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LA INNOVACIÓN Y LA CREACIÓN DE NUEVOS EMPRENDIMIENTOS

Presentada por Igor Alexander Bello Tasic para optar al grado de Doctor
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INNOVATION AND NEW VENTURE CREATION

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Declaration

I hereby declare that the work presented in this thesis has not been submitted for any other degree or professional qualification and that it is the result of my own independent work.

Igor Alexander Bello Tasic

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Resumen

Crear lo "nuevo" para resolver problemas es una hazaña incierta. Aun así, el ser humano ha innovado y aplicado el ingenio durante milenios, llegando a crear nuevas herramientas, puentes y empresas, a pesar de la falta de recursos o de claridad en los objetivos. En este sentido, el problema de la asimetría de información (cómo se desplegará el futuro) y de la asimetría de recursos (de qué medios se dispondrá) motivó esta tesis. En particular, el problema de cómo los emprendedores crean nuevos emprendimientos e innovan bajo la incertidumbre y sin objetivos iniciales claros.

Esta tesis pretende contribuir a la comprensión de la innovación y la creación de nuevos emprendimientos utilizando una lógica no predictiva (*effectuation*) y métodos ágiles (utilizados por las aceleradoras de *startups*) como principios orientadores de esta discusión.

Effectuation es una lógica común aplicada por los emprendedores expertos para resolver los problemas típicos de la innovación y creación de nuevas empresas. Se trata de una heurística de control no predictiva que los emprendedores ponen en práctica a través de cinco principios de acción *effectual* al abordar las incertidumbres y sorpresas en la creación de nuevos productos, servicios o mercados: 1) Principio de "pájaro en mano": construyen un nuevo emprendimiento no necesariamente con un objetivo en mente, sino partiendo de sus propios medios y recursos (quiénes son, qué saben, a quienes conocen), 2) Principio de "pérdida asequible": no hacen grandes apuestas con la expectativa de obtener grandes beneficios, sino que evalúan las oportunidades en función de las desventajas aceptables, 3) Principio de "colcha loca": reducen la incertidumbre formando asociaciones y obteniendo compromisos iniciales en las primeras fases de sus nuevas empresas, 4) Principio de la “limonada”: aprovechan las contingencias en lugar de rechazarlas, permaneciendo flexibles y adaptando sus proyectos según sea necesario, 5) Principio del “piloto en el avión”: se centran en controlar lo que sea controlable en su entorno, entendiendo que el futuro no se encuentra ni se predice, sino que se hace a través de la acción humana.

Las aceleradoras y los métodos ágiles activan los principios *effectual* a través de herramientas y prescripciones que reducen sistemáticamente las inversiones mientras se crea un nuevo emprendimiento. Las aceleradoras promueven ampliamente los métodos ágiles (por ejemplo, el modelo de desarrollo de clientes, los *sprints* de diseño, el ciclo de innovación rápida) para construir prototipos y primeras versiones de productos y servicios mientras se descubren los clientes y *partners* iniciales. Además, reduce el riesgo para los inversores en todas las fases de crecimiento de las *startups* al validar la idea del emprendimiento y aclarar qué recursos serán necesarios.

En este sentido, esta tesis examinó si, y en qué medida, los emprendedores construyen nuevas empresas utilizando *effectuation* y métodos ágiles mediante la creación de tres innovaciones reales con aplicaciones en el mundo real.

Los tres casos eran pruebas de concepto implementadas en contextos del mundo real con el objetivo explícito de lanzar Productos Mínimos Viables (*Minimum Viable Products*, MVP) pero bajo incertidumbre y con ambigüedad de objetivos sobre su funcionalidad. Las tres aplicaciones eran soluciones tecnológicas a problemas de congestión del tráfico, pandemias y confianza en las transacciones digitales. La aplicación 1, "Lemur", es una aplicación *edge* para el control del tráfico; la aplicación 2, "Dolphin", un sistema de geolocalización basado en sensores e Internet de las Cosas (*Internet of Things*, IoT) aplicado para el control de pandemias y la aplicación 3, "Crypto Degrees", una solución basada en *blockchain* para verificar títulos universitarios.

En todas las etapas del desarrollo de cada aplicación, los equipos implicados la abordaron de forma emprendedora/eficaz, afrontando las incertidumbres y emprendiendo acciones para comprometerse con múltiples partes interesadas al tiempo que apalancaban las contingencias.

Tras implementar las tres soluciones y analizar sus resultados e impacto, los tres casos validaron las predicciones teóricas de que, aplicando principios *effectual* de

forma ágil, se pueden crear nuevos emprendimientos de forma emprendedora e innovadora.

Palabras clave: Innovación, Effectuation, Emprendimiento, IoT, Blockchain, Sistemas Inteligentes, Ingeniería

Abstract

Creating the "new" to solve problems is an uncertain feat. Still, humans have innovated and applied Ingenium for millennia, eventually creating new tools, bridges, and ventures, despite a lack of resources or clarity of objectives. In this sense, the problem of information asymmetry (how the future will deploy) and resource asymmetry (what means will be available) motivated this thesis. In particular, the problem of how entrepreneurs create new ventures and innovate under uncertainty and without clear initial goals.

This thesis aims to contribute to understanding innovation and the creation of new ventures using a non-predictive logic (effectuation) and agile methods (used by startup accelerators) as guiding principles of this discussion.

Effectuation is a common logic applied by expert entrepreneurs to solve the typical problems of starting new ventures and innovating. It is a non-predictive control heuristics entrepreneurs operationalize through five principles of effectual action while addressing the uncertainties and contingencies in creating new products, services or markets: 1) Bird-in-hand principle: they build a new venture not necessarily with a goal in mind, but starting with their own means and resources (who they are, what they know, who they know), 2) Affordable loss principle: they do not place large bets with the expectation of high returns, but rather assess opportunities based on acceptable downsides, 3) Crazy quilt principle: they reduce uncertainty by forming partnerships and gaining initial commitments early in their new ventures, 4) Lemonade principle: they leverage contingencies instead of rejecting them, remaining flexible and adapting their projects as required, 5) Pilot in the plane principle: they focus on controlling whatever is controllable in their environment, understanding that the future is not found or predicted, but it is made through human action.

Accelerators and agile methods activate the effectual principles through tools and prescriptions that systematically reduce investments while creating a new venture. Accelerators extensively promote "agile" methods (e.g., customer development model, design sprints, rapid innovation cycle) to build prototypes and early versions of products and services while discovering the initial customers and partners. Additionally, it reduces the risk for investors across all startup growth phases by validating the venture idea and clarifying what resources will be required.

In this sense, this thesis examined whether and to what extent entrepreneurs build new ventures using effectuation and agile methods by creating three actual innovations with real-world applications.

The three cases were proofs of concept implemented in real-world contexts with the explicit goal of launching Minimum Viable Products (MVPs) but under uncertainty and with ambiguity of objectives about its functionality. The three applications were technological solutions to problems of traffic congestion, pandemics, and trust in digital transactions. Application 1, "Lemur," is an edge application for traffic control; application 2, "Dolphin," an Internet of Things (IoT)-based geolocation system applied for pandemic control and application 3, "Crypto Degrees," a blockchain-based solution to verify university degrees.

In all stages of each application development, the teams involved approached it in an entrepreneurial/effectual way, facing uncertainties and engaging in actions to engage with multiple stakeholders while leveraging contingencies.

After implementing the three solutions and analyzing their results and impact, the three cases validated the theoretical predictions that by applying effectual principles in an agile form, new ventures can be created in an entrepreneurial, innovative way.

Keywords: Innovation, Effectuation, Entrepreneurship, IoT, Blockchain, Intelligent Systems, Engineering

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Acronyms

AI	Artificial Intelligence
AP	Access Point
API	Application Program Interface
BLE	Bluetooth Low Energy
CFR	Channel Frequency Response
CO	Carbon Monoxide
CO2	Carbon dioxide
CPSS	Cyber-Physical-Social Systems
CPU	Central Processing Unit
CSI	Channel State Information
DAC	Decentralized Autonomous Corporation
DAO	Decentralized Autonomous Organization
DAPU	Data Acquisition and Processing Unit
DAS	Decentralized Autonomous Society
DAU	Data Acquisition Unit
GB	Giga Byte
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
HTTP	HyperText Transfer Protocol
ID	IDentifier
IIoT	Industrial IoT
IoT	Internet of Things
IPO	Initial Public Offer
ITS	Intelligent Transportation Systems
KPI	Key Performance Indicators
LoS	Line of Sight
LQI	Link Quality Indicator
M2M	Machine to Machine
MAC	Medium Access Control

ML	Machine Learning
MQTT	Message Queueing Telemetry Transport
MVP	Minimum Viable Product
NYCDOT	New York City Department of Transportation
OS	Operating System
PEM	Percentage of non-zero EleMent
PII	Personal Identifiable Information
PLC	Programmable Link Controllers
PMBOK	Project Management Body of Knowledge
QoE	Quality of User Experience
QoS	Quality of Service
QR	Quick Response
R&D	Research & Development
RAM	Random Access Memory
RBV	Resource Based View
REST	REpresentational State Transfer
RF	Radio Frequency
RSS	Received Signal Strength
SLA	Service Level Agreements
SME	Small and Medium Enterprise
SSD	Solid State Drive
SSID	Service Set Identifier
STP	Segmentation-Targeting-Positioning
SUMO	Simulation of Urban MObility
SVM	Support Vector Machine
TRL	Technology Readiness Level
UPCT	Universidad Politécnica de Cartagena
URL	Uniform Resource Locator
VC	Venture Capital

1. Introduction

Humans have the unique skill of solving complex problems. We use our ability to think in abstract terms and visualize the solution yet to be created. Two sides across a river let us invent the bridge. Nevertheless, first and foremost, the bridge was created in the human mind. Creating solutions through objects and ideas is at the core of innovation. This thesis aims to understand this process and how we create new ventures and innovate through them.

For several decades, the systematic study of entrepreneurship was neither legitimized nor conclusive in its results. Most academic efforts focused on analyzing the creation of new ventures from a siloed perspective, typically prescriptive, connected to opportunities and the personality of the entrepreneur [1]–[3].

Most research focus on explaining what entrepreneurship is, aiming to validate it as a field by itself, or who is the entrepreneur, trying to identify distinct behavioral characteristics of the persona involved in the process of creating something new [1], [2].

More interesting questions, though, should understand what the entrepreneur does and how innovation comes to be. How do entrepreneurs create new ventures and innovate under uncertainty and without clear initial goals? When creating it, how do they invest their resources? Do they search for control? Do they leverage surprises along the way?

These questions require a multidisciplinary approach to be understood, linking both science and humanities in an interconnected continuum formed around the problem-solution construct.

Thus, in many ways, the context where entrepreneurs operate resembles (if it is not the same) the context in which engineers operate. Engineers systematically apply the cartesian method to come up with solutions to existing or new problems. The application of Ingenium by an engineer is no different from the application of a systematic approach used by an entrepreneur to build new ventures. In fact, the growing interest in educating engineers to become entrepreneurs, particularly in the field of technology, validates this connection [4].

The field of Technology is a fertile ground for such intertwined relationships to be observed. It is such the case that even in popular culture, entrepreneurs often praise the interconnection between entrepreneurship and engineering [5]:

> *"I don't spend my time pontificating about high-concept things; I spend my time solving engineering and manufacturing problems."*
> *Elon Musk, technology entrepreneur.*

The objective of this thesis is to understand the process of creating new ventures connecting a non-predictive logic such as effectuation [6] and agile ways of approaching problem-solving through new venture acceleration [7]–[9].

This work does not have the ambition to characterize what would be an entrepreneurial process but rather to explore the ideas inherent to how innovators and entrepreneurs make decisions under uncertainty and ambiguity of objectives.

An overarching research question that persisted in the deployment of this work was: If some innovators and entrepreneurs start new ventures without clear goals and under uncertainty, how do they decide to go ahead and get things done?

To this end, this study sought to address this question through the logic of effectuation [6], [10], which serves as a fit framework for making decisions based on choices among the effects that can be produced from a given set of means and resources, consequently eliminating the premise of pre-existing objectives.

According to this theory, which is further examined in chapter 2, the entrepreneur is not independent of the context in which his/her decisions are made. He/she[1] is part of a dynamic environment involving multiple decisions, which are interdependent and simultaneous. In this sense, several decision-makers take part in refining the entrepreneur's aspirations until they crystallize into goals.

By this logic, entrepreneurs focus on how much they can bear to lose and experiment with as many different strategies and resource combinations as possible, given the resources that are already under their control.

The goal in this model is not necessarily to maximize potential financial returns but rather to reduce the uncertainty embedded in specific strategies and combinations of resources.

When using effectuation, the entrepreneur, through actions, creates the outcomes from these combinations of resources while reducing the uncertainty surrounding him / his new venture. In this theory, decisions about what actions to be done exist in the face of unknown future values [11].

In this sense, this thesis examined whether, and to what extent, entrepreneurs build new ventures in the real-world using effectuation.

Creating actual innovations, with real-world application, further discussed in chapter 3, this thesis sought to understand the use of effectual rationality and accelerated methods in the decision events that lead to the creation of new ventures.

[1] Please note that for simplicity the pronoun “he” is used throughout this Thesis disregarding the gender

1.1. Summary Description of the Chapters

This introduction (chapter 1) presents the primary purposes and reasons for this thesis, identifying the scope of the work, its objectives, justifications, and the problem to be researched.

Chapter 2 refers to the literature review to form a theoretical and conceptual framework that serves as a basis for field research and real-world applications.

This chapter is divided into two sections. First, it describes and analyzes the logic of entrepreneurship and innovation through the effectuation theory, defining the theoretical pillars on which this approach is structured. The second section maps the current research and definitions of new venture acceleration.

Chapter 3 describes the innovations, with real-world applications implemented to test the overarching question of this thesis. It also discusses the methodology used and the results identifying in practice how some of the theoretical concepts discussed in Chapter 2 are characterized and implemented.

Finally, chapter 4 lists the main conclusions and contributions of the thesis.

1.2. Scientific Contributions Derived from this Thesis

I. Tasic, M.-D. Cano, "Sparking innovation in a crisis: An IoT Sensor Location-Based Early Warning System for Pandemic Control", *Applied Sciences*, 12(9), 4407, 2022. DOI: https://doi.org/10.3390/app12094407. IF: 2,474 Q2 (32/91 Engineering, Multidisciplinary)

Member of the research team in the project "*Prueba de Concepto - Sistemas inteligentes para la optimización del tráfico urbano*" funded by Fundación Séneca, Región de Murcia (20539/PDC/18). Number of researchers: 3. From 01/01/2019 to 31/12/2019. Principal researcher (entity): María Dolores Cano Baños (UPCT).

Member of the research team in the project "*Programa +Spinoff*" funded by Universidad Politécnica de Cartagena. Number of researchers: 3. From 01/01/2020 to 31/03/2021. Principal researcher (entity): María Dolores Cano Baños (UPCT).

Other relevant publications from the author:

I. Tasic, A. Montoro-Sánchez, and M.-D. Cano, "*Startup accelerators: an overview of the current state of the acceleration phenomenon,*" in Proc. XVIII Congreso AECA "Innovación e Internacionalización: factores de éxito para la Pyme", pp.1-23 (130C), Cartagena, Spain, October 2015. ISBN 978-84-16286-14-0

I. Tasic and A. Montoro-Sánchez, "*The Startup Acceleration Phenomena: Premisses, Processes, and Performance of Business Accelerators*," In Proc. Doctoral Consortium, IE Business School, Madrid, Spain, April 24th, 2015.

D. Alonso, J. Pastor, B. Álvarez, T. Suarez, and **I. Tasic**, "*Improving the learning experience and outcomes in entrepreneurial courses*," in Proc. IEEE 26th International Symposium on Industrial Electronics (ISIE), 2017, pp. 1581-1586, DOI: 10.1109/ISIE.2017.8001482.

I. Tasic, "Startup Ecosystems and Effectuation: Impact analysis of new ventures creation processes, " in Proc. V Jornadas Doctorales, Escuela de Doctorado de la Universidad de Murcia, Murcia, Spain, May 31st, 2019

I. Tasic, "Teaching and Practice Case: Startup Europe Week" in Proc. 2019 Effectuation Conference, Jean-Baptiste Say Institute for Entrepreneurship of ESCP Europe, Berlin, Germany, November 26th, 2019

C. Musso-Gutierrez, **I. Tasic**, M.-D. Cano, J. Ochoa-Rego, P. Gómez Di Marco, J. A. Fernandez, C. Egea-Gilabert, and M.-D. De Miguel-Gomez, "*Estudio de seguimiento y trazabilidad de productos en agricultura urbana con tecnologías blockchain,*" In Proc. III Symposium Ibérico de Ingeniería Hortícola 2022 Smart Farming, pp. 1-4, Cartagena, Spain, April, 2022. (Selected for Special Issue "Applications, Challenges and Potential of Intelligent Equipment in Agriculture" in Agronomy, IF 3.417).

2. Literature Review

The theoretical framework that directed this thesis aimed to reconnect with the Engineering guiding principle of solving problems through *Ingenium*. In many ways, as discussed in this section, this is also the space where entrepreneurs and innovators operate. By combining and recombining resources, engineers and entrepreneurs create the “new” in a similar form, making a case for a “bridge” to connect the creation process of new ventures.

This section dissects the creation phenomena from a process perspective, aiming to understand how entrepreneurs and innovators start new ventures. It frames the process in which they de-risk the innovation process by applying a series of heuristic principles that collectively allow one to experiment and evolve in its journey towards creating a new product or service.

Since uncertainty and resource allocation plays an essential role in creating the “new,” non-causal approaches seem to fit better the way new ventures come into being. Specifically, the framework of effectuation and accelerated (or agile) creation seem to provide a fit model for understanding new venture creation under uncertainty guiding the real tests performed in the development of this thesis, as explained in chapter 3.

2.1. The field of study of Entrepreneurship

The objective of this section is to present in a non-exhaustive way the main theoretical streams in the field of entrepreneurship and the objectives obtained so far with the studies in this field.

Without a theoretical consensus on its main concepts, the field of study of entrepreneurship is very close to the plurality of schools [12] concepts and ideas that structure the field of corporate strategy [13]–[16].

Gartner [17] , for example, distinguishes the field of entrepreneurship studies into two major approaches - (i) the entrepreneur and venture traits and characteristics approach and (ii) the behavioral and entrepreneurial process approach.

Thus, this section is subdivided into three parts. The first part explores the plurality of the concept of entrepreneurship. The second presents the traits/characteristics approach. The third part introduces the behavioral and entrepreneurial process approaches, upon which the rest of the chapter will be based, focusing on the concept of effectuation.

2.1.1. What is entrepreneurship?

The concepts "entrepreneur" and "entrepreneurship" are ambiguous and uncertain.

The traditional definitions of entrepreneur and entrepreneurship are found in the essays by Schumpeter [18], who positions the entrepreneur at the core of capitalism's dynamics and evolution, highlighting its capacity to spark innovation and transformation, and linking it to the dynamics of economic growth. From this perspective, entrepreneurship is the engine of capitalism since it stimulates the constant creation and destruction of companies and new businesses.

However, this definition, although widely verified and accepted, is not the only plausible nor the most complete in addressing the multidisciplinary characteristics of the construct "entrepreneurship."

When evaluating the origins of the concept, the term "entrepreneur" was already used since the Middle Ages to describe both an actor and a person who managed large projects (e.g., building castles and forts) [19].

In the 17th century, the notion of risk associated with entrepreneurship appeared, in which the entrepreneur was the one who accepted a certain degree of risk when financing contracts or providing services for the government.

Nevertheless, it was in the 18th and 19th centuries, as proposed by Cantillon and Say [20] , that the term *entrepreneur* begins to be closer to that of a modern businessman, differentiating him from the capitalist and associating him with the primary function of transforming raw materials into products and services with real economic value [19], [21].

Although there is no definite consensus on this concept, most researchers and practitioners accept the notion that entrepreneurs perform a social function of identifying opportunities and converting them into economic value [22]. In this sense, there is a wide range of definitions that associate the practice of entrepreneurship as the act of creating an innovative economic organization (or network of organizations) with the goal of obtaining profitability or growth under conditions of risk and uncertainty[18], [23]–[27].

Some scholars expand the concept of entrepreneurial action [28], in which the entrepreneur is the one who starts, operates, and develops a business. In contrast, other researchers [29] emphasize the differences between entrepreneurship and management.

To organize this multiplicity of concepts Fillion [21] sought to categorize the several lines of thought of entrepreneurship into three groups:

- **Economists Group**: associating risk, innovation, and profit. For this group of thinkers, the entrepreneur is seen as a person who seeks to take advantage of new opportunities, foreseeing profits, and acting in the face of certain risks. Along these lines, several economists have associated entrepreneurship with innovation, seeking to clarify the influence of entrepreneurship on economic development.

- **Behaviorists Group**: seeking to understand the rise and fall of civilizations through human action (David C. McClelland (1971)). The behaviorists were encouraged to draw a profile of the entrepreneur's personality, seeking to find relationships between the need for achievement and power and the notion of social and economic development.

- **Personality traits Group**: derivative from the behavioral view, this school of thinking, widely disseminated, seeks to trace the idiosyncratic characteristics of entrepreneurs to portray an ideal type of entrepreneur and his business. The ambition of this line of research, in general terms, is to outline an orientation plan for entrepreneurs, aiming to maximize their chances of success by avoiding certain behaviors/traits and stimulating others.

However, despite the clear confusion about the entrepreneur and entrepreneurship concepts [21], scholars accept that entrepreneurship consists of the phenomenon of business generation itself, related both to the creation of a new company and/or to the expansion of an existing one, such as the development of a new business unit in large corporation [30]. In the same manner, entrepreneurship could be understood as any attempt to create a new business or new venture, or the expansion of an existing one, by an individual or groups of individuals and firms [31].

Overall, until recently, researchers, practitioners and the media leaned on the traits/characteristics dimension of the entrepreneur, resulting in the general orientation observed in several studies on entrepreneurship [2], [12].

Being more descriptive and prescriptive, entrepreneurship research usually seeks to establish general rules, expected behaviors, and personality traits of entrepreneurs to classify and extrapolate its results. It aims to define some general aspects that can be used to describe which factors determine the success or failure of new businesses. As expected, most of these studies are inconclusive, if not contradictory [2], [17].

In part, this seems to be the result of both lack of legitimacy and the lack of a greater insertion in other fields, allowing a clearer differentiation of the unique contributions that the field of entrepreneurship can offer to other areas such as physical sciences and engineering, life sciences, health sciences or even social sciences and humanities [12].

In sum, entrepreneurship is a field of knowledge in formation [2], still lacking broader definitions of concepts and cohesion among studies, as well as systematic applications of methodologies that go beyond the often-exploratory analysis that are not statistically generalizable.

