MECHANICAL ENGINEERING | PHYSICS | PRESERVATION OF THE ARCHITECTURAL HERITAGE | SPATIAL PLANNING AND URBAN DEVELOPMENT | STRUCTURAL, SEISMIC AND GEOTECHNICAL ENGINEERING | URBAN PLANNING, DESIGN AND POLICY | AEROSPACE ENGINEERING | ARCHITECTURAL COMPOSITION | ARCHITECTURE, BUILT ENVIRONMENT AND CONSTRUCTION ENGINEERING | ARCHITECTURE, URBAN DESIGN, CONSERVATION OF HOUSING AND LANDSCAPE | ARCHITECTURAL, URBAN AND INTERIOR DESIGN | BIOENGINEERING | DESIGN | ELECTRICAL ENGINEERING | ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY | ENVIRONMENTAL AND INFRASTRUCTURE ENGINEERING | INDUSTRIAL CHEMISTRY AND CHEMICAL ENGINEERING | INFORMATION TECHNOLOGY | INTERIOR ARCHITECTURE AND EXHIBITION DESIGN | **MANAGEMENT ENGINEERING** | MATERIALS ENGINEERING | MATHEMATICAL MODELS AND METHODS IN ENGINEERING

DOCTORAL PROGRAM IN MANAGEMENT ENGINEERING

Dean:
Prof. Paolo Trucco

Introduction

The Ph.D. Program in Management Engineering (DRIG) offers students advanced training and preparation to conduct research in the field of management, economics and industrial engineering. It aims at training professionals who are able to carry out high-quality research in the fields of management, economics and industrial engineering at universities or other research institutions. PH.D. graduates from DRIG are also well equipped with distinctive skills and advanced knowledge to pursue a professional career in manufacturing and service companies, regulatory authorities and other public bodies. The program allows the student to develop a sound methodological background and multidisciplinary knowledge by attending courses designed to provide a multiplicity of visions, theories and approaches, a broad cultural panorama. The program emphasizes the benefit of studying problems in an innovative manner, combining various analytical approaches and research methodologies.

The commitment of the Department of Management, Economics and Industrial Engineering (DIG) to research and scientific cooperation with other academic institutions, major industrial companies and other organisations creates an ideal environment in which for students to acquire leading-edge knowledge and cultivate their own research interests in a broad range of research subjects.

Ph.D. Program Structure and Contents

The Full Time doctoral program covers three years, whereas the Executive Program lasts four years. They are entirely taught in English.

The Faculty of DRIG includes, in addition to professors of the Department of Management, Economics and Industrial Engineering, several international scholars: Rodney Turner, Editor of the International Journal of Project Management; Mike Wright, Imperial College London, UK; Irvine Lapsley, University of Edinburgh, UK; Hans De Bruijn, Delft University of Technology, The Netherlands; Abraham B. Rami Shani, California Polytechnic University, USA; Christopher Worley, University of Southern California, USA; David Coghlan, Trinity College Dublin, Ireland; Donald

Huisingh, University of Tennessee, USA; Tobias Kretschmer, Ludwig-Maximilians-Universität München, Germany.

The program covers three main types of training activities.

Main courses
Mandatory courses in Epistemology of Research in Social Sciences and Academic Publishing. Methodological courses, addressing specific research methodologies and related skills relevant to research in management, economics and industrial engineering; Thematic courses, aiming at introducing students to the reference theoretical background and the cutting edge research in specific disciplines, such as Entrepreneurship and Entrepreneurial Finance, Innovation Economics and Management, Supply Chain Management, Organisational Theory and Design, Service Operations Management, Enterprise and Operations Risk Management, Sustainability and Social Challenges in Industrial Systems.

Elective courses and training in specific themes
Elective training activities are customised according to the specific needs and research interests of students. The aim is to extend the scientific knowledge of students in very specific topics and to introduce them to the international research community through their active participation to international scientific conferences and PhD schools.

Thesis
The aim of the PhD programs at Politecnico di Milano is to instil in candidates a research-oriented mind-set, along with expertise and skills relating to a specific research topic. To develop a research-oriented mentality, candidates must acquire the ability to solve complex problems, including a thorough analysis of the problem, identification of an original solution and the ability to evaluate the solution and its applicability in given contexts. PhDs who possess these abilities will have greater opportunities for advancement in research positions, both in the academic environment as well as in public and private organisations. The main goal is the development of an original research contribution. The Ph.D. thesis should help increase knowledge in the applicant's research field.

It also needs to be consistent with the research topics studied at the Department. The final thesis can be submitted in the form of either a monograph or an edited compilation of papers. The research projects presented in the following section are typical examples of the research work carried out by DRIG students.

Scientific and Industrial Collaborations

Students are required to spend at least one semester in a foreign research institution. In addition, students are encouraged to attend doctoral schools and workshops organized by other institutions and to participate in international scientific conferences. The presentation of an original research work in an international conference is mandatory for admission to the final exam. To his end, students are granted of a personal research budget, covering a three years research period, and have access to mobility support measures aimed at promoting international collaborations between the doctoral programs in Europe and overseas.

In addition, Double Degree agreements are in place at the PhD level:
- EDIM (European Doctorate in Industrial Management, www.edim-phd.eu) is an Erasmus Mundus Joint Doctoral Programme run by KTH (Sweden, Co-ordinator), POLIMI (Italy) and UPM (Spain) and is funded by the European Commission (EACEA);
- Double Degree Program with the Pontificia Universidad Católica de Valparaíso (Chile), Escuela de Ingeniería Industrial, Doctorado en Ingeniería Industrial (started in 2013).

DRIG has also developed several research collaborations with private manufacturing and service firms, regulatory bodies, and other public research institutions to fund PhD oriented research. In recent years, the following organisations supported DRIG Scholarships: Value Partners, TXT e-solutions, D'Appolonia, Consorzio MIP, Fondazione Rosselli, Eupolis, Società Banknord GE.PA.FI. SIM, Siemens, ANIMP-OICE-FONDAZIONE LUIGI DE JANUARIO, PIRELLI & C., EUROCONTROL, C.T.G. Italcementi Group, Telecom Italia.

Professional opportunities and the job market

Typical career opportunities opened up by the doctoral program include:

- Post Docs, research fellows and young lecturers at Italian and foreign universities;
- Researchers and scholars in Management Engineering at public and private organisations;
- Highly qualified personnel at research and training institutions, or at technology transfer centres in Italy and abroad;
- Professionals at leading management and strategic consulting firms who can provide deep and advanced insights into companies' business areas;

- High-level professional roles at national and international public institutions;
- Managerial roles at multinational companies with a strong focus on innovation;
- Entrepreneurs in contexts characterised by a high level of innovation.

Support actions for placement are provided with the purpose of sharing experiences, services and information through a number of initiatives fitting the different types of career opportunities. Particular emphasis is given to career development in the Management Engineering area.

ADVISORY BOARD	
Name	**Affiliation**
Punam Sahgal	VP/HR, National Institute for Smart Government, Indian Institute of Management, Lucknow
Wayne W. Huang	Dean School of Management Xi'an Jiaotong University, China
Maryam Alavi	Dean Scheller College of Business, Georgia Institute of Technology)
Valerie Suslow	Associate Dean a Johns Hopkins, Baltimora
Joahn Roos	Chief Academic Officer, Hult International Business School, UK
Mats Engwall	Head of Division of Industrial Management, KTH Royal Institute of Technology
Georg von Krogh	Dipartimento di Management di ETH - Zurich
Reinhilde Veugelers	Professor of Managerial Economics, Strategy and Innovation, University of Leuven
Martin Schader	Associate Director of Quality Services, EFMD, Germany
Carlo Purassanta	Amministratore Delegato, Microsoft Italia
Aldo Fumagalli Romario	Presidente e Amministratore delegato di SOL s.p.a..
Andrea Pignataro	Founder & CEO, ION Trading
Giuseppe Falco	CEO di BCG Italia
Laura Frigenti	Direttore Agenzia Italiana per la Cooperazione allo Sviluppo
Melissa Peretti	AD American Express
Elena Zambon	Presidente Zambon
Matt Symonds	QS

ANALYSIS OF CONSUMER-BRAND ENGAGEMENT WITH FASHION BRANDS IN SOCIAL MEDIA

Artha Sejati Ananda – **Supervisors: Prof. Lucio Lamberti**

Co-Supervisor: Prof. Ángel Hernández-García

The rapid utilization of social media as marketing tools by industries and organizations has changed profoundly the consumer behavior, including shopping behavior – throughout all consumer purchase decision stages and beyond. On the other hand, the presences of fashion brands in various social media platforms have been evident, notably through their establishments of social media embedded brand communities. As fashion managers become more comfortable with the use of social media applications, social media are becoming ubiquitous and need to be managed like all other forms of media that organizations employ to meet their marketing objectives. Moreover, there has been a growing managerial and scholarly interests in the field of *social media marketing* (SMM) regarding its role and impact on relationship marketing, as such how it can be utilized to engage and maintain relationships with customers.

Despite the rapid adoption of social media from both organization and consumer perspectives, current scholarly works still lack of empirical validation of consumer-brand engagement concept within social

media context and its impact on brand-related outcomes. Furthermore, current studies lack attention to the effect of strategical tactics and actions of SMM in relation with consumer engagement formation and the following consequences. The main purpose of this research is to investigate the role of SMM actions employed by fashion brands in the formation of consumer-brand engagement, with the emphasis on behavioral dimension, under the lens of brand community concept. Besides, the research investigates the consequences of such social media engagement on marketing outcomes such as brand loyalty, brand love, and purchase intention. Moreover, it studies the influences of consumer involvements (i.e. fashion, fashion-brand, and social media brand-community involvements) in the generation of social media consumer-brand engagement.

This research is set for seven main objectives in fulfilling its purpose. Firstly is to build the conceptualization of SMM strategy. The conceptualization includes a proposal for a framework on how companies may deploy their SMM strategies and translate them into marketing actions in various social media platforms

– i.e. the 'N-REL framework'. Second objective includes the identification of specific SMM activities by companies. Third objective covers the testing of the proposed framework on fashion brands. Fourth objective is related with development of the measurement items of SMM actions by fashion brands. Fifth objective is aiming at investigating how consumer may engage with fashion brands through their responses towards brands' SMM actions. Sixth objective covers the study of the influence of fashion consumer involvements – fashion, fashion brand, and social media brand-community involvements – on social media consumer-brand engagement. And the last, seventh objective explains to what extent social media consumer brand-engagement affects marketing outcomes – brand loyalty, brand love, and purchase intention.

In order to achieve its goals and objectives, the design of this research requires both companies and consumer perspective analyses, as such multi-stage studies are conducted on fashion brands and consumer sides. Based on the built N-REL framework for SMM strategies, the research begins with studies of holistic perspective – both companies

and consumer views – that measure and refine dimension of SMM strategic actions by fashion brands. Exploratory case studies were conducted on fashion brands to examine their SMM strategy practices. Specifically, the study examines brands from two mature European countries whose fashion industries have different and distinctive characteristics: Italy and Spain. Further studies address how consumers interact and engage with fashion brands in social media brand communities, in terms of their behavioral responses – including electronic word-of-mouth engagement – towards brands' marketing actions. A quantitative study using a sample of Indonesian fashion social media brand community members – part of one of world's biggest social media populations and a relevant emerging market – then attests how consumer involvements may affect consumer engagement towards four most relevant SMM actions employed by four representative European fashion brands of fast-fashion and luxury segments; and how in the end those social media consumer-brand engagements relate to brand loyalty, brand love, and purchase intention.

Key findings suggest that social media consumer-brand engagement is useful for brand loyalty and purchase intention with brand loyalty apparently is a stronger and prominent outcome variable of the consumer engagement towards all the actions throughout brand community members of fast-fashion and luxury fashion. On

one hand, social media consumer-brand engagement can leverage well fashion involvement and involvement towards social media brand community into purchase intention across consumer members of both segments most notably through action related with online shopping. Besides, fashion involvement and involvement towards social media brand community are found to be the most crucial antecedents in affecting social media consumer engagement behavior. Yet, conclusion cannot be drawn from this research on the effect of social media consumer-brand engagement on brand love, since brand love construct are dropped in the final model due to the discriminant validity issue towards brand loyalty and purchase intention. Another key insight is the eminent of marketing actions distinctive to SMM – engaging influencers as promotional means or brand advocacy, as well as engaging consumers for participatory promotions by encouraging them for content co-creations in relation with their experiences with the brand – which are found to be especially critical for luxury fashion brands to boost brand loyalty.

From academic perspective, this research extends prior literature on firms' strategical approach of SMM. The study enriches the theoretical body of knowledge to understand the consumer-brand engagement in social media brand community context by introducing a conceptualization of 'social media consumer-brand engagement (social media CBE)'

construct and operationalization of the construct in term of its behavioral sub-dimensions. This research explores the impact of social media CBE towards a specific brand's SMM action on brand-related outcomes by developing and testing a theoretically grounded research model which considers the influences of fashion consumer involvements in the social media CBE generation. This research is amongst the pioneers that link social media CBE with a specific brand's SMM tactic or action, more specifically in the context of fashion social media brand community.

Aside from the theoretical implications, the findings of this study also provide valuable implications for fashion marketers or practitioners in the industry. This research addresses the important trends in marketing research and practices involving social media, in particularly social media embedded brand communities, by offering a holistic view on utilization of the brand communities to perform fashion brands' strategic marketing actions and how consumer engage with brands. In the end, this research offers some valuable insights to fashion managers on enhancing consumer-brand relationships, as well as achieving sales and customer retention within the important trends of SMM and social shopping.

