	0.353	--				
<b>11 ADDITIVE</b>	0.04	0.04	1.415	1.308	0.625**	0.124	0.356	0.522**	0.669**	0.107	0.314	0.139	0.323	0.463*	--			
<b>12 CLOUD</b>	0.06	0.03	0.043	0.069	0.064	-0.020	0.050	-0.191	-0.207	0.409*	0.418*	0.115	-0.078	0.041	0.042	--		
<b>13 Control_tech_low</b>	0.48	0.51	0.079	-2.160	0.014	-0.395*	-0.228	-0.348	-0.298	-0.465*	-0.239	-0.244	-0.345	-0.229	-0.264	-0.114	--	
<b>14 Control_tech_high</b>	0.26	0.45	1.164	-0.702	0.279	0.415*	0.045	0.496**	0.444*	0.173	0.283	0.049	0.087	0.491**	0.356	0.225	-0.570**	--

\*\* p< 0.01; \* p<0.05.

## 2.4 Results

We used an ordinary least square (OLS) regression<sup>5</sup> to understand the association of Industry 4.0 related-technologies to three types of expected benefits: Product expected benefits [PRODUCT], Operational expected benefits [OPERATIONAL] and Side-effects expected benefits [SIDE-EFFECTS]. OLS regression should be used only if some standard requirements of the database are achieved, such as normality, linearity, and homoscedasticity (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). The skewness and kurtosis values reported in Table 5 suggest that the variables can be assumed as normal distributed, since they are below the threshold of 2.58 ( $\alpha=0.01$ ) (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). We also assessed data normality graphically by means of an examination of the residuals. We analyzed collinearity by plotting the partial regressions for the independent variables while homoscedasticity was visually examined in plots of standardized residuals against predicted value. All these requirements were met in our dataset. Moreover, multicollinearity could be also a problem for OLS regression (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009). Therefore, we tested the variance inflation factor (VIF) among the independent variables, resulting in  $VIF < 3.5$  for the independent variables and control variables, excepting for CAD/CAM, ENG\_SYS and SENSORING which resulted in  $VIF < 8.14$ . As all these values were below the threshold  $VIF = 10.0$ , multicollinearity may not be a concern in our regression model (HAIR, J.F., BLACK, W.C., BABIN, B.J., ANDERSON, 2009).

We performed three independent regression models, one for each of the expected benefits (i.e. PRODUCT, OPERATIONAL and SIDE-EFFECTS). The results of the regression models for the three industrial expected benefits metrics are shown in Table 6. Two of the three models were significant at  $p < 0.05$  and one did not show statistical significance. The first regression model ( $F = 14.245$ ,  $p < 0.001$ ) explained 84.9% of the variance of PRODUCT; while the second model ( $F = 3.042$ ,  $p = 0.024$ ) explained 46.3% of the OPERATIONAL variance. Lastly, we identified that SIDE-EFFECTS was not significant ( $F = 0.751$ ,  $p = 0.679$ ).

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<sup>5</sup> OLS regression was performed using IBM SPSS Statistics ® version 20.



Regarding the association of the specific Industry 4.0 related technologies with the expecting PRODUCT, the following technologies presented positive and significant effects: integrated engineering systems for product development and manufacturing [ENG\_SYS] ( $\beta = 0.438$ ,  $p = 0.063$ ); incorporation of digital services into products [DIGITAL\_SERV] ( $\beta = 0.286$ ,  $p = 0.022$ ); additive manufacturing [ADDITIVE] ( $\beta = 0.261$ ,  $p = 0.050$ ); and Cloud Services [CLOUD] ( $\beta = 0.255$ ,  $p = 0.043$ ). In addition, one technology is negatively associated to the expected outcome of this expected benefits metric: big data analysis [BIG\_DATA] ( $\beta = -0.388$ ,  $p = 0.004$ ).

In the second expected benefits metric, OPERATIONAL, the technologies with positive and significant association were: Computer-Aided Design with Computer-Aided Manufacturing [CAD/CAM] ( $\beta = 0.774$ ,  $p = 0.046$ ); digital automation with sensors for process control [SENSORING] ( $\beta = 0.778$ ,  $p = 0.064$ ) and Big Data [BIG\_DATA] ( $\beta = 0.658$ ,  $p = 0.008$ ). On the other hand, additive manufacturing [ADDITIVE] had a negative association ( $\beta = -0.529$ ,  $p = 0.036$ ) to this expected benefits metric. ADDITIVE also showed a positive association to SIDE-EFFECTS ( $\beta = 0.622$ ,  $p = 0.081$ ), although the complete model for SIDE-EFFECTS was not statistical significant.