This thesis aims to contribute to this discussion, by connecting Effectuation and agile methods to applied sciences in engineering and technology, potentially expanding the impact of entrepreneurship in several fields of knowledge.

2.1.2. Who is the entrepreneur?

Understanding entrepreneurship as traits and characteristics is perhaps the research branch with the longest tradition in the field of entrepreneurship studies. The attempt to identify the unique characteristics of entrepreneurs has been a main driver of interest for both academics and practitioners [2], [12], [17], [32]. Nevertheless, just like the definition of entrepreneurship, efforts to define "who is an entrepreneur" are also controversial and not precise.

Gartner [17] points out in his research at least 32 different definitions about who are the entrepreneurs and what are their characteristics. Similarly, Fillion [21] presents different views on who are the entrepreneurs (according to the view of experts from different areas, Table 1).

Dornelas [33] also highlights some qualities that are important for entrepreneurs, such as ability to take risks, identification of opportunities, organization of resources, teamwork, confidence in decision making, leadership, dynamism, independence, optimism, intuition, search for wealth, ability to plan, creation of value for society, networking, and vision of the future.

Table 1. Different perspectives on the entrepreneur, based on [21]

Area	Who is the Entrepreneur
Economics	Innovative, promote economic development
Behavioral	Creative, persistent, leaders, tolerant to ambiguity
Engineering	Good distributors and resource coordinators
Finance	Able to calculate, measure, and price risks
Marketing	Identify opportunities, are differentiated, have a customer-oriented mentality
Management	Organized resourceful, visionary.

Spinelli [34] points out other entrepreneurs' characteristics like commitment and determination, leadership, constant search for opportunities, tolerance to risk, ambiguity, and uncertainty, creativity and adaptability, and motivation for excellence in operations and customer service.

Vale et al. [35] compile the view in which the entrepreneur can impersonate several roles such as a person who takes risks under conditions of uncertainty, as an innovator, as a provider of financial capital, as someone who makes decisions, as an industrial leader, as a manager or executive, as a business owner, as someone who starts a business, as a contractor, as a market and resource broker, as an individual who allocates resources among different alternatives, as an organizer and coordinator of productive assets.

According to these views the ideal definition of the entrepreneur would be much closer to the stereotype of a comic book superhero (therefore, perfect and endowed with unique characteristics that mortals do not possess) than to a real human being, effectively ambiguous in his goals and rationally limited and bounded [36]–[38].

The focus on a prescriptive model that aims to characterize the entrepreneur according to specific traits creates confusion and does not provide cues for further methodological improvements in research. Perhaps part of the lack of legitimacy of the field of entrepreneurship research lies precisely in the attempt to address ambiguous issues and definitions similarly to what other areas in social sciences such as organizational studies, sociology, and psychology have pursued equally without consensus for decades [17].

Since decades of research have provide little observable evidence, it seems to be more fruitful to avoid such divided and unclear discussions on who is the entrepreneur and who is not [2], [12], [17], [39]. Alternatively, the contribution of the entrepreneurship and new venture creation research lies probably in the intersection of multiple theories [2], [12], [32], [39], [40]

2.1.3. What does the entrepreneur do?

Typically, the discussion about how the entrepreneurial process gets started speculate about the impulse that moves an individual to build a new venture (e.g. a new business). Are new businesses started out of necessity? From the identification of an opportunity? By chance? Luck?

Thus, it is usually accepted to define opportunity-driven entrepreneurship and necessity-driven entrepreneurship [31] as mutually exclusive factors, in which the type of venture that aspires to profit from exploiting an opportunity is superior or more desirable than the one started out of necessity.

Some research seeks to understand which conditions allow for the emergence of new ventures (Table 2).

As discussed in previous sections, such definitions (albeit widely accepted and disseminated) lack empirical evidence, and typify the circumstances (i.e., to be encouraged or to be avoided) in the formation of the entrepreneur.

From this viewpoint, one can ask: To what extent do these concepts help explain the entrepreneurship phenomenon? What are the consequences? What are the possible generalizations? Is there a fundamental difference between opportunity-driven entrepreneurship and necessity-driven entrepreneurship? Do the chances of economic survival of a new venture differ for one type or the other? Do the individuals involved in the entrepreneurial process have distinct characteristics?

Table 2. Characteristics that favor the emergence of new businesses, based on [41]

Condition	Delimitation
Born entrepreneurship	Vocation developed because of family environment and authority, such as values, skills, and business acumen.
Heritage	Continuation of an enterprise received by inheritance. This circumstance can impact the termination of the entrepreneurial activity.
Limitations as an employee	The employee decides to start an entrepreneurial activity out of frustration regarding his personal fulfillment at some point in his career.
Technical education	Knowledge and know-how about a certain product or service. The knowledge holder chooses to start his own business.
Unemployment	A risky venture that can result in economic success/failure according to specific entrepreneur’s characteristics and ability to plan the new venture.
Retirement	New venture started out of necessity due to difficulties for re-insertion in the labor market

Some authors conceptualize what the entrepreneurial process would be (Table 3).

Despite its limitations, the focus on understanding the "how" rather than the "who" in the new venture creation phenomenon is a contribution toward building a distinct field of study of entrepreneurship [17].

However, as can be seen from these descriptions, the entrepreneurial process is usually designed as deliberate and essentially rational. There is an intentional search for opportunities, evaluation, measurement, and finally, the entrepreneur's action to create the company.

Table 3. Different views on the entrepreneurial process

Author	Process Steps/ Process Drivers
Stevenson et al. (1985)	1. Strategic orientation 2. Commitment to the opportunity 3. Commitment to resources 4. Resource Control 5. Management Structure
Timmons (1999)	1. Founder's characteristics 2. Opportunity characteristics 3. Gap Assessment 4. Resources needed
Bhidé (2000)	1. Initial business conditions 2. Nature of Business 3. Opportunistic Adaptation 4. Assurance of control over resources 5. Entrepreneur traits and skills
Hisrich & Peters (2002)	1. Identification and evaluation of opportunities 2. Business plan development 3. Determination of required resources 4. Company Management

Thus, one perceives a convergence in entrepreneurship research towards what have being specified as "Discovery Theory." [32] According to this theory, the idea of intentionality and action is usually described from the systematic elaboration of a business plan, acquisition of resources, and deliberate execution of the plan.

New theories, however, point to the idea of "creation"[32] in which cognitive processes and the notion of strategic emergence [42], [43] that best explain how entrepreneurs organize resources under uncertainty [23], delimit goals under ambiguity[44], [45], and finally act [46]. This is the essence of the notion of the entrepreneurial process proposed under the rubric of effectuation [6], [10], described in the next section and a core element of the discussion of entrepreneurship, innovation, and new venture creation in this thesis.

2.2. Effectuation

The discussion about corporate fads and isomorphic pressures on organizations is quite broad and influential in academia in an attempt to clarify how organizational forms change over time, what impact this has on the agents that execute them, and vice versa [47]–[50].

The institutionalization of some managerial practices, such as the need for strategic plans and the quantification of future scenarios, helps to understand some of the phenomena behind the classical view of causality and rational choice of agents, especially entrepreneurs [47].

The decoupling between organizational discourse and practice has, at least in part, roots in some concepts widely disseminated by business schools and consulting firms, in which decision making is analyzed as a rational process and is therefore logical and sequential [47].

However, most of these theories assume the existence of artifacts (e.g., industries, markets, firms), from which a rational agent will make a cause-effect analysis and scenario modeling to ultimately make a (calculated) decision from among the multiple existing options [6].

As described in section 2.1, this seems to be a major driver not only in many of the influential works in the field of strategy and entrepreneurship but also in business practice, where the logic of analysis [51] prevails over the logic of artifact creation [36].

Regardless of how prevalent these works are in this research area, how one explains much of the evidence regarding the limits of the rationality of individuals, and decision-makers [37], [38], [52] and, at the same time, provide answers to the following questions?

- How do we make the pricing decision when the firm does not yet exist (i.e., no revenue functions or cost functions are given) or, even more interesting, when the market for the product/service does not yet exist (i.e., there is no demand function)?

- How do we hire someone for an organization that does not yet exist? How do we even get able people to apply to a contingent organization - an organization whose existence is contingent upon acquiring employees (e.g., a knowledge-intensive firm, such as a software company)?

- How do we value firms in an industry that did not exist five years ago end is barely forming in the present (e.g., internet companies)? More interesting, how would we have valued them five years ago, when internet companies were barely emerging?

- At the macro level, how do we create a capitalist economy from a formerly communist one? Or, more interesting, what should a postcapitalist economy look like?

Each of these questions involves the problem of choosing certain effects that may or may not be the result of intentional goals, pre-established by the entrepreneur-agent [6]. Therefore, the classical idea of prediction and causality seems to lack the necessary foundation to understand the phenomenon of how new artifacts are created.

In general terms, one can say that effectuation is the inverse of causality [10]. In this sense, effectual rationality is not merely a deviation from classical causal rationality, but an alternative mode of rationality, based on a logic distinct from causal logic [10]. Therefore, it is important to critically evaluate the limits imposed by classical (rational-causal) logic.

Traditionally strategy and entrepreneurship research provide few clues to the resolution of questions, such as those exposed above, in which markets and firms cannot be merely pre-existing data, but rather, can be constantly destroyed and created[18] by an agent [36], [38], [46], [52] endowed with bounded rationality [36]–[38]and with ambiguous objectives [11].

In this sense, this section seeks to understand the entrepreneurship phenomenon through the effectual approach from its formative pillars up to its explanatory boundaries. The section is dived into four parts (i) the conceptual differences between causality and effectuation, (ii) the theoretical bases on which the effectual model was built, (iii) how the theoretical principles of the effectual process are operationalized and, finally, (iv) the limits of what is not effectuation, avoiding conflicts with other decision-making theories.

2.2.1. Causality vs. Effectuation

As previously explained, the idea of effectuation is opposed to the classical logic of causation. The following defines the main differences between both decision models, followed by examples and evidence to make this distinction clearer [6].

> *"Definition: Causation processes take a particular effect as given and focus on selecting between means to create that effect. Effectuation processes take a set of means as given and focus on selecting between possible effects that can be created with that set of means."*

According to the classical view, the market is a pre-established and knowable entity. Therefore, according to this approach, for a new business to become a reality, one must start by defining and segmenting target markets, followed by establishing marketing plans and positioning a set of products and services [53]. Traditionally known as the STP process (Segmentation-Targeting-Positioning), this top-down approach (Figure 1, top) has been the prevalent form of new business analysis, since the mid 1960s, and widely disseminated as a practice in organizations and one of the building blocks of theories and manuals that explain how new businesses come into being [33].

The effectual view, on the other hand, inverts the cause-and-effect relationship (Figure 1). As a bottom-up approach to building new markets, the entrepreneur starts by defining one of the many markets in which he could work, choosing to start the new venture with less information (aiming at predictability), but taking advantage of the contingencies and partnerships that he forges through experimentation in the effective sale of his products and services.

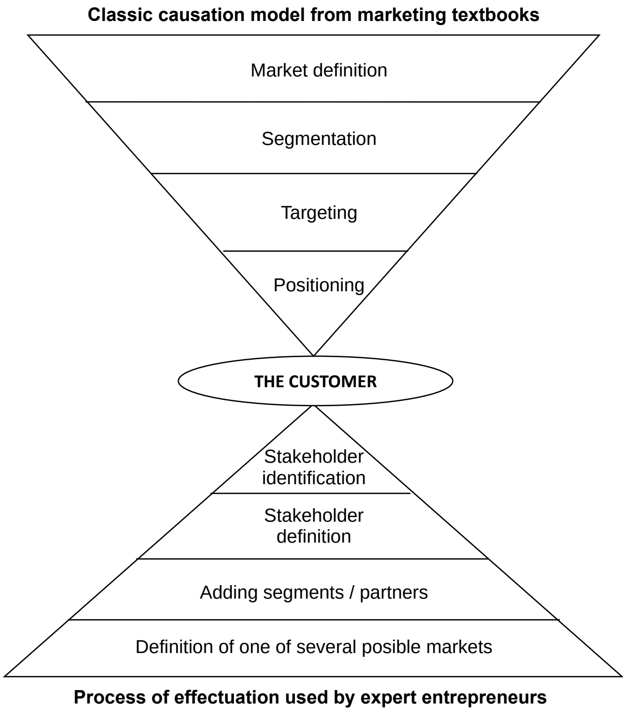


Figure 1. Contrasting the textbook (causal) model of marketing with effectuation (based on Figure 2.1, page 39, [54]).

Thus, the effectual entrepreneur does not stop trying to understand the needs of his customers, but, since he starts from the premise that the future is, by definition, uncertain [23], he prefers to build an environment and a set of relationships that will allow the desired future to be, in fact, much closer to the one originally envisioned.

The difference between the two decision models can be better understood by adapting a hypothetical example worked out by [6] and described below:

a) Causal Process

Assuming the creation of a new business, following the prescriptive process proposed by [53] using product segmentation and positioning in a given market, one can imagine the creation of a new restaurant, "Paella Express".

Paella Express is a restaurant bringing an innovation in the local gastronomic market, let's say a typical Spanish food (paellas) restaurant that only sells through delivery. According to the causal processes' paradigm, the entrepreneur should start with the universe of all potential customers of his/her new restaurant. Let's imagine that he wants to build a restaurant in the city of Madrid, which will therefore be the initial universe or "market" for Paella Express.

Starting from the premise that it is possible to know the percentage of people in Madrid that would be willing to become Paella Express customers, the entrepreneur can begin the STP process by defining his/her marketing strategies.

Many relevant segmentation variables could be used: demographics, residential areas, marital status, income level, average food delivery orders, for example. Based on this data the entrepreneur could send questionnaires to some selected neighborhoods and organize, for example, focus groups in two universities in Madrid. By analyzing the answers from the questionnaires and the focus groups he could arrive at the target segment - for example, upper-middle-class students that have the habit of ordering food at least twice a week. This would help him/her determine the menu, prices, packaging, opening hours, and other operational details. He could then design marketing and sales campaigns to induce his target segment to buy (trial) Madrid Express' dishes. He could also order food from his competitors and visit other restaurants to evaluate new products and new ways to research his/her market and then develop some plausible future scenarios for his/her new restaurant.

In any case, the process would involve spending of a great deal of time and analytical effort. It would also require resources (human and financial) to conduct the research and to implement the marketing strategies to test the initial hypotheses. Thus, according to this paradigm, the entrepreneur should proceed in a "top-down" fashion, starting from a broad vision (the universe, in this case, Madrid) to a specific one (say, exclusively serving upper middle-class neighborhoods, such as Salamanca), thus optimizing its choices and focusing on a pre-determined market with greater potential to generate results for the restaurant.

b) Effectual Process

Instead of starting from the process described above, one can imagine the entrepreneur starting his/her restaurant from an exactly opposite logic. Thus, instead of assuming the existence of a market and investing money and other resources to design the best possible delivery restaurant for a given market, he could start by examining the set of idiosyncratic means available to him/her at that moment.

Assuming the entrepreneur has extremely limited financial resources, he could think creatively about how to bring an idea to market with as few resources as possible. He could do this by convincing an established restaurant owner to become his/her strategic partner or by doing enough market research to convince an investor to finance the start-up of the restaurant. Another method of effectuation would be to convince a Spanish food restaurant or a delivery food chain to let him/her sell his/her “paellas” through their already established sales channels.

Alternatively, the new business could be started in many other ways. He could contact some friends or family who work in commercial areas of Madrid and send them some degustation dishes to try at lunch. If they like the food, they can start ordering delivery lunches. After some time, however, it could be difficult to develop a sufficient customer base to justify setting up a structure for Paella Express. The entrepreneur could then give up the food delivery business and could start writing a book, start teaching, and finally start a consulting business for new chefs!

Given exactly the same starting point - but with a different set of contingencies - the entrepreneur could build a business from among many possible ones. To evaluate some of the possibilities, one might consider the following: regardless of who first buys the imaginary Paella Express food becomes, by definition, its first target customer. By continuously listening to its customers and building a growing network of customers and partners, the entrepreneur can identify a segment in which he can work. Depending on what the first customer is willing to buy, the entrepreneur can begin to define his/her market. If the customer is really interested in food, the entrepreneur can start targeting, for example, healthcare workers in a certain region of Madrid or he could think about seat-in restaurants for this consumer profile - a "Paella Express for healthcare workers" franchise network?

But if the client is more interested in the cultural background of these typical dishes, their stories, and ways of preparation, maybe the way is to open a school with short courses about Spanish food - "The Spanish Food School"? Or even, the clients might be interested in going on a tour to taste the dishes locally, at the place of origin, making the case to create "Spain Gastronomic Tours & Travel”?

In summary, by using effectuation processes to start a new venture, the entrepreneur can build different types of ventures in completely different industries. This means that the original idea (or set of causes and means) does not imply a single strategic universe (or effect) upon which the firm can establish itself. Instead, the process of effectuation allows the entrepreneur to create one or more possible effects, despite having initially not very clear goals. The process not only allows the effective realization of several possible effects (even if only one or a few ideas are actually implemented), but also allows the entrepreneur to change his/her goals, adapting and even building on many of them over time, while taking advantage of the several contingencies that occur in his path. Many successful businesses and even large companies seem to have started similarly to the example described, without any predefined initial intention of its founders [6].

Schematically (Figure 2 and Figure 3), we can summarize the principles of effectual logic, where the focus lies on the control of a given set of means to envision new imagined ends.

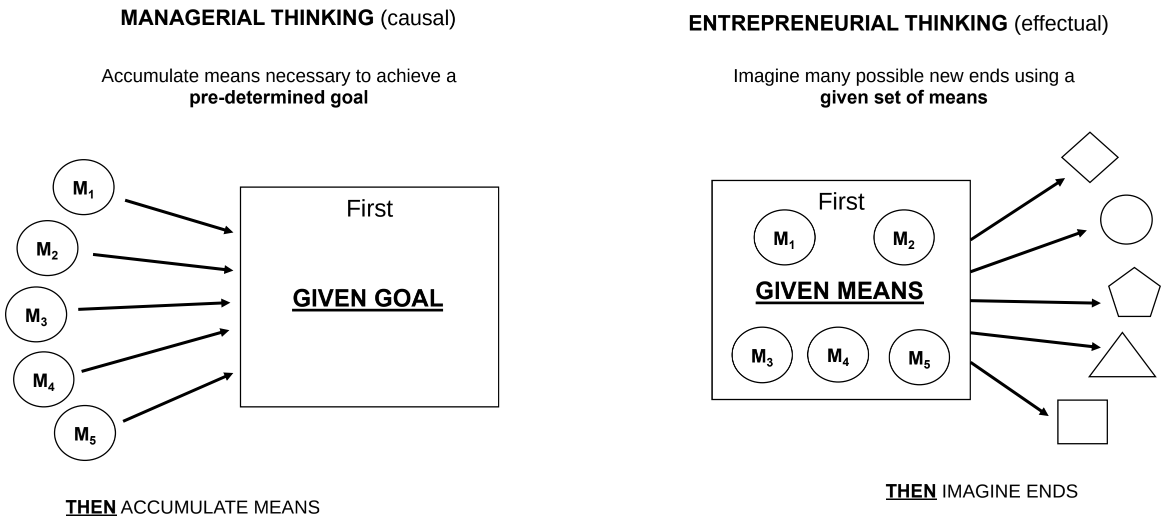


Figure 2. Causal versus effectual reasoning (page 111, [55]).

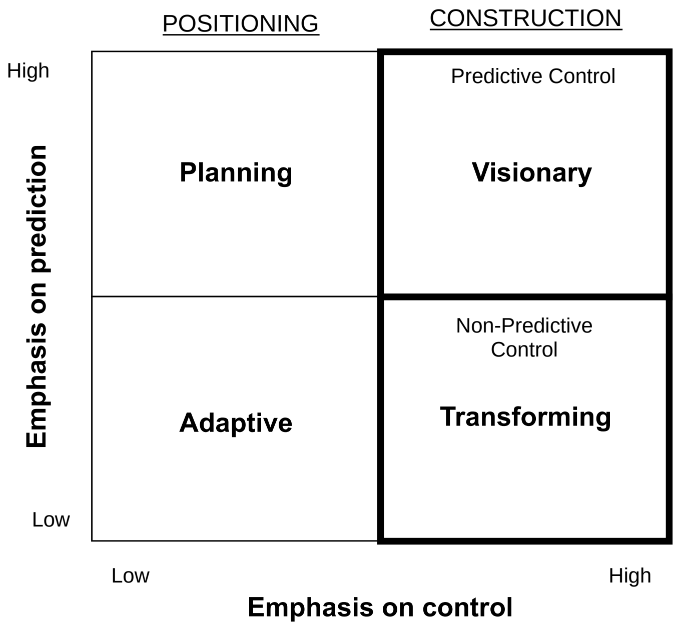


Figure 3. Predictive versus non-predictive strategies in the survey instrument (based on Figure 3.3, page 58, [54]).

In general, the idea of effectuation is very close to the discussion started a few decades before, in which organizations must seek a balance between the invention of new products and services (*exploration)* and the maximization of the use of products and services already offered (*exploitation*) [44]. A direct association of these concepts with the concept addressed in this thesis allows for the definition of the causal logic as "effect-dependent", in which the exploitation of previously acquired knowledge provides conditions for the emergence of a new business.

Alternatively, the effectual logic can be defined as "actor-dependent", in which it is from the exploitation of contingencies that the entrepreneur/innovator is able to create a promising environment for the emergence of new ventures. The main differences between the two logics can be summarized in Table 4.

In this way, it is possible to establish, in broad terms, some of the main contributions of the effectuation theory in entrepreneurship studies [6], [10], [56]:

- Uncertainty becomes a resource and a process (upon which decision making will happen), rather than a constant state of disadvantage.

- In the same way, the initial ambiguity of objectives is also a factor for creativity and generates opportunities to the extent the entrepreneur is more open to take advantage of the contingencies that come his way.

- The ability of the entrepreneur to act (enactment) on the environment and the structures around him eliminates one of the basic premises of the causal logic, the deterministic notion of markets and the entrepreneur's passivity before the environment and contingencies.

- Finally, and perhaps the greatest contribution of this approach, the notion of control over what can be done with currently available resources, rather than optimizing decisions about what one would expect to be done, given a set of predictions about the future.

Because of this set of characteristics and contributions it is relevant to understand why effectuation is based on the logic of control and how this logic is operationalized in entrepreneurial practice. These analyses are best described in subsections 2.2.2 and 2.2.3, respectively.