EXPLORING ENTREPRENEURIAL ECOSYSTEM RESEARCH: TOWARDS A HOLISTIC PERSPECTIVE

Angelo Cavallo - Supervisor: Ing. Antonio Ghezzi

Entrepreneurship has been widely recognized as the engine of countries' economic growth. The extant literature in entrepreneurship has been mostly preoccupied with the characteristics and behaviors of individuals or firms. This, despite there is a long legacy from disciplines such as geography, sociology and business research that emphasized the importance of relationships between entrepreneurs and their local economic and social contexts. Indeed, several scholars highlight the need to understand entrepreneurship in broader contexts such as their regional, temporal and social settings. There is a lack of a holistic approach to entrepreneurship that focuses on interrelated aspects of entrepreneurship. As regard, there is widespread agreement among scholars expressed in recent papers that the systemic nature of the entrepreneurial activity is still underdeveloped. Few studies embrace entrepreneurship from a truly systemic and interdisciplinary perspective. As result, a new concept that goes in this direction i.e. "systemic view of entrepreneurship" emerged recently: the Entrepreneurial Ecosystem (EE). Cohen (2006), Isenberg (2010) and Feld (2012) are considered pioneers of the EE concept. These works have popularized the idea amongst key entrepreneurial leaders and policymakers that a place's community and culture can have a significant impact on entrepreneurship. The growing popularity of this concept leads also scholars to investigate on EE approach. Empirical studies focused on how a rich EE enables entrepreneurship and subsequent value creation at the regional level. Mack and Mayer (2016) explore entrepreneurial (ecosystem) successes in Phoenix (Arizona) while Spigel (2017) considers Waterloo and Calgary (Canada). Previous research, though earlier than the emergence of the EE approach, described how interaction among entrepreneurs and other contextual elements/actors may create conditions for long term entrepreneurial success. Recently, Acs et al. (2014) identified strong EE in a multi-countries study. By employing a large scale quantitative methods, he was able to show the different underlying local factors associated with high levels of innovative entrepreneurship.

Besides these valuable contributions, Stam (2015, p. 1764) argue that "seductive though the entrepreneurial ecosystem concept is, there is much about it that is problematic and the rush to employ the entrepreneurial ecosystem approach has run ahead of answering many fundamental conceptual, theoretical and empirical questions". This call for action was quite shared and felt in the academic community, thus (among others) two leading journal in the entrepreneurship field embraced the challenge: Strategic Entrepreneurship Journal and Small Business Economics. Their recent (Autun/Winter 2015) call4papers together with a number of international conferences has been specifically addressed on advancing the Entrepreneurial Ecosystem literature. As result, we observe several recent and extremely valuable contributions on the EE topic. For instance, Kuratko et al., 2017 illustrates the paradox of new venture legitimation within the EE, while Acs et al. (2017) examine the roots of EE in terms of antecedents in literature. Sussan and Acs (2017) propose an integrated framework of "digital entrepreneurial ecosystem" as composed by Schumpeterian (1911) entrepreneurs creating digital companies and innovative products and services for many users and agents in the global economy (Acs et al., 2017). Summing up, particulars attention has been dedicated to EE in its definition, key dimension or attributes. However, the current debate on Entrepreneurial Ecosystem (EE) is still open on several critical points. Many studies examine antecedents of EE taking from regional development and strategy literature. Empirical investigations were also conducted in specific social contexts. Acs et al. (2014) analyze strong entrepreneurial ecosystems leading to innovative entrepreneurship by leveraging on quantitative methods. Other studies focused on how a rich EE enables entrepreneurship. Even without using the specific term EE, additional works on regions such as Silicon Valley, Washington DC and Kyoto examine the factors fostering entrepreneurship in a specific environment. Recently, Acs et al. (2017) consider the number of Unicorns (new ventures valued at more than $1 billion) as a measure of performance of an EE. This is consistent with the definition of EE provided by Stam (2015) which predominately entails productive entrepreneurship originated from ambitious entrepreneurs seeking to rapidly grow and scale.

Even though there are several empirical investigations on EE, there is still little known about how we can study, evaluate and measure an EE. The EE has been widely recognized as complex and "evolving" or dynamic system: studying a dynamic and complex system as a whole may result an irksome task, and scholars are still interrogating on which methods best suit for this challenge. One of the main goals of this thesis is to provide guidelines on how to gain a more comprehensive understanding on the EE. As part of this Ph.D. Thesis contributions, while embracing an EE approach, we provide specific guidelines in order to study and gain a comprehensive understanding on the EE. Furthermore, following these guidelines we develop and collect three stand-alone but strongly intertwined studies focused specifically on the Italian EE.

Building on the main constituting concepts found in EE's definition from Stam (2015), in Table 8 we illustrate the EE approach guidelines, the relative and supportive extant research and related topics addressed in this Thesis and stemming from such concepts and guidelines (Thesis Topics). Following Table 8, we provide the theoretical foundation and description of each Entrepreneurial approach guidelines which provided the occasion to introduce the main rationales of each paper part of this Ph.D. Thesis.

EE conceptualization (Stam, 2015)	EE approach - Investigation Guidelines	Extant research	Thesis Topics
"set of interdependent actors"	1) Study the main entrepreneurial dynamics	e.g. Dutta and Folta, 2016; Croce et al., 2016; Colombo and Grilli, 2010; Stam and Elfring, 2008; Grimaldi and Grandi, 2005.	New venture creation.
	2) Start from analysis of sub-systems or micro-systems part of the wider Entrepreneurial Ecosystem	e.g. Miller and Acs, 2017; Sterman, 2000; Ghaffarzadegan et al., 2011; Forrester, 2007; Pruyt 2013.	New venture growth.
.."enable productive entrepreneurship"..	3) Focus on innovative and growth oriented entrepreneurship	e.g. Shane, 2009; Stam et al., 2012; Mason and Brown, 2013; Henrekson and Sanandaji, 2014; Stam and Spigel, 2016.	Collaboration between new ventures and established companies.
.."within a..territory"	4) Focus on a specific territory	e.g. Neck; 2004; Acs et al., 2017; Anselin et al., 1997; Florida, 2004; Florida et al., 2017; Acs et al., 2017	Focus on hi-tech new ventures.

Tab. 1 - The EE approach guidelines

Conclusion

This Thesis deals with a complex and dynamic system: the Entrepreneurial Ecosystem. Due to its nature, several difficulties emerge while trying to gain an understanding of EE. More importantly it results significantly complex for policy makers to set forth specific and effective measures addressing EE development: still, EE development deserves attention from policy makers, since its importance for countries' economic and sustainable growth is widely recognized. The main aim of the Thesis was to provide guidelines and future directions for researchers willing to put forward the current EE knowledge. Advancing the literature might be accomplished only whether researcher ask themselves the right questions.

Following the guidelines proposed in this thesis that stem from Stam (2015) EE conceptualization, we "focused on a specific territory" and specific EE: the Italian Entrepreneurial Ecosystem. Three overall findings emerged from this Thesis. First, incubating initiatives and industrial districts emerged as key players in fostering innovative new venture creation. Second, formal venture capital (VC funds) rather than informal investors (Angel groups) are supporting the growth of innovative (digital) new ventures. Third, this Thesis highlights how beneficial might be a collaboration program (e.g. innovation contest) between innovative new ventures and established firms.

EE researchers may benefit from this work when the complexity of the EE may inhibit any form of in-depth analysis. For instance, we implicitly suggest caution on cross-country analysis while dealing with EE. Each ecosystem has its own peculiarities, history and heritage that should be taken very seriously - as we made it very clear by considering the recent and successful story of Italian Industrial Districts. Moreover, we show features on the finance dimension of under-developed EE such as the Italian one, while several studies offer valuable contributions on well-developed EEs (such as the US or UK ones). Research value is also connected with the emerging role of collaboration program such as innovation contest that involves three different but key actors of EEs: incubators, new ventures and incumbent companies. From an incumbent side, we show that those programs may stimulate change and innovation, thus revealing how beneficial might be being in contact with innovative new ventures - especially those incumbent companies that are struggling in the current competitive scenario (i.e. stagnant firms).

This Thesis has also several direct managerial and policymakers' implications. For instance, it emerges that incubating initiatives and angel groups organization should be supported with specific measures. Similarly, policy makers should consider favouring the connection between SMEs (as those populating Industrial Districts) and innovative new ventures. Therefore, entrepreneurs could benefit from this work. Indeed, they should be aware of the relative contribution of angel groups and venture capital funds to venture performance and growth. Finally, managers should be aware that collaboration program with startups may result beneficial for their companies, without pretending to obtain strategic results in the short term.

A METHODOLOGY TO GUIDE MANUFACTURING COMPANIES TOWARDS DIGITALIZATION

Anna De Carolis - Supervisor: Prof. Marco Taisch

Within the era of Industry 4.0, digital technologies are seen as the main drivers for manufacturing industry transformation. If on one hand manufacturing companies have to be able to "ride" this wave of transformation in order to remain competitive, on the other hand, before investing in digital technologies, they have to understand what their current situation is and what their needs are with respect to both digital technologies and organizational processes in different functions. Indeed, the success of the transformation process mainly depends on the company ability to be ready to apply the technological change that some of these digital technologies envision. From these considerations, after having figured out their current readiness level for starting the digital transformation fostered by the Industry 4.0, it is possible to state that the next step manufacturing companies have to undertake is to define their transformation roadmap. With the aim to guide them towards this transformation process, a maturity model, called DREAMY (Digital REadiness Assessment MaturitY model) and based on the inspiring principles of the CMMI (Capability Maturity Model Integration) framework, has been developed and utilized. To define the model

architecture, it was fundamental to identify manufacturing relevant processes that are strategic for the digital transformation. When structuring the manufacturing relevant processes, the first considerations done were about how they highly depend on the company's production strategy (i.e. Engineer-To-Order –ETO-, Make-To-Stock –MTS-, etc.). ETO companies, for example, can build their competitive advantage thanks to a perfect management of quotation and customer requirement comprehension phases, while MTS companies have to be very well organized in forecasting demand and in stock management processes. As the objective is not to focus on a single manufacturing company's strategy, a modular and scalable architecture was built, enabling to adapt to the needs, and thus assessment, of companies using different production strategies. In order to make the architecture as general as possible, manufacturing company's processes were grouped in five main areas: 1) (product and process) Design and Engineering; 2) Production Management; 3) Quality Management; 4) Maintenance Management; 5) Logistics Management. Each process area can be considered as a self-contained module and

therefore it is possible to add or remove one or more areas in case of they are not meaningful in certain industrial situations with no impact on the macro-structure foundation. Horizontally to these process areas, it interposes the Digital Backbone, within which all the information exchange processes inter-areas are covered. Once the architecture is given, maturity levels are still undefined; they are however relevant issues in maturity assessment. Indeed, for the objective of this work, the digital readiness of a manufacturing company is defined through a scale of maturity levels. These levels describe a proper set of company capabilities, to provide a snapshot of their current (digital) abilities. The main reason of choosing the CMMI as reference framework is that it provides a defined structure of maturity levels, specifying what are the capabilities a company has at each level. In this way, as the five-scale CMMI maturity levels provided a generic model to start from, they have been re-adapted in order to gather the definitions, and so the semantic, of the digital readiness maturity levels. Along the maturity levels, it is worth remarking the relevance of integration, either vertical or horizontal one, as well as intra- or inter-companies, and of interoperability: they are two

primary levers to enable digital-orientation. Integration is a commonly known concept: it is the first systemic paradigm used to organise humans and machines at different levels, field, management and corporate level, to produce an integrated enterprise system. It has been recognized since long in its importance for the manufacturing chain within the networked enterprise, in order "to control and to manage the customised manufacturing of both goods and services as desired by the Internet society". Interoperability (Enterprise interoperability) is the "ability of enterprises and entities within those enterprises to communicate and interact effectively". This is an enabler of business collaboration (intra- or inter-companies), and it is not just a technology problem. Indeed, interoperability requires solutions to overcome barriers of different nature, i.e. conceptual, technological and organizational ones. Nowadays, interoperability is clearly a relevant requirement that comes out along the journey towards the digital transformation. From what already defined in the maturity levels, it is clear that, when evaluating the digital capabilities of a company, not only the technologies used to support the processes have to be considered. Indeed, without

structured processes and defined organization structures, a company will not be able to exploit the opportunities these technologies offer. From these considerations and considering the objective of the maturity model itself, it was decided to evaluate the digital readiness of manufacturing companies through four analysis dimensions: Process, Monitoring and Control, Technology and Organization. The decision of considering these analysis dimensions was made mainly taking into account the units of analysis of the DREAMY, which are manufacturing relevant processes. To this aim, it was decided to assess: 1) the way in which these processes are carried out (Process dimension); 2) the way in which these processes are monitored and controlled through the evaluation of feedbacks received from their execution (Monitoring and Control dimension); 3) the technologies that support these processes (Technology dimension); 4) the organizational structures behind these processes (Organization dimension). Thus, the maturity model provides a normative description of practices in each area and dimension, building a ranked order of practices (i.e. from low to high maturity). The method should be useful both

to manufacturing companies and researchers interested in understanding the digital readiness level in the state of practice. In fact, the objectives of this model are twofold. Firstly, it allows the assessment of the current digital readiness of manufacturing companies and the identification of their strengths and weaknesses with respect to implemented technologies and organizational processes. Secondly, it enables the identification of a set of opportunities offered to companies by the digital transformation, considering their strengths and aiming to overcome their weaknesses. Through the application of this methodology into case studies, it has been possible to reach two main results. On one hand, the analyzed manufacturing companies have been aware of their digital readiness level, of their strengths and weaknesses and of the main opportunities they can exploit from the digitalization process starting from their current situation. On the other hand, empirical evidences were gathered on the current level of manufacturing companies' digital readiness and on the possible common traits among the identified opportunities.

HOW LARGE EUROPEAN COMPANIES CAN DEVELOP SOCIAL BUSINESS AT THE BASE OF THE ECONOMIC PYRAMID

Claudio Di Benedetto - Supervisor. Prof. Giovanni Azzone

This thesis aims to analyze how large European companies develop social business at the bottom of the economic pyramid (BOP).