Table 6: Results of the regression analysis<sup>(a)</sup>

	Expected benefits for...		
	PRODUCT	OPERATIONAL	SIDE-Effects
CAD_CAM	0.310	<b><u>0.774</u>**</b>	-0.306
ENG_SYS	<b><u>0.438</u>*</b>	-0.129	0.118
SENSORING	-0.189	<b><u>0.778</u>*</b>	0.303
FLEXIBLE	0.212	0.062	-0.409
MES-SCADA	-0.246	-0.345	0.078
BIGDATA	<b><u>-0.388</u>***</b>	<b><u>0.658</u>***</b>	-0.040
DIGITAL_SERV	<b><u>0.286</u>**</b>	0.192	-0.308
ADDITIVE	<b><u>0.261</u>**</b>	<b><u>-0.529</u>**</b>	<b><u>0.622</u>*</b>
CLOUD	<b><u>0.255</u>**</b>	-0.149	0.009
Control_tech_low	0.257	0.379	-0.300
Control_tech_high	<b><u>0.426</u>*</b>	0.241	-0.126
F-value	14.245***	3.042**	0.751
R <sup>2</sup>	0.913	0.690	0.355
Adjusted R <sup>2</sup>	0.849	0.463	-0.118

<sup>(a)</sup> Significant effects are represented in bold and underlined; \* $p < 0.1$ ; \*\* $p < 0.05$ ; \*\*\* $p < 0.01$ .

Furthermore, we performed a statistical power analysis of our two significant models (PRODUCT and OPERATION) based on (COHEN; COHEN; STEPHEN, 2003). We first estimated the population effect size of  $R^2$  using Cohen's  $f^2$  estimation<sup>6</sup>. For the PRODUCT model we obtained a  $f^2 = 10.45$ , which represents a statistical power of  $> 0.99$  at  $\alpha = 0.01$ , while for the OPERATION regression model the  $f^2$  was 2.23, which represents a statistical power of  $\approx 0.93$  at  $\alpha = 0.01$ . We also considered the statistical power of the partial coefficients using Cohen's  $f^2$  estimation for the predictors<sup>7</sup> and the range of effects suggested by them: 0.02– small effect, 0.15 – medium effect, and 0.35 – large effect (COHEN; COHEN; STEPHEN, 2003, p. 95). Considering the statistical significant independent variables in the PRODUCT model, two of them showed large effects: BIGDATA (0.78) and DIGITAL\_SERV (0.44), while all the others showed medium effect ( $\geq 0.27$ ). For the significant regressors in the OPERATION model, two technologies indicate large effect: BIGDATA (0.63) and ADDITIVE (0.35), while the other two CAD\_CAM and SENSORING presented medium effects (0.32 and 0.27 respectively). Therefore, we can conclude that the significant effects have also satisfactory statistical power in our sample.

## 2.5 Discussions

We summarized our findings in Figure 1, aiming to illustrate the connections between the different Industry 4.0 related technologies and the expected benefits. We use this framework (Figure 1) to guide the discussion of our findings and to clarify how these Industry 4.0 technologies can be understood in the Brazilian context. Firstly, we divided our framework (Figure 1) in two set of technologies as our findings showed in Table 6. The first set is related to (i) *Product Development Technologies* of the Industry 4.0 while the second set is related to (ii) *Manufacturing Technologies* of the Industry 4.0. We divided technologies in these two groups because, as we shown in our results, the industrial sectors have different expectations for them. According to our findings of

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<sup>6</sup> According to Cohen et al. (2003, p. 92):  $f^2 = \frac{R^2}{(1-R^2)}$

<sup>7</sup> According to Cohen et al. (2003, p. 94):  $f^2 = \frac{sr^2}{(1-R^2)}$ ; where  $sr^2$  represents the squared semipartial correlation coefficient for the predictor of interest.