Table 4. Differences between causality and effectuation [57]

Differentiation Categories	**Causal Processes**	**Effectuation Processes**
Data	Effect is given	Only some means, resources and tools are given
Selection Criteria for Decision Making	Helps to choose between means to achieve the given effect effects that can be created with given means. Selection criterion based on expected returns. Effect-dependent: choice of means is driven by the characteristics of the effect the decision maker wants to create and his knowledge of possible means.	Helps to choose among possible effects that can be created with given means. Selection criteria based on tolerable loss or acceptable risk. Actor-dependent: given specific means, the choice of effect is directed by the actor's characteristics and his abilities to discover and use contingencies.
Skills Employed	Excellent at exploring knowledge	Excellent at exploiting contingencies
Context of relevance	More present in nature. Most useful in static, linear, and self-contained environments.	More present in human actions. Explicit assumption of dynamic, non-linear, ecological environments.
Nature of what cannot be known	Focus on the predictable aspects of an uncertain future.	Focus on the controllable aspects of a non-foreseeable future.
Core Logic	To the extent that we can predict the future, we can control it.	To the extent that we can control the future, we do not need to predict it.
Results	Market share in existing markets through competitive strategies.	New markets created through alliances and other cooperative strategies.

2.2.2. Why effectuation theory is focused on the logic of control: Theoretical foundations

As mentioned in previous sections, there is a consensus among business strategy theorists - in its initial stage as a research area, originating from economic traditions (microeconomics, in particular) - on the notion of the market as a given, pre-existing entity. However, alternatively logics have also emerged during that period as well [14]:

> *"Although predominant in the field of business strategy, the objectivist approach to social reality is not the only epistemological and methodological alternative possible in social sciences. Interpretive approaches applied to business strategy have been suggested by several authors since the 1960s and 1970s."*

The notion that there is an embedded relationship between the environment/social structure and the agents that make up this society is quite influential, and that, therefore, the idea of social construction of reality is plausible, as well as the idea that each individual is endowed with a capacity for agency, which allows and restricts the very possibility of change [58]–[60].

This explanation is of fundamental importance to accept the traditional definition of entrepreneur as one who acts in his environment, leverages himself from contingencies, and inevitably creates new ventures, enterprises, and markets [18], [54]. In short, under these conditions, one can accept the very notion of control over the future, a key concept in the effectuation theory.

In particular, we can analyze more clearly the influences of four authors (Knight, March, Weick and Mintzberg) in the construction of the effectuation theory and how these influences interrelate with the notions of entrepreneur-agent and socially constructed environments. In this way, the foundations of the effectuation theory and some of the justifications why this approach is oriented towards the logic of control rather than an objectivist prediction are presented.

2.2.2.1. Frank Knight's contributions: the future distributions of events cannot be predicted, nor modeled

Perhaps one of the most intriguing questions in entrepreneurship research is the one that seeks to understand how, in the absence of existing markets for future goods and services, such goods and services are created [2]. As previously stated, it is the destruction and creation of new markets that seems to be the essence of capitalism and, therefore, the "engine" of entrepreneurial activity and innovation in markets [18].

It is in the notion of uncertainty that resides the economic potential for exploitation arising from contingencies. Therefore, it is the central idea of information asymmetry arising from the uncertainty of individuals that makes the notion of profit *per se* viable.

And it is precisely by questioning the classical economic tradition that Frank H. Knight provides one of the first exploratory essays around the idea of uncertainty and profit. In his seminal work of 1921, Knight, less known in the tradition of entrepreneurship and innovation research, can be seen as an important role model in the formation of the thought of authors such as Schumpeter and other economists more linked to the idea of information economics (Hayek, Arrow, Akerlof, among others).

As Blaug [61] notes, "the beauty of Knight's argument was in showing that the presence of true 'uncertainty' about the future could allow entrepreneurs to achieve positive profits despite perfect competition, long-run equilibrium, and productive exhaustion”.

In Risk, Uncertainty and Profit [62], Knight identifies what would be the three existing types of uncertainty:

i. The first (also known as the notion of **risk**) consists of a future with a distribution that is known, predictable, and therefore quantifiable.

ii. The second (usually known by the term **uncertainty**) deals with a future whose distribution is unknown but can be estimated from the study of probabilistic events over time.

iii. The third, called by Knight 'true' uncertainty (also known as **Knightian uncertainty**) consists of a future whose distribution is not only unknown, but essentially cannot be known.

Table 5 summarizes and exemplifies each of the three types.

Following Knight's [62] explanation, the plausible way out to bypass the problem of "true" uncertainty seems to lie in effectual logic. As illustrated in the example of the urn (table 5), Sarasvathy [6], the process of effectuation seems to suggest the following conjecture about the decision maker logic:

> *“I don't care what the colors of the balls inside the urn are or their underlying distribution. If I'm playing a game where removing a red ball generates a win of $50, I will acquire red balls and put them in the urn. I will also seek out other people who have red balls and induce them to put their balls into the urn and play the game with my partners. As time goes on, there will be so many red balls in the distribution that almost any withdrawal will result in a red ball. Also, if neither I nor my partners have red balls but only green balls, we will put enough of these balls into the urn so that the original game becomes obsolete, and we create a new game where green balls win.”*

This conjecture forms the conceptual basis that enables the operationalization of the effectuation concept: (a) the idea of tolerable loss rather than expected returns, (b) strategic alliances and pre-agreed commitments rather than competitive analysis, and (c) exploitation of contingencies rather than pre-existing knowledge.

Thus, it can be stated that entrepreneurial action is only possible and occurs from the uncertainty inherent to the future results of any new venture, business or market.

However, the confusion between the terms risk and uncertainty (often defined as synonyms) is widespread in the literature [40], [64]. Therefore, it is important to differentiate the concepts of risk and uncertainty, given that it is only under the latter that the entrepreneurial decision becomes viable [65].

Table 5. Three Types of Uncertainty and How to Deal with Them. Based on [32], [63]

Type of Uncertainty	**Risk**	**Uncertainty**	**Knightian Uncertainty**
Distribution of the Future	The future has a known distribution	The future has an unknown distribution	The future has no distribution - it is not knowable
Type of probability	A priori	Statistics	Unclassifiable Instances
Example 1	Suppose a fair balanced die with six sides. Each side on this die is a possible outcome of a roll. Each outcome has a known probability (1/6) that is less than or equal to one and greater than zero, and the probability of any one of these outcomes occurring has sum equal to one	The number of sides of the die is known and equal to six, but it is not known whether the die is fair and balanced. The probability of an outcome occurring cannot be known.	The number of sides of the die is not known (it can be two, four, eight, or infinite), nor is it known whether the die is fair and balanced. Under these conditions, the die player may not know for sure whether he is actually playing dice or some other game.
Example 2	An urn contains 5 green balls and 5 red balls. Whoever draws a red ball receives $50.	An urn contains an unknown number of balls. Whoever draws a red ball receives $50.	The urn may or may not contain any ball - even the existence of the urn can be questioned.
Possible outcomes	Known or knowable	Known or knowable	Unknown
Likelihood of Results	Known or knowable	Unknown	Unknown
Method of Dealing with Uncertainty	Analysis	Estimation	Effectuation

The idea of uncertainty can be defined in the terms of Knight [62], as exposed above. The concept of risk, in turn, is seen in the tradition of classical finance theory, in which information asymmetries must be reduced or easily overcome so that capital markets can operate efficiently [66].

In this sense, evidence points to a clear differentiation between the concepts.

According to Tasic [67], capital markets - in particular, credit markets for micro and small companies - reach their equilibrium in an inefficient way. Such results both confirm the existence of information asymmetries in entrepreneurial activity and demonstrate that capital markets still do not know how to evaluate businesses and new ventures under conditions of uncertainty.

As Alvarez & Barney [40] point out, "under risk, banks and venture capital firms appear to be reasonable sources of capital. Under uncertainty, trusted relationships between parties for an exchange [...] appear to be a more important source of capital than banks and venture capital firms."

Problems in encouraging entrepreneurial initiative seem, in part, to stem from the difficulty or impossibility of pricing new ideas and evaluating new markets [67], making it paradoxically ineffective to maintain the use of predictive analysis techniques and business plans in entrepreneurial situations [40].

2.2.2.2. Contributions by James G. March: The existence of goal ambiguity

For decades, March's ideas have influenced an expressive body of theories and empirical evidence about how human beings behave, make decisions, and interact with each other and with the external environment in organizations [6].

Two of his ideas, however, are fundamental in the construction of a theory of effectuation:

i. The *tradeoff* between *exploration* and *exploitation* in organizational learning and the process of strategic choices [44].

ii. The questioning regarding the idea of pre-existing goals in decision making [11], [45], [68].

March [44] emphasizes that the idea of organizational learning essentially involves an allocation of scarce resources. However, since the nature of these resources is distinct, a distinction of allocation processes is also necessary. Thus, the author tests the *trade-off* between the allocation of organizational resources to activities aimed at exploring new possibilities and innovations (*exploration*) and activities aimed at improving existing processes (*exploitation*).

In this way, the author defines:

- *Exploration* activities such as: search, variation, risk-taking, experimentation, play, flexibility, discovery, innovation.

- *Exploitation* activities such as: improvement, choice, production, efficiency, selection, implementation, and execution.

From this definition of concepts, the author hypothesizes that companies that maintain an appropriate balance between *exploration* activities and *exploitation* activities tend to have greater chances of surviving and thriving. He uses an ecological (survival) argument to support this hypothesis.
From this point on, one of the main questions raised, therefore, becomes the decision for the type of investment: incremental improvements (in existing and dominated processes) or inventions of new opportunities? However, since this decision involves several levels of analysis (individual, organization, and social system), defining the proper balance between these activities becomes particularly complex.

Thus, taking an ecological view, the author argues that through processes of variation and selection, organizational practices end up reflecting, in the long run, the level of equilibrium that organizations find in this *trade-off*.

Due to the different nature in which both activities are based, *exploration* initiatives end up being neglected due to the uncertainty inherent in new discoveries and innovative processes. In turn, *exploitation* activities, or continuous improvements, accumulate higher levels of adoption, since their returns are easily measurable and relatively certain to be achieved (in contrast to those expected in innovative processes).

Next, the author appraises organizational learning processes to stimulate this balance, involving trade-offs between short and long term, between individual and collective knowledge.

In this sense, the first point evaluated is the speed of learning. Using a closed system model, the author assesses that a good mix between individuals with accelerated learning rates and reduced learning rates forms a favorable environment for the emergence of a balance between *exploration* and *exploitation* activities. This is because fast learning causes individuals to quickly learn corporate codes and practices, thus settling into a level of accommodation very early. Conversely, individuals who take time to incorporate these codes and standards represent "the new" in the organization and therefore, by questioning the *status quo,* create an environment for the emergence of innovations.

Similarly, the level of socialization of individuals implies in the creation of this environment, since less "socialized" individuals tend to continually represent the new, to the extent that they do not fully adhere to corporate codes. Thus, a certain level of organizational heterogeneity and diversity allows for an adequate mix between "old" knowledge and "new" knowledge, which is necessary to effect improvements in the codes.

Finally, the author states that it is through learning, analysis, imitation, regeneration, and technological change that an organization strengthens its competitive advantages. And each one of these components is acquired or developed in the adequate balance between the *exploration* and *exploitation* activities within the organization.

Thus, one can verify in March's argument the direct association between innovation and alternative decision models that are not based on causal analyses, aiming at the reduction of organizational risk. The organization limitation to face environments characterized by uncertainty (true, in Knightian terms) prevents the organization from innovating and launching new ventures [44].

This discussion is very close to that proposed by Christensen [69], [70], in which entrepreneurs face a "dilemma" insofar as, by listening to their current customers, they allocate a good part of their resources to develop better products, among those of their current product portfolio. However, the dilemma emerges when other companies (in principle, non-competitors) develop innovative products for markets that do not yet exist, but inevitably end up replacing old technologies and dooming to failure the companies that maintained the policy of allocating resources to opportunities whose risk could be calculated and returns predicted. Innovation history shows several, from the substitution of LPs by CDs (and now, by cloud streaming), to film cameras by digital cameras (an now, by smartphones), among others.

In another fundamental contribution to understand individuals' choice process, March [11] questions the possibility of goal clarity, pointing to the need for alternative decision models that incorporate present action in contrast to uncertain future outcomes:

> *"To say that we make decisions now in terms of goals that will only be knowable later makes no sense - insofar as we accept the basic reference framework of choice theory and its pre-existing goal assumptions [...] we should actually be able to develop better techniques. Whatever these techniques are, however, they will certainly weaken the superstructure of biases erected on purpose, consistency, and rationality. They will involve some form of thinking about action now as occurring in terms of a set of unknown future values."*

In line with this argument, Cohen et al. [68] propose what would be a *garbage can* model of decision making, suggesting that in organizations, problems and solutions arise, are stored and used conveniently.

Thus, one of the major characteristics of the *garbage can* process is the existence of a partial detachment between problems and choices. Although decision making is thought of as a problem-solving process, the evidence shows that this is not necessarily the case. In this sense, problems are worked out in the context of some choices, but choices are made only when the combinations among contingencies, solutions, and decision makers change in ways that allow action to happen [68].

This seems to be one of the main arguments in the defense of the operationalization of the *effectual* logic based on the capacity of entrepreneurs to leverage themselves over contingencies along the way [6], [45], [56]. Such argumentation, associated with the ideas of bounded rationality, directly opposes the assumptions of the planning and positioning schools, based on a deliberate process of strategic planning [57]. Thus, the bases are formed for an analysis of the strategy-making process and its implications, such as the emerging strategy (further detailed in following sections).

2.2.2.3. Contributions by Karl E. Weick: Enactment and the impossibility of detachment between decision maker and environment.

The idea that the decision maker (agent) plays a central role in the evolutionary process of organizations can be considered a main contribution to the construction of an effectuation theory [46], [71] . After all, it is from the *enactment of* the entrepreneur that generic aspirations begin to crystallize into new ventures in the future.

Under this assumption, the logic of control is largely based. It is the entrepreneurial action (*enactment*) that overcomes the existing uncertainties and creates the future, despite the environment and the structure of its surroundings. In the words of Weick [46]: "Decision makers in organizations intervene between the environment and its effects within the organization, which means that selection criteria become more decision maker-centric than environment-centric".

But, as Sarasvathy [6] points out, this intervention is not consistently planned or deterministically prescribed in the way that much research in entrepreneurship and strategy seems to emphasize. Rather, in this theory of *enactment*, Weick advocates the idea of a non-linear process, which is strongly guided by the assumptions of the effectuation model, in that the entrepreneur chooses to control some aspects of an unpredictable future, rather than trying to predict them.

The author establishes some of the assumptions used by the cognitive and learning schools in strategy in demonstrating that strategy formulation occurs both as a mental and a learning process. It is in this sense that Weick[71] presents a relation between *enactment* and the issue of the Construction of Meaning (*sensemaking*) within organizations and how this view influences a way of perceiving strategy within organizations. For the author, strategy would be "a stage for a retrospective construction of meaning within the organization" [71] where individuals could create a common interpretation of the environment they are in and of their actions in this environment.

From this perspective, strategy would not only be perceived after the actions, but would have the role of justifying them, without seeking a prescriptive definition or trying to recognize a pattern of action. Weick, however, points to the need of having a sense of direction, to think that one is going somewhere, even if one is not going in any direction. The preferred example used by Weick [71] to present this issue is the case of a Hungarian battalion who got lost on an excursion in the Alps, and who found their way back after finding a map that they believed to be of the Alps, but which was actually a map of the Pyrenees.

Thus, for Weick [71], the important thing is to have some kind of map, not because it shows the path, but because it makes the organization move forward. Such a vision helps in the construction of the effectuation theory, insofar as it relaxes the hypothesis of predetermined objectives and causal rationality in the effectuation of strategies. One perceives, therefore, an alignment with the ideas proposed by March [11] concerning the ambiguity of objectives.

In this sense, Gioia & Chittipeddi [72], argue that there are two steps in the process of organizational learning and cognition. In the first step, there are four stages that subdivide this process: (1) *Envisioning phase* (idea of a vision and the beginning of a social construction of the reality), (2) *Signaling phase (*sharing of the vision), (3) *Re-visioning phase* (redefinition of the vision from the feedback of subordinates), (4) *Energizing phase* (expansion of the vision's implementation). In the second step, the authors compressed each phase within the concept of *sensemaking / sensegiving*, providing a perspective about change as a constant and recursive negotiation between leaders and staff (Figure 4).

It is in this context that Weick proposes a theory, using an ecological argument, of *enactment,* selection and retention. According to this idea, the first step is to act (regardless of clear objectives), then, one should discover and select what works, thus promoting a *sensemaking* of the set of actions undertaken up to this point. Finally, the entrepreneur must retain and replicate the behaviors and decisions that suggest that they are desirable.

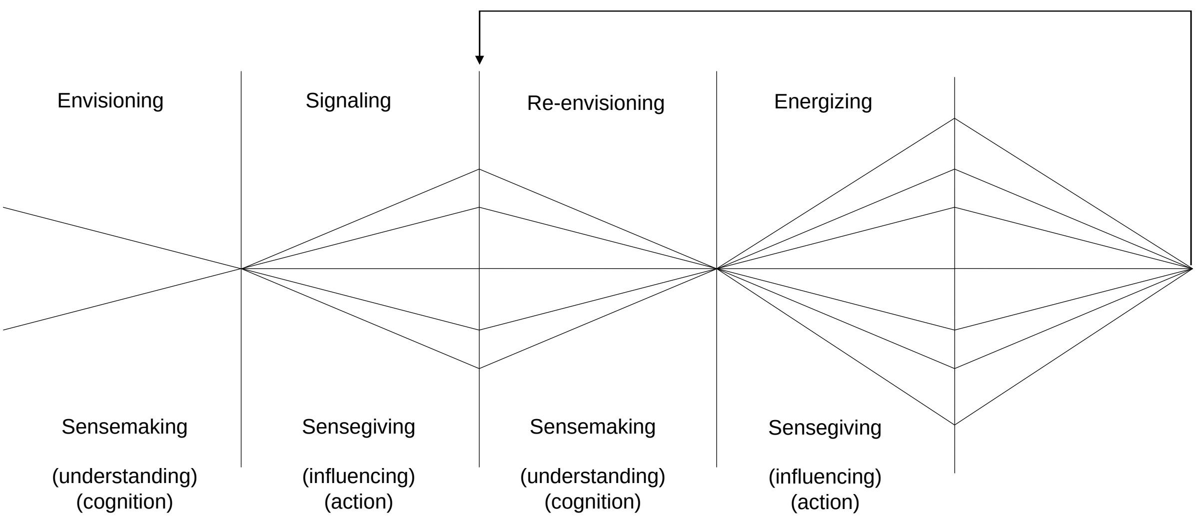


Figure 4. Process involved in the initiation of strategic change (Figure 3, page 444,[72]).

Once again, this idea resonates with the decision-making effectual model, since it assumes the idea of variation, given that the more actions the entrepreneur performs (*enactment), the* greater the range of available options on which he can reflect upon (*sensemaking*) and, therefore, the greater his chances of success and survival in an uncertain and unpredictable environment. Therefore, a continuous and pragmatic learning cycle is formed, making it essential to the effectual decision-making process, with a continuous negotiation with stakeholders, leading to a convergence of objectives and means/resources over time.

2.2.2.4. Henry Mintzberg's Contributions: Learning organizations and the notion of emergent strategies

Since the late 1970s, Henry Mintzberg has been a major critic of the traditional classical view of strategic planning and deterministic rationality in management. For him, it is necessary to understand that strategic planning is neither strategic thinking nor strategy formation. As a central factor in this conceptual confusion, Mintzberg argues that the most successful strategies are visions, not plans [73].

Mintzberg, as the most prolific author of what would come to be consolidated as the school of learning in strategy, recognizes the fundamental works of Lindblom [74], as a precursor of this school, and Quinn [75], as a precursor of the idea of incremental logic in strategy formation.

Lindblom [74] points out that the process of building public policy is not a "clean" process, clearly conceived, coordinated, planned, or decided by policy makers. Instead, the process could be compared to a person walking across a field full of mud while getting dirty, escaping from problems, but still making it across the field. This process, known as incrementalism and called by Lindblom as *muddling through,* is not the process of setting a goal and following a path, but rather a process of walking by adapting to the problems, obstacles, and opportunities along the way.

As Mintzberg et al. [13] point out, Quinn [75] starts from the point where Lindblom [42], [74] ends, in the sense of structuring a logic of incrementalism and placing the idea of conscious learning as a central discussion in strategy. Quinn [75] argues that since the notion of formal strategic planning does not seem to account for the effective implementation of strategies, decision makers should seek to create organizational awareness and commitment, incrementally, to allow strategies to emerge and effectively come to its execution.

According to this discussion around deliberate and emerging strategies, there are three ways to analyze strategies [42]:

1. Deliberate strategies: intended strategies that are realized.
2. Unrealized strategies: intended strategies that are not realized.
3. Emergent strategies: realized strategies that were not intentional or that arose from the non-implementation of another strategy.

Thus, the author points out that a classical definition of strategy, understood as an explicit plan, consciously developed, and intentionally created before the decisions to which it refers, is incomplete. He proposes expanding the concept to also consider strategy as a pattern, in a flow of decisions. This allows one to consider two sides of the strategy formation process, the idea of an intended strategy and an emergent strategy. Figure 5 schematizes these differences.

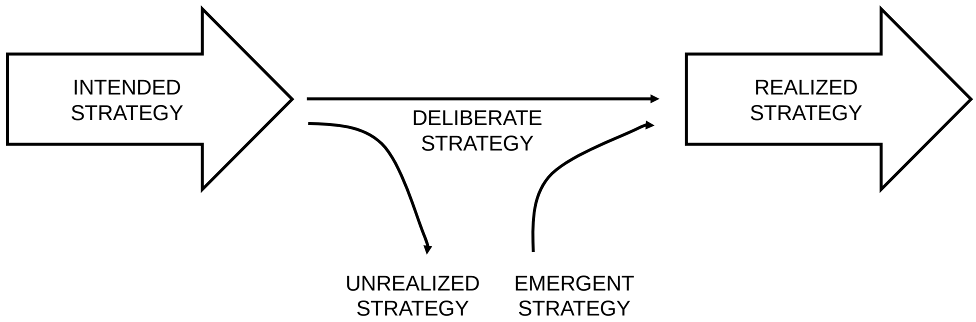


Figure 5. Types of Strategy (Figure 1, page 258,[42]).

It is precisely in criticizing the idea of intended strategy that Mintzberg's ideas become an important pillar in the construction of an effectuation theory.

Strategic programming (formal plans) may be useful to the entrepreneur in more stable environments or when more complex resource allocations, or in a ceremony are required [76]. While strategic formation in entrepreneurial firms occurs via a learning process, in which strategies emerge from a set of actions taken over time [42].