Relevance of Social Business in the BOP Context

The base of the economic pyramid (BOP) is defined as the four billions people living with an annual income below $3,260 in local purchasing power (London and Hart 2011). Despite BOP markets are heterogeneous in terms of geographic range and income level, on one hand are characterized by high levels of poverty and deprivation on the other represent a fast growing market with huge unmet needs. We suggest that the concept of social business (SB) is, for companies, an innovative and promising model to satisfy unmet social needs and to experience new forms of value creation (Power and Wilson 2012; Seelos and Mair 2007; Yunus et al. 2010). From a company perspective the social business can be defined as: *"A new way of corporate social engagement where large companies start-up or expand a business venture created for a social purpose, with the aim of generate blended value through the development of "socially innovative activities". It is managed with the financial discipline, efficiency and tools of a private sector business".*

The Research Problem

Despite the growing engagement of large companies in social business initiatives at BOP a comprehensive understanding of the diffusion of the phenomenon is still lacking. Furthermore, unlike traditional CSR, in literature there is a relative paucity of information about both the characteristics of companies engaging in social business at BOP and the social business configurations they have developed (Husted 2003; Power and Wilson 2012).

The Research Objective

This research aims to contribute to the current debate mapping the state of the art of European companies doing SB at BOP. In particular, the research analyzes the diffusion and the key characteristics of European companies doing Social Business at BOP. Indeed, the research investigates how a number of company's characteristics influence the engagement of companies in SB at BOP. On the other hand to understand the role of companies in the development of social business, the whole spectrum of social business configurations through which companies create or expand SBs at BOP have been identified and classified.

Research Development:

To achieve the research objectives, the study is articulated into four steps.

First Step: Literature Analysis
According to the first objective of the research, in the literature analysis have been identified as potential determinants of the engagement of companies in social business at BoP the following characteristics: Size, Sector, Country, Age of Membership, GC Differentiation level. According to the second objective, the literature review was useful to identify the appropriate research framework to analyze the social business configurations. The social business model developed by (Yunus et al. 2010) was chosen as a proper framework to achieve the second objective of the research.

Second Step: Data Collection
Data collection has been performed through the creation of a database. The database was created starting from the database of the United Nation Global Compact (UNGC), the world's leading corporate responsibility program. Companies have been selected by 32 European countries. The resulting sample amounts at 1745 companies from 30 countries. Once defined the sample, the researcher visited the website of each company to identify whether it does SB or not. For the 111 companies identified a rich amount of information have been collected from the company's website and sustainability

Company Characteristics:	Values positively associated to the engagement in SB at BOP
Size	Large Companies
Sector	Energy and Wash, Financial Services, Food and Beverage and Healthcare and Pharmaceutics
Country	Switzerland, Italy, Germany, France and UK
Age of Membership	Old Members of the UNGC
GC Differentiation level	Advanced CSR Practices

Tab. 1 - Characteristics of Companies Doing SB at BOP

reports according to the research frameworks selected.

Third Step: Data Elaboration:
To understand if and to what extent companies' characteristics influence the engagement of companies in SB at BOP a logistic regression has been performed. Results show that the companies engaged in SB at BOP are characterized by the following features On the other hand to analyze the role of large companies in the development of social business at BOP and to classify the social business configurations they have developed, the researcher has coded, the information collected, in categorical variables. Subsequently, to classify the social business collaborations developed by companies a multiple correspondence analysis and a cluster analysis has been performed.

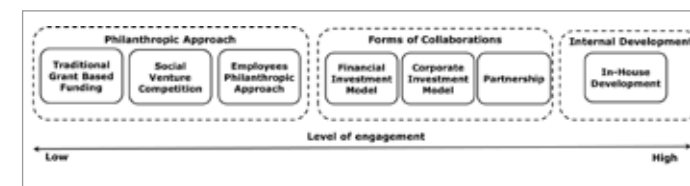Fourth Steps: Classification of Social Business Configurations

The fourth step consisted in the development of a model that classifies the whole spectrum of social business configurations resulting from the cluster analysis. In particular, have been identified seven SB configurations.

The thesis Contribution

The research contributes to broaden the validity of existing CSR theory to the context of social business and adds new original findings to the social business literature. First, the thesis represents one of the first attempt to quantitatively map the state of the art of European companies doing SB at BOP, in order, to outline the diffusion and the characteristics of such emerging phenomenon. Second, the research broaden the validity of existing CSR literature to the context of social business pointing out whether and to which extent a number of companies' characteristics influence the

engagement of companies in SB at BOP. Third, the research analyzing and classifying the whole spectrum of social business configurations that firms can develop shed additional light on this emerging phenomenon.

Limitation and Further Researches

The main limitation of the research is related to the sample selection, however we can assert that results are generalizable and are representative of companies actively engaged in CSR. Further researches are needed to support results related to companies' characteristics. Furthermore, would be interesting to replicate the study in other geographic region such as the USA and assess the differences Finally, further researches are needed to further develop the analysis of companies' objectives. Indeed, companies do not clearly state their objectives in the website or in the public reports, as a results a survey approach would be very useful to understand the relation between objectives and SB configurations even if get a significant sample's size can be problematic.

Fig. 1 - Classification of Social Business Configurations

ACHIEVING SUPPLY CHAIN RESILIENCE AGAINST DISRUPTIVE EVENTS: A MULTI-STAGE ANALYSIS

Mattia Donadoni - Supervisor: Prof. Raffaella Cagliano

Supply Chain Resilience has become a focal point of interest in the last years due to an increased exposition of companies to disruptions. Such exposition derives from recent trends such as globalisation and market instability. Indeed, companies are looking for the "best in class" suppliers all over the world, creating complex and intertwined supply chains with heterogeneous actors involved. As a result, supply chains have become more vulnerable than ever. This research aims to investigate how resilience is pursued within the supply chain by analysing the relationships between upstream and downstream partners of the chain. The novelty of the thesis is to study three supply chain stages (focal companies, first and second tier suppliers) in the Italian Biomedical context. Specifically, the research objectives are: 1) to understand how resilience is perceived by academics and practitioners; 2) to empirically investigate the link between disruptions and company performance; 3) to empirically test the mitigating effect of resilience capabilities on disruptions outcomes; 4) to understand how supply chain stages achieve resilience considering the type of practices implemented in three specific stages of the chain and finally, 5) to comprehend

whether the deployment of resilient strategies depends on the resilience approach developed in others supply chain stages. This doctoral thesis is developed through five empirical studies which are introduced by a cover essay. Overall the research is structured according to three distinct stages: exploratory, theory testing and theory building. Besides, the research is grounded in a mix of qualitative and quantitative methods. Thus, according to the primary objective of the specific research paper, the method that better suited the goal was deployed for carrying out the research. First, the exploratory phase is based on a literature review coupled with a Delphi study aimed to gather experts' opinions on supply chain resilience from both academia and business (Paper 1). Second, the theory testing phase is grounded on quantitative analyses of an international sample of companies within the assembly industry for testing both the negative outcomes of disruption on performance and the counteracting effect of resilience capabilities on disruption (Paper 2 and Paper 3). Last, the theory building based on a multi-stage analysis (e.g. focal companies, first tier and second tier suppliers) of different supply chains in the

Italian Biomedical industry (Paper 4 and Paper 5). Findings suggest how companies tend to approach resilience differently according to the supply chain stage to which they belong. On the other hand, the resilient approach depends on how companies interact with upstream and downstream partners due to the interdependences existing across supply chains.

MANAGING THE JOINT INFLUENCE OF STRUCTURAL AND DYNAMIC COMPLEXITY ON SUPPLY CHAIN PERFORMANCE

Pablo Fernández Campos - Supervisor: Prof. Paolo Trucco

Co-Supervisor: Dr. Luisa Huaccho Huatuco

Rationale: In recent decades, globalisation and technological disruptions have made complexity a critical and growing concern for manufacturing organisations and Supply Chain (SC) managers. There are two main and interrelated types of complexity: structural and dynamic. Structural complexity arises in relation to the variety of elements involved in SC operations (e.g. products, processes, suppliers and customers) and to the connections between them. Dynamic complexity stems from the uncertain motion and evolution of these SC elements over time. Consequently, it is necessary that complexity management theory and practice address both these complexity types as well as their interplay (i.e. the effect these have on each other).

Purpose: Drawing from the literature on SC, business and systems complexity a preliminary research framework is adopted (Figure 1), and three research questions are explored:

RQ1: What are the mechanisms underpinning the interplay between structural and dynamic complexity in the SC function?

RQ2: How can manufacturing companies manage the joint influence of structural and dynamic complexity factors on the performance of their internal SC?

RQ3: How do contextual factors influence structural complexity and dynamic complexity and its management in the internal SC?

Methodology: An empirical qualitative investigation is carried out in two phases: exploratory semi-structured interviews with SC managers followed by in-depth inductive case studies in four global manufacturing companies which operate in different industrial sectors. Structural and dynamic complexity factors related to the firm's product portfolio, internal SC design, and customer and supply bases are analysed; and a wide range of complexity management practices is reviewed.

Findings: The results show that structural complexity exacerbates the negative effect of dynamic complexity on SC performance through four distinctive interplay mechanisms: silo-thinking, limited adaptability, increased uncertainty and localism. In this respect, the mechanisms of interplay that are predominant in the interactions between structural and dynamic complexity factors are identified (see Figure 2). Moreover, firms can leverage four clusters of practices to lessen complexity's hindering effects on their internal SC's performance: variety reducing, confinement and decoupling, coordination and collaboration, and decision support and knowledge generation. Each of these clusters of practices has their own scope and limitations; thus, companies can combine them to cover a specific ra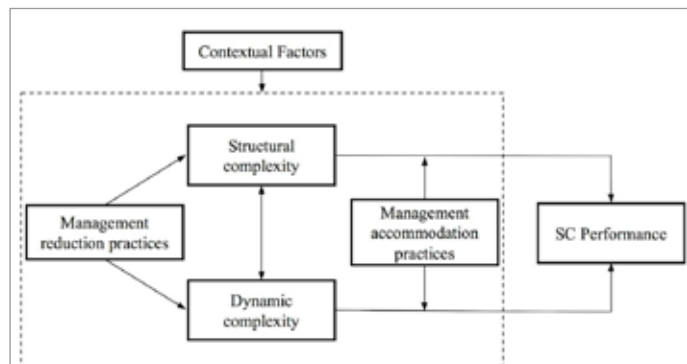nge of structural and dynamic complexity factors. The adopted practices can accentuate or lessen the interplay between structural and dynamic complexity. On one hand, coordination and collaboration along with decision support and knowledge generation practices can be used to respectively overcome silo-thinking and increased uncertainty. On the other, decision support and knowledge generation practices can accentuate silo-thinking and limit the adaptability of the SC. Lastly, a number of contextual factors emerge from the analysis, and their influence on categories of complexity factors is discussed. Furthermore, industry, country and firm contextual factors are found to influence the extent and type of complexity reduction practices that are adopted by the SC function. Based on the discussion of these findings, propositions and a revised theoretical framework are advanced.

Theoretical implications: The findings on the interplay extend current understanding of the relationship between complexity and SC performance and suggest a synergistic adverse joint effect of the two complexity types on SC cost. In addition, the study extends current knowledge on the management of complexity by putting forth a theoretically and empirically supported classification of practices and identifying distinctive approaches that can be leveraged to either reduce or accommodate complexity. Moreover, the findings suggest that firms may not only accommodate, but reduce strategic and customer-valued complexity. In this sense, the study adds to the discussion of value-adding and value-destroying complexity in the literature. Drawing from the discussion of the findings, propositions on the relationships between the constructs and a revised theoretical framework are introduced.

Practical implications: From a practical standpoint, the study allows managers to better understand the effects of complexity on the performance of their SCs. More importantly, the study offers a practically usable classification and review of practices that managers can rely upon to design complexity management approaches to cope with the specific structural and dynamic complexity factors faced by the SC. In this respect, the findings on the scope of individual and clusters of practices serve to inform managers' practice adoption decisions. Lastly, the understanding of the influence of contextual factors on complexity has strategic implications for managers, as complexity factors that are driven by the firm's strategy may be better identified and managed.
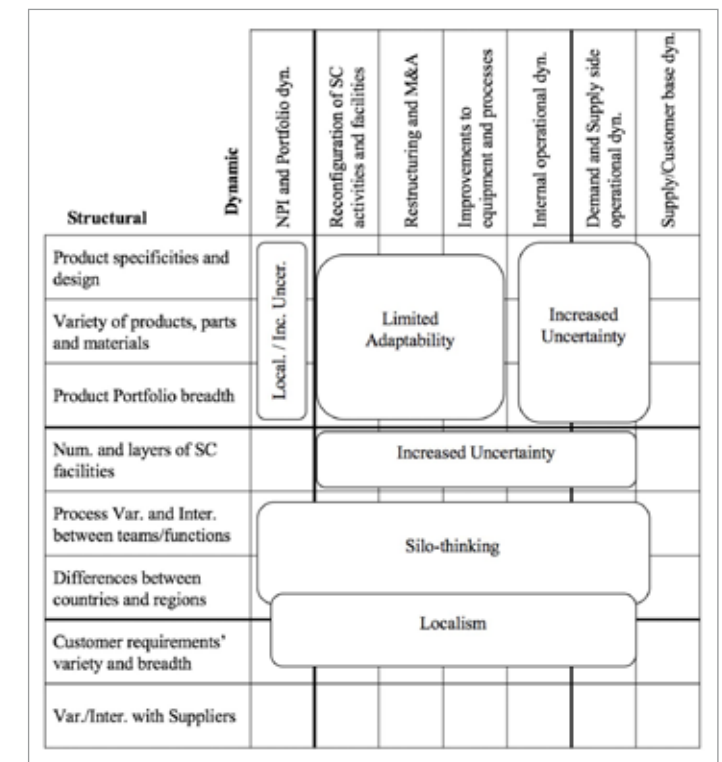

Fig. 1 - Research Framework.

Fig. 2 - Areas of predominant influence of the mechanisms of interplay between structural and dynamic complexity factors.