Table 6, technologies that are expected to contribute for Product Performance (i.e. *Product Development Technologies*) are ENG\_SYS, DIGITAL\_SERV, ADDITIVE and CLOUD, while the technologies expected to bring benefits for operational performance (i.e. *Manufacturing Technologies*) are CAD\_CAM, SENSORING and BIGDATA. Two technologies, integrated engineering systems [ENG\_SYS] and Computer-Aided Design and Manufacturing [CAD/CAM] are considered integration systems in the interface between product and operational processes, as shown in Figure 1 (TAO et al., 2018a). Next, we discuss in detail the configuration of this framework based on our findings and on prior evidences from the literature.

Firstly, regarding the *Product Development Technologies* (Figure 1), *additive manufacturing* [ADDITIVE], which in product development is represented by 3D-printing, is associated with the expected benefits for new product development. This expectation is aligned with the literature, which highlights that the use of additive technology brings several advantages since products can be digitally modified before their physical production, reducing the processing times, resources and tools needed. This technology accelerates product innovation and assists co-design activities, promoting more customized products (YIN; STECKE; LI, 2017). While additive manufacturing (3D-printing) promotes customization of the products, our findings (Table 6) show that the industry also expects *digital services in products* [DIGITAL\_SERV] and *Cloud Services* [CLOUD] to increase the value perceived by the customers (Figure 1). According to Porter and Heppelmann (2014) digital services connected in the cloud are a global trend in companies, allowing them to launch smart products with embedded sensors, processors, software and connected via internet, which enables new functions and capabilities related to their monitoring, control, optimization and autonomy. With the Internet of Things (IoT), products can communicate with other products and systems of products, optimizing overall results and enabling after-sales service solutions. These technologies should improve the performance of extant products and the development of new products, and its utilization shows some degree of differentiation strategies expected by Brazilian industrial sectors. However, as the (CNI, 2016) report state, there are still few industrial sectors that incorporate digital services in their products with cloud systems and that use additive manufacturing.

On the other hand, the use of Big Data collection and analysis [BIG\_DATA] showed a negative association to the benefits expected for product performance. This is a surprising result for us, since the literature describes this technology as of great potential to leverage innovation, competition and productivity in business processes (WAMBA et al., 2015). While the industry is expecting positive outcomes for integrating data in the cloud (i.e. CLOUD was positive), they do not present an optimistic perspective for the latter technology. In other words, IoT technologies are perceived as useful for real-time processing but not for data storage and analysis. This may suggest that the Brazilian industry still lags in the implementation of one of the most promising tools in the Industry 4.0 for product improvement and innovation (WAMBA et al., 2015). Therefore, even though these technologies have been widely diffused in developed countries, their diffusion and adoption in Brazil is still behind the competitive level expected. Such problem can be corroborated with a recent industrial survey conducted by PwC consulting (PWC, 2016) that indicates that around 63% of Brazilian companies considered themselves in a weak maturity level for Big data analytics, 30% in a middle maturity level and those that represented the remaining 7% outsourced data analytics competencies. As most industrial sectors do not have the capacity to properly analyze the large amount of data they generate, we conclude that this lack of knowledge might impair the perception of usefulness for the development of new products, which represents a diffusion-adoption gap for the Industry 4.0 in Brazil.

Regarding the interface between the (i) *Product Development Technologies* and (ii) *Manufacturing Technologies*, our findings (Table 6) showed that there are two complementary integration technologies: ENG\_SYS, which is positively associated to PRODUCT expected benefits, and CAD/CAM, which is positively associated to OPERATIONAL expected benefits (Figure 1). We argue that based on the findings and on the fact that ENG\_SYS work with the integration of the whole product lifecycle data, from the product conception to its production and commercialization (ABRAMOVICI, 2007; BRUUN et al., 2015; STARK, 2011). This technology can aid different industrial sectors to overcome the well-known communication and coordination barriers they face when involving suppliers in a collaborative NPD for complex products (LANGNER; SEIDEL, 2009; PENG; HEIM; MALLICK, 2014). Moreover, as horizontal integration is one of the main Industry 4.0 characteristics, integrated engineering systems also have

an important role for connecting people, objects and systems through digital platforms, what clearly simplify the orchestration of services and applications in industrial activities (KAGERMANN; WAHLSTER; HELBIG, 2013). On the other hand, CAD/CAM can help the operational aspects for vertical integration, since it can help to translate the product lifecycle data from end-to-end engineering into product design specifications, enhancing the visibility of manufacturing processes still in the design phase (JESCHKE et al., 2017).