In summary, the contributions of this school of learning to the construction of an effectual process can be described as [13]:

1. *"The complex and unpredictable nature of the organization's environment, often associated with the diffusion of knowledge bases necessary for strategy, prevents deliberate control: strategy formation needs, above all, to take the form of a learning process over time, in which, at the limit, formulation and implementation become indistinguishable."*
2. *"Although the leader must also learn and can sometimes be the main learner, in general it is the collective system that learns. In most organizations there are many potential strategists."*
3. *"This learning proceeds emergently, through behavior that stimulates retrospective thinking so that action can be understood [...] This means that strategies can arise in all sorts of strange places and in unusual ways [...]"*
4. *"Thus, the role of leadership becomes not to preconceive deliberate strategies, but to manage the strategic learning process by which new strategies can emerge [...]"*
5. *"In this way, strategies appear first as patterns from the past; later, perhaps, as plans for the future and, finally, as perspectives to guide overall behavior."*

2.2.2.5. Other theoretical contributions underlying the idea of Effectuation: Social Networks and Agency

In addition to the theoretical bases on which Sarasvathy [6], [10] builds the idea of *effectuation*, it is important to highlight the influence of two other approaches on the formation of the entrepreneurial process: (a) the social network approach, in particular, the one proposed by Ronald Burt [77] and (b) the notion of agency, in particular, the one described by William Sewell [60].

Burt [77] highlights the fundamental role of entrepreneurs by connecting innovation and the networking phenomenon through bridges between social networks, triads, and the role of the tertius (broker) [78].

According to this vision, the entrepreneur is "a person who adds value by acting as a broker of connections among others", expanding the notion of innovation by including new elements such as [78]:

- Creativity and learning (What should be done?).

- Adaptive implementation (Who should be involved?).

- Results and rewards (What are the benefits?).

According to this view, the emergence of innovations stem from the brokerage between structural holes [77] and the creation of bridges between non-redundant groups, adding diversity of knowledge that allows for improved pattern recognition, problem-solving and decision making under uncertainty. Successful entrepreneurs, defined in this context as owners of businesses with sustained financial performance, who have social capital as their main resource create value from it through brokering between structural holes [79]:

> *“"Bridging" roles are based on recognizing assessment discrepancies, which requires an information advantage on both sides of the bridge. Because this requires a network of information, connectors will commit time, energy, travel, and sociability to develop their personal networks. For many entrepreneurs, their most significant resources are their branching personal networks.”*

The ability to interconnect with distinct and non-redundant groups allows entrepreneurs to group seemingly disconnected information in innovative ways. Under this rubric, innovation is not only about creativity (in this case, information pooling), but also the ability to allocate resources to new ventures (e.g., attracting investors for each endeavor) and obtain profits from it in an intertwined relationship with the entrepreneur’s network. This argument is directly aligned with the principles established by Sarasvathy [6], in which alliances and partnerships among stakeholders play a central role in the process of new ventures formation. In Burt's argument [78]:

> *"Social capital offers an advantage in knowing who to connect to for financial help, how to connect to them, and when [...] Networks rich in structural holes (a) provide a broad base of references for customers, suppliers, alliances, and employees for a project, (b) improve assessment about potential customers, suppliers, alliances, employees, financiers, and alternative organizational models, and (c) increase the likelihood of knowing which of the alternative paths to sell the project will be most attractive to specific customers, suppliers, or other sources of potential financial support. Therefore, individuals rich in social capital [...] are also more likely to launch projects that will gain advantages over opportunities. And (d) the projects they launch are more likely to become reality because entrepreneurs who structure networks are more likely to anticipate and adapt to problems that will inevitably arise. They are aware of problems beforehand, more flexible in reshaping a project to adapt to exogenous changes [...] and more able to control the interpretations others give to the project as they customize solutions for the specific individuals brought into the project."*

It seems, therefore, that the networking phenomenon explains, at least in part, the emergence of innovations, since entrepreneurs - who, by definition, innovate [18] – by using networks can i) refine the vision of what to create, ii) gather investors and other stakeholders for their venture, and iii) generate business results through the diffusion of their innovation.

In addition, the central idea of agency and structures complement the effectual processes. Agency and structure build on the idea of duality between rules and resources as structures are conceptualized. For, it is from the recursion between the agency capacity of individuals and the interpretative schemes of these individuals that structures are formed. These, therefore, do not assume a static character, but a "virtual" one, which endows them intrinsically with a dynamic bias that incorporates change and self-transformation as forming elements. Agency capacity, in turn, also ceases to be pre-determined by the structure on which the agent acts and assumes a dynamic role as it defines and is defined concomitantly by it [59], [60].

In this sense, this idea (i) recognizes the agency of social actors, (ii) builds the possibility of change within the concept of structure, and (iii) introduces the notion of intersubjectivity to explain the possibility of duality and dynamics within the concept of structure.

Finally, Sewell [60] examines the idea of agency - the ability to exercise some level of control over the social relations in which the actor is inserted, implying the actor's own ability to transform the social reality to some degree. Being an innate capacity of all individuals, the capacity for agency is developed and shaped differently according to the schemes and resources available to the agent, in the context in which he or she is inserted. Thus, the notion of agency implies the very existence of structures, from which actors learn and, over time, transform them, in a dual and constant way.

This view is aligned with that proposed by Berger & Luckmann [58] in the sense of analyzing the agents based on the premise that they are responsible, in part, for shaping the environments that surround them, thus constructing a social reality that, ultimately, also shapes their visions and strategies.

This discussion builds on the idea of understanding how beliefs, interpretative schemes, and the dynamics of organizational culture influence and interfere in the process of innovation and new venture creation [80]. Therefore, such an approach is adherent to that proposed by Sarasvathy [6], [10], insofar as the entrepreneur can control some aspects of the future and, therefore, can build an environment favorable to his aspirations.

2.2.3. How the effectuation theory operationalizes the logic of control

This section establishes the fundamental principles of the effectual approach that operationalize the logic of control [81]

- Tolerable loss, rather than expected returns.

- Strategic alliances and pre-agreed commitments, rather than competitor analysis.

- Exploration of contingencies, rather than pre-existing knowledge.

2.2.3.1. Tolerable loss, rather than expected returns

As discussed in previous sections, the logic that drives the causal models of decision making in entrepreneurship focuses on the maximization of potential returns of a decision made from the selection of optimal strategies [63]. In contrast, the idea of effectuation pre-determines the tolerable amount of loss and encourages experimentation with as many strategies as possible within the limits given by the means/resources the entrepreneur controls. In this model, options that create more options in the future are preferred over maximizing returns in the present, which indicates a clear preference for *exploration* over *exploitation* [44]. The extreme case of this hypothesis is the strategy of bringing an idea to market from zero resources [6].

The idea driving this principle is to make uncertainty irrelevant as the entrepreneur focuses on controlling some aspects of the worst-case scenarios, allowing returns to emerge as a residual of the *stakeholder* acquisition process [81] .

Therefore, each *stakeholder* engaged in this process will seek to invest only what he can tolerate losing, since it is not clear in the early stages of the effectual process what the "pie" will be, nor will it be possible to determine the actual value that each "piece" will have. Thus, *stakeholders* cannot effectively use the logic of expected returns as their immediate criterion for selecting the investment of resources. Instead, each must perform a personal analysis of their ability to live despite the (eventual) loss of what they are investing in the company. Such a premise relaxes the need to predict what returns will be observed. Thus, the calculation of this bearable loss depends exclusively on the entrepreneur's current situation, as well as on a subjective judgment about what he can tolerate under his control [82].

2.2.3.2. Strategic alliances and pre-agreed commitments, rather than competitor analyses

Through effectual logic, entrepreneurs emphasize the establishment of strategic partnerships and pre-agreed commitments with stakeholders as a way to reduce and/or eliminate uncertainty as well as to create barriers to entry [63]. The strategies are therefore cooperative rather than competitive.

In doing so, the entrepreneur seeks to reduce uncertainty through agreements that shape the future – a future that will come to resemble the contracts agreed upon over time. Through pre-established commitments, entrepreneurs focus on creating new markets according to the image established together with their partners, rather than trying to guess exogenous market structures through forecasts and competitive analysis. Therefore, control is directly related to choices made through a growing network of stakeholder relationships. And as this network develops, it creates the path on which the company's development trajectory and, in many cases, even the new market structure will depend [56].

Specifically, this idea of networks is close to the concept proposed by Burt [78] to define the entrepreneur by positioning him with a central role of a broker of information and contacts in networks. According to the author, it is through this brokerage between networks that the value of innovation emerges and creates the conditions for the future to develop in line with the aspirations of the network of stakeholders involved.

However, for this network to be established, each stakeholder must first consider who he is, what he knows, and who he knows. Thus, stakeholders, based on their means/resources, begin to imagine possible actions and engage with other stakeholders whose strategies are directed by other types of identity, knowledge, and networks.

Thus, when new and valuable combinations are established, stakeholders commit those means that will promote valuable contributions to the new world that is being created, consequently facilitating its creation. Therefore, initially, each *stakeholder* interaction has the potential to change the shape of the new market or artifact being created as they change the initial endowments of their means/resources [82].

2.2.3.3. Exploitation of contingencies, rather than pre-existing knowledge.

The idea of leverage over contingencies that arise throughout the entrepreneurial process is the logic that guides the effectual model, especially when it comes to radical innovations with multiple (e.g., new internet ventures) or even unknown potential markets. Contrary, therefore, to the causal logic, in which pre-existing knowledge of innovations for known markets (e.g., a cure for cancer) suggests the use of objectivist and predictive models, more aligned with the idea of sources of competitive advantages [63].

In this context, the decision maker leverages the uncertainty by treating the emergence of contingencies as opportunities and ends up exercising control over the emerging situation. Under the effectuation paradigm, therefore, the relationship between planning, contingencies, and uncertainty is radically altered vis-à-vis the classical causal conception. Since decisions made in this way usually begin with a vague notion of goals, decision makers can assemble a plan in an incremental way, using uncertainty and contingent information as resources for constructing their goals[74], rather than relying on predetermined goals as essential factors in choosing and acquiring resources. Decision makers, therefore, accumulate path dependencies and take advantage of them as they choose effects. Thus, uncertainty is taken as a resource and a process, rather than a continuous state of disadvantage [56].

Given that any environment and situation will always be shrouded in uncertainty [83], all predictive efforts that seek to avoid or protect against contingencies are futile. The effectual logic seeks, conversely, to capitalize on these events. In other words, surprises can provide unexpected opportunities and present unanticipated problems. The inherent idea is that contingencies do not reduce the ability of the means currently under control to achieve the goal and provide opportunities to create value from these means to achieve new goals. Therefore, stakeholders operating with effectual processes deliberately allow surprises to be incorporated into the innovation process [82].

2.2.3.4. Integrating the operational principles: the effectuation process

The dynamic and interactive effectuation model (Figure 6) outlines a specific process of how entrepreneurs can create and decide what to do next under uncertainty.

The effectual process starts from three basic categories of means under control of entrepreneur and stakeholders: (1) identity, (2) knowledge, and (3) social networks. Entrepreneurs start with (1) who they are, (2) what they know, and (3) who they know to imagine things they might come to realize. This reflects an emphasis on future events that they can control rather than predict [82].

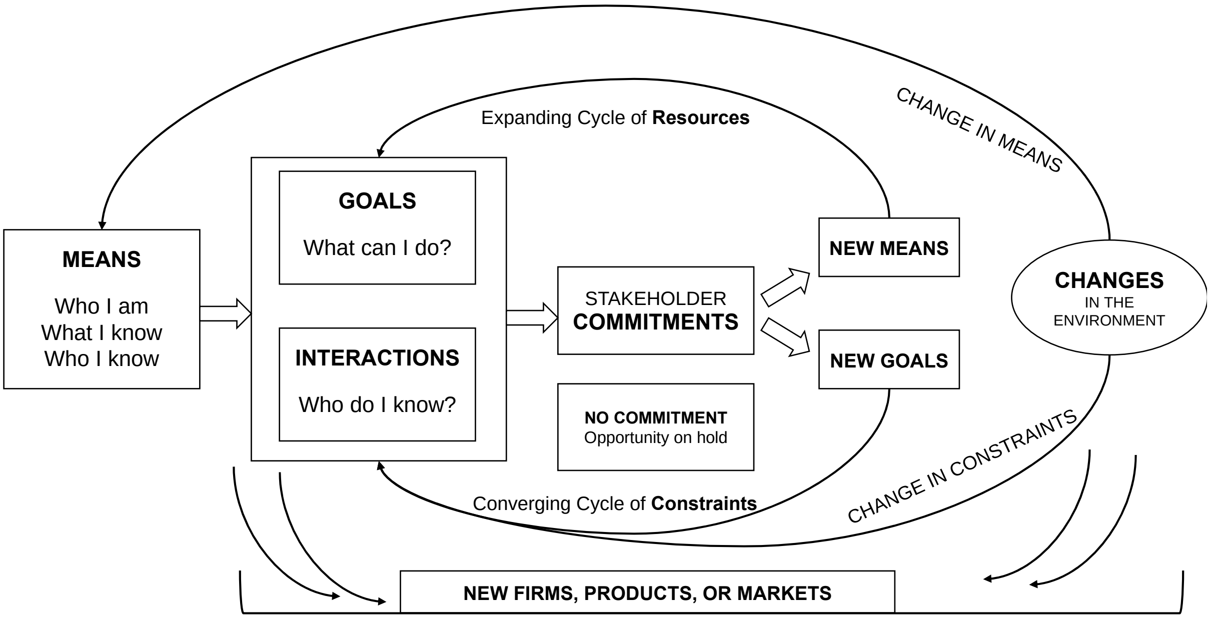


Figure 6. The effectuation process (Page 195, [55]).

Next, the entrepreneurs begin to advertise their project to other people to get input on how to proceed with some of the things they could (possibly) do. The people they talk to could be potential stakeholders, partners, friends and family, or random people they meet over time. As they find people who want to participate in efforts to build something (at this point, "something" can be vague or concrete but is always open to change), they get real commitments from these potential stakeholders. What counts is the willingness of the stakeholders to commit to the building process, not alignment with some preconceived vision or opportunity. Each person who commits something (anything) to join the endeavor contributes to refining the vision and opportunity while helping to enable and execute unique strategies to achieve them.

Any part of the stakeholder's commitment then becomes a "scrap" of an ever-larger "quilt," the pattern of which only makes sense through continual negotiation and re-negotiation of its proposal to get new stakeholders on board. In other words, stakeholders commit resources in exchange for an opportunity to reshape the project's goals, to influence what future will ultimately be created.

Finally, this process of negotiation and persuasion defines two cycles in the parallel formation of a new enterprise and a new market: (a) an expansive cycle that increases the means available and (b) a converging set of constraints on the goals of the growing network of stakeholders.

These constraints help solidify the structures of the new market in the same way that they clarify and re-order the preferences of the stakeholders in this market. However, at some point in the process, the convergent cycle terminates the stakeholder acquisition process. There is no more room for negotiation and re-adaptation of the shape of what will be created and path dependency ends. As market structures become visible, it may be essential to re-assess the balance between prediction and control as a strategic approach.

As a result of this process dynamic and ever-evolving process, five principles of effectuation emerge:

1) Bird-in-hand - starting with one's own means and resources

Starting with internally assessing who they are (characteristics, preferences, and skills), what they know (education, expertise, and background), and who they know (social networks), entrepreneurs can launch new ventures by considering a world in which the only scarce resource is their own mind space, and time.

2) Affordable loss - defining an acceptable downside

Humans face both loss aversion and myopic gain as consequences of the evolutionary biology of fear. Thus, entrepreneurs examine and commit to both what is affordable to lose and what is not at different moments and contexts. This principle combines with bird-in-hand to highlight that resources are scarce only if entrepreneurs ignore the fact that every resource they need is conceivable within the affordable loss level of someone else in the world. In this sense, both the problem of abundance and instruments to overcome loss aversion require an understanding of working with self-selected stakeholders.

3) Crazy Quilt - forming partnerships early on

Experienced entrepreneurs focus on building partnerships rather than competing. They start new ventures without assuming the pre-existence of a market for their idea; thus, they start engaging early on with potential partners, clients, and suppliers and getting pre-commitments from them. As some of them self-select in this partnership, the entrepreneur (and his partners) transform zero-sum competitions into structures with positive sums, even in the face of negative surprises and contingencies.

4) Lemonade - leveraging contingencies

"When life gives you lemons, make lemonade." Because expert entrepreneurs do not get started out a preconceived market for their ideas, anything and everything can potentially become a surprise that can lead to a valuable opportunity. In this way, they develop the ability to turn unexpected surprises into profitable resources for their new venture. They stimulate co-creative responses to negative contingencies.

5) Pilot-in-the-plane - controlling what is controllable

Entrepreneurs in many ways resemble plane pilots in the way that they are "pilots of their new ventures." In this way, as pilots do, they focus on controlling those aspects of the environment within their control. Then, concurrently forging their vision and values and engaging in a cycle of action, interaction, and reaction, they expand their ventures, not needing (or wanting) to expand the scope of control beyond the minimum required to perform.

2.2.4. What is not effectuation

To finish this theoretical explanation of the concept of effectuation and its epistemological bases, it seems beneficial to adopt a dialectical method, even if brief, to define in a mutually exclusive way what effectuation is. This section focuses on demonstrating what is not effectuation, using mainly the discussion proposed by Sarasvathy et al. [56]

To this end, Table 6 summarizes nine main concepts that differentiate the idea of effectuation from other theories to avoid theoretical overlaps (and, therefore, confusion) and, thus, highlight the unique position of academic integration that the model proposes [6], [56].

The implications generated from this dialectical definition of effectuation are [56]:

- Helps position entrepreneurship knowledge as a valid and rich research field.
- Eliminates the importance of luck and intuition from explanations of the entrepreneurship phenomenon.
- Places the notion of entrepreneurship under perspective in creating routines and new social patterns, in line with the idea of creating new institutions, among which capitalism stands out.

This understanding positions the central idea that effectuation is not another form of rational choice but rather a distinct alternative to it, thus creating a significant challenge in the sense of advocating a new paradigm [56]:

Paradigm shifts are grounded not so much in the invention/discovery of new knowledge as in new ways of looking at things we already think we know. This is the essence of human cognition, to absorb new information into familiar and well-understood patterns [...] we have tried to demonstrate why effectuation is not another form of rational choice, but a distinct and irreconcilable alternative to it.

Table 6. What is not effectuation vs. what is effectuation [56]

Effectuation is not...	**Effectuation is...**
1. A set of heuristic deviations from the idea of rational choices	It is an alternative paradigm that does not override the idea of rational choices
2. A generic replacement for the idea of predictive rationality	It exists in parallel to the idea of predictive rationality
3. Irrational or non-rational	Helps, in conjunction with other notions, to pluralize the notion of rationality, not deny it
4. A random process	Is systematic and developed, with eminently assimilable and teachable principles, as well as practical prescriptions of its own
5. A theory in which "anything goes	It is a theory of constrained creativity
6. A resource-based view of individual decision making	It does not assume the pre-existence of valuable resources but rather questions what makes things valuable and how one can acquire them and/or create value in resources
7. Only for small, medium-sized companies or start-ups	It can be applied to both large companies and economies in general
8. Restricted to the realm of entrepreneurship	Like the philosophy of rational choice, it can unify all the sciences of human action
9. An independent theory	Integrates and builds on the work of several well-established theories in the field of economics and management

2.3. Brief discussion

Vasconcelos & Ramirez [84] propose the example of building two structures from LEGO-type blocks, to explain the strategic decision-making process under complexity. In this sense, they propose (i) building the tallest tower, with a given set of blocks and (ii) building the best toy for children with the same given set of blocks.

If in the first case, the construction of a taller tower would only involve the application of a specific algorithm that delimits the possibilities of construction from a set of blocks, in the second, the challenge is completely different. As the authors state, this task begins by questioning the very construct "toy", going through the definition of what is "good". In short, the solution lies in overcoming contradictory and incomplete information [84]:

> *"It is not a matter, in other words, of finding the best algorithm and optimizing resources. Rather, it is a matter of communication, interpretation of desires, clarification of intentions, and building on ambiguity. In this case, priorities among ends are neither well defined nor given a priori. Solutions to such problems are invented rather than discovered because they are not logical consequences of the problem. They are created in the interaction between the problem and the actors working on it, often changing the meaning of the terms used to describe it."*

This discussion raises the relevant questions about research in entrepreneurship and, therefore, about the decision-making process that entrepreneurs carry out to transform ideas into real artifacts (e.g., products and companies). This is because there is always ambiguity and uncertainty [83], which leads entrepreneurs to constantly face high complications and high complexity and, therefore, surprises ("*I don't know that I don't* know") [84].

In this sense, theories of entrepreneurial action are no exception to the generalizations made about the assumptions of teleological theories of human action (i.e., assumptions about the nature of human goals, the nature of individuals, and the nature of the decision context in which individuals act). Thus, teleological theories of entrepreneurial action must make assumptions about the nature of entrepreneurial opportunities, the nature of entrepreneurs as individuals, the nature of decision-making contexts upon which entrepreneurs operate [32].

Based on these assumptions that Alvarez and Barney [32] compare what they call two major branches in entrepreneurship research: (i) the "Discovery" theory and (ii) the "Creation" theory, along the lines of what has been raised by Shane and Venkataraman [64].

2.3.1. Discovery Theory vs. Creation Theory

Almost all prevalent economic theories of entrepreneurship are theories of the firm Sarasvathy [57]. As seen in previous sections, these theories either attempt to explain the entrepreneurship phenomena as the existence and survival of firms or as firm performance. Such explanations usually rely on market forces, industry dynamics, or population ecology. Even theories based on the psychology of the entrepreneur attempt to relate entrepreneur variables (e.g., attributes, behavior, cognition, etc.) to the existence, survival, and performance of firms rather than focusing on the realizations of individual aspirations or entrepreneurs' goal performance. This is the essence of the Discovery Theory.

On the other hand, there are at least three good reasons to study entrepreneurship through approaches that go beyond the theory of the firm: "[...] because theories of the firm (a) tend not to distinguish between the firm and the entrepreneur, (b) tend to assume homogeneity of goals for the entrepreneur; and (c) tend to rely on assumptions of opportunism at both the individual and firm levels of analysis [57].

Thus, "a constructivist approach, recognizing the human character of social action and its particularity of being guided by values, can effectively contribute effectively to a relevant theory of strategy, which at the same time feeds the practice and learn lessons from it [32], [85]. This is one of the greatest contributions that the effectuation theory brings to the field of entrepreneurship, promoting a direct link between this discipline of knowledge and the new theoretical currents in the field of business strategy. This characterizes the Theory of Creation.

In summary, the premises that define both theories are described in Table 7.