ESTIMATION OF URBAN INFRASTRUCTURE DEFICIT IN DEVELOPING COUNTRIES AS A FUNCTION OF HISTORICAL CEMENT CONSUMPTION

Guillermo Grassi - Supervisor: Prof. Matteo Kalchschmidt

As per 2014 estimations, 881 million people live in slums under the life-threatening conditions associated to urban infrastructure deficits. This research proposes the application of reference class and analogy forecasting methodologies to diagnose urban infrastructure deficits in developing countries while offering a valid long-term forecasting technique for cement consumption. Whereas governments need to understand current urban infrastructure shortages and have a valid forecasting methodology for planning resource allocations; industrial companies can benefit from efficiently assessing attractive related investment opportunities in developing countries. As other capital-intensive industries, the expensive assets used in the cement production require large operations to avoid high production cost per unit. Therefore, considering the financial risks and the logistics limitation inherent to the cement industry, producers' accurate demand forecasting is crucial to achieve positive financial return. The objective of this research is to use references of historical cement consumption in advanced economies to quantify the current deficit on urban infrastructure in developing countries and to simulate potential demand evolution through the application of

analogy forecasting methodologies. The initial assumption for this thesis is that while the level of urban infrastructure and cumulative cement consumption per capita are closely related, the cement demand cycle in advanced economies has similar pattern regimes. This similarity can be used to foresee future demand development in developing countries.

The literature review of this research covers three central topics throughout the understanding of the objective within this research, main supporting concepts and current state of the art. Firstly, the cement industry was reviewed from the most relevant angles. The second section addressed the relation between cement consumption with urban infrastructure quality and availability together with its social-economic impact. Thirdly, a review was provided around the substantive findings on demand forecasting methodologies and the specificities of the cement demand in the context of forecasting. The review of the current literature revealed substantial gaps offering the opportunity to bridge them through the development of this research work. While the literature review on cement markets sizing and trends appeared will covered, the true demand potential (based on necessity) of most developing

world remains unquantified in its full dimension. The accumulated knowledge in terms on urban infrastructure, its driving forces (i.e. urbanization process and public investment in public-structure) and its economic relevance is extensively covered by several authors, however, the perspectives on urban infrastructure deficit are limited to quantifications of housing units and public-structure investment estimations. An efficient quantification methodology of the resources needed to narrow urban infrastructure gaps to minimum functional levels is still missing, particularly in the developing world. Lastly, the work of recognized authors only illustrates the limitation of missing the external view and are usually restricted to providing a cement stock references for the Chinese cement demand potential. Current reviewed literature lacks insights about cement consumption patterns and thus of thorough understanding of the demand function and its prescriptive application to estimate the potential in developing countries.

The theoretical foundations of this research are mainly based on reference class forecasting and analogy forecasting. We structured our research methodology on these premises providing a solid and compatible theoretical-analytical background to our research. The

absence of a known and diffused cement forecasting methodology which benefits from comparable cases (external view – analogies) opens an opportunity to build a prescriptive long-term technique. The tendency to neglect distributional data is connected to the adoption of the term "internal approach" to prediction, where one focuses on the constituents of the specific problem rather than on the distribution of the outcomes of similar cases likely producing underestimation. Evidence suggests that people are insufficiently sensitive to distributional data even when data are available and rely primarily on singular information even when is scanty and unreliable, or give insufficient weight to distributional information. The adoption of "external approach" which treats the specific problem as one of many could help to overcome this bias by relating the problem at hand to the distribution of the problem for similar projects. Forecasting by analogy assumes that since two diverse types of phenomena share the same behavioral patterns, it is possible to predict the future outcome of one by observing the historical development of the other. In analogy forecasting, equivalence group is defined as the groups of products or services which are often analogous in ways that make them

follow similar time-series patterns causing their time-series to covary over time.

The research methodology was organized in two main phases. The exploratory analysis, aimed to cover the rationale behind the regional and economic categorization of countries, the description of the variables and the main objectives of the data analysis. The explanatory part covers the long-term forecasting model structure, the steps involved on its construction, and the processes for both the diagnose of urban infrastructure deficit and the forecasting of the selected case-study country (developing market). The empirical work is based on data collected for 129 countries containing hundred-year period observations of cement consumption and other measures to characterize the local urban infrastructure development. The results shown by our forecasting methodology (pooled models) are promising as the simulation of growth predictions obtained are substantially more accurate than the outcomes provided by standard models in all analyzed metrics. For instance, the pooled models predicted with higher accuracy the Cement demand per capita measured in Mean Absolute Percentage Error (28% as compared with 105% achieved by the standard models

in average). The resulting economic cost estimations to narrow the urban infrastructure deficits in developing countries are alarming. Out of the 129 countries in scope, 76 suffer Cement stock per capita deficits with the most severe cases concentrated in Africa and Asia. As per our methodology based on reference values, narrowing the urban infrastructure deficit globally could demand USD ~12.9 trillion for housing construction and USD 24.7 trillion investment in public-structures. We found support for the validity of our estimations on the review of current literature for housing financial needs and for public-structure investment.

SUSTAINABILITY INTEGRATION IN LUXURY FASHION SUPPLY CHAINS: AN EMPIRICAL INVESTIGATION OF LEATHER AND TEXTILES IN ITALY

Hakan Karaosman - Supervisor: Prof. Alessandro Brun

Co-Supervisor: Prof. Gustavo Morales-Alonso

This study explores the extent to which both environmental and social sustainability is integrated in luxury fashion supply chains producing textile garments and leather shoes in Italy. Firstly, a systematic literature review was conducted in order to categorise environmental and social sustainability practices implemented in fashion operations. Subsequently, from a natural resource-based view perspective, a multiple case study method was adopted, covering ten companies located at multiple stages of Italian textiles and leather supply chains. To investigate sustainability integration in luxury fashion supply chain management, industrial practices were systematically decomposed into product, process and supply chain levels in accordance with the three dimensional concurrent engineering framework. Hazardous chemical elimination and organic material use appeared to be the emergent product-level practices that deliver operational benefits such as cost reduction and market benefits such as improved product quality. Process-level practices, on the other hand, mainly focused on water and energy reduction due to cost reduction strategies rather than environmental stewardship. Supply chain-level practices encompassed traceability and supplier audits but only to a limited extent as a consequence of a lack of supply chain visibility. Furthermore, the study investigated the factors impeding sustainability in luxury fashion supply chain management. Lack of knowledge, lack of awareness, lack of supplier engagement, and competing commercial pressures impede sustainability and make it difficult to translate sustainability objectives into daily based activities. Results reveal that supplier engagement, collaboration, innovativeness and knowledge sharing are greatly needed across supply chains in order to advance transparency and supply chain traceability. Lastly, the study concludes that relational and technical components must be developed and deployed across supply networks and that sustainability must be embedded in the business philosophy to embark on rather radical strategies to truly embrace sustainability in luxury fashion. Keywords: Sustainable supply chain management, luxury fashion, sustainability, qualitative study, luxury fashion supply chain management, sustainable luxury

EXPLORING THE USEFULNESS OF ORDER REVIEW AND RELEASE METHODS IN MTO FLOW SHOPS

Kundu Kaustav- Supervisor: Prof. Alberto Portioli Staudacher

Due to changes in customer needs and the increased competition from low cost countries, more and more companies are strategically focusing on customization. This leads to Make-To-Order (MTO) low volume high variety production (Dean et al., 2009; Zhang et al., 2012; Melchert et al., 2006). MTO companies represent a very important part of the total Production of European economies and of the Italian Economy as well. These companies usually adopt job shop configuration to manage customization. But there is lot of variation in the process due to uncertainty in demand and processing time in MTO companies (Hopp and Spearman, 2004). Several methods and techniques like delayed differentiation, due dates setting are applied to mitigate this variation (Su et al., 2010). Hendry and Kingsman (1989) explored the applicability of production planning and control (PPC) system design for MTO companies. Many authors suggested WLC techniques like order review and release (ORR) methods specifically designed for job shops. These methods try to hold the orders in the pre-shop pool for some time before releasing them to the shop floor. In this way, the companies are able to reduce work in process,

any wastages due to cancellation of demand or changes in specifications.

With the development of Industry 4.0, there are new possibilities for computerization and digitization of products, production and logistics which lead to new ways of controlling the organization within a company and in cooperation along the entire value chain (Lasi et al., 2014). Moreover, with the advent of lean management, the companies, particularly the MTO companies, are not concentrating at the single resource but looking at the flow. Therefore, companies in MTO sector are more concerned about the flow of products or the internal flow (supply chain). This results in flow shop configurations rather than job shops. Therefore, we are witnessing a new generation of companies characterised by MTO production with high processing time variability and a pure flow shop configuration. Although there is significant contribution of ORR in job shops, much less work has been done in investigating the applicability of ORR methods in flow shops.

In the past, research is more concerned about improving the performance of job shops in MTO companies. Therefore, different Lean techniques and load based ORR methods are designed for

the purpose. The field is more or less matured. Due to change in requirements from the customers, the companies now start looking into the internal flow. Therefore, researchers are designing new ORR methods and most of these methods are particularly meant for pure flow shop environment. This is quite well reflected in the literature in the last decade. Few authors studied and found out Upper bound Aggregate Limiting method works well in pure flow shop environment (Oosterman et al., 2000). Thurer et al. (2011) pointed out that workload norm plays an important role while using ORR methods for pure flow shops. Later on Portioli-Staudacher and Tantardini (2012) tried to integrate most of the characteristics and developed a Lean based ORR method which performs much better than Aggregate Limiting method in a pure flow shop environment. Also Thurer et al. (2015) pointed out importance of continuous COBACABANA and SPT dispatching in a pure flow shop with with high demand and processing time variability. But there is still confusion which characteristics of ORR methods are most important in a pure flow shop environment. Moreover, in MTO companies, uncertainty is still a major hindrance. Many external factors

like variation in processing time, breakdown events can cause uncertainty situation which directly affects the MTO companies. Very few authors tried to study the randomness in processing time (stochastic processing time). Therefore, it is really interesting to see the performance of the different ORR methods meant for internal flow of MTO companies under such environment. Apart from processing time estimation, there are different kinds of breakdown events which happen time-to-time. It decelerates the delivery performance and interrupts the manufacturing planned schedule. How to cope with the issues and handle in a proper way to alleviate the downturn effects using ORR methods becomes another indispensable aspect to be focused on.

In this thesis, the different characteristics of order review and release (ORR) methods are investigated by focusing in particular on understanding how the different characteristics would affect the internal flow of MTO companies. The work is organized in two parts. In the first one, the objective is to get an overview of MTO companies, ORR methods in MTO companies and different realistic environments like stochastic processing time, breakdown events, etc. In the second part of this thesis, the different characteristics of ORR methods are identified from literature. Then, the different characteristics of ORR methods are tested for pure flow shops under deterministic and realistic environments.

Objectives

ORR has attracted the attention of both researchers and practitioners in the last years because of its ability to control the complex job shop configuration in MTO companies. But the research stream investigating how to implement ORR in the flow shop is quite recent (it has developed in the last decade) and almost at an early stage of maturity. There is still confusion how implementing ORR modifies the management of MTO companies' flow shops. In particular, it is not clear which characteristics that managers of MTO companies have to emphasis for introducing ORR in the flow shops. The specific objectives of this thesis are as follows:

Objective 1: to understand what are the different characteristics of ORR methods that affect the performance of flow shops.

Objective 2: to understand the influence of stochastic processing time on different characteristics of ORR.

Objective 3: to evaluate the performance of ORR methods under breakdown events.

Objective 4: to evaluate the performance of ORR methods under stochastic processing time and breakdown events in pure flow shops.

Methodological framework

Designing the methodological approach for the different phases means to define the activities that will be carried out in each phase and the methodologies that will be used. The brief description of the methodologies used in this thesis is presented below.

Deterministic environment

In this phase the objective was to

study the different characteristics of ORR methods in pure flow shops assuming the processing times of the orders are assumed to be known on acceptance. Two sub-tasks are identified in this phase. Firstly, the different characteristics of ORR methods which are important in pure flow shop environment are highlighted. Secondly, the most important characteristic is investigated in this phase. The research question in this phase is: *How and to what extent do the characteristics of ORR methods identified from literature contribute to improvements in pure flow shop performance?* The methodology used in this phase is simulation. Simulation can provide quantitative feedbacks of the impacts under different scenarios and conditions. Due to its advantages, several authors (Land and Gaalman, 1998; Oosterman et al., 2000; Abdulmalek and Rajgopal, 2007; Portioli-Staudacher and Tantardini, 2012; Syberfeldt et al., 2013; Zhou et al., 2013; Yang et al., 2015; Dehghanimohammadabadi et al., 2017; Thurer et al., 2017) used simulation as the methodology in their research, especially in manufacturing.

Stochastic processing time

In this phase the objective was to study the different characteristics of ORR methods in pure flow shops assuming that the processing times of the orders are stochastic, that means, they are not the same in the planning stage as well as in the real situation. The performances of the identified ORR characteristics in situations with different distortion factors are compared with the performances

of those characteristics in deterministic environment. The research question in this phase is: *How do the different characteristics of release methods respond to stochastic processing time in pure flow shops?* The methodology used is simulation.

Breakdown events
In this phase the objective was to study the different characteristics of ORR methods in pure flow shops assuming there are breakdown events in the shop floor. The performances of the identified ORR characteristics are investigated using different breakdown levels. The research question in this phase is: *What is the influence of breakdown events on the different characteristics of release methods in pure flow shops?* To answer this question, simulation is used.

Stochastic processing time and Breakdown events
In this phase the objective was to study the different characteristics of ORR methods in pure flow shops assuming there are stochastic processing time as well as breakdown events in the shop floor. The research question in this phase is: *How do the different characteristics of release methods respond to uncertainty factors in pure flow shops?* To answer this question, simulation is used.
Different characteristics of ORR methods that are important in pure flow shops are: Workload Balancing in ORR methods, Aggregation of workload measure, Schedule visibility, Sequence of released orders. Aggregate workload Limiting ORR method (AL), Released workload Limiting ORR method (RL), Aggregate

workload Balancing ORR method (AB) and Released workload Balancing ORR method (RB) are the four different ORR methods, resulting from combination of different characteristics, are used in this thesis. In addition to FCFS, the Shortest Processing Time (SPT) rule is used to sequence the orders that are selected for release and then compared with the FCFS rule. Next the simulation model is described.