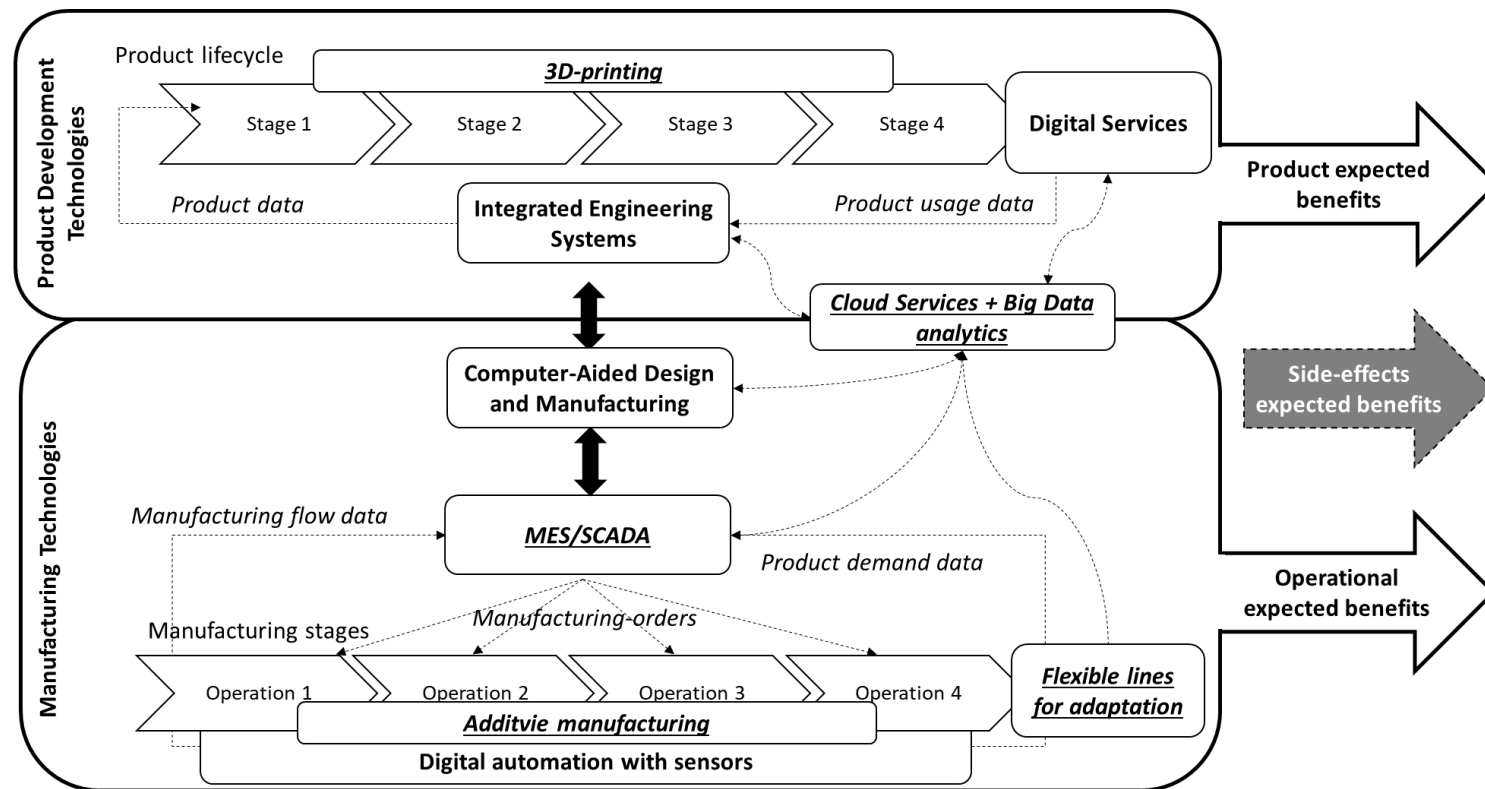
Following the *Manufacturing Technologies* dimension, surprisingly neither MES/SCADA nor flexible manufacturing lines [FLEXIBLE] were significantly associated to the OPERATIONAL expected benefits. Based on the extant literature, we were expecting a positive association of them, jointly with the integration systems (ENG\_SYS and CAD/CAM) and the digital automation with sensors [SENSORING], as a set of standard technologies for the Industry 4.0 manufacturing system. While ENG\_SYS and CAD/CAM integrate product development data with manufacturing processes (MIRANDA et al., 2017), SENSORING enables data collection in the manufacturing process (KONYHA; BÁNYAI, 2017), which could be used by the flexible manufacturing lines [FLEXIBLE] to reconfigure or adapt the processing sequence, schedule, etc. (WANG; TÖRNGREN; ONORI, 2015) with MES/SCADA support (JESCHKE et al., 2017). In other words, these technologies should form a system that enables both, horizontal and vertical integration (ZHOU et al., 2015). ENG\_SYS contributes for information sharing among functional areas in the factory, both internally and externally, which in the latter constitutes the horizontal integration. FLEXIBLE and MES/SCADA contribute to the integration among process stages in the hierarchical areas. The first aims to build reconfigurable lines with sensor technology, in order to ease the change the product types in the production lines (BRETTEL et al., 2014; STEIMER et al., 2016), while MES/SCADA generate daily production orders from the ERP, considering several restrictions from machine data (Jeschke et al., 2017), SENSORING acts at the most basic levels of the equipment operation (GERBER; BOSCH; JOHNSON, 2013). One reason because MES/SCADA and FLEXIBLE might be not statistically associated to the OPERATIONAL expected benefits is because they are in very early stage of adoption in the Brazilian industry, since only around 8% of the industry has adopted these technologies for operational processes,