In this sense, some differences can be observed in the view of the entrepreneurship phenomenon from these two perspectives (Table 8).

The discovery theory has been dominant in entrepreneurship research and amongst practitioners. However, since the dot-com crisis in 2001 and the financial crisis of 2008, new "agile" approaches that embrace most of the principles of the creation theory have dominated both academia and the business world. One of such approaches, the "startup acceleration phenomenon," is further analyzed in the following section.

Table 7. Key Assumptions of Discovery and Creation Theories [32]

Assumptions	**Discovery Theory**	**Creation Theory**
Nature of the opportunities	Objective, it exists independently of individuals	It emerges as a function of the process of seeking economic wealth
Nature of Entrepreneurs	Entrepreneurs are different from non-entrepreneurs. Among the critical differences is the "state of alertness"	Entrepreneurs can be the same or different from non-entrepreneurs. Any difference reflects the effect of the search, not the cause of the search
Nature of the decision-making process	Risky	Ambiguous or uncertain

Table 8. The Entrepreneurship Phenomenon: Discovery vs. Creation [32]

Phenomenon	Discovery Theory	Creation Theory
Decision Making Process	Entrepreneurs collect information about opportunities from focus groups, government reports, etc. They use this information to calculate the present value of the opportunities to be exploited. Cognitive bias and iterative learning play a limited role.	Entrepreneurs use their biases and heuristics and/or iterative learning to make decisions about which opportunities to pursue. Focus groups, reports, and present value tools can be used to evaluate a specific opportunity but cannot be used to describe the complete search process.
Business Plan	Assumptions about the nature of opportunities can be modified, but rarely abandoned. Several significant changes in the business plan suggest weak planning skills (e.g., inability to collect and analyze available data).	Assumptions regarding the nature of the business can be dropped several times. Several significant changes in the business plan suggest good planning skills (e.g., flexibility, ability to learn, creativity).
Funding	External sources of capital including banks and venture capital firms are preferred. External sources of capital invest in opportunities they can understand.	Self-financing or financing from people close to the business is preferred. These sources of capital invest in the entrepreneurs they trust

2.4. Startup Accelerators

As discussed in the previous section, the creation of new ventures is an uncertain endeavor in which entrepreneurs pursue the construction of new artifacts by addressing information asymmetries in markets that, often, must be built [6], [18], [83], [86]. This effort typically leads to liabilities of newness that must be overcome by aspiring entrepreneurs wanting to create enduring organizations [8].

To support entrepreneurs in this challenge, incubation programs traditionally have been created, providing entrepreneurs with several resources that aim to increase the odds of a startup survival while de-risking the entrepreneurial venture [87], [88].

In the last decades, a number of factors have incentivized the growth in entrepreneurial activity and influenced the context in which support programs operate: the “dot-com” bubble burst in 2000, the financial crisis in 2008, associated with the decrease of operating costs to start a company (in particular, internet-related ones), the rise of widespread internet usage (e.g., cloud computing, social media), a generational change whose life values differ from previous generations (e.g., the digital nomads' movement) and the shift of seed and early-stage investment from venture capitalists towards angel investors. The convergence of these factors, associated with effective non-predictive logic when starting new ventures (effectuation), has allowed entrepreneurs to reduce cost and time-to-market significantly. As a result, professionals increasingly understand entrepreneurship as a career path, leading to an exponential increase in new companies and projects being launched, even in midst of a pandemic [89].

Such context created the basis for a new type of startup incubation program: the seed or innovation accelerators [7], [9], [90]–[92].

2.4.1. Introduction to acceleration programs

Accelerators are business entities that make seed-stage investments in promising companies in exchange for equity as part of a fixed-term, cohort-based program, including mentorship and educational components, that culminates in a public pitch event or demo day [7], [91].

The first accelerator (Y Combinator) was created in Boston and Silicon Valley in 2005 by Paul Graham, a former entrepreneur who transformed into an angel investor. With a similar profile, the second accelerator (Tech Stars) was founded in 2007 in Boulder by Brad Feld and David Cohen to promote local development in their region while supporting startups in a more active ("hands-on") manner. These two accelerators quickly became benchmarks to be followed, inspiring hundreds of similar programs worldwide [93].

Some of the results demonstrate the evolution of the accelerator model:

Y Combinator [94]:

- Companies funded: 3,000
- Total valuation of all companies supported: USD 600 billion
- Total funding raised by companies supported: Over USD 40 billion
- Number of companies supported worth more than USD 1 billion: 25
- Number of companies supported worth more than USD 100 million: 110

Tech Stars [95]:

- Graduate companies: 2,958
- Total funding: USD 21.3 billion
- Average first funding raised post-program graduation: USD 1 million
- All-time graduate market capitalization: USD 71 billion

The acceleration model expands the means/resources of entrepreneurs in its earliest stages - from the idea to a minimum viable product. It accelerates the effectual process in many ways, allowing entrepreneurs to experiment with it early on and learn while advancing their entrepreneurship careers.

Accelerators activates the effectual process through tools and prescriptions to systematically reduce financial and time investments in the new venture creation process. Accelerators extensively promote the use of "agile" methods (e.g., customer development model, design sprints, rapid innovation cycle, etc.) to build prototypes and early versions of products and services while discovering the initial customers and partners. Additionally, it reduces the risk for investors across all startup growth phases by validating the venture idea and clarifying what resources will be required [96]. Examples of such tools are seen on Figure 7, Figure 8, and Figure 9.

In many ways, the accelerator operationalizes the five principles of the effectual logic for the entrepreneur and the stakeholders involved in the new venture creation process:

- Bird-in-hand (means)
- Affordable loss (risk)
- Lemonade (contingencies)
- Crazy quilt (partnerships)
- Pilot-in-the-plane (control)

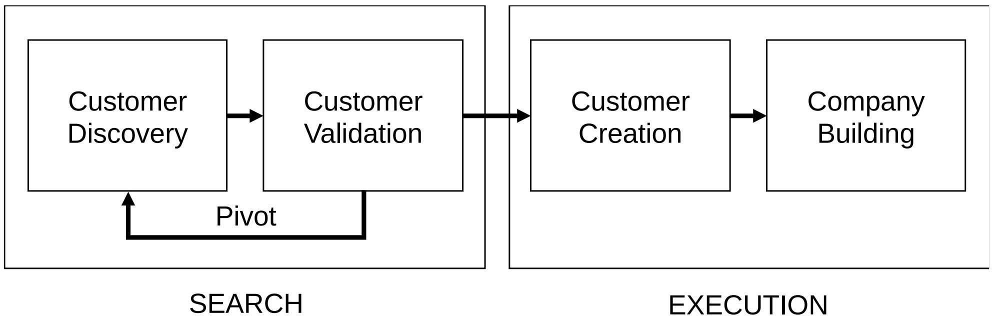


Figure 7. Customer Development Process [97].

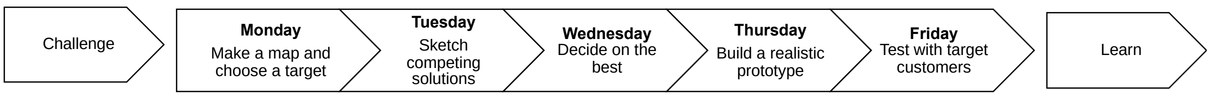


Figure 8. Design sprint [98].

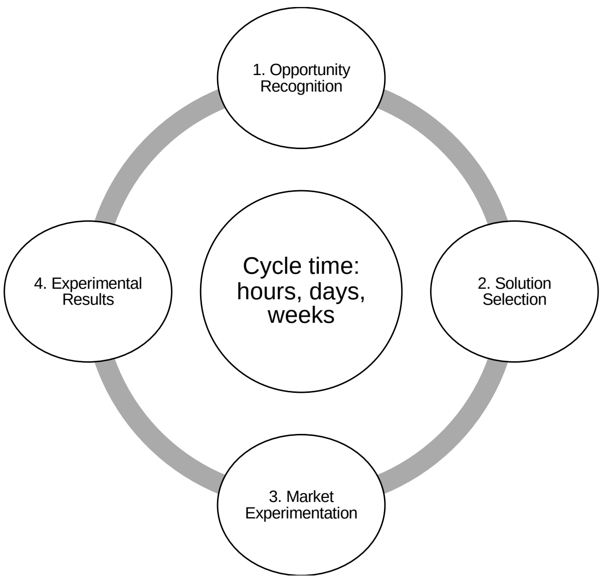


Figure 9. Rapid Innovation Cycle (Figure 3, page 2, [99]).

Despite the lack of consensus regarding its positive and negative effects, the effectiveness of the startup accelerator relies on the acceleration of learning for nascent entrepreneurs [100], [101]. Exposing entrepreneurs to a wide range of methods and stakeholders that can contribute to the new venture allows the most inexperienced entrepreneur to "taste" what it takes to launch a new product or service. It materializes heuristics and a non-predictive logic, allowing entrepreneurs to learn how to effectuate.

An example is Y Combinator's Startup School; whose stated goal is to allow entrepreneurs to "Learn how to start a company, with help from the world's top startup accelerator" [102] By programming a curriculum that leverages online (e.g., Online talks by Y Combinator partners) and in-person resources (e.g., meetups with Y Combinator alumni in 50 cities worldwide), it delivers the basic know-how inexperienced entrepreneurs should learn to start the effectual journey.

Another example is the EU-XCEL accelerator, a hybrid in-person and virtual acceleration program co-developed by six multidisciplinary, multinational partners with positive results [101]. The program accelerated novice entrepreneurs with a curriculum and mentorship divided into two blocks across 12 weeks (Figure 10 and Figure 11, Table 10):

- Block 1 (training week) when entrepreneurs meet up to learn essential tools and create teams that will launch new products and services

- Block 2 (virtual incubation) is when the teams will apply most of the tools learned and engage with mentors and stakeholders to test the idea and develop a new venture.

The wide range of learnings the entrepreneurs that participated in the EU-XCEL program acquired validate the effectiveness of such a heuristic approach.

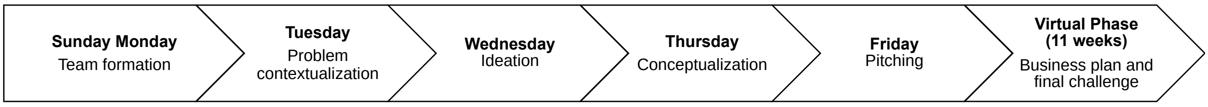


Figure 10. Organization of EU-XCeL: training week and virtual phase (Figure 1, page 1582, [101]).

Figure 11. EU-XCEL. Examples of final challenge agenda and program participants during week 1.

Entrepreneurs learned critical elements of the effectual principles in an accelerated format, from working with an international entrepreneurial team to learning how to identify and validate a business idea [101].

The novelty and impact of such programs in entrepreneurial ecosystems have led not only to an increase in the total amount of early-stage investments, particularly in the US and Europe, but also to an increase in interest by policymakers to promote regional development through new venture creation [90]. The following sections aim to understand this phenomenon through existing typologies that define acceleration programs, explain how it works, then offer a comprehensive review of the current research.

2.4.2. Definition: what is a startup accelerator

In the aftermath of the “dot-com” bubble, a new way to stimulate and invest in new entrepreneurial ventures emerged: the seed or innovation accelerator [9], [91], [103]. Paul Graham and his partners, former internet entrepreneurs (pre-dot-com bubble burst), founded Y Combinator in 2005 in Boston and Silicon Valley, recognized as the first accelerator [9]. This movement was quickly expanded to other regions in the US, being the second most prominent accelerator (Techstars) founded in 2007 by David Cohen and Brad Feld, former internet entrepreneurs.

In the following years, accelerators and programs alike aggressively expanded worldwide, reaching over 2.000 programs, spanning six continents [7], [103].

The novelty of such a phenomenon in the entrepreneurial ecosystem has brought significant challenges for entrepreneurship researchers, being the most critical, the lack of data and empirical research, and the absence of consensus around a proper definition or taxonomy [91], [104]. Nevertheless, some authors agree on a generic definition that characterizes such accelerators [9], [90]:

- An application process that is open (to all, "in principle") yet highly competitive
- Provision of pre-seed investment (typically £10 thousand – 50 thousand), usually in exchange for equity (typically 5-10 percent)
- Focus on small teams, not individual founders
- Time-limited support (typically 3 to 6 months) comprising programmed events and intensive mentoring
- Startups are supported in cohort batches or "classes" rather than individually
- The program finishes with periodic graduation (demo day/investor day).

Table 9. EU-XCEL Program: milestones and activities for the virtual incubation phase (Table 1, page 1583, [101])

Virtual pase stage	Outcome	Support activities
Week 2	Problem validation	1. Desk research findings 2. Stakeholder research 3. Reference site development 4. Technical feasibility analysis 5. Customer analysis
Week 4	Business model refinement	1. Value proposition 2. Market sizing 3. Market segmentation 4. Competitor analysis 5. SWOT analysis 6. Stakeholder map 7. Technical feasibility analysis
Week 6	Initial proof of concept	1. Key research findings 2. Reference site feedback 3. Idea validation
Week 8	Idea elaboration	1. Detailed business model 2. Strategic positioning 3. Detailed segment analysis 4. Draft business plan 5. Technical demonstration
Week 10	Advanced proof of concept	1. Marketing strategy 2. Financial plans 3. Go-to-market strategy 4. Technical demo findings
Week 12	Implementation roadmap	1. Available technical demo or accessible platform 2. Website landing page and social media presence 3. Business plan document

As pointed out by Dempwolf et al [91], some of the most recognized sources of information on accelerators (such as Seed-DB) advocate and apply most of these criteria for compiling key performance metrics in its database.

Attempts to provide a more succinct and operational definition were given by Cohen [105] and Cohen and Hochberg [7]:

> *"A fixed-term, cohort-based program, including mentorship and educational components that culminates in a public pitch event or demo day."*

In addition to this definition, Dempwolf et al. [91] stress the differentiator aspect that accelerators are private, for-profit organizations with a transparent business model:

> *"Innovation accelerators are business entities that make seed-stage investments in promising companies in exchange for equity as part of a fixed-term, cohort-based program, including mentorship and educational components, that culminates in a public pitch event or demo day."*

Finally, although Dee et al. [104] concurs with such definitions, they advocate for a broader working typology that positions accelerators among other startup support programs in terms of their business model (seek financial returns based on startup growth and exit) and stage at which founders are accepted to the program (startup or early-stage).

There is still no consensus on a more formal operating definition due to the variety of forms accelerators can take – from government-sponsored entities focused on regional development to private for-profit organizations [100]. In this thesis it was assumed the typologies provided so far that highlights the private/for-profit component [91].

Incubators, in contrast, are usually associated with a business model more alike to a tenant/service provider relationship with startups. They are typically (i) nonprofit organizations, frequently associated with universities, (ii) provide office space at reasonable rates for the startups they support, (iii) target local startups, and (iv) do not invest in the startups [91]. A summary of these critical differences with the acceleration model is presented in Figure 12.

Another emerging perspective on differentiating such programs is provided by Dee et al. [104], categorizing it according to the business model used (growth-driven, fee-driven, or independent) and the stage in the entrepreneurial journey at which it best supports entrepreneurs. A summary of this typology is presented in Figure 13.

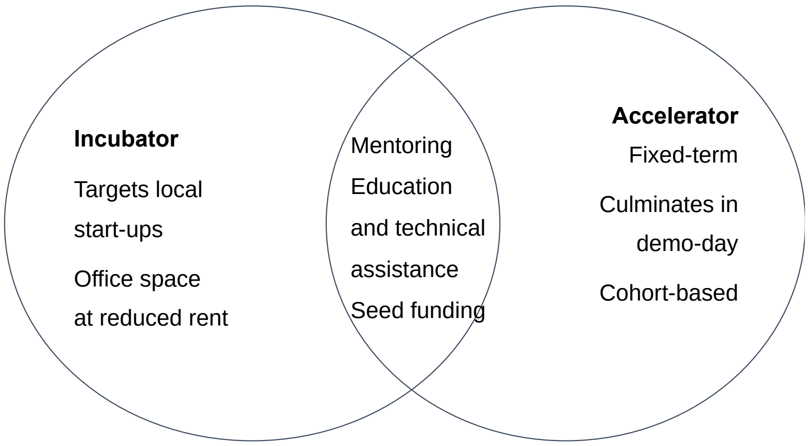


Figure 12. Venn diagram of incubator and accelerator characteristics (Figure 1, page 14, [91]).

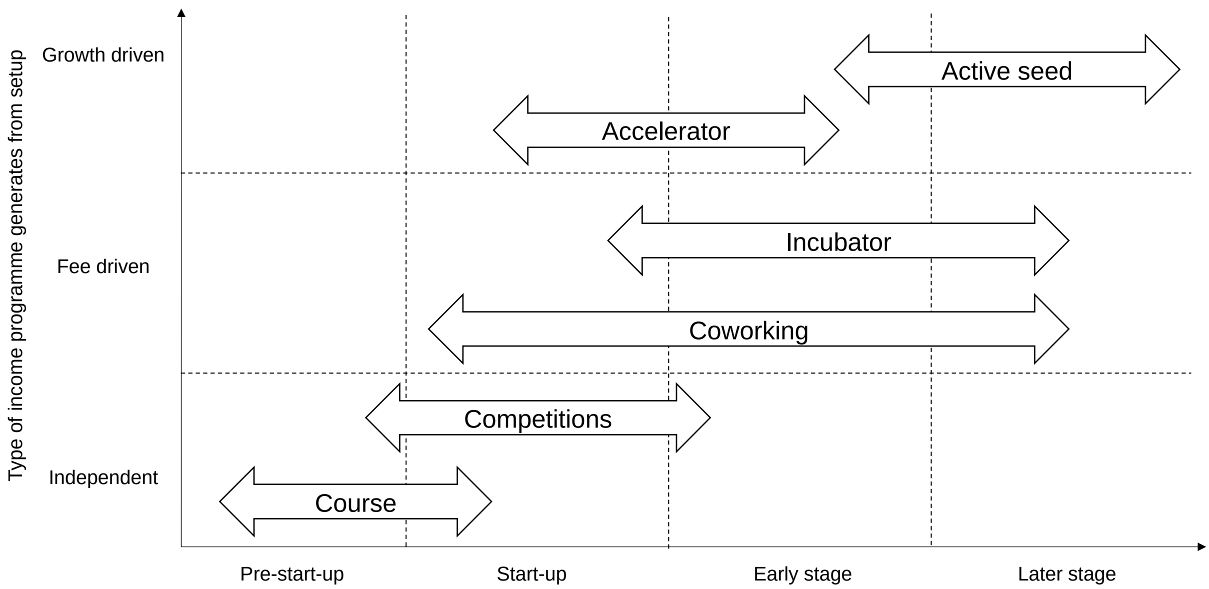


Figure 13. Typology of startup programs (Figure 11, page 22, [104]).

2.4.3. How accelerators work

As a starting point, most acceleration programs are highly competitive, and to guarantee a minimum quality level of the startup batches accepted; it is typical to emulate the application process usually found in graduate courses (e.g., MBA programs). Figure 14 summarizes the main steps of a typical acceleration cycle (from founders' awareness to startup “graduation).

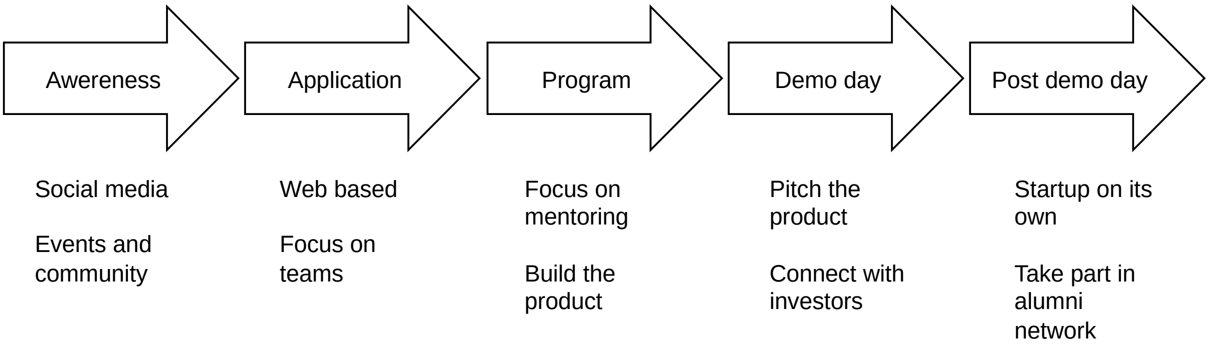


Figure 14. The accelerator cycle (Figure 8, page 51, [106]).

Whereas accelerator programs vary significantly in scope and depth worldwide, five essential components can be highlighted [90]: (1) strategic focus, (2) program package, (3) funding, (4) selection process, and (5) alumni services. Table 10 summarizes this operating model.

Table 10. The accelerator model (page 10, [90])

1. Strategic focus	**2. Program package**	**3. Funding**	**4. Selection process**	**5. Alumni service**
• Key objectives • Sector focus (diversified vs specialization) • Geographic focus (local vs global)	• Standardized Curriculum • Mentoring Package	• Funding of the accelerator • Funding of startups	• Screening criteria • Selection processes	• Alumni interaction

1. Strategic focus. Accelerators differentiate themselves from other startup support programs in its [90], [91]: (i) objective, private and for-profit, being backed up by investors that typically are private, public funders, or large corporates; (ii) focus, that can range from being generic (no industry focus) to specific (specializing in one industry/vertical or technology); (iii) geography, ranging from local programs (running in only one location, such as Y Combinator in Silicon Valley) or in multiple locations (running "franchises" in parallel, such as the Techstars program).

2. Program package. The educational and social network components are cornerstones of all acceleration programs, being used as a competitive advantage to attract and retain the best startups and founders. The "acceleration package" typically includes [7], [90]:

- Limited duration (typically three months), demanding complete focus of founder's attention to building a Minimum Viable Product (MVP) around a business idea.

- All accepted startups go through a "curriculum" or "educational program" that all accepted startups go through. Like business school courses, this can cover a wide range of topics from finance, marketing, and logistics to legal and human resources.

- A program of events, expert workshops, and inspiring talks (incidentally, Y Combinator organizes weekly dinners, inviting prominent Silicon Valley entrepreneurs to speak and using them as informal accomplishment milestones for founders).

- Structured mentoring, usually in the form of weekly "office hours," when accelerator directors and program mentors (experienced professionals, entrepreneurs, and investors) meet founders on a periodical basis to provide guidance, network opportunities, and create mutual trust with stakeholders that potentially could become later-stage investors and advisors.

- Co-location in a shared open office space, promoting peer-to-peer opportunities to learn and collaborate while informally stimulating “peer pressure” to guarantee quality and time management while building the MVP.