Simulation model and ORR parameters
The model represents a pure flow shop with five workstations, each consisting of a single resource. The maximum capacity of each workstation is 8 hours per day. A Poisson distributed number of orders (mean 15) is assumed to enter the pre-shop pool each day just before each release opportunity. Following the study of Portioli-Staudacher and Tantardini (2012), the processing times at each workstation are assumed to be independent and follow a lognormal distribution with a mean of half an hour and a coefficient of variation of 0.8. The average service rate of 16 orders every day, combined with the arrival rate of 15 orders per day leads to an average utilisation of 93.75%.
In order to keep the due date assignment method simple with a reasonable percentage of tardy orders, a constant delivery time allowance of 7 working days (56 hours) is added to the order arrival date to calculate the due date. Based on tests in preliminary simulation runs, the planned shop floor time is set to 3 working days

to calculate latest release dates. Following Perona and Portioli (1998), Portioli-Staudacher and Tantardini (2012), a release period length of 1 day is adopted in this paper. The release methods RB and AB include a ratio ρ between the penalty associated with the overload and underload for each workstation. These penalties are set equally (ρ=1), as in (Cigolini and Portioli-Staudacher, 2002) and (Portioli-Staudacher and Tantardini, 2012).
Four performance measures are used in this study. Those measures can be grouped in two types. The first one deals with shop oriented measures and it encompasses the average shop floor time and the average gross throughput time. The second one deals with order oriented measures and it encompasses the standard deviation of lateness and the percentage of tardy orders. The average shop floor time is used as an intermediate variable to represent the level of workload reduction realised by the different target types and their levels.

Results
Deterministic environment
The workload limiting methods have less balancing capabilities and clearly result in longer gross throughput times. The choice between balancing and limiting is responsible for a larger part of the performance difference than the workload aggregation characteristic. In general the aggregate workload methods perform better than the released workload methods. It is interesting to compare the points where the minimum gross

throughput time is achieved for aggregate limiting and balancing methods. This is realised at 31.8 hours of average gross throughput time and 29.1 hours of average shop floor time for AL. For AB it is achieved at 27.2 hours of average gross throughput time and 21.3 hours of average shop floor time. Thus, by using AB instead of AL, a 14% reduction is achieved in average gross throughput time with a 27% reduction in average shop floor time. Both patterns and relative differences for the standard deviation of lateness and the percentage tardy are rather similar to those described for the gross throughput time. However, using tight workload targets for balancing methods has an even more deteriorating impact on the standard deviation of lateness. With SPT rule, the relative positions of all methods remain more or less the same. But there is clear improvement in performance when SPT is used instead of FCFS. This result confirms the assumption that the initial sequence of orders released to the first workstation has a strong impact. For workload balancing methods this effect is mainly present at low workload levels. Moreover, a comparison of the lowest point shows that using AB with SPT (1) a 19% reduction can be achieved in average gross throughput time combined with a 33% reduction in average shop floor time compared to AL with SPT and (2) even a 22% reduction can be achieved in average gross throughput time with a 35% reduction in average shop floor time when compared to AL with FCFS. Comparing AB with SPT to

AB with FCFS, an 8.5% reduction is achieved in average gross throughput time combined with an 11% reduction in average shop floor time.

Stochastic processing time
Using AL is detrimental to performance and is consequently outperformed by AB for both deterministic and 20% distortion. There is deterioration in performance for AL in respect of all the performance measures. For AB, only standard deviation of lateness gets deteriorated but the other measures remain more or less overlapped with the deterministic. With increase in distortion factor (40%, 80%), the deterioration in performance for AL as well as for AB in respect of all the performance measures increases.
There is a positive impact of SPT for both AL and AB. From the previous studies, it is seen that SPT rule significantly reduces gross throughput time as well as shop floor time compared to FCFS rule. In SPT rule, the orders with smallest processing time on one hand decreases the idleness at downstream workstations and on the other hand reduces the gross throughput time. This happens because it is possible to process many small orders quickly by delaying only few large orders. Decrease in gross throughput time and average lateness reduces the percentage tardy as well. It can be observed that all the performance measures for both the methods (AL and AB) are getting better with SPT rule for both deterministic scenario and 20% distortion. AB with SPT rule even remains better at the extreme left with

20% distortion. Therefore, 20% distortion hardly affect AL and AB with SPT rule. But with increase in distortion factor, the performance difference with respect to deterministic scenarios becomes more and more prominent.
The percentage difference of all the performance measures between AL and AB decreases with increase in distortion factor. It seems that AL method suffers less if the processing time cannot be estimated precisely at the planning stage. But the fact is that as the mismatch in processing time increases, the importance of release rule decreases. In that sense, balancing workload is still a better option in case of stochastic processing time.

Breakdown events
With increase in the breakdown level, the average gross throughput time is increasing very fast. In general, for all three breakdown levels, under the same average shop floor time, the average gross throughput time of balancing methods is lower than limiting methods. It proves that balancing methods perform better than limiting methods regardless of breakdown occurrences. As for SPT sequencing rule apparently all the curves slightly shift to the left hand side. It supports that SPT sequencing rule is much desirable than FCFS one. AB method behaves the best under all three breakdown levels among all ORR methods for both percentage of tardy orders and standard deviation of lateness. As for average gross throughput time, when decreasing the average shop floor time, the curves of AB method are decreasing

until reaching the lowest gross throughput time; in the opposite, the curves of AL method show trend of inversely proportional to average shop floor time and without any lowest gross throughput time.

The values of the best gross throughput time, corresponding shop floor time, percentage of tardy orders and standard deviation of lateness for AL and AB are compared. Then, the percentage differences are evaluated. All the differences are proven statistically significant at 95% confidence level via two-tailed paired t-test. Although the balancing workload achieves lower gross throughput time and shop floor time, it results in high percentage of tardy orders and standard deviation of lateness with the progressive breakdown.

Stochastic processing time and Breakdown events

The effect of the distortion factor within the same breakdown level is quite interesting. As the degree of distortion increases, the pattern or distribution shifts to higher values of shop floor time but barely increases the values of gross throughput time that only moves slightly upwards on the graph. Increasing from 20% to 40% distortion induces a medium shift to higher shop floor time, but increasing from 40% to 80% has a much greater shift. In each of the three distortion factors the performance on gross throughput time of each ORR method is quite the same. By looking at the other breakdown levels, it is seen that the response of shifting the pattern to higher values of shop floor time only, is the same when

increasing the distortion factor degree. This suggests that the impact of the degree of distortion is almost entirely on the delays happening in the shop floor therefore increasing the values of shop floor time. Overall the degree of distortion has a negative impact on any ORR method and this impact is similar for all the methods. On the other hand, both the gross throughput time and shop floor time increase rapidly with increase in breakdown levels. Balancing workload deteriorates more than limiting workload but still balancing performs the best across all the scenarios. Again SPT rule always have a positive impact on the performance of all the methods for all the scenarios. The distortion has similar effect on standard deviation of lateness and percentage of tardy orders.

By looking separately the results of each ORR method at each scenario doesn't give clear indications about the performance on variance of results among the different scenarios. Therefore, analyzing the Robustness including the different breakdown levels will give the results for more realistic situations. AB with SPT is better at gross throughput time and shop floor time, and AB with FCFS is better at other performance measures. As the main objective of the company is to reduce the throughput time, GTT and SFT will be preferred over other performance measures and hence balancing workload with SPT rule is the robust method.

Conclusion

First of all, the identified ORR characteristics are evaluated in a pure flow shop environment

under deterministic condition. Initial simulation results demonstrate that balancing, aggregation of workload and sequencing of released orders have significant impacts, whilst extended visibility has a very limited impact on performance in preliminary tests. Therefore, the main experimental design does not include extended visibility. The results of the simulation runs show that considering the distribution of the workload already released of each workstation is better than only looking at balancing the released workload.

As unlike in job shops, in flow shops explicitly aiming at balancing workload among workstations, rather than simply limiting it, improves significantly all performance measures and it is the most impacting characteristic. It not only allows achieving shorter gross throughput time, but also helps in maintaining smaller WIP, shorter queues in the shop and thereby shorter shop floor time. In fact, without increasing gross throughput time, the order stays longer in the pre-shop pool and much less time in the shop floor (about 40% less time). This gives a huge advantage to the company because making changes is much easier and less costly in the pre-shop pool, rather than in the shop floor. Finally, also sequencing of released orders with SPT rule has shown to have a significant impact on all performance measures. A sensitivity analysis shows that balancing workload methods are more robust than limiting workload methods in case of variation in utilization rates and

processing times. Furthermore, due date setting hardly affects the limiting methods but has smaller influence on balancing methods. An additional analysis shows that the threshold setting in released load calculation plays an important role in balancing methods, especially at tight workload targets.

In addition, a study is carried out to evaluate how balancing workload performs in case of mismatch in processing time between planning stage and shop floor. The results of the simulation runs show that balancing workload works still better than the limiting workload as the distortion factor is increased. As distortion increases, the performances for both the methods deteriorate. But balancing always perform better than limiting, especially at lower workloads. The ORR characteristics are also evaluated in environment where breakdown may occur in the shop floor. The results of the simulation runs show that balancing workload works still better than the limiting workload as the breakdown level is increased. At low breakdown level, all the performance measures for balancing methods are better than limiting methods. With increase in breakdown level, the performance difference for balancing methods is getting worse compared to limiting methods. But still balancing method is found out to be the robust method, because its performances could be affected very little by environmental changes. The deterioration in performance of balancing methods is explained by the fact that at high uncertainty

level, any ORR method will lose its performance. Thatswhy the performances for both limiting and balancing methods are getting closer with increase in level of stochastic processing time or breakdown events. But those issues can be solved or minimized in Industry 4.0 where there will be proper data retrieval as well as information technology system. Finally, similar to previous observations, sequencing of released orders with SPT rule has shown to have a significant impact on all performance measures for both limiting and balancing.

The main innovation in this thesis is that the MTO companies should focus on creating and maintaining the flow of orders among the different stages or workstations and implement the relevant ORR methods (explicitly aiming at balancing) in order to eliminate all the causes of blocks and variation. The different characteristics of ORR methods for a pure flow shop are analyzed in this study. The directions for future research are mentioned below:

• To propose and test ORR methods which not only control input, but also control output (capacity).
• To investigate the impact of having continuous rather than periodic release opportunities.
• To investigate the same phenomena in some other areas like divergent/ convergent flow shops, a general flow shop or multiple production cells.
• To study ORR methods in sectors other than manufacturing, such as service sectors. Service sectors

like insurance companies nowadays try to help the client using a series of steps, which resembles the pure flow shop that is focused in this thesis.

ENERGY AND RESOURCE EFFICIENCY IN MANUFACTURING

Claudio Palasciano - Supervisor: Prof. Marco Taisch

Manufacturing, responsible of huge amount of energy and resources consumption, is becoming more and more important for the world sustainability. Currently, manufacturing systems design and operations rely on local optimization of separate sub-systems, achieved under different viewpoints by stakeholders at various levels. The Ph. D. research focuses on investigating how to manage and control the future eco-factories, characterized by multi-dimensional criteria including costs, performance, environmental impacts, towards a wider optimization. The research addresses the efficiency of energy and resource use, under a systemic approach.

The Ph.D. thesis is a cover essay presenting achievements of the work: i) contributions to high rank journals (such as Journal of Cleaner Production SJR Q1 ranking 2016) and ii) international level conferences in the area of sustainable manufacturing and clean and competitive production systems.

The cover essay includes firstly a discussion of the context and general challenges and problems on the way towards sustainable manufacturing and energy and resource efficiency (ERE), then introduces the state of the art and theoretical foundations of the work, categorized along relevant themes important for the field of resource efficiency, such as manufacturing decision making configurations, machine and line control, production planning and scheduling approaches, resource aware modeling, simulation and assessment. The State of the Art is completed with discussion of ICT enablers and some important literature items on which the Ph.D. work has been based, such as holistic approach, manufacturing control paradigms (Holonic Manufacturing) and novel Industry 4.0 ready ICT technologies.

After an identification of specific research questions and objectives towards the overarching goal of the work, management and control of the future eco-factories, the research framework and methodology are detailed in the scope of applied research in industrial engineering.

Then, the reseach achievements are presented with reference to five papers, which cover the whole range of identified research questions and objectives. The first two papers are tagged in this document as previous work as they correspond to research developed and published before the Ph.D. period, anyway they are included because they laid the basis for the next development recounted in the three papers listed as Ph.D. research results.

Previous work to the Ph.D. period includes: i) Paper I, *Towards Environmental Conscious Manufacturing* (ICE conference, 2014), which presents the main elements of holistic model of manufacturing systems towards future eco-factories; ii) Paper II, *Back to Intuition: Proposal for a Performance Indicators Framework to Facilitate Eco-factories Management and Benchmarking* (GCSM conference, 2014), which presents an holistic KPI framework and complete KPI system, able to capture the multi-dimensional characteristics of eco-factories, including a specific indicator for energy and resource efficiency assessment.

Results of the Ph.D. research period include: i) Paper III, *A new approach for machine's management: from machine's signal acquisition to energy indexes* (Journal of Cleaner Production 2016), which introduces validation in industrial use case of the eco-factory KPI framework and KPI system proposed in Paper II, and specific identification of leading and lagging KPIs enacting actual/target control at machine level, enabling identification of possible anomalies in operating conditions in real-time during the operational cycle; ii) Paper IV, *Autonomous energy-aware production systems control* (XXI Summer school "Francesco Turco", 2016), which presents and validates by simulation a novel production system control which enables each machine in a serial line to share its digital twin with the other machines in the line, allowing autonomous decision about processing, exploiting time available for stand-by mode or, even, postpone processing in order to optimize energy consumption without relevant impact on productivity; iii) Paper V, *Deployment architecture for Energy and Resource Efficient Cyber-Physical Systems* (APMS conference, 2017), which recounts about testing and validation of the autonomous ERE control proposed in Paper IV by deployment of a Cyber Physical Production System in a laboratory setting, with use of state of the art Industry 4.0 ready ICT technologies, such as OPC UA industrial automation technology.