according to the CNI report (CNI, 2016). Thus, several industrial sectors may not be aware of their contribution for operational benefits.

Digital automation with sensors for process control [SENSORING] showed a significant association to the OPERATIONAL expected benefits, being one of the most implemented technologies (around 27%) in the industries of the survey (CNI, 2016). Even though this is one of the less advanced technologies in the Industry 4.0 concept (YU; XU; LU, 2015), it provides the basis for production cells control and data collection of manufacturing flow and cells demand, aiming to provide inputs for the flexible lines and the MES/SCADA, as shown in Figure 1. SENSORING also allows to create operational big data [BIG\_DATA] – also positively significant in our findings – for further analysis aiming for predicting maintenance, machine-learning (self-adapting), scheduling for the Manufacturing Execution System (MES) and to provide information for new design and manufacturing in the CAD/CAM system (TAO et al., 2018b), as we show in the framework of Figure 1. On the other hand, it is worth noticing that cloud services [CLOUD] did not show significant association to the OPERATIONAL expected benefits while BIG\_DATA did, as we explained before. Based on prior studies (e.g. GILCHRIST, 2016; JESCHKE et al., 2017) we expected a joint contribution of these technologies. One possible reason is that CLOUD is associated with external data warehousing and this is still a concern in the industry due to data security, which represent a barrier for its implementation (WANG; TÖRNGREN; ONORI, 2015).

The last Industry 4.0 technology at the operational level is additive manufacturing [ADDITIVE] which we represented in Figure 1 as overlapped with different manufacturing operations. This means that ADDITIVE could be used in different operation stages and for different production purposes. However, our findings showed a negative association of this technology with OPERATIONAL expected benefits. According to Weller et al. (2015), additive manufacturing still has several restrictions for its application in manufacturing processes, such as the availability of materials and lack of defined quality standards. Moreover, although this technology can improve product development, this equipment has still low production throughput speed, when compared to conventional manufacturing, which may affect larger-scale production levels with cost efficiency, as suggested by our results.

Finally, regarding the SIDE-EFFECTS expected benefits, Figure 1 represents it as a possible secondary perceived benefit from the Industry 4.0. Our results indicated a positive association with additive manufacturing. However, the complete model for SIDE-EFFECTS was not statistically significant – even when ADDITIVE has a positive association to this output – suggesting that this performance is not expected with the use of most of the Industry 4.0-related technologies. This is an unexpected finding, since the improvement of resource consumption efficiency is one of the main areas of Industry 4.0 (KAGERMANN; WAHLSTER; HELBIG, 2013), and the technologies analysed in this paper are suggested to contribute to sustainability (e.g. DE SOUSA JABBOUR et al., 2018a; KIEL, D., ARNOLD, C., COLLISI, M., VOIGT et al., 2016; MAN; STRANDHAGEN, 2017; STOCK; SELIGER, 2016), and indirectly for labor claim reduction, by automatizing the production process which reduces the need for manpower (e.g. HOZDIĆ, 2015). The concern with Industry 4.0 as a way to deal with these side-effects aspects has been addressed in studies of developed economies. However, when considering emerging economies such as Brazil, other aspects may be priority in the industry's concern. As acknowledged by the CNI report (CNI, 2016), the main efforts of Brazilian industries with digital technologies has been to increase productivity, while the side-effects benefits are not yet a clear objective of the industry when investing in Industry 4.0 technologies. Therefore, they could be a secondary benefit only perceived after the achievement of product and operational benefits. This is also in line with the general literature about sustainability in industry, which evidences differences in such concern between developed and emerging countries (HANSEN et al., 2018; VIOTTI, 2002).