- Investor day or demo day is the primary milestone of all acceleration programs and typically marks the “graduation” of a startup to the market. On such occasions, potential investors and customers are invited to attend a full-day meeting where they will listen to and assess startup pitches, with presentations of an MVP and their intended growth and organizational strategies.

3. Funding. Accelerators are usually funded (obtaining working capital to invest in startups) by shareholders such as private investors (angels, venture capitalists), large corporates, and public authorities (i.e., universities or regional economic development agencies). Unlike venture capital firms, accelerators do not charge “management fees” from investors but expect to obtain significant returns when portfolio startups grow and pursue follow-on investments or an exit such as an Initial Public Offer (IPO) or acquisition [91]. Startups usually receive a small seed investment (USD 22 thousand on average with a range from zero to USD150 thousand, in exchange for an equity stake for the accelerator (6% on average, with a range from 5 - 8%) [7], [103]. Although this initial funding is insufficient to scale a typical high-growth startup, it aims to guarantee founders’ focus during the three months they are part of the acceleration program building an MVP. After the demo day, most graduating startups will receive follow-on investments either pre-committed (as convertible notes) or secured in subsequent investment rounds with new investors. Additional descriptive statistics are presented in Table 11.

4. Selection process and criteria. The typical accelerated startup is formed by teams with the most promise to build high-growth ventures [9], [91]. Top accelerators (such as Y Combinator and Techstars) typically have an acceptance rate of 3% or less in each cohort batch [9], [94] As a result, it enforces a highly selective admission process [107] usually organized with (i) an online application, (ii) an executive or core team review, and (iii) an initial interview with shortlisted candidates, and (iv) a final face-to-face interview. During this process, the teams are expected to present their initial

business ideas and, most importantly, present themselves as founders. This latter aspect is considered the most critical component of the selection process since it is expected that the initial business idea may change during the program, requiring entrepreneurial-minded founders to be flexible enough to accept the feedback and pivot the business concept.

5. Alumni service. Alongside the mentorship component during the program, “graduated” startups form an essential aspect of the acceleration process since they expand the resources and networks accessed by accelerated teams. For instance, in more extensive programs (such as Y Combinator), the alumni network is actively used by startups to test their MVPs in real customer scenarios, get support in recruiting new founding members, or access complementary technologies that will enhance their competitive advantage in the short-term.

2.4.4. Accelerator Programs Growth

In the decade since the dot-com boom, the environmental conditions for building tech startups have changed dramatically. In this sense, current conditions are perfect for nimble internet and mobile tech startups with talented teams and big ambitions, and the demand from investors and buyers has never been greater. In this environment, accelerator programs seem to be addressing a growing opportunity in the market for innovative products and services. Such market conditions are rapidly and constantly changing, partly due to technologies and the reductions in the cost to start a company, promoted by the tech sector during the boom years (1995-2000). As Megan Smith, Vice President for Business Development at Google, mentioned, “they (accelerators) are an idea whose time has come” [9].

As a result, the number of new accelerator programs created yearly has grown steeply. For example, in the United States, startup accelerators grew from 16 programs in 2008 to 27 in 2009 and 49 in 2010, reaching 170 programs in 2014 and mainly holding steady, growing 50% yearly on average [108].

Table 11. Examples of finance from accelerator programs (table 1, page 9, [90])

Accelerator	Location	Date created	Length of program	Investment size	Equity stake taken	Output (# active companies / follow-on funding
Techstars London	UK, London	2013	3 months	£ 12.500 + option conv. loan	6%	22 / ~£10,4M
Healthbox Europe	UK, London	2012	4 months	£ 50.000	10%	7 / undisclosed
Fintech Innovation Lab	UK, London	2012	3 months	/	/	14 / undisclosed
Bethnal Green Ventures	UK, London	2011	3 months	£ 15.000	6%	34 / ~£9,3M
Climate-KIC Europe	Europe	2010	12-18 months	Max. of £ 75.500	/	45 / ~£46,5M
Microsoft Ventures Acc.	Germany, Berlin	2013	4 months	/	/	16 / undisclosed
Axel Springer Plug & Play Acc.	Germany, Berlin	2013	3 months	£ 19.900	5%	46 / £6M
ProSiebenSat.1 Accelerator	Germany, Münich	2013	3 months	£ 19.900	5%	26 / undisclosed
Startupbootcam p Berlin	Germany, Berlin	2012	3 months	£ 11.900	8%	16 / £4,9M
Le Camping	France, Paris	2010	6 months	£ 3.600	3%	72 / £14,8M
TheFamily	France, Paris	2013	indefinite	/	3%	Undisclosed
L'Accélérateur	France, Paris	2012	4 months	£ 7.900 + option for more	7-10%	49 / undisclosed

It is remarkable, though, that the growth inflection points in 2007-2008 was noted both in the US and Europe. It coincides with the beginning of the financial crisis. It can be perceived as a clear way out for alternative ways for startups to get funded (since financial borrowings dried-up alongside the capital markets) and entrepreneurs to start new ventures in a global economic scenario less robust in terms of employment alternatives. These findings were also consistent during the Covid-19 crisis, when entrepreneurial activity raised significantly [89].

2.4.5. Research on Accelerators

Given the novelty of the accelerator phenomenon (whose foundation milestone dates to 2005 with the creation of Y Combinator), existing research on the topic is scant and primarily conceptual, with only very early-stage empirical studies [7], [91], [100], [103].

The lack of trusted and structured data is a significant obstacle. The private nature of accelerators and startups results in the absence of large-scale datasets on accelerator programs, portfolio companies, and the larger stakeholder ecosystem that gravitates around them. Initial attempts to collect and organize relevant data on accelerators are formed by seed-db.com (which aggregates publicly available data from Crunchbase) and the Seed Accelerator Ranking Project [7].

Some of the most relevant research found on the topic is presented below and summarized in Table 12.

- Miller and Bound [9] and Caley and Kula [109]) offer a thorough description of the accelerator model and phenomenon based on case studies of Canadian and global (with an emphasis on the US) programs, respectively. Both reports suggest that accelerators positively impact founders, helping them learn rapidly, create robust networks and become better entrepreneurs, despite the current lack of consensus around a typology that defines it.

- Hoffman & Radojevich-Kelley [88] use exploratory case studies of accelerator programs in the US to assess the success rate of graduated startups, based on how such programs facilitate startups to connect and subsequently raise additional funding from angel investors and venture capitalists. The authors analyze the results in light of the Resource-based view (RBV) theory, suggesting that mentorship-driven programs increase the success rates of startups by providing entrepreneurs with access to angel investors and venture capitalists, which tend to increase success rates.

- Kim and Wagman [110] use a game theory-based model to assess the dynamics of accelerator programs in a competitive market for venture financing. The authors provide cues on the signal effects (quality) it provides for its accelerated startups and the tension existing with investors when selecting and disclosing specific information (typically positive) to potential follow-on investors. The propositions offered in this theoretical work investigate the inefficiencies that are introduced by the accelerator in terms of the participating class size, the equity fee charged to participating ventures, and information sharing with investors. The authors also studied some of the accelerator's benefits in improving the quality of information, providing training, and facilitating access to investors, and discussed the potential inefficiencies when the accelerator can selectively disclose signals and when entrepreneurs perceive receiving funding as success.

- Barreahag et al. [106] compared accelerators in Europe and the US to map and describe the overall accelerator phenomenon and confirm the research findings offered by Miller and Bound (2011).

- Cohen [105] used multiple case studies of nine accelerators in the US to assess how organizational learning occurs and accelerates new venture creation in such time-compressed programs. Among the key findings in this work, the author highlights the importance of four components in the learning / new venture creation process in accelerators: (i) mentor overload, (ii) accelerator director expertise, and (iii) learning in divided teams and (iv) cohort peers learning. The results suggest that time compression enhances learning (contrary to previous theoretical predictions), firms delay "doing" until strategy emerges and begins to stabilize, and teams dividing each member's area of expertise enhance overall organizational learning. Ventures accelerated in the same cohort (regardless of industry focus) to improve their aspirational goals and expand founders' overall capabilities and knowledge. Finally, it suggests that the concentration of expertise among focal firms matters, particularly the knowledge transfer by accelerator directors to startups.

- Hallen, Bingham, and Cohen [8] offer one of the first empirical studies to assess the impact of accelerators on startups' ability to raise follow-on investment through venture capital by comparing accelerated and non-accelerated ventures. The authors found that startups backed by top accelerator programs can raise venture capital investment in a shorter time, exit by acquisition, and gain initial customer traction. These results suggest that accelerators do accelerate. However, only top accelerators (older, more established programs) seem to have such an effect, helping startups overcome new liabilities by providing a unique form of learning and access to networks. Additionally, the authors' empirical findings suggest that this impact is neither due purely to credentialing nor selection but arises from how accelerators improve the quality (through learning) of participating startups. It also suggests that accelerators are complements to (and not substitutes) experienced founders.

- Winston-Smith and Hannigan [111] compare startups that went through two top accelerators (Y Combinator and Techstars) to equivalent startups (non-accelerated) that eventually raised angel funding. The results suggest that startups graduating from these leading programs typically have founders with educational backgrounds from elite universities, receive additional investments (after graduation) quicker, and are more likely to be acquired or exit by quitting (fail).

- Isabelle [112] compares accelerators and incubators, presenting five factors (stage of the venture, fit with incubator/accelerator's mission, selection and graduation policies, services provided, and network of partners) that founders use to assess the benefits of joining one type of support program or the other.

- Salido et al. [93] map the accelerator and incubator ecosystem in Europe using multiple case studies in 10 key European economies, offering a first attempt to understand each ecosystem's differences, characteristics, and needs to provide cues for regional policy makers interested in stimulating entrepreneurial-related initiatives. The study identified seven key findings: Europe has a thriving early-stage startup scene, Europe and the US are comparable in the number of accelerators per capita, there has been a dramatic increase in programs since the financial crisis (2007-2013), and diversity of the accelerator ecosystem, lack of data available, significant variability of equity taken from startups, European-level initiatives could improve the overall entrepreneurial ecosystem.

- Birdsall et al. [113] identify the critical success factors and best practices of accelerator programs, examining the performance of participating startups, using company survivorship and acquisition data compared to benchmark competitors. The authors also propose the development of accelerator funds as a new type of investment/asset class.

- Dempwolf et al. [91] present a taxonomy of startup assistance programs based on this value proposition (to startups) and business model. As a result, the authors identify three categories of startup assistance organizations, (i) incubators and venture development, (ii) proof-of-concept centers, and (iii) accelerators that are subdivided into innovation, corporate, university, and social accelerators. The study also discusses the metrics that should be used to measure the performance of such programs.

- Nesta [107] presents a definition of acceleration programs, laying out its best practices and critical benefits to startups and founders of both new ventures and accelerator programs.

- Cohen and Hochberg [7] provide a first attempt to formally define what is an acceleration program while pinpointing the difference between other startup support programs and investments, in particular incubators and angel investors. The authors also review past and current research about such programs, presenting summary statistics on several primary accelerator outcomes: (1) Proportion of accelerator graduates that receive follow-on funding? (2) Proportion of graduates that have meaningful exits for founders. (3) How do programs differ in offerings, including mentorship and education. Finally, they discuss (4) what questions and data would be fruitful for informing further research and identification.

- Fehder and Hochberg [103] offer a first empirical-based attempt to understand the impact, efficacy, and role of acceleration programs on entrepreneurial ecosystems of the regions in which they are based. They analyzed the effect of accelerators on the overall funding pool (from seed and venture capital investors) present in the local region, providing cues for local authorities and accelerator founders aiming to promote local economic development through entrepreneurial ecosystems. Their findings suggest that accelerators have a regional impact on the entrepreneurial ecosystem by noticing an increase in seed and early-stage venture financing activity, affecting accelerated and non-accelerated startups due to an increased attraction of Venture Capitals (VC) and mentors to accelerator activities (such as demo days). The authors, however, raise two critiques, suggesting that the increase in financing activity in new regions (other than traditional hubs such as the US west and east coasts) is a result of investment shifts from central to more peripheral areas, to the detriment of other regions. They also point to the fact that companies funded locally would otherwise be funded in other regions, minimizing the local investment effect.

- Clarysse et al. [90], [104] present an inductive study of accelerators in Europe, analyzing its internal systems and creating a first attempt to categorize different types of accelerators in emerging archetypes, (i) investors, accelerators funded by private investors with a transparent business model, (ii) ecosystem builders, typically funded by public authorities trying to reduce early-stage failure rates, and (iii) matchmakers, typically funded by corporates with a wide range of objectives towards its program.

- Dee et al. [100], [104] present a thorough review of different startup support programs offering a typology to categorize them based on (i) how programs are funded and (ii) at what stage programs intervene in the startup formation process.

- Cohen et al. [100] introduce a correlation of accelerator programs background, organization design, and operations to firm-level entrepreneurial performance. They found a strong correlation between the type of founding partner (who provides funding) and the background of the founding managing director (who runs the program operations). For example, government-sponsored accelerators may focus on regional development, while professional investor-sponsored programs focused on return-on-investment maximization. Their study also suggests different performances in the portfolio firms of different accelerator typologies (e.g., differences in capital raised after the program's graduation).

Table 12. Summary of Existing Literature on Accelerators

Paper	Research Question	Methodology	Sample	Findings
[9]	What is the accelerator phenomenon?	Qualitative / Quantitative – case studies complemented with descriptive statistics	Interviews and descriptive data from accelerator programs	First comprehensive report to map the accelerator phenomenon globally and suggest a formal definition of what is an accelerator program (in comparison to other initiatives, like incubators). Early evidence derived from the report suggests accelerators have a positive impact on founders, helping them learn rapidly, create powerful networks and become better entrepreneurs.
[88]	How accelerator companies work and perform?	Qualitative - case studies, interviews, website analysis, and observation	Three extensive within-case and three between-case analyses were conducted.	Mentorship driven programs increase the overall success rates of start-ups by providing entrepreneurs with access to angel investors and venture capitalists which tend to increase success rates.
[110]	How is the early-stage financing and information gathering dynamics in the context of accelerators?	Game theory framework	Theoretical model (no empirical evidence)	The authors provide cues on the signal effects (quality) it provides for its accelerated startups and the tension / inefficiencies existing with investors when selecting and disclosing specific information (typically positive) to potential follow-on investors.
[106]	What is the accelerator phenomenon? What are the characteristics of accelerators?	Qualitative – case studies, complemented with quantitative analysis	17 interviews, articles and blog posts of 7 European accelerator programs and universities, and 2 american programs	Validate initial definitions of what is an accelerator, providing additional features regarding the network of stakeholders surrounding the accelerator, the organization and frameworks used by accelerators, and the accelerator program cycle.

Paper	Research Question	Methodology	Sample	Findings
[105]	How firms can accelerate learning? And broadly, how entrepreneurship can be taught?	Qualitative – case studies	Nine accelerators in the US	Accelerator programs do accelerate startups learning through four major components – (i) mentor expertise transfer overload, (ii) accelerator director expertise transfer, (iii) learning through divided teams, and (iv) learning through cohort peers.
[112]	What are the key factors entrepreneurs should take into consideration before joining an incubator or accelerator?	Qualitative – surveys with Canadian and US managers	Two surveys of managers and users of incubators and accelerators	Five key success factors to be considered: (i) stage of venture, (ii) fit with incubator's mission, (iii) selection and graduation policies, (iv) services provided, and (v) network of partners
[109]	What is the startup accelerator model in Canada and who are the key players in the ecosystem?	Qualitative / Quantitative – case studies complemented with descriptive statistics	18 interviews (60 minutes long) conducted with accelerator directors and entrepreneurs in Canada, complemented with descriptive data from Canadian accelerators webs	Canada's accelerators are in their own "startup phase" and pivots, despite the variations on the accelerator model. The authors suggest that these continued iterations contribute to the refinement of best practices and may potentially lead to new, distinct models in the future.
[93]	How is the accelerator and incubator ecosystem in Europe?	Qualitative / Quantitative analysis - interviews, site visits and conference calls	Data from accelerators and incubators in 10 European countries	Map the differences, characteristics and needs of each European ecosystem in order to provide cues for regional policy makers interested in stimulating entrepreneurial-related initiatives.
[113]	How accelerator programs have developed over time and what value they create for different parties within the ecosystem, including	Qualitative – case studies, complemented with quantitative analysis	Interviews with 14 accelerators, 15 investors, and a survey of over 130 entrepreneurs	Quality of the mentors, brand of the accelerator, and networking opportunities are the three major factors entrepreneurs consider when selecting programs. For follow-on funders, accelerator programs provide a filtered source of deal flow, but have little

Paper	Research Question	Methodology	Sample	Findings
	founders, angel investors and venture capital funds?			impact on investment decision making. Accelerators have the potential to evolve into a new asset class.
[7]	What is an accelerator and how it differentiates from previous and existing programs with similar or related goals?	Qualitative – case studies, past research summary Quantitative – proprietary data analysis	Not disclosed	Accelerator programs form a different type of startup support (compared to angel investing and incubators) in a number of dimensions – duration, incentives, cohorts, business model, colocation, educational and mentorship programs and networking.
[103]	Do accelerator programs have and impact on the entrepreneurial ecosystem of regions in which they are established?	Quantitative - fixed effects and hazard-rate matched models	Panel data set of 38 US Census Metropolitan Statistical Areas (MSA) regions across 10 years (2005-2012) in which 59 accelerators were founded	Accelerators do have regional impact on the entrepreneurial ecosystem, by promoting an increase in seed and early stage venture financing activity, affecting accelerated and non-accelerated startups.
[8]	Do accelerators accelerate startups that engage in such programs?	Quantitative – matched sample analysis Qualitative – interviews with accelerator directors, founders etc.	328 internet-related ventures, being 164 accelerated and 164 non-accelerated. Additionally, there were 75 interviews with stakeholders involved in 11 accelerators worldwide	Accelerators do accelerate startups reaching specific success milestones. In particular, startups backed by top accelerator programs are able to raise venture capital investment in shorter time, exit by an acquisition and gain initial customer traction.
[111]	How do accelerators impact exit and VC financing in new firms?	Quantitative – multinomial logit regression and competing risk cox hazard models	619 matched startups and their founders that participated in two US top accelerators from 2005 - 2011	Startups graduating from these leading programs typically have founders with educational background from elite universities, receive additional investments (after graduation) quicker and are more likely to be acquired or exit by quitting (fail).

Paper	Research Question	Methodology	Sample	Findings
[91]	What defines an accelerator and how to distinguish the many types of accelerators from other startup assistance programs, such as business incubators?	Qualitative – literature review complemented with descriptive statistics	Thorough literature review and data analysis of accelerator and similar programs	Identify three categories of startup assistance organizations, (i) incubators and venture development, (ii) proof-of-concept centers and (iii) accelerators, that are subdivided into innovation, corporate, university and social accelerators. The authors also discuss the metrics that should be used to measure performance of such programs.
[107]	What is an accelerator? Why consider an accelerator program?	Qualitative	N/A – practical report	Best practices and key benefits to startups and founders of both new ventures and accelerator programs.
[114]	How different accelerators operate, how they differentiate themselves from each other, and why?	Qualitative – case studies	Interviews with managing directors of 13 accelerators in Europe (London, Paris and Berlin)	In–depth insights on the accelerator models and the heterogeneity of their strategies and operations, providing (i) an adapted definition, (ii) a set of diverse features to describe the architectural blueprint of an accelerator and (iii) emerging archetypes that categorizes accelerators in, (a) investors (private funded), (b) ecosystem builders (public funded), (c) matchmakers (corporate funded)
[104]	How do support programs fulfill different roles for startups within startup ecosystems?	Qualitative - semi–structured interviews	50+ interviews with a range of ‘startup support programs’ in Europe and Israel	Provide some definitions and boundaries for terms related to startup support programs, map the startup ecosystem (particularly in Europe) and, finally, the results suggest there are links between how developed a startup ecosystem is and the ability of programs to be successful.
[100]	Are there performance differences across different organizational accelerator designs?	Quantitative – correlation	Dataset of 146 US accelerator programs, obtained from the Seed Accelerator Rankings Project	Find initial correlations of accelerator programs background, organization design, and operations to firm-level entrepreneurial performance.

The existing literature on accelerators is recent and incomplete, given not only the novelty of the phenomenon but the difficulty of obtaining reliable data, typically privately owned by accelerators and startups.

A significant effort in most non-academic works has been providing a coherent typology about accelerators while differentiating them from previous startup support programs. These works succeed in describing the phenomenon, how it works, what are the initial figures (descriptive statistics), and, potentially most importantly, what are the critical business model characteristics that make accelerators unique.

The scant academic works have also focused on describing the phenomenon while offering early attempts to understand the performance of such programs for all stakeholders involved, the accelerator itself, entrepreneurs, and the ecosystems in which they are established.

Most existing studies are excessively descriptive, trying to create their typology/taxonomy on the topic. As pointed out previously, the lack of available and reliable data associated with the novelty of this phenomenon has led to scant research, theoretical and empirical, leading to the existing flaws in a consensual definition of what is an accelerator and initial insights on how to measure the performance of such programs, and its accelerated startups.

An additional critique of such studies relies on the fact that most studies focus on US-based accelerators, leaving an open field for observation of the entrepreneurial ecosystems in other countries. Such observations may provide cues on how adaptive the US or Silicon Valley accelerator model to other realities is. It may also contribute to police makers and entrepreneurship practitioners by defining specific requirements and performance metrics of such programs in regions with different levels of early-stage investments and institutional environments (cognitive, normative, and regulative).

Additional theoretical and empirical contributions are required to advance the existing knowledge of how accelerators can contribute to enhancing the performance of all stakeholders involved, startups, accelerators, and entrepreneurial ecosystems. In this sense, theoretical works could help consolidate some of the fundamentals around the acceleration model, building on the groundwork provided by previous research in strategy (i.e., institutional analysis and network analysis) or entrepreneurship (i.e., effectuation). Empirical works can provide essential insights into the performance of such programs while contrasting explaining and predictive models about how it operates. Such additional studies can benefit not only from diverse methodological approaches but also from the unit of analysis that gives room further to investigate accelerators, startups, entrepreneurs, and ecosystems.

Finally, several additional lines of future contributions are worth noticing as the comparison among ecosystems and regions (in central and noncentral areas) in countries and continents other than North America and Europe.

- Analysis of how different acceleration models evolve, absorbing the feedback from early results and failures while adopting legitimating characteristics founded in other programs or required by stakeholders involved (most notably, investors)

- The study of the variability of performance and characteristics of accelerators focused on areas other than digital startups, such as social, hardware, and health.

- Analysis of the impact accelerators have on startups according to the phase they joined the program (idea, early-stage, startup) and the long-term performance of accelerated companies, and understanding the impact accelerators have on the entrepreneurial process.