The cover essay is completed with discussion of managerial implications, contributions to advancement of knowledge and how to research work has contributed to pave the way to solutions of the identified problems and challenges. Finally, further work is described, including on-going research preliminary results, aiming at continuing the research addressing a wider scope, in particular extending the Ph.D. research beyond production machines and work center level, to material handling systems and technical building services. To this extent, the following papers, submitted to high ranked journals, are highlighted: i) Paper VI, *Integrating Energy and Resources Aspects in Layout Design: Holistic Modeling of Material Handling Systems,* submitted to Applied Energy; ii) Paper VII, *Integrated Modeling of Energy and Resources Efficient Manufacturing Systems*, submitted to International Journal of Production Research.

DIGITAL GAME-BASE LEARNING (DGBL) IN MANUFACTURING EDUCATION: FROM AWARENESS RAISING TO KNOWLEDGE IMPROVEMENT

Stefano Perini - Supervisor: Prof. Marco Taisch

Co-Supervisor: Dr. Manuel Fradinho Duarte de Oliveira (SINTEF)

Although manufacturing is currently rapidly evolving according to the so-called Industry 4.0 paradigm, the sector is suffering a serious skills gap. Therefore, in order to increase the supply of young talent to European manufacturing industry, the change ofthe societal appeal ofthe sector is a key element. Among the wide range of possible solutions, the use of interactive learning environments (ILEs) such as serious games can be used as an enabler for the attraction and education of young generations. In particular, digitai game-based leaming (DGBL) approach can allow the association of the active involvement of the leamer with the fun element, that is not used anymore for mere entertainment but to support the motivation of the student in the leaming process. However, despite these potentialities, empirica! evidence of the educational and motivational effectiveness of DGBL for manufacturing education at ali levels is stili limited. For these reasons, two digitai games (DGs) were developed *ad hoc* in order to understand the effects ofDGBL on the Awareness and Interest in manufacturing of Children, Teenagers and University Students, and assess the e:ffectiveness of DGBL on the

Knowledge about manufacturing concepts of University Students. The results ofthe experiments done with Children and Teenagers (with EcoFactory) and with University Students (with the LCA Game) showed a significant e:ffect of DGBL on the Awareness and Interest ofChildren but not on those ofTeenagers and University Students. On the other hand, DGBL proved to have a significant effect on all the types of Knowledge analyzed (i. e. Factual, Conceptual, Procedura!) and to be able to overcome the main limitations of the two other learning approaches investigated (i.e. non-gamified digitai approach and non-gamified paper-based approach). Together with the results ofthe initiallevels of Awareness and Interest in manufacturing and of the Usability and Enjoyment of the educational interventions that were also collected, the findings were used to propose a fmal version of an Integrated strategy for the attraction and education of youngsters for manufacturing. On this basis, the contributions of the PhD research to both theory and practice are highlighted. Eventually, the limitations of the study and the directions for future research for both manufacturing education and DGBL are identified.

Keywords: Manufacturing, Education, Serious games, Digitai game-based leaming (DGBL), Knowledge, Skill

NEW FOOD DEVELOPMENT PROCESS PERFORMANCES: THE ROLE OF PRODUCT LIFECYCLE MANAGEMENT SOLUTION IN THE FOOD INDUSTRY

Claudia Pinna - Supervisor: Prof. Sergio Terzi

Over the last years, the food industry has become increasingly relevant since it represents excellence in the worldwide economy. However, despite the growing importance of this sector, food firms still face many challenges in managing their products and competing in the market. In fact, over the last years, an accelerating number of tasks have influenced these firms, pushing them to focus on innovation to maintain or to gain competitive advantage. Most of these challenges are related to drive change and to create new demands on product development. Successful companies have to understand and to accept these challenges and find new ways to address them through processes and solutions focused on new product innovation and development. For these reasons, this research focuses on a new product development process - called *New Food Development* process (NFD) for the specific food context - being recognized as an added value process for food companies. NFD generates value for the product that the company has to introduce to the market, contributing consequently to greater success. This is necessary since in a highly competitive market food companies must develop new products valued by consumers.

Traditionally, new product success requires excellence in three areas: (1) reducing product development cycle time, (2) increasing product development innovation, and (3) reusing company knowledge assets. To achieve success in these three areas, companies must look to the factors that drive innovation: people, knowledge, and systems. Concerning systems for NPD process management, one kind of solution is currently preferred: the Product Lifecycle Management (PLM) solution. Such solution has come to signify what some call the 21st-century paradigm for product development as it addresses the entire lifecycle of a product and its intimately cross-functional nature. This solution theoretically makes it possible for food companies to accelerate innovation, increase profits from product introductions, reduce risks, and ultimately improve competitive advantage. As a result, PLM can be seen as a key driver for innovation and success: this is the reason why this topic is addressed in the thesis.

In order to evaluate the NFD process evolution and to understand the way the use of the PLM functionalities affects the different NFD phases a dashboard of performances have been defined. Furthermore, to better understand the strategy applied by the companies, a series of *Critical Success Factors* (CSFs) have been identified. The analysis will focus on those performances associated with the relevant CSFs recognized. The main objective of the research is to understand how the implementation of a PLM affects the NFD process performances in large food firms. The study utili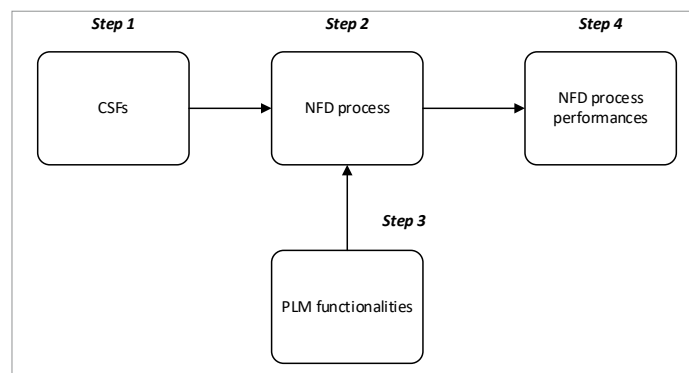zes a literature review analysis that was conducted in order to understand the level of knowledge of the topic from a scientific literature point of view. The review concludes with research gap identification concerning: the NFD process, the CSFs topic, the NFD performances and, the use of the PLM functionalities in the NFD process.

From these literature gaps, the research aims at filling each through the use of case studies that: (i) defines a framework, (ii) identifies PLM functionalities, and (iii) PLM performances.

As already mentioned, this work focuses on the impact of the PLM solution on the NFD process performances. Based on a preliminary theoretical framework defined by the literature analysis, a similar one was developed for the food industry.

The purpose of the framework is to lay out an overview of the main concepts involved in the present research and to illustrate how they are logically related.

Questionnaire has been chosen as a research tool, allowing the data gathering process through several semi-structured interviews. A two-stage multiple case study research methodology has been adopted and implemented considering several multinational companies within the food industry. The figure below summarizes the results of the research, showing the representation of the NFD process phases, PLM functionalities, and NFD process performances map.

This study clearly highlights that big food companies implementing the PLM solution to support their product development phases will be subject to several performance improvements. In fact, different benefits have been found following the PLM implementation, among which: (i) *optimizing processes by sharing and capitalizing on knowledge*, (ii) *enhancement of data availability*, (iii) *less error* and, (iv) *economic benefits*.

In conclusion, this study comes up with different managerial implications. NFD performances topic is a very important theme because allows food companies: to understand which phases and activities are more relevant,

Fig. 1

Fig. 2

adding value to the process and consequently to the new product. The PLM solution is a supporting tool that assists food companies to manage their NFD. The correct use of this solution and of its functionalities could help companies to keep the good practices identified, adding value to their products and consequently improving their competitiveness on the market. In addition, the research results contribute to various streams of the literature. Firstly, it also adds knowledge to the significant and growing scientific debate focused on the relationship between digital technologies and information systems, and innovation management. From this study, it can be derived the crucial role played by PLM solutions in supporting the NFD stages and enhancing NFD performances. This finding is consistent with the arguments advanced in IT business value studies, namely the positive impact of IT systems on firm performance. Secondly, it demonstrates that the implementation of a PLM solution could have a different impact on different NPD process stages and their specific performances. These results are new for the PLM literature, as they unveil the impact of PLM systems at a deeper level of analysis. I believe that they

could both reinforce scholars and managers' comprehension of PLM systems and their importance in NPD environments and stimulate new research and investigations in this complex but challenging context. Finally, it implicitly adds knowledge to the literature dealing with NPD in mature industries. In fact, in the preliminary results, an NFD framework has been formalized and it clearly summarizes all the NPD stages for the food industry.

ANTECEDENTS AND CONSEQUENCES OF THE DIFFUSION OF DIGITAL INNOVATIONS IN HEALTHCARE

Andrea Pistorio - Supervisor: Ing. Luca Gastaldi

Digital innovations are nowadays diffused in many sectors and contexts, allowing the introduction of new products and service, and requiring the contribution of several actors that collaborate to develop innovations. The study of digital innovations in inter-organisational settings and their diffusion is at the centre of the academic debate for innovation management and information systems scholars.

Healthcare is a context in which digital innovations have the potential to improve the performances of healthcare systems both regarding quality improvement and cost reduction. Nevertheless, despite the efforts of many governments in promoting and supporting the adoption of these technologies, the diffusion is often beneath its potential, and the related reasons are not fully comprehended.

Given the lack of practical and theoretical knowledge for fostering the adoption of these technologies, this PhD thesis analyses the diffusion of digital innovations in healthcare settings in terms of antecedents and consequences. Consequences constitute, if they are favourable, the reasons that induce healthcare actors to adopt these solutions while antecedents are the starting points for the diffusion.

The dissertation is based on three papers, each of which covers one separate perspective and adopts different theoretical lenses. The first paper is based on a longitudinal analysis concerning the progress in the diffusion of digital innovations in a regional healthcare system and the policy strategy of the related regional council supporting the spread of these technologies. The second paper focuses on the hospital perspective, investigating the consequences of the diffusion of digital innovations and, in the case of the most advanced digital technologies, crosses the boundaries of these hospitals considering the interactions among hospitals and other actors. Finally, the third paper inspects the phases before the creation of services enabled by digital innovations. More specifically, it analyses the antecedents of the design of business models characterised by the integration of several digital innovations through a multi-sided platform.

Results concerning antecedents highlight the relevance of several aspects that academics and practitioners should take into account when they deal with the diffusion of digital innovations. These aspects include the centrality of the organisation promoting the diffusion in a network of actors, the adoption of a multi-sided platform, the time dimension, the portfolio of digital innovations or the integration related to the process of business model re-design.

Regarding the consequences, the main findings are related to different topics such as quality and cost, the degree of innovativeness, the skills for the management of exploration-exploitation tensions, the opportunities offered by digital transformation programs, efficiency frontier, impacts on policy mixes.

BUSINESS LOGISTICS MODELS IN OMNI-CHANNEL: CLASSIFICATION FRAMEWORK, EMPIRICAL ANALYSES AND DECISION-SUPPORT TOOLS

Monica Rasini - Supervisor: Ing. Sara Perotti

1. Research Problem and Motivation

This research project is based on the awareness that logistics plays a strategic role in retailers' business success, especially in a changing environment as one in which companies are now operating. Traditional retail is experiencing a phase of substantial changes. As the line between online and traditional channels is blurred, a new approach is emerging, named omni-channel (OC), which aims to offer a seamless customer experience regardless the channel(s) used. For traditional companies, the adoption of an OC approach means creating new business logistics models, evaluating the trade-off between process integration and separation of multiple channels. In recent years, the research community has also expressed increasing interest in designing business logistics models in a multi-channel (MC) environment, and OC promises to be an exciting research stream for the near future.

2. Research Design

The cornerstone of this project is to deeply understand the business logistics models adopted by companies in implementing an OC approach and the value created by these models, since this understanding has relevant potentialities to support strategic decision-making. Specifically, the aim of the present research is three-fold. First, to propose a classification framework of the key elements involved in designing the business logistics model in OC. Second, to provide empirical evidence on company decisions when setting up their business logistics model in OC, identifying the models currently adopted and investigating their application areas. Third, to develop functional and easy-to-use tools that could support retailers in evaluating costs and benefits of different solutions and properly (re-)design their business logistics model. To achieve these objectives both qualitative and quantitative methods were adopted, in a complementary way. First, a Systematic Literature Review (SLR) and three case studies were performed. Then, a qualitative survey was conducted and statistical analyses were carried out. Lastly, analytical models were developed to address three specific logistics sub-problems related to the development of an OC system (distribution configuration design, distribution system for e-fulfilment in grocery retailing and pickup point supply) and applied using real-life data or simulation. The formalisation of the results was achieved through a collection of papers, four papers submitted in an international scientific journal and two contributions presented in international conferences.