Notes: - - (data/information flow); **Technologies underlined**: proposed by the literature but not evidenced or partially evidenced in the findings

Figure 1 – Framework summarizing the findings and discussions of the paper



## 2.6 Conclusions

In this paper we analyzed the perception of the Brazilian Industry about the benefits of Industry 4.0 related-technologies for three industrial performance metrics: product, operational and side-effects. Our results showed that some of these technologies are positively associated to the expected industrial benefits while others are still at a very early stage of adoption and, thus, without clear expected benefits. We discussed reasons for the lack of expectation of benefits for some of the promising technologies of the Industry 4.0 in this specific emerging industry.

Our main contribution to the state-of-the-art is that we show how these technologies are used and seen in an emerging economy, since most of the studies on this matter have been conducted in developed countries. In this sense, we showed how different set of technologies are associated with different expected benefits. We showed that the Brazilian industry has not yet taken advantage from some promising technologies such as product big data analysis, cloud services for manufacturing, among other technologies for the digitalization of the factory and for the analysis of the product performance. A further contribution is that we could not find any relation between the Industry 4.0 and the expected benefits for sustainability and labor claims [SIDE-EFFECTS], which represents a different pattern when comparing to developed economies. Based on prior evidences from developed countries, we argued that since side-effects tend to be at the second level of priority in the industries, after achieving operational and product performance benefits, the Brazilian industry is still not focused on this aspect, but this deserves future investigation.

### 2.6.1 Practical implications

Our results can be useful for both, operations managers and industrial policy-makers. For operations management, our results showed which are expected to be the most powerful technologies to enhance product and operational performance in the Brazilian context, according to the industry perception. Companies that want to initiate their digitalization journey towards the Industry 4.0 should first think, before implementing any technology, what are their strategic goals. Thus, companies with a focus on differentiation should prioritize the implementation of those technologies pointed as significantly associated to the Product Development Technologies dimension (Figure 1), according to what is expected by the

industry and the literature; while companies with a focus on low cost, productivity or operational flexibility should prioritize those Industry 4.0 technologies that have significant contribution for the Manufacturing Technologies dimension. On the other hand, industrial policy-makers in emerging countries can use our findings as a guideline about what technologies still need to be developed for the industry to achieve the competitiveness standards of developed countries. For instance, big data, cloud services and additive manufacturing (e.g. 3D printing) are strong industrial trends in developed countries that should be considered for the future of the emerging countries. However, this field needs further debates regarding the industrial policy approaches to foster the national competitiveness of the country.

## **2.6.2 Limitations and future research**

The use of a secondary dataset for our analysis allowed us to obtain a broad overview of a still little explored emerging industry. However, some limitations are present due to this kind of research. Firstly, our results have limitations on the statistical inferences since we considered expecting benefits from the industry 4.0 technologies and not current benefits obtained from them. This is because the implementation of many of these technologies are recent and the benefits are not feasible to be obtained in the short-term. Future works can use our findings to advance in the study of real improvements, which could be done only in the middle or long-term of this new industrial trend. Experimental studies can provide quicker answers to these aspects when compared with survey studies. However, it is well known that experimental studies have also limitations regarding the generalization of the results.