3. Applications

The entrepreneurial process adopted by companies during their structuring and development phase may be unique and, consequently, difficult to identify and measure [63]. Such a situation leads to questions such as "How can researchers study a unique phenomenon and then generalize from such situations and circumstances?" The challenge, therefore, is to identify such processes and the rationality principles that underlie them in the creation of new firms.

This challenge is typical of inquiries from nascent theories, typically dealing with new constructs and few forms of measurement [115]. Therefore, the authors suggest that qualitative methods of data collection (interviews and observations) and analysis (identifying patterns) are more appropriate to structure a suggestive theory, thus opening space for future work on the issue or set of issues studied. In this sense, Edmonson and Macmanus [115] contrast this research method (exclusively qualitative) to hybrid (qualitative-quantitative) or purely quantitative methods to prove respectively intermediate theories (e.g., exploratory testing) or mature theories (e.g., hypothesis testing).

With this, the challenge proposed in this thesis, of understanding how innovation and new ventures are created despite the imprecision of objectives and uncertainty, can be correctly overcome by the case study methodology.

After all, as Yin [116] points out, in general, the case study is the preferred research strategy when "how" or "why" type questions are asked, when the researcher has little control over events, and when the focus is on contemporary phenomena occurring in a real-world context. This seems to be precisely the case for a study concerning innovation and new venture creation processes.

Yin [116] further specifies three parameters where case studies are particularly appropriate:

- Copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result

- Benefits from the prior development of theoretical propositions to guide design, data collection, and analysis, and as another result

- Relies on multiple sources of evidence, with data needing to converge in a triangulating fashion

The decision to use applied case studies in this thesis, like experiments, was to understand how to generalize some of the principles defined in the theoretical propositions presented in chapter 2. This thesis did not aim to extrapolate conclusions to populations or universes. The case studies dialogued with other research methods such as ethnography and autoethnography since the researcher was directly involved in developing the applications. In many ways, the researcher was also the entrepreneur-in-residence, applying the effectuation principles while observing how they deployed in creating new ventures [116]–[119].

The following sections present three applied case studies that extensively applied and validated the theoretical principles described in chapter 2 to understand how innovation and new ventures are created. Specifically, the applied cases tested the effectual process, the five principles of effectuation, and agile methods to accelerate the creation of new ventures.

The three cases were proofs of concept that were actually implemented in real contexts with the explicit goal of launching Minimum Viable Products (MVPs). In all stages of its development, the teams involved approached its development as entrepreneurial teams, facing uncertainties and engaging in actions to minimize and/or leverage its impact.

As predicted by the theories presented in chapter 2, there was never a clear goal about what the final product would be. The only commitment was to apply the effectual and agile principles, engaging in the actual creation of innovative solutions. In the spirit of this thesis, innovation can only be achieved and new ventures can only be created if such an effectual process is put in place.

The solutions presented in this chapter can also serve as a case-in-point of technology transfer. It involved the work of multidisciplinary teams from UPCT and the collaboration of several public and private stakeholders, whose continuous feedback and pre-commitments allowed the effective implementation of each solution.

In many ways, these works effectively created innovations, by implementing in practice initial ideas that eventually became proofs of concept and minimum viable products:

- Section 3.1 presents "Lemur", an edge application for traffic control.
- Section 3.2 presents "Dolphin", an IoT sensor location-based system applied for pandemic control.
- Section 3.3 presents "Crypto Degrees", a blockchain-based solution to verify university degrees.

3.1. Lemur – Edge application for traffic control

In the short and medium-term, cities will face significant challenges in traffic and road safety: congestion, energy consumption, noise pollution, pollution, and loss of quality of life are a few examples. Thanks to the evolution of information and communication technologies, promising new solutions are emerging. In this project, Proof of Concept "Intelligent systems for urban traffic optimization" 20539/PDC/18, funded by the Seneca Foundation, we have worked on the validation of components and technology of a novel system capable of managing and optimizing traffic in intersections and avenues of a city in real-time, improving mobility and reducing travel times, waiting times and pollution levels. Our solution, called Lemur - Smart Traffic Systems, is a traffic signaling control system capable of working in a distributed, adaptive, and coordinated way.

The project started with a tested and patented solution, the result of two research projects funded by the Spanish Directorate General of Traffic-Ministry of the Interior, and results published in prestigious international journals and international conferences of relevance. The technological maturity of our solution at the beginning of this project corresponded to a Technology Readiness Level (TRL) 3 since the computer simulation and experimental studies executed placed our system in an appropriate context, and laboratory demonstrations, modeling, and simulation validated initial analytical predictions.

From this initial point, during the project, we created several prototypes and a corresponding minimum viable product (MVP) with a TRL 6, having a system model with demonstrations in relevant environments, including operational environments. Thanks to the tests executed, the solution works in real-time in tiny devices, making it possible to use them in real scenarios.

To achieve these results, we systematically applied agile methods (e.g., design sprints) and the effectual principles described in chapter 2. It allowed the project team to progress rapidly by incorporating feedback from potential customers/ partners (e.g., municipalities) while executing pilot tests. By doing so and continuously validating the application with end-users, we were able to identify new applications for our product in the smart urban mobility field, expanding the project's innovation impact.

It is viable to increase citizen welfare and achieve sustainable mobility using specific technologies like Lemur. Our system can reduce up to 50% of drivers' waiting time stopped at traffic lights while reducing CO emissions by more than 30%. Based on the results obtained in this project, we foresee three possibilities for the future deployment of the proposed technology: as plug&play elements for traffic pattern studies, as a complementary technology to understand and analyze an expanded traffic user ecosystem (e.g., pedestrians, bicycles, scooters, connected cars), or as a complete traffic light management system.

3.1.1. Introduction

Traffic congestion, increased energy consumption, noise pollution, pollution, and even the dehumanization of urban spaces are some of the challenges that the cities of the future will have to face. Intelligent Transportation Systems (ITS), particularly traffic control and management systems, represent one of the simplest and most effective solutions to mitigate congestion, improve mobility, and at the same time guarantee road safety. The scientific community recognizes this fact. Based on state of the art in the field, the increasingly trending need for traffic signaling control systems capable of working in a distributed, adaptive, and coordinated manner is clear without forgetting that both the computational requirements and the deployment cost should be kept as light as possible to facilitate its implementation in real scenarios.

We proposed a traffic control system that meets these characteristics to address this need. It can manage and optimize traffic at intersections and arteries in the city in real-time, improving mobility and reducing travel times, waiting times, and pollution levels. Our system's three key elements are:

- The Data Acquisition Unit (DAU).
- The Data Acquisition and Processing Unit (DAPU).
- The communication capacity between them.

Our proposal derives from two research projects funded by the Spanish Directorate General of Traffic-Ministry of the Interior, whose results are supported by publications in prestigious international journals, relevant international congresses, and a national patent. The state of technological maturity of our system matches a TRL 3, corresponding to computer simulations and experimental studies executed in an appropriate context, with laboratory demonstrations, modeling, and simulation validating analytical predictions.

The objective was to create a prototype and apply it in a natural environment of use (pilot-testing) so that the post-test versioning could result in a minimum viable product that could potentially serve as a basis for commercial exploitation and scaling. As previously mentioned, the team extensively used agile methodologies (e.g., design sprints) to develop a prototype (minimum viable product) while incorporating inputs and feedback from the customer/pilot testing in an effectual manner.

The market potential of this application is inserted in the broader context of technologies that contribute to the consolidation of Smart Cities, with an increasing number of startups in the mobility ecosystem and an annual market size estimated at USD25 billion. Specifically, the product aimed to optimize traffic in cities, providing a real economy for the local GDP, reducing CO2 consumption, and increasing the general welfare of citizens.

3.1.2. Goals

The research results were supported by two research projects funded by the Spanish Directorate General of Traffic-Ministry of the Interior: SPIP2017-02230 "Multi-objective optimization system for intelligent traffic management" and SPIP2015-01780 "Proactive and distributed intelligent system for optimized traffic signaling." As a result, a patent was granted with the title "System and method for self-regulating traffic lights," which was the basis for developing this Proof-of-Concept project.

After the design definition, the system was evaluated and validated by simulations. Using SUMO, Omnet, and Matlab, the performance of our proposal was analyzed and compared with others in the specialized literature, showing that our solution presented significant improvements in terms of waiting time at intersections, vehicle travel time, and CO2 emissions, thus confirming our starting hypothesis.

The system was then implemented in alpha version prototypes. We built it using Beaglebone development boards (e.g., image processing, interval optimization algorithm, communication, etc.). On the Beaglebones, we used the Ubuntu Operating System, OpenCV software, and programming in C and C++ language. For prototyping and the complete testbench, we used Programmable Link Controllers (PLC) as traffic light controllers and network material. We built a test platform with prototypes equivalent to two signalized intersections of four arms and tested their correct operation.

From this point that we consider TRL3, the objectives of the Proof-of-Concept project were the following:

- Creation of a prototype with minimum viable product characteristics, serving as the basis for an industrial prototype that can be used to scale production in later stages of product development and commercialization.

- Overall advancement of the technology developed in previous projects, moving from a current TRL 3 to a TRL 6, including (i) obtaining all the necessary certifications to scale its application at the national and European level and (ii) validation by end-users of specific traffic data collecting methods (e.g., pollution microdata).

- Establishment of strategic alliances with municipalities at the regional and national level for advanced pilot testing (e.g., multiple intersections in different traffic scenarios), real market prospecting to validate the economic interest, and the social and economic impact of the technology on cities and the general welfare of citizens.

3.1.3. Related research works

We are witnessing a rapid urbanization process that brings significant challenges: traffic congestion, increased energy consumption, noise pollution, pollution, and even the dehumanization of urban spaces. Today, finding solutions to these problems is more feasible thanks to Intelligent Transportation Systems using optimized signaling systems for traffic control. These systems are one of the simplest and most effective solutions to mitigate congestion, increase traffic flow, improve mobility at signalized intersections, avoid the harmful effects of congestion (e.g., pollution, quality of life), and, simultaneously, ensure road safety.

However, the design philosophy of traffic control systems is experiencing a transition: from systems based on feedback (cause/effect or action/response) to systems that anticipate the cause. Since a few years ago, adaptive signaling control has become the focus of researchers in the [120]. Unlike *pretimed* control systems (duration and phase intervals preset based on a history of known traffic patterns) and *actuated* control systems (duration and phase intervals adapted to current traffic conditions from traffic detectors), "adaptive" systems use more complex techniques to optimize the duration, phase, and maximum and minimum times of each control system signal.

For example, several optimization techniques have been proposed in the literature based on dynamic programming techniques, Petri nets, genetic algorithms, fuzzy logic, or neural networks. Moreover, they have proven effective, giving rise to models such as the Split Cycle & Offset Optimization Technique, the Sydney Coordinated Adaptive Traffic System, and PRODYN, among others. However, despite the good results in traffic flow optimization at intersections, these solutions' applicability in real-time is limited by the high degree of computation required and the need to install specific hardware.

Similarly, improving the performance of isolated intersections using an optimized control system is an incomplete solution [121]. Central controllers (microprocessors) currently manage the signals that regulate traffic at a signalized intersection. They activate/deactivate the signals based on traffic history and detectors, among other data. If developing a mathematical model for an intersection to calculate the optimal phases for a given traffic demand is complex due to the non-stationary characteristics of the vehicle flow at the intersection itself, the presence of signaling systems at neighboring intersections causes pseudo-random behavior limiting the use of stochastic control models. Thus, for a large-scale traffic management system, it is difficult to predict the change in traffic state due to a specific signal control parameter variation because of traffic flows behavior, as mentioned earlier.

Therefore, when we extend the application of intelligent traffic control systems to entire cities, adjectives such as self-learning, self-organization, adaptive and autonomous are often highly desired attributes. The rationale for seeking these characteristics can be found in the expected benefits of avoiding (or minimizing) human intervention/control in these systems (e.g., provision of fast response to traffic conditions without deploying communication infrastructure (usually wired) between the traffic signals and the central control station, achieving higher efficiency). On the other hand, this requires using a distributed control architecture where each intersection autonomously self-manages itself by selecting the optimal signaling control policy based on local information and information from neighboring intersections [121]. This, in turn, leads to undesirable side effects that arise in many algorithms when attempting to follow this "self-x" approach, such as the level of complexity and computational load. The complexity of a self-organizing algorithm is one of the critical factors to be considered to achieve high applicability in real devices (sometimes resource-limited elements) [122].

Early proposals for urban traffic control systems employed cumbersome computational techniques such as neural networks [123], [124] or fuzzy logic [124], and only recently the proposed algorithms have somewhat relaxed their computational demands. For example, the work presented in [125], [126] and extended in [94], proposed a set of rules for the self-regulation of traffic lights driving an intersection. Under this scheme, a count of vehicles behind each red light (stopped or coming) is performed within a given time interval. When this count reaches a predefined threshold in either direction, the light changes from red to green. Therefore, the generation of vehicle platoons of a specific size is encouraged. Additional rules are established to ensure traffic smoothness so platoons may not stop at intersections while proceeding through an arterial. This proposal was compared with the green wave method (a traditional traffic light coordination methodology), confirming its effectiveness against the latter.

From a different perspective, Płaczek presented in [127] a control algorithm that bases its decisions on the expected cost of its actions. Thus, each agent employs a microscopic traffic model to calculate the impact of possible corrective actions on various performance metrics of each vehicle. The data used to build the traffic model are extracted from current traffic conditions. Since these predictions are obtained before implementing corrective decisions, they can be suspended if the predicted results are not desirable. The performance of this algorithm was compared with that proposed in [128] and an earlier version of the previously described algorithm presented in [125], obtaining outstanding results in terms of average vehicle delay. The work in [128] presented a decentralized control strategy for traffic flows based on local information from each control unit, local interactions, and local processing. Another proposal that computes a traffic model to explore the most appropriate corrective action was presented in [129]. In this case, the duration of the following green phase is calculated by considering the number of vehicles that crossed the intersection in the last green cycle. The authors called this methodology History-Based Self-Organized Traffic Lights, although the traffic data considered are not extracted from an extensive historical database. The presented results showed a general improvement over the performance of classic self-organizing approaches.

From a completely different perspective, other works have proposed self-organizing algorithms to regulate intersections but without using traffic lights [130] [131]. In the solution described in [130], an intersection control unit receives requests from approaching vehicles to access the shared resource (the intersection). Therefore, the controller simulates the vehicle travel considering other vehicles that previously requested access to the intersection and the geometry of the scenario. Then, an appropriate trajectory is calculated and sent to the vehicle, which must obey the assigned trajectory to avoid collisions. For that reason, only fully autonomous vehicles were considered in this work. The results showed higher throughput and reduced latency at the center of the intersection, which is always beneficial for traffic uniformity.

A different approach was adopted in [131]. In this case, a distributed algorithm was used. It has been shown that distributed algorithms offer more robust operations than centralized algorithms [132]. Specifically, in this approach, vehicles in the vicinity of an intersection exchange messages with each other with the objective of prioritization, with particular attention to emergency vehicles. The proposed solution is based on a priority scheme with a set of local rules for vehicles approaching the intersection; these rules consider the presence or absence of emergency vehicles. By applying this proposal, the authors obtained a 5-minute reduction in the travel time of an emergency vehicle within a typical 10 x 10 Manhattan network scenario.

Finally, it is relevant to mention the case of New York City as one of the pioneering and most advanced scenarios in implementing city traffic control systems. The New York City Department of Transportation (NYCDOT) launched the "Midtown in Motion" (MIM) project in 2011 to improve multimodal mobility in Manhattan's Midtown Core, a 110-block area. The MIM project utilizes active traffic management and the full capabilities of NYCDOT's ITS infrastructure (e.g., traffic controllers, sensor network, wireless communication system, and a New York City-specific Traffic Control System software system). Preliminary results from the first phase showed an overall 10% improvement in travel times. The project's second phase was launched in 2012, doubling the zone of influence of the adaptive control system, and by 2013 they managed to convert thousands of intersections to the new system. The project required more than USD 5 million in funding and served as the basis for all the communication infrastructure deployed in the city by NYCDOT.

Based on the state of the art in the field, the trending need for traffic signal control systems capable of working in a distributed, adaptive, and coordinated manner is clear without forgetting that both the computational requirements and the cost of deployment should be kept as light as possible to facilitate its implementation in real scenarios. Therefore, our proposal is framed within the Urban Computing concept. It is defined as the process of acquisition, integration, and analysis of heterogeneous data coming from different sources (e.g., people, vehicles, buildings) and acquired in different ways (e.g., sensors, telecommunication, historical) in order to address the previous significant challenges mentioned that cities have to face. For example, the effects of congestion can be mitigated, and energy efficiency can be improved with proper active traffic management by applying a correct optimization and characterization of the urban environment, also increasing road safety.

The research results included in the research team’s patent "Control system and method for self-regulating traffic lights" was the basis on which to develop the first stages of the innovative process, advance in the value chain, and reduce the time to market, as shown by the objectives of this project.

The novelty of our innovation concerning the procedures and developments used so far lies in the application of techniques used in packet-switched networks (telecommunication networks) for congestion control but extrapolated and adapted to vehicular traffic systems, which represents a new avenue of study with few but promising results [133]. The study of congestion and traffic engineering has been extensively investigated in packet-switched networks. Architectures such as Differentiated Services have shown that it is possible to perform data traffic planning and management to avoid congestion, reduce the loss of information packets and, ultimately, guarantee what is known as Quality of Service (QoS) in telecommunication networks [134].

However, little has been studied to transfer these techniques to vehicular traffic networks. Our team raised resources for this purpose. Specifically, two research projects funded by the Spanish Directorate General of Traffic-Ministry of the Interior, SPIP2017-02230 (12 months, EUR 49,995) and SPIP2015-01780 (12 months, EUR 49,995). Our system cannot only manage and optimize traffic at intersections and arteries of the city in real-time but also characterize the urban environment. For this purpose, the system is composed of a network of devices called DAU and DAPU located at intersection road signs. Each DAU/DAPU acquires and processes input data (e.g., vehicle traffic), and each DAPU applies an algorithm that calculates the best signal intervals for an intersection. The DAUs/DAPUs has the additional feature of communication between them, forming a network, thus collaborating for decision making. Note that DAPUs include the QoS provisioning techniques inherited from telecommunication networks, modified according to the new scenario, and in the previously mentioned research projects (SPIP2015-01780 and SPIP2017-02280), we demonstrated that it is possible to transfer them to the road environment with remarkable performance and low computational cost.

3.1.4. Methodology

Guided by the principles described in chapter 2, we applied an adapted version of the sensemaking and sensegiving process (Figure 4) as the basis for the agile method used in this project.

At all stages, the objectives were to build prototypes, apply them in real-world environments (pilot tests) and develop a minimum viable product that could serve as the basis for future commercial exploitation of the product and its scaling to international markets.

The project had three phases, as described in Figure 15.

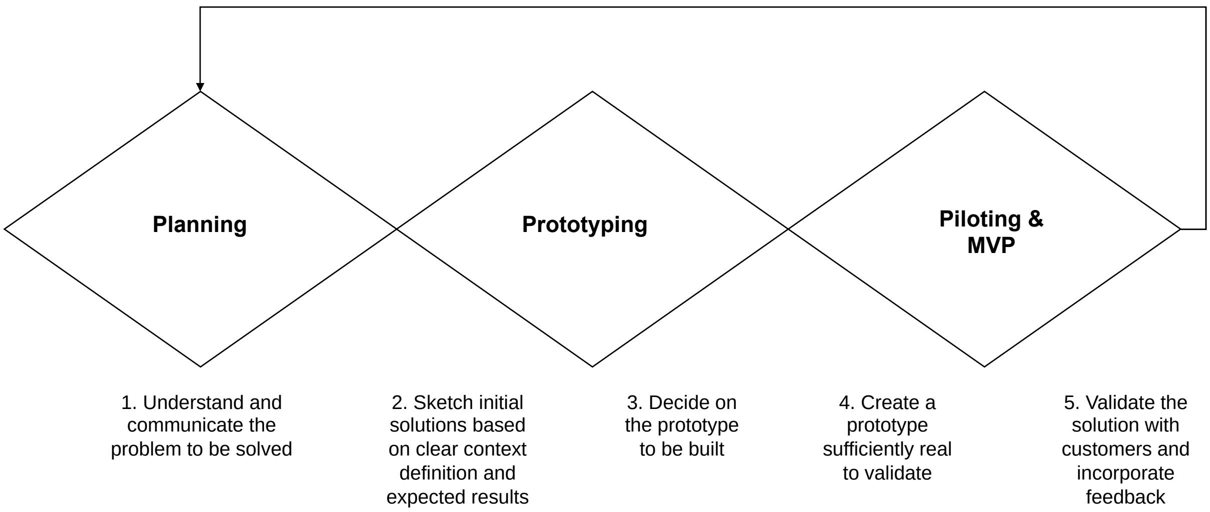


Figure 15. Lemur project phases.

- Phase 1 (Planning): define the prototype development roadmap and pilot tests necessary to refine the prototype towards constructing a minimum viable product.

- Phase 2 (Prototyping): build a prototype (beta) from the results obtained in the technical-scientific stage and validate the expected value proposition (functionalities, usability, impact) in an agile way.

- Phase 3 (Pilot testing and Minimum Viable Product): execute pilot tests in real-world environments where the product could be used and obtain the necessary inputs to construct a minimum viable product.

From a technological perspective, the maturity status of our system corresponds to a TRL 3 since the computer simulation and experimental studies placed our system in an appropriate context, and laboratory demonstrations, modeling, and simulation validated initial analytical predictions. Specifically, after the design definition, the system was evaluated and validated by simulation. Using SUMO, Omnet, and Matlab, the performance of our proposal was analyzed and compared with others in the specialized literature, demonstrating that our solution presents notable improvements in terms of intersection waiting time, travel time, and CO2 emissions, thus corroborating our starting hypothesis. The system was then implemented in alpha version prototypes. We built the system using Beaglebone development boards (image processing, interval optimization algorithm, communication, etc.). On the Beaglebones, we used the Ubuntu Operating System, OpenCV software, and programming in C and C++ language. For prototyping and the complete testbench, we used Programmable Link Controllers (PLC) as traffic light controllers and network material. We built a test platform with prototypes equivalent to two signalized intersections of four arms and tested their correct operation.

The use of agile methodologies allowed rapid decision-making in the definition and construction of the prototype. The systematic application of the effectual principles allowed the incorporation of feedback from multiple stakeholders in this process. In combination, this process allowed for the definition of a commercialization plan that included the adequate definition of the value offer, its initial specification, and agreements for the expansion of the pilot tests, which are fundamental for the adoption of the product by the municipalities at the national level.

3.1.5. Results

The activities performed and main results achieved are detailed below.