3. Research Contributions

Logistics in omni-channel retailing: a systematic literature review. This paper provides an up-to-date literature review on logistics in OC retailing. A SLR methodology was adopted. The review is based on 58 papers published from 2002 to 2017 in 34 international journals. Papers were analysed and categorised according to their defining characteristics, methodology adopted and theme addressed. An overview of the main logistics issues experienced by companies moving from MC to OC is provided, highlighting the fields for further investigation.
Business logistics models in omni-channel: a classification framework and empirical analysis. A systematic combining approach with scientific literature review and case studies allowed to derive a framework for classifying the key logistics variables and the related options. Applying the framework to a sample of 92 Italian companies revealed a picture in which the definition of the business logistics model is still ongoing, with a mix of dedicated and integrated solutions and the coexistence of multiple configurations according to both product and customer requirements. The cluster analysis highlighted four business logistics models, differing in terms of both business sector and OC maturity.
Designing logistics in omni-channel retailing: drivers behind company distribution configurations. This paper extends the empirical analysis, by exploring the factors driving the company decisions in terms of logistics integration between the online and traditional channel. Theoretical propositions describing the relationship among contextual and logistics variables were formulated and checked using chi-square tests for association. Results confirmed that when companies (re-)design their distribution configurations looking for an OC approach, many choices depend on service- and operational-specific factors.
Logistics in omni-channel retailing: modelling and analysis of three distribution configurations. Retailers adding an online channel to their traditional businesses need to (re-)design their distribution configuration. We developed an assessment model of the operational costs for three distribution configurations, using the Activity-Based Costing approach. The model was then applied to a real Italian case operating in the consumer electronics industry. Results highlighted that the search for synergies between online and traditional flows in both warehouse and transport activities is important for the economic sustainability of OC systems.
E-fulfilment in grocery retailing: a model for designing the store-based distribution system. E-commerce dynamics are making the design of distribution systems more and more challenging, especially in grocery retailing where stores are typically used for e-fulfilment. This paper addresses the tactical problem of selecting stores to be used as picking location and defining the related delivery zones. We developed a model for the delivery cost estimation using the continuous approximation approach, as well as a metaheuristic procedure to compare multiple store-based distribution systems. The application of the model to a real case showed that properly selecting the picking locations can yield cost saving up to 40%. The most cost-effective number of picking locations decreases with an increase in the online demand.
Anticipatory shipment for pickup point supply. More and more retailers offer customers the option to shop online and collect their orders from a pickup point nearby. In this paper, we focus on the anticipatory shipment of items to such pickup points in order to improve both operational efficiency and customer lead-times. We formulate a stochastic programming model to support the selection of the products and the associated quantities to store at pickup points in anticipation of customer demand. To evaluate the effects of different strategies, we simulate the fulfilment operations by using a simple vehicle dispatching policy. Our experiments suggest significant benefits from using anticipatory shipments as compared to on-demand dispatches. The benefits increase with more available storage space at pickup location and smaller online product assortment.

4. Conclusions

This research addresses a recent phenomenon such as OC, by investigating key logistics issues related to the development of an OC management strategy and offering new insights into the underlying mechanisms of developing an OC system. This may prove particularly beneficial for both practitioners and academics.

Three main potential extensions to this research may be identified. First, the classification framework developed in this project could be extended including other views that characterised the OC phenomenon, e.g., marketing or information management. Second, the empirical analyses could be extended to a larger sample that covers multiple countries and more business sectors; the performance of different business logistics models and the evolution of company choices over time could be investigated. Third, as regards the development of decision-support tools, several logistics sub-problems related to the development of an OC system require further studies, e.g. inventory visibility and priorities management.

ASSESSING THE VALUE OF INTELLIGENT TRANSPORT SYSTEM FOR SMART MOBILITY: MODELS AND APPLICATIONS

Giulio Salvadori - **Supervisor: Ing. Angela Tumino**

1. Premise

Cities all over the world face similar issues regarding urban mobility (e.g. congestion, road safety, security, pollution, climate change due to CO_2 emissions), all having a huge impact on the economy, the environment, the health and the quality of life of citizens. With regard to Europe, road transport produces about 20% of the total CO_2 emissions, of which 40% is generated by urban mobility. In addition, urban population is expected to significantly grow in the next decades: from 3.9 billion people that already live in cities (54% of the whole global population) to 6.3 billion by 2050 (i.e. 66%). Today cities are responsible for more than 75% of waste production, 80% of emissions, and 75% of energy utilisation. Therefore, there is a huge interest in understanding how urban transport can become more sustainable. In such a complex environment, Information and Communication Technologies (ICTs) can play a key role in improving transport sustainability through controlling systems more efficiently, facilitating behavioural changes and reducing energy consumption. 'Intelligent Transport Systems' (ITS) is the most common expression used to indicate the integrated application of ICTs to transport. ITS can be applied to all modes of transport, i.e. air, ship, rail and road, and to every element of a transport system, i.e. the vehicle, the infrastructure, and the driver or user, interacting together dynamically. The overall function of ITS is to support transport network controllers and other users (citizens, companies and city governments) in the decision-making process, leveraging on accurate real-time information about traffic and vehicle conditions. As a result, the operation of the entire transport system is expected to improve, leading to a better use of resources and to a more rational coordination of physical flows.

2. Research objectives and methodology

The present research, besides the academic contribution to the extant literature on ITS applications, aims at supporting governments, public administrations, logistics companies, public transport operators, and all the managers interested in analysing the impact of ITS within the urban context, to provide them a comprehensive view of ITS applications for urban Smart Mobility and an in-depth analysis of how ITS could impact on urban mobility considering both people and freight transport, quantifying the effects in terms of efficiency (time, costs), environmental footprint and payback time of the investment. More in details, the main goal of this work can be summarised in three research questions briefly described in the next rows, highlighting the methodologies used and how the papers included in the thesis contribute to the goal. Indeed, this dissertation is constituted by a collection of three papers.

In particular:

- "Paper 1": "A comprehensive view of Intelligent Transport Systems (ITS) for urban Smart Mobility".
- "Paper 2": "The benefits of Intelligent Transport Systems (ITS) for people and freight urban road transport: a quantitative assessment model".
- "Paper 3": "Smart Parking management in a Smart City: costs and benefits".

RQ1. What are the main ITS applications for urban Smart Mobility, considering people and freight transport, and the main literature gaps in this field?
Paper 1 investigates - through an in-depth literature review - the role of ITS for urban Smart Mobility, highlighting the most diffused research methods to assess the benefits achievable by logistics operators, city governments and city users in the fields of people (Traffic management, Public transport and Parking management) and freight transport (City Logistics). The selected papers were first classified and examined according to the main research method adopted, namely *literature review, simulation, case study, analytical model, benchmarking, survey,* and *conceptual framework*. Moreover, they were also categorised according to the type of data analysis (i.e. qualitative and/or quantitative analyses) and the type of urban transport, i.e. people vs. freight, in order to detect possible relationships with the choice of the method.

RQ2. What are the ITS-enabled benefits and costs for the main urban Smart Mobility applications for freight and people transport, considering the viewpoint of the several stakeholders (e.g. logistics operators, parking operator companies, municipalities, citizens)?

The aim of Papers 2 and 3 is the analysis, through a simulation and a quantitative assessment, of how ITS technologies could impact on urban mobility considering both people and freight transport, quantifying the effects in terms of efficiency (time, costs), environmental footprint and payback time of the investment. The two papers are focused on the two main areas of urban mobility: the urban road traffic management (Paper 2) and the urban parking management (Paper 3). In both papers two methodologies are used. First, the developing of a model able to simulate an urban traffic system (Paper 2) and a parking management system (Paper 3) considering both freight and people transport, which can be used to depict and analyse the current AS IS scenario and to compare it with an innovative traffic system based on ITS (TO-BE scenario). Second, the developing of a quantitative assessment to evaluate the costs of the ITS solutions and the economic and environmental benefits that can be obtained through the reduction of city congestion (Paper 2) and the possibility to reach the nearest free parking place (Paper 3). The results obtained in real contexts are presented in both papers.
RQ3. What are the mutual benefits related to the joint application of ITS for people and freight transport within the urban perimeter?
In the current literature there is a lack of clarity about the combined impacts of ITS considering both people and freight transport in the urban perimeter. In addition, models (e.g. simulation, analytical model) able to quantitatively evaluate these benefits are still rare. In line with these premises, it is necessary to design an integrated approach for urban Smart Mobility, by developing analytical and simulation models to show the potentialities of ITS for both freight and people urban transport and the benefits which can be jointly obtained in a smart urban context. In order to evaluate the combined impacts of ITS considering both people and freight transport, the results derived from the model in Paper 2 and 3 were compared with similar simulation models in which the installation of ITS solutions only applies to cars or trucks. This analysis allowed to fully-explore the potentialities of ITS for people and freight transport and to verify the entity of the combined benefits (e.g. additive, super-additive) in a smart urban context.

3. Results

Three contributions can be identified. First, this research provides a clear and comprehensive picture of the potentialities of ITS for both freight and people urban transport. Indeed, although good pictures of the extant literature on ITS for urban mobility have been taken by several authors, these analyses are not up-to-date and complete. In order fill this gap, a complete overview of the extant body of knowledge has been taken. Second, this research highlights that ITS solutions can significantly enable several typologies of benefits in the urban contexts, both considering people (e.g. reduction of the time spent in the traffic for cars) and freight transport (e.g. reduction of delivery time for trucks, improving productivity of transport processes). More specifically, this study aims to develop quantitative models intended to evaluate the ITS-enabled benefits and the payback of the investments. Third, this study contributes to the development of joint research in the field of people and freight transport within the urban Smart Mobility. This research allowed to fully-explore the potentialities of ITS for people and freight transport and to verify the entity of the combined benefits (e.g. additive, super-additive) in a smart urban context.

THE PSS DESIGN GURU METHODOLOGY AND THE LEAN DESIGN RULES TOOL: SUPPORTING PRODUCT MANUFACTURERS IN THE DETAILED DESIGN OF PRODUCT SERVICE SYSTEMS (PSS)

Claudio Sassanelli - Supervisor: Prof. Sergio Terzi

DESIGN FOR PRODUCT SERVICE SUPPORTABILITY (DFPSSU)	
DfX making the solution more customer driven	**DfX minimizing the cost of providing the solution**
Design for Usability (DfU) (Mital et al. 2008; Gould & Lewis 1985; Medina et al. 2011; Bevan 1999; Norman 2002):	Design for Manufacture and Assembly (DfMA) (Miyakawa et al. 1990; Tibbetts 1995; Boothroyd 1994; Boothroyd et al. 2011; Huang 1996)
Functionality (Kuo et al. 2001; Mital et al. 2008; Norman 2002; Welch & Dixon. 1992; Welch & Dixon 1994; Shackel & Richardson 1991)	Design for Validation (DfV) (Medina et al. 2011; Alexander & Clarkson 2000; Alexander & Clarkson 2002)
Ease of operation and Aesthetic (Mital et al. 2008; Norman 2002)	Design for Reliability (DfR) (Kuo et al. 2001; Aguirre 1990; Huang 1996; Pahl & Beitz 1996; Ireson & Coombs Jr. 1988)
Design for Quality (DfQ) (Kuo et al. 2001; Hubka 1992; Erixon 1996; Huang 1996)	Design for Modularity (DfMo) and Customizability (DfC) (Huang 1996; Pimmler & Eppinger 1994; Kamrani 2002)
GC Differentiation level	Design for Maintainability (DfMt)/Serviceability (DfS) (Kuo et al. 2001; Huang 1996; Abbatiello 1995)
	Design for Inspectability (DfI) (Drury 1992; Black 1990; Goranson 1993; Huang 1996)
	Design for Testability (DfT) (Huang 1996; Drury 1992; Black 1990; Markowitz 1992)

Tab. 1 - The Design for Product Service Supportability (DfPSSu) approach

Recently, lot of manufacturing companies facing commoditization of offering and intense competition have been attracted by the possibility to differentiate themselves from competitors by introducing product related services in their traditional portfolio. This change in their offering is due to the modification of the customers' behaviors and their increasing interest in companies' services. As a result, manufacturers are changing their business models by delivering Product-Service System (PSS) through incorporating service related activities in their value proposition. However, the lack of methods and tools able to systematically bridge the integration of product and service in the design and engineering of PSS is acknowledged. This research seeks to address this gap by examining the limitations of existing PSS design methodologies to support manufacturers to simultaneously address both the customer's and company's perspective, and at the same time to properly support with a concrete approach the integration of service and product design along their whole lifecycle. Notwithstanding the whole bunch of attempts of PSS design methodologies proposed in the literature, none of them

successfully managed to explain how to integrate traditional product design processes with service features since they are all either focused on the concept phase or stuck on a theoretical level. Thus, a shift from concept to detailed design phase and from the theory to practice level is needed. Design for X (DfX) approaches, coming from the product engineering area, have been already theoretically proposed in the PSS context as a mean to address designers' lack of knowledge in certain lifecycle stages and product functions: thus they can be considered a solution to help filling this gaps both in theory and practice. To this purpose, the objective of this research is twofold. On one side, from a literature point of view, the research wants to propose an advancement in the PSS design context of a DfX based approach. On the other side, it wants to provide practitioners with both a methodology, generating new DfX guidelines able to support the early integration of service features already in the product design of PSS, and a related aiding tool to store and manage consistently this knowledge. In order to achieve this dual objective, a DfX approach in the PSS design context has been proposed: the Design for Product