Furthermore, we used aggregated-level data analysis and thus we studied the industrial sector behavior. In this sense, we call the attention to the risk of ecological fallacy, when macro-level analysis using aggregate data is used in micro-level conclusions (firm-level) (CLARK; AVERY, 1975). In this sense, our results are only valid at the industry-level behavior. Other future studies could, therefore, deepen our research by conducting company-level surveys. We also studied a cross-sectional sample, thus future longitudinal studies on the effect of the Industry 4.0 technologies could evidence patterns and maturity levels of the adoption of such technologies. We know that future research is called to address the endogeneity problems that can be present in large-scale survey studies (BASCLE, 2008), especially because the adoption of technologies might depend not only on internal decisions but on the access to public funds and other kind of governmental incentives (FRANK et al.,

2016). There are other inherent aspects regarding endogeneity in operations management that we did not address in this work and are part of an emerging discussion in this field (KETOKIVI; MCINTOSH, 2017). We were aware about these limitations, but due to the limitation of information in our dataset we cannot include instrumental variables that may be helpful to test alternative models to the OLS models used in this paper. Finally, we mentioned in our work that, from a sociotechnical perspective, organizational and human factors are very relevant to the implementation of technologies. Since we delimited our research only to technological factors in a specific environment, future studies could expand to these other two factors, in order to consider how they facilitate or not the implementation of the technologies addressed in our work.

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### 3 CONSIDERAÇÕES FINAIS

Este capítulo apresenta as conclusões da proposta da dissertação, apresentando as principais contribuições acadêmicas e práticas, assim como algumas sugestões para trabalhos futuros a partir dos resultados encontrados.

#### 3.1 Conclusões

A Indústria 4.0 tornou-se um conceito de interesse em nível mundial, dadas as diferentes iniciativas promovidas por governos de vários países desenvolvidos e emergentes (LIAO et al., 2017). O amplo envolvimento de governos para difusão do conceito e para promover ações que viabilizam a sua implementação indica a magnitude da importância da Indústria 4.0 para a competitividade industrial, atualmente. O interesse em nível governamental no desenvolvimento de fábricas inteligentes reforça a necessidade de maior compreensão do conceito, que ainda é caracterizado por incertezas quanto à correta adoção das tecnologias difundidas inclusive em países desenvolvidos (SCHEER, 2015). Portanto, tendo em vista a sua inovatividade, esta dissertação propôs a entender os benefícios esperados com o conceito da Indústria 4.0 na indústria brasileira, estudar quais tecnologias relacionadas ao conceito da Indústria 4.0 permitem tais benefícios e definir os padrões de adoção de tecnologias da Indústria 4.0 no contexto das empresas brasileiras.

Desta forma, o Artigo 1 analisou uma amostra com empresas de todos os setores industriais no Brasil, a partir de *survey* conduzida em escopo nacional pela Confederação Nacional da Indústria (CNI, 2016). A análise foi realizada considerando a adoção de tecnologias pelas empresas e os benefícios esperados com esta adoção. Embora um tema crescente, existe pouca literatura sobre o assunto, principalmente no contexto de países emergentes.

O Artigo 2 propôs hipóteses sobre a adoção de tecnologias digitais da Indústria 4.0 compreendidas em tecnologias de aplicação, tecnologias complementares e bases tecnológicas. Em cada classificação, diferentes elementos são relacionados com o elemento central da Indústria 4.0, considerado pela literatura como a manufatura avançada. A literatura



aborda este tema, porém existem poucas evidências quantitativas sobre a tendência de adoção de tecnologias do conceito, visto a inovatividade do tema.

### **3.2 Contribuições acadêmicas**

Esta dissertação traz importantes contribuições para um tema recente e com grandes lacunas na pesquisa acadêmica. O Artigo 1 demonstrou estatisticamente como as tecnologias da Indústria 4.0 estão sendo utilizadas no contexto de países emergentes, sob a perspectiva de diferentes dimensões da performance industrial. Nos resultados apresentados, foram identificadas as tecnologias com maior contribuição para performance operacional e para o desenvolvimento de novos produtos. Não foi evidenciada uma relação entre as tecnologias e a terceira dimensão de performance industrial em análise, relacionada à sustentabilidade. Esta falta de relação é justificada pela baixa priorização das empresas industriais brasileiras em melhorar o desempenho sustentável de suas operações, focando apenas em maior produtividade, conforme indicado na *survey* conduzida pela CNI (2016). Ainda, foram encontradas disparidades entre a percepção industrial e a literatura sobre os benefícios das tecnologias digitais do conceito, como a percepção negativa de big data analytics e manufatura aditiva para o desenvolvimento de novos produtos e para a performance operacional, respectivamente. Big data analytics é um tema crescente em publicações acadêmicas e relatórios de consultoria, sendo que autores apostam nesta tecnologia como uma determinante para a competitividade em diversos setores da economia (PORTER; HEPPELMANN, 2015; WAMBA et al., 2015; BABICEANU; SEEKER, 2016). A importância desta tecnologia é corroborada parcialmente no Artigo 2, no qual o grupo com maior adoção de tecnologias de manufatura avançada também apresentou maior adoção de big data analytics.

O Artigo 2 comprovou uma dependência do elemento central da Indústria 4.0, manufatura avançada, com outros elementos externos à fábrica e que transcendem a manufatura, como as tecnologias de integração da cadeia de suprimentos e tecnologias que visam aumentar a performance do trabalhador em atividades compreendidas nos diferentes estágios do ciclo de vida do produto. Também foi comprovada uma maior tendência de desenvolvimento de produtos inteligentes pelas empresas mais desenvolvidas no conceito de manufatura avançada. Por fim, considerando a alta complexidade do conceito da Indústria 4.0, foram encontradas evidências que as tecnologias consideradas como base do conceito são

determinantes para a implementação de um sistema produtivo inteligente, com foco na manufatura avançada. Embora mais estudos sejam necessários para comprovar estas relações, a tendência de adoção das tecnologias 4.0 indica um caminho a ser seguido, em orientação similar à de *roadmaps* sugeridos para desenvolvimento da Indústria 4.0 (SCHUH et al., 2017; LEE et al., 2015; LU; WENG, 2018).

### **3.3 Contribuições práticas**

Os resultados encontrados permitem contribuições práticas, principalmente para a gestão de operações industriais e também para o desenvolvimento de novos produtos. Conforme os resultados do Artigo 1, algumas tecnologias são destacadas conforme a orientação estratégica: diferenciação dos produtos ou redução de custos operacionais. Estes resultados podem contribuir para a perspectiva estratégica das empresas, priorizando investimentos em tecnologias conforme as dimensões de performance industrial consideradas no artigo. Ainda, a identificação de percepções negativas sobre tecnologias como big data analytics contribui para a diretriz das empresas às tecnologias digitais. Considerando a importância desta tecnologia destacada por diversos autores e os interesses governamentais em difundir as tecnologias do conceito, de forma a orientar o país à nova revolução industrial, o resultado encontrado serve como um ponto de atenção para este fim. Logo, este resultado é um importante indicador da condição do Brasil frente à Indústria 4.0, pois de modo geral, esta percepção negativa indica uma tendência de não adoção de uma tecnologia com crescente influência na performance industrial.

Os resultados do Artigo 2 também auxiliam as empresas na diretriz da Indústria 4.0. Ao analisar, nas empresas mais avançadas no conceito, o grau de maturidade nas tecnologias específicas para aplicação em fábricas inteligentes e também em outros elementos complementares. Estes resultados podem servir de exemplo para empresas que visam a atualização digital de suas fábricas, assim como os resultados referentes as bases tecnológicas requeridas para este fim.

### **3.4 Sugestões para trabalhos futuros**

A partir dos resultados dessa dissertação, algumas contribuições podem orientar trabalhos futuros. Os resultados indicam que apesar dos diferentes benefícios com a adoção de tecnologias digitais, existe uma tendência de adoção destas tecnologias. Esta tendência deve

ser analisada com maior profundidade quanto às limitações técnicas das tecnologias consideradas. Assim, é possível confirmar se algumas tecnologias podem ser implementadas em uma sequência diferente, conforme os objetivos estratégicos das empresas sem comprometer o *roadmap* para o desenvolvimento da Indústria 4.0 em todo sistema produtivo. Considerando o alto custo das tecnologias compreendidas pelo conceito como uma importante barreira para a adoção destas (CNI, 2016), torna-se importante estudar um *roadmap* mais flexível à Indústria 4.0, principalmente em países emergentes que possuem um parque industrial mais heterogêneo quanto a sua intensidade tecnológica do que países desenvolvidos. Ainda, objetivos estratégicos das empresas não foram considerados nas análises dos artigos desta dissertação, assim como outros fatores que podem impactar na adoção das tecnologias, como a existência de setores de pesquisa e desenvolvimento nas empresas, o capital humano nas organizações e a existência de métodos de gestão da produção (LEONARD-BARTON, 1992). Estes fatores são importantes para o desenvolvimento de diferenciação estratégica em um contexto organizacional, e a relação destes com a adoção das tecnologias da Indústria 4.0 deve ser entendida para a adaptação das empresas ao conceito.

### 3.5 Referências

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