Service Supportability (DfPSSu) approach (Table 1). It has the aim to design a product more customer driven, maximizing the customer value of the solution provided and, at the same time, minimizing the cost of providing the solution during the whole lifecycle phases of the PSS. The main concept behind the DfPSSu is that some services need to be supported by some specific DfX approaches: the heterogeneity of the service brings to develop and enhance the tangible part according to different goals. Referring to service, DfPSSu encompasses all the DfX approaches aimed at systematically designing products able to deliver different types of services. Based on this approach, a new methodology, the PSS Design GuRu Methodology (Figure 1) and a related tool, the Lean Design Rules Tool, are proposed. Their aim is to enhance the PSS detailed design process and raise designers and engineers' consciousness in designing PSS with a lifecycle perspective in a systematic and integrated way, through the generation of new sector and service specific DfPSSu Design Guidelines and Rules. The use of the PSS Design GuRu Methodology enables design teams to understand how to add value to the PSS but also

to the process needed to its development. Created through the conduction of an interactive and interpretative research approach, the PSS Design GuRu Methodology and the Lean Design Rules Tool result to be an effective method and tool for improving the PSS detailed design process of companies willing to go towards servitization. Thanks to this, not only the product and the supporting infrastructures can be fully integrated with the service components with a PSS lifecycle view, but also new design knowledge can be generated improving companies' innovative, problem solving and knowledge management capabilities. Furthermore, the Lean Design Rules Tool is a support to assist manufacturers to consistently manage the knowledge useful for companies

to start their servitization process, practically bridging product and service divisions. All this enables companies to begin their path towards servitization with a more adequate and conscious PSS offer and mind-set, helping them in

avoiding to fall into the service paradox and in addressing the always growing customer need of a prolonged support throughout the whole product lifecycle.
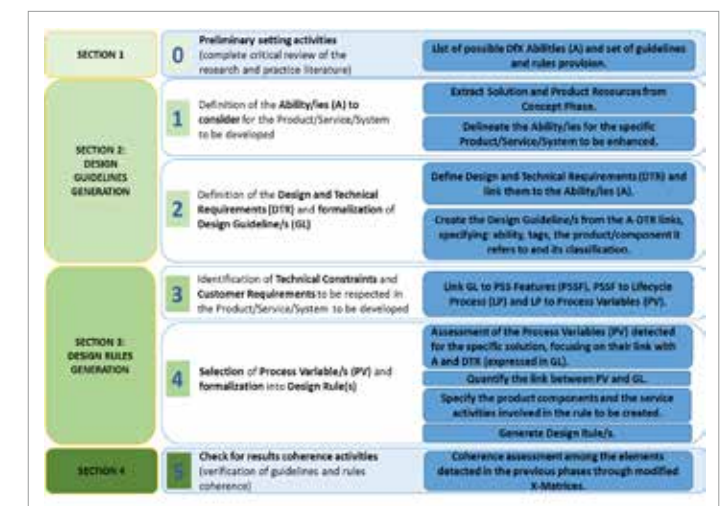

Fig. 1 - The PSS Design GuRu Methodology

THE PURSUIT OF RESPONSIVENESS IN HIGH VARIETY MANUFACTURING ENVIRONMENTS: TOWARDS BUILDING THE DYNAMIC RESPONSE CAPABILITIES

Sayyed Shoaib-Ul-Hasan - Supervisor: Prof. Marco Macchi

Co-Supervisor: Prof. Ruth Carrasco-Gallego

Mass customization is considered as a viable business strategy for Small and Medium-Sized Enterprises (SMEs) to increase their growth and profitability. However, in operations management literature, most of the research on mass customization is geared towards large enterprises while there is little guidance for SMEs in its implementation. Without proper guidance, implementing mass customization in SMEs poses many challenges. The product variety increases which increases complexity in products and production. Besides, due to high variety the manufacturing systems face different types of recurring disturbances from multiple sources that affect the planned production operations with adverse effect on performance. Nonetheless, successful implementation of mass customization requires an appropriate and responsive order fulfilment process capable not only to meet the differentiated customer needs but also to cope with different types of recurring disturbances that may arise at different times, different places in relation to stages in the order fulfilment process, and with different intensity. How such process is developed and maintained may differ among large enterprises and SMEs

mainly due SME specific factors such as low sales volume, limited organizational and technological resources, close customer interaction and high demand variability. Therefore, this research aims to understand and explain how responsiveness in the order fulfilment process can be achieved for successful implementation of mass customization in SMEs. For this purpose, the thesis investigates two key aspects: i) designing an appropriate order fulfilment process for mass customization in SMEs; ii) developing the Dynamic Response Capabilities (DRCs) to cope with different types of recurring disturbances arising along the order fulfilment process.

The first aspect, designing an appropriate order fulfilment process for mass customization in SMEs, aims at setting the scope of the research work. For this purpose, the research particularly focuses on Assemble-to-Order (ATO) fulfilment strategy for catalogue mode of mass customization in SMEs. To design the order fulfilment process under ATO fulfilment strategy two key elements are identified from literature: i) Workload Control (WLC) is considered as a relevant PPC method for SMEs to plan, prioritize, and coordinate order fulfilment activities starting from the order enquiry/entry stage; ii) similarly,

based on the volume-variety requirements within SME context, six shop configuration types have been considered as relevant for SMEs to structure the order fulfilment activities.

The second aspect – developing the DRCs to address recurring disturbances arising along the order fulfilment process, which is the core contribution of this thesis –, aims to formalize a framework that can be used as a guiding tool to develop the DRCs of the manufacturing system in SME context. This research defines DRCs as the ability of a manufacturing system to (re)adjust its planned operating routines (i.e. planned capacity, lead time, and workload) in the wake of customer, supplier, and internal disturbances to achieve its operational goals. Based on the reviewed literature, the research employs a routine-based approach to build DRCs as higher order operational capabilities of the manufacturing system by implementing adaptive decision-making routines at different stages in the order fulfilment process. This research argues that in SME context DRCs can be developed by implementing WLC-based decision-making routines at different stages in the order fulfilment process. The I/OC mechanisms of WLC utilize different types of buffer

and flexibilities (i.e. lower level capabilities) to readjust the planned workload, capacity, and/or lead-time in the wake of disturbances from customers, suppliers, and internal manufacturing operations. For I/OC mechanisms to be effective, they should be supported with proper sensing routines and mechanisms to have visibility into the current operating conditions in order to recognize the disturbances as they arise along the order fulfilment process and to adapt the planned capacity, lead time, and workload by using available buffer and flexibilities. Thus, to develop DRCs a routine-based framework is proposed which implements WLC-based adaptive decision-making routines at different stages in the order fulfilment process to readjust the planned operating routines in the wake of recurring disturbances. Figure 1 shows the routine-based framework to develop DRCs of the manufacturing system.

The routine-based framework of the DRCs is tested for its relevance, feasibility, and effectiveness using two case studies from the SME sector and a simulation study performed in collaboration with one of the case companies. Findings from case studies show that mass customization SMEs are already developing different types of DRCs by implementing WLC-based adaptive decision-making routines at different stages of their order fulfilment processes. The findings from case studies provide evidence for DRCs by identifying the adaptive decision-making routines and mechanisms implemented by the case companies to address multiple types of recurring disturbances. In particular, the DRCs to cope with recurring disturbances due to volume demand variability, mix demand variability, rush orders, internal performance variation, and unreliable component supply have been identified. Based on the findings from case studies it is concluded that the routine-based framework is relevant and feasible for mass customization

SMEs to build DRCs and to achieve responsiveness in the order fulfilment process. Furthermore, simulation results show that performance in terms of order fulfilment rate and capacity utilization is improved in the presence of recurring disturbances due to volume and mix demand variability by implementing DRCs that utilize WLC-based adaptive-decision making routines at order enquiry/entry and release stages of the order fulfilment process. Based on the findings from the case studies and the collaborative simulation study, it is concluded that the proposed routine-based framework and the I/OC mechanisms can be effectively used to identify, analyze, and develop different DRCs to cope with multiple types of recurring disturbances and to achieve responsiveness in the order fulfilment process for successful implementation of mass customization in SMEs.
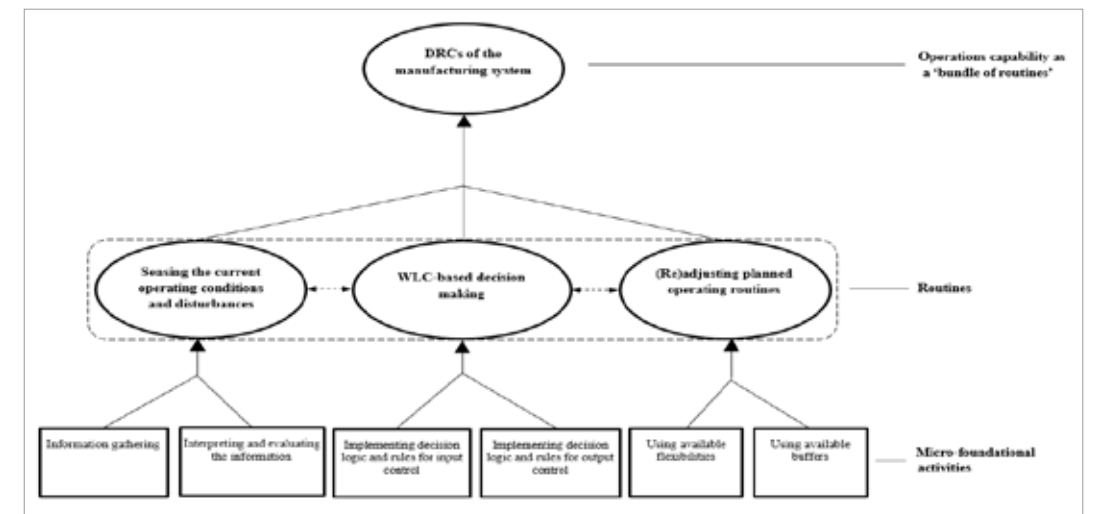

Fig. 1 - framework to develop Dynamic Response Capabilities by implementing WLC-based adaptive decision-making routines at different stages in the order fulfilment process

INNOVATION MANAGEMENT AND DIGITAL TECHNOLOGIES: OPENING UP THE BLACK BOX

Andrea Urbinati

Supervisors: Prof. Davide Chiaroni, Prof. Federico Frattini

Introduction to the thesis

In the last years, digital transformation has enabled a large proliferation of digital technologies that companies can use to support their innovation activity. This proliferation has triggered existing innovation management research to pay particular attention to the theoretical perspectives and research domains that address this issue in companies. In particular, the innovation management research started to focus on the role that digital technologies have in transforming the innovation process, and their use can be even more important today in a context where innovation processes are becoming increasingly open to the knowledge and information flows coming from the external environment. Despite the growing efforts in the innovation management research, the main contributions dealing with this issue still belong to the broader fields of information systems and business model innovation. This calls for the need of providing a structured and integrated vision on the role of digital technologies in the innovation activity of companies within the innovation management research. In addition, according to the existing scientific contributions, there is a lack of a clear definition of what digital technologies are, a lack of strategic and innovation frameworks that identify how value and competitive advantage are created in companies that use digital technologies in their innovation activity, as well as of practical implications of how companies use digital technologies to transform their work practices and management of knowledge resources. Moreover, innovation management research in this domain does not properly consider the open nature of innovation processes and this calls future research on the application and use of digital technologies to enable such open processes. Starting from the above premise, the goal of the thesis is to investigate the role that digital technologies can play for companies in their innovation activity in the attempt to increase their innovation performance and gain a competitive advantage over competitors. The thesis is edited as a collection of three papers. In particular, Paper 1 sheds light on the concept of digital technologies within the innovation management research, providing both a comprehensive theoretical framework for future research and highlighting the main theoretical perspectives and research domains. Paper 2 empirically investigates the role that several digital technologies can play for companies to foster the open innovation activity. Paper 3 empirically investigates the role that digital technologies (and, in particular, the Big Data technology) can play for companies to create and capture value.

Contributions

The role of digital technologies in the innovation activity of companies can be studied through several theoretical perspectives and in different research domains. In particular, through Paper 1, the thesis identifies the research areas of digital innovation strategy, value creation and capture, organizational and dynamic capabilities, knowledge creation and transfer, new product development (NPD) and innovation adoption and diffusion. In addition, it conceptualizes a definition of digital technologies in the innovation management field, after clustering the key emerging themes in a theoretical framework, which maps the digital technology families and related digital tools and applications. This represents another important finding ensuing from the systematic review process that deserves particular attention in a period of new theorizing about digital technology and innovation concepts. In addition, through Paper 2, the thesis establishes inductively a framework and maps, onto the framework's dimensions, the managerial actions at organizational and at process level that companies need to perform to implement digital technologies. On one hand, companies are called to reorganize their R&D units and activities (and sometimes to create *ex-novo* R&D departments) for open innovation through digital technologies, focusing on (i) technologies' features standardization, (ii) budget formalization for digital investments, and (iii) development of new and formalized procedures for innovation activities (due to digital technologies). On the other hand, at a process level, companies perform *ex-ante* and in a particular timeframe deliberate actions to adopt digital technologies. In addition, companies perform *ex-post* new actions triggered by the digital technologies as effect of their previous adoption. These actions sometimes change from technology to technology and from phase to phase of the open innovation process. Finally, through Paper 3, the thesis establishes a framework of innovation service strategies through Big Data technology and highlights the critical role they play for companies to improve the value proposition towards customers and capture differential value. From a managerial perspective, the results of the thesis invite managers to reflect on the potential of digital technologies application. In particular, managers with a role of responsibility in the innovation units of companies are provided with a set of tools, insights and examples of how and why digital technologies can be used to manage innovation processes in an open perspective and in service innovation to create and capture value.

Limitations and avenues for further research

The theoretical perspectives and the research domains identified in Paper 1 could be not exhaustive in the innovation management field, as they are influenced by the queries we used in the sampling criteria. Moreover, the same queries influence the key themes ensuing from the extant research and, consequently, the proposal of a conceptual definition of digital technologies in the innovation management research. As for the theoretical limitations of Paper 2, the findings were not able to provide any insight on the impact of digital technologies application in the specific phases of the innovation process from the analytical point of view. In addition, the inductive framework is built on the basis of antecedent studies, which address specific industries and contextual factors, and they have surely influenced the way the framework was established. As for the Paper 3, it is worth to underline how the huge proliferation of Big Data technology is triggering service innovations towards a radical transformation in terms of new strategies, new actors, new competitive environments, and new contextual factors. This path surely has an influence on the proposed framework of innovation service strategies and calls for its refinement, enrichment or modification according to these ongoing changes. Although the interesting findings, the thesis deserves particular attention in terms of its managerial limitations. In particular, Papers 2 and 3 are exploratory in nature. In addition, the managerial actions and the innovation strategies they have highlighted cannot be addressed to any population of companies or industries. Moreover, the specific benefits or challenges ensuing from the application of digital technologies in the specific contexts where the sampled companies operate deserve much more empirical effort. We invite future research to consider more key words in the queries used for the review process, such as the names of the digital technology families or, for example, to add the acronyms of more innovation journals, to increase the number of relevant publications for innovation management scholars. As for Papers 2 and 3, we invite future research to enlarge the number of companies to involve in the study and try improving the generalizability of the findings.