Phase 1 (Planning):

1. Definition of product architecture. Based on the tests and results obtained in simulations, software algorithms were integrated into different types of

development boards. It was necessary to consider the peculiarity of running all software and algorithm in real-time from the perspective of use as traffic light signaling. When choosing the final hardware support, the ease of configuration/setup, security options (e.g., use of keys and encryption), CPU, and memory usage performance, among other factors, were considered. It was also necessary to test, compare and implement several communication protocols on the selected development boards that are essential for inter-device communication (Machine to Machine, M2M).

2. Planning of design sprints. Each team member was assigned a specific role. In addition, two new members were added to the core team, a graduate in telecommunication systems engineering and a master in telecommunication engineering, who collaborated in method validation tasks, pilot tests, prototype implementation, support functions in the development of the prototyping phases (e.g., sprints, stress testing) and pilot testing of the product. The team planned the consumable material required and acquired different materials according to the tests performed throughout the project.

3. Definition of pilot agreements. Initial contacts were established with local administrations (Madrid City Council, Cartagena City Council, Murcia City Council), as well as with entities such as the Campus of the University of São Paulo (Brazil) and the Prince Sultan University (Saudi Arabia), in order to carry out further tests on relevant scenarios. Finally, several pilots were executed on various avenues, roundabouts, and intersections in Cartagena. Additional tests in Murcia and Sao Paulo were planned for 2020 and 2021, but due to the SARS-Covid2 pandemic, the team needed to cancel them.

4. Market study and definition of an initial value proposition. The results are described in phase 2 (prototyping).

Phase 2 (Prototyping):

1. A total of four sprints were executed, including team members, experts, and potential customers (validation task only). During these sprints, different prototype versions were built and validated, mainly with different hardware equipment (e.g., motherboard, sensors, antennas, connectors, encapsulations). Figure 16 shows an example of one of the prototypes in the beta version.

2. Several stress tests were executed on the various prototypes. The objective was to stress the devices as much as possible to detect shortcomings and possible improvements. The main problem to be solved was the execution of the algorithm responsible for image processing on the development boards/selected hardware in real-time and within limits set by traffic lights. In addition, limitations were detected in the wireless communications between devices, finally opting for Message Queueing Telemetry Transport (MQTT) throughout the system.

3. Market study and value proposition definition. In brief, the market offer is characterized by two types of solutions, usually integrated, and sold as "one-stop-shop" systems, directly (embedded as a built-in feature) or indirectly (through specialized partners) - (1) Hardware (Cameras, Sensors, Traffic integration systems) and (2) Software (Data collection, Real-time traffic monitoring, Predictive analytics for traffic studies). This offering is often dominated by traditional traffic management systems industry players, creating significant barriers to entry for new players. These companies align to the characteristics that define typical customer behavior in this sector, in particular, their safety orientation and public service nature, which are summarized as: conservative, perceived high costs of deploying new solutions, low readiness for digital transformation, low openness to work with startups and SMEs, the prominence of traditional companies acting in the industry, operational complexity of public administration (the typical buyer of this type of solution). However, we believe that cities can capture several potential positive impacts, in particular (1) Environmental impacts (reduction of fuel consumption and CO and CO2 emissions, improvement of air quality), (2) Social impacts (health and

safety, employment and labor market, privacy and personal data), (3) Economic impacts (direct economic impacts, secondary effects such as changes in competitiveness, congestion, reliability and distributional impacts, impacts on cities' GDP). As a result, we envision three possibilities for the future deployment of the proposed technology. Each deployment possibility is not mutually exclusive, being potentially adopted by cities either collectively or independently: (1) Traffic pattern study with a focus on improved road planning and management systems, (2) Complementary technology to understand and analyze the expanded traffic user ecosystem (e.g., pedestrians, bicycles, scooters, connected cars), (3) Complete traffic signal management system, automating the complete management of signal systems at intersections and secondary roads.

Phase 3 (Pilot testing and Minimum Viable Product):

1. Pilot design. In conversations with Cartagena City Council, it was decided to focus the pilots in two areas due to specific traffic characteristics and difficulty managing them. Specifically, the Mandarache traffic roundabout and Paseo de Alfonso XIII Avenue (Figure 17). Once defined, the tests were carried out using batteries to power the devices and alter the public space as little as possible. These pilots were not carried out by acting on the traffic lights since this cannot be done through the administration, and it is essential to do so in collaboration with an integrator company, as indicated previously. This implied technology transfer in the form of a license or purchase of a patent or similar. For this reason, the system was tested with all its functionalities implemented in the MVP, but not working on the traffic light itself. In this way, we also verified alternative and novel functionalities detected in phase 2, using a system for detecting real traffic patterns and urban mobility studies, considering the various actors on the public road (e.g., pedestrians, cyclists, public transport). For example, Figure 18 shows an origin-destination graph of the evaluated intersections. According to our studies, this analysis fits the current market needs, as mentioned above. For this reason, we believe there is room for creating a second product dedicated to monitoring flows of people, vehicles, and other equipment, allowing comprehensive management of physical

spaces. Moreover, given the open characteristics of the product, it is possible to add "add-ons" that allow a constant evolution of the monitoring capacity and integration of traffic managers and companies, as well as surroundings (e.g., stores, shopping malls, schools).

Deriving from the prototype and its extensive testing, the team defined an MVP (Lemur - Smart Traffic Systems), including software visualization (see example in Figure 19) and a redesigned hardware (shown in Figure 20).

2. We contacted APPLUS and AENOR (reference companies in certification and standards compliance). However, these companies work directly on product certification and do not offer consultancy services. In our case, given the TRL of the solution to date, it was necessary to perform a full product audit prior to the certification itself, including laboratory testing.

3. Strategic roadmap. The main opportunities identified were:

    a. There is a diversity of systems used in each city. This context creates a myriad of legacy systems and locally deployed skills, but also an opportunity to integrate and simplify traffic management systems.

    b. Most cities have extensive legacy systems spanning decades, creating a de facto ecosystem of solutions that is difficult to manage and maintain. This situation often requires a critical amount of budget and human resources to keep the overall system up and running, which prevents cities from optimizing resource allocation and customer service (citizen usability of current traffic systems).

    c. Most traffic system vendors sell single/integrated solutions that add to legacy systems, amplifying the "ecosystem of solutions" problem. This situation creates an additional dependency on these vendors and barriers to entry for new companies and technologies that need testing ground to be validated and grow locally.

d. Most of the new "native" ITS solutions in the market are focused on inconsistent offerings, primarily around "smart" cameras and analytic dashboards. We could also identify the increasing use of sensors, both standalone and integrated into existing hardware (e.g., cameras). Examples include (1) Smart cameras: thermal cameras with the ability to detect road incidents in real-time, (2) Sensors: still embryonic but increasingly incorporated into cameras or used for one-off traffic studies and additional surveillance statistics (e.g., pollution conditions), (3) Algorithms: still maturing, but frequently used for traffic studies that identify time series patterns and vehicle flows (e.g., deep learning techniques).

Based on these industry characteristics, we identified critical requirements for new ITS vendors in this segment: (1) Reliability and robustness, especially concerning security requirements; (2) Accuracy and ability to provide real-time alerts, helping traffic system managers respond and allocate appropriate resources; (3) Ease of use and maintenance, without adding costs and complexity to existing infrastructure (4) Leveraging deployed infrastructure and human resources, including retraining the workforce on new technologies (e.g., artificial intelligence) (5) An increased ability to provide safety for cars and pedestrians in an expanded "traffic ecosystem" that will be a reality in a few years and include autonomous or semi-autonomous vehicles, alternative public transportation systems, electric bikes, scooters, for-hire vehicles, among others.

As mentioned above and considering these industry characteristics, the goal of our solution was to provide flexibility to both the project team and potential customers in the design and use of the product, offering solutions that span three complementary areas.

- Traffic pattern study with a focus on improving road planning and management systems,

- Complementary technology to understand and analyze the expanded traffic user ecosystem - e.g., pedestrians, bicycles, scooters, connected cars,

- Complete traffic signal management system, automating the complete management of signal systems at intersections and secondary roads.

4. Finally, some initial commercial contacts were established to understand the product-market fit through the deployment of the first pilot projects. Given the complexities of commercial development, as discussed in the previous points, contacts have been sought within the infrastructure and traffic departments of the municipalities, with occasional involvement of other departments open to testing the solution. The highest traction, as expected, has been in the Region of Murcia (Spain) - cities of Murcia and Cartagena - due to the proximity and lower cost of deployment of the pilot projects. This included local press releases and open dialogue for future collaborations, particularly in Murcia (e.g., Press Release - https://www.laopiniondemurcia.es/murcia/2020/02/10/cientos-sensores-mediran-actividad-comercial/1089819.html). In this regard, in addition to the test pilots carried out in Cartagena, different additional pilots with different commercial and technical characteristics were planned to be conducted throughout 2020 and 2021, but due to the pandemic they were canceled.

The preliminary contacts established in the City Council of Murcia included the Department of Urban Development and Modernization of the Administration, Department of Sustainable Mobility and Youth, the Technical Secretariat of Local Government, Traffic Service Headquarters, Department of Culture and Heritage Recovery, Directorate of Museums and Exhibition Spaces and Department of Commerce, Markets and Public Roads.

This initial result encouraged the team to develop the product and associated services further and expand its application to other customer profiles (e.g., industry, commerce).

Figure 16. One of the Lemur prototypes in alpha version.

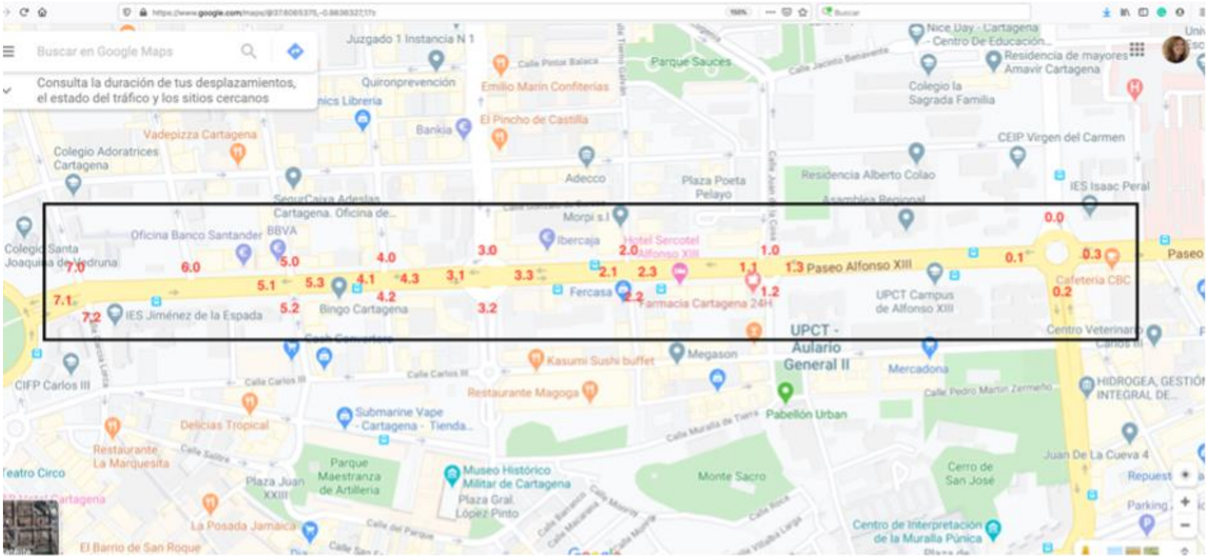


Figure 17. Street map of one of the pilots at Paseo Alfonso XIII (Cartagena, Spain).

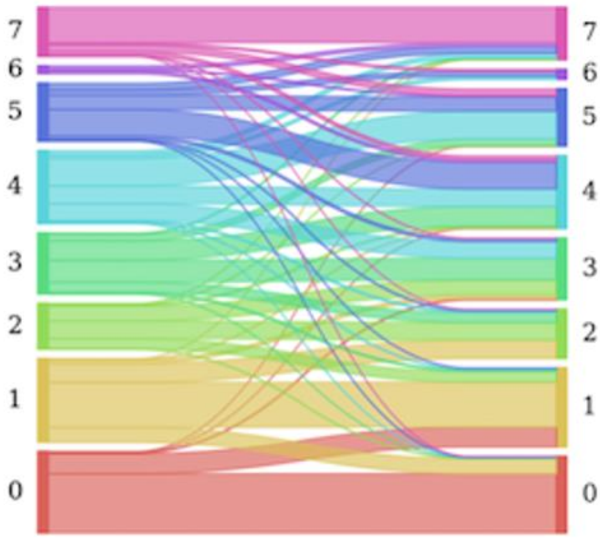


Figure 18. Sankey diagram of vehicles and pedestrian flows among intersections from 7:45 pm to 8pm at Paseo Alfonso XIII (Cartagena, Spain).

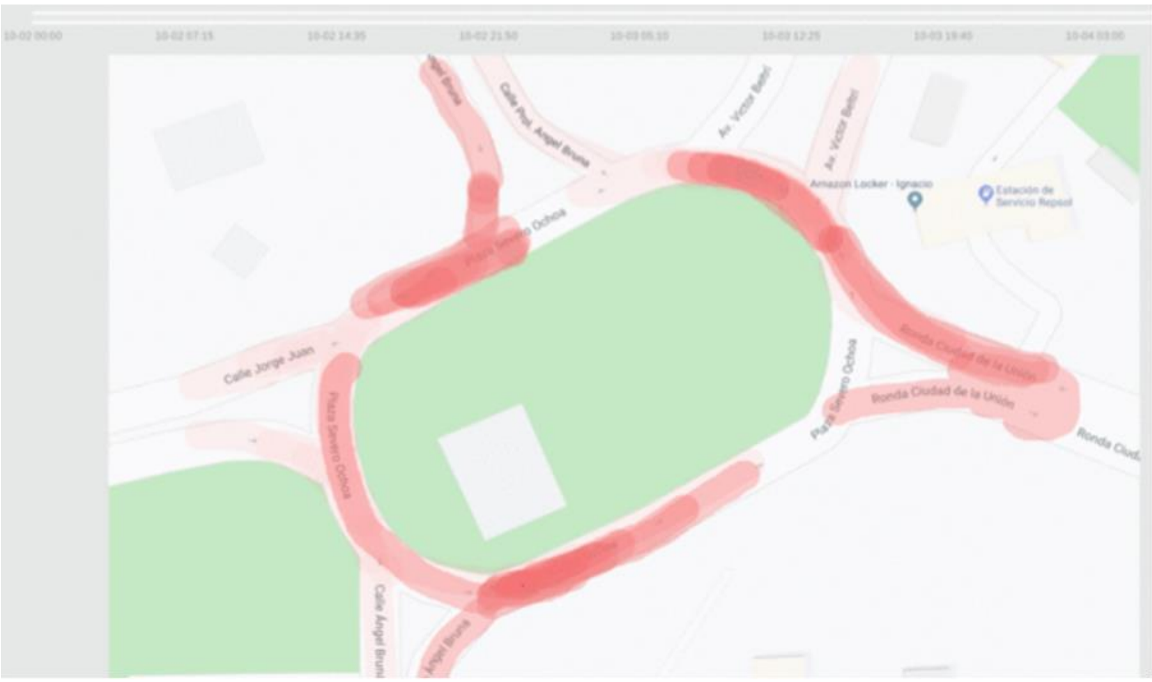


Figure 19. Visualization snapshot of the traffic at Rotonda Mandarache (Cartagena, Spain).

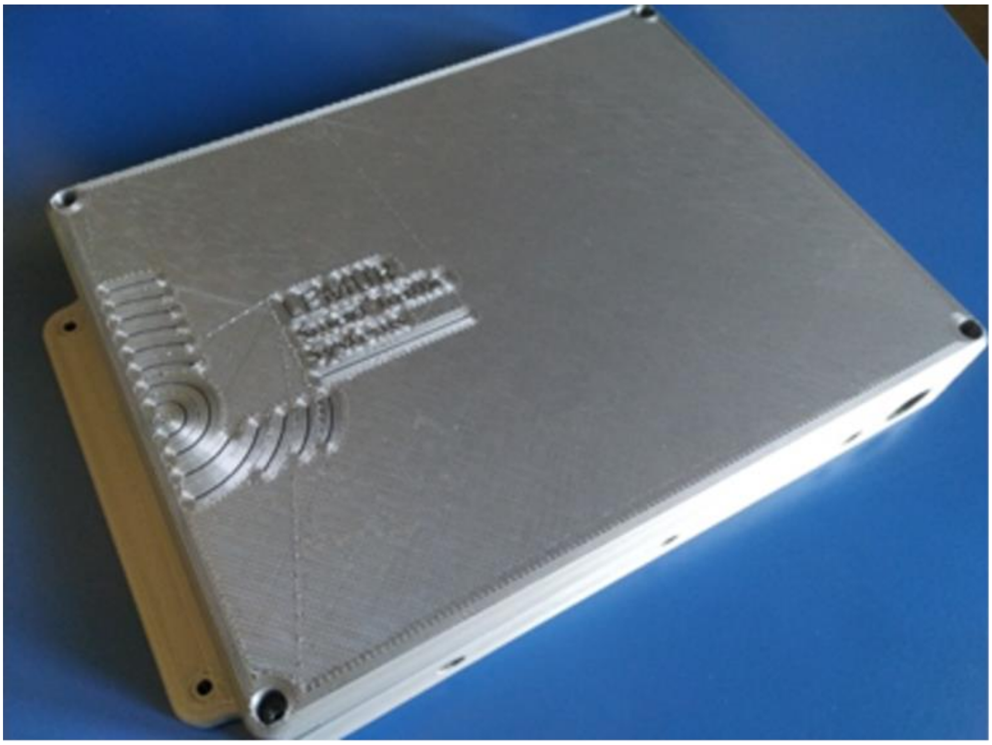


Figure 20. Lemur MVP TRL6/7.

Figure 21. Next roadmap from the results obtained in the project.

3.1.6. Impact

Several potential impacts of this solution were identified.

- Contribute to the adoption and expansion of the Smart Cities concept in the region of Murcia, seeking to be a pioneer among the European regions contributing to the European Commission's "Sustainable Urban Mobility Plan."

- Increase citizens' well-being, in line with various global studies on the development of urban environments.

- Reduce the total economic cost to cities - currently, the economic cost of congested traffic is estimated to represent between 2% - 4% of cities' GDP
- Reduce CO2 consumption and contribute to the global agenda of combating climate change
- Increase the adoption of automated and intelligent systems at the regional and national level, contributing to increased road safety and connection with future telematics technologies, such as in autonomous cars and "Smart roads."
- Use legacy technology to collect traffic and pollution data at the level of each road intersection, generating greater capacity for robust data analysis and predictability, as well as urban traffic contingency and maintenance equipment improvements

3.2. Sparking Innovation in a Crisis: An IoT Sensor Location-Based Early Warning System for Pandemic Control

At the beginning of the Covid pandemic in 2020, a new opportunity for further deployment and adaptation of "Lemur" (detailed in section 3.1.) was identified. There was a clear need to track and trace potential risks from overcrowded environments.

This section describes an innovative solution that builds upon previous know-how and is deployed in the context of an early warning system for pandemic control.

The U.S. government launched Operation Warp Speed [135] to promote private and public partnerships, enabling a fast-track for the approval and production of COVID-19 vaccines. It applied a venture capital approach to investing in the discovery of an effective vaccine by funding private efforts in R&D, manufacturing, and logistics. Eventually, the program was able to bring to market new effective vaccines months before standard timelines. On the other hand, the South Korean government launched the COVID-19 Smart Management System, a system that allowed for the automation of the epidemiological investigation process by relying on the application of Smart City technologies to collect, process, and analyze large volumes of urban data. It created the informational background that allowed for the effective “Track, Trace, and Test” strategy applied in the country to contain the pandemic by analyzing people’s displacement flows at the city level [136], [137].

These programs are examples of how entrepreneurial action combined with technological advances can effectively create warning systems that prevent future outbreaks. As societies assess the human and economic consequences of the COVID-19 pandemic, the increasing development of new and accessible technologies can provide novel warning applications. Smartphones, IoT-connected devices, and wireless sensor networks can supply an additional layer of information for innovative Early Warning Systems (EWS) by monitoring human behavior (e.g., human overcrowding) and combining it with other data sources.

In this thesis, a predictive location-based early warning system is proposed, implemented, and tested in real testbeds. The proposal can measure people density, people flow, and behavior in specific areas of indoor and outdoor environments. The hypothesis to be tested is two-fold:

- First, to determine if an effectual approach could be applied in an engineering environment with previous solid experience in research but less experience in innovation and creation of minimum viable products with a high TRL. To the author’s knowledge, there is a lack of contribution in the research literature approaching effectuation from the perspectives of information and communication engineering.

- Second, to propose and implement the system and evaluate its performance during a long period of time in a non-controlled environment (a real scenario as it would be the case of a high TRL 7–8). Technological innovation projects would be TRL 8, since technological innovation requires the introduction of a new product or service in the market, and for this purpose, tests and certifications must have been passed as well as all the relevant approvals.

> Once this phase is completed, large-scale deployment or implementation follows. The solution described in this section starts at a TRL 6, verified by simulations in other scenarios, evolving to a TRL 7, testing the system in a real-world scenario. Then, it moves to TRL 8, certifying the system/product to be used as a commercial solution, being available for companies as technology transfer from the university.

The proposed warning system measurements include several key performance indicators such as the number of people that enter a specific location in a given time, the average time spent in particular areas, or the amount and density of people that interact over a particular period. An EWS sensor data fusion approach was adopted in this work by combining multiple sensor data sources using IoT technology, artificial intelligence algorithms, and application programming interfaces, creating a robust real-time early warning system for pandemic control at specific areas, allowing for efficient, cost-effective event prevention policy implementation and community warning.

This EWS approach to disease outbreaks in a population can serve as a critical application toward a more extensive adoption of intelligent management systems by health organizations and multiple stakeholders. Such systems, combined with appropriate infrastructure, data hubs, and service applications at the city/regional level, can eventually lead to the implementation of smart cities, significantly improving the overall quality of life for citizens and creating a trusted system for governments and organizations to manage event-led situations.

Next subsection explains how complex contexts such as those where warning systems are used can become a booster for innovation and how effectuation can be applied. Following, previous works from the specific scientific literature are presented. Then, the proposed warning system and the results are shown.

3.2.1. Innovation, Effectuation, and COVID-19 Contact Tracing

The creation of new ventures is an uncertain initiative. Entrepreneurs and innovators create new products and services to reduce existing information asymmetries and create value while solving a problem faced by one or many individuals [62], [86], [138]. In this context, creating an EWS for pandemic control is an impactful innovation that allows for novel solutions for an unknown problem with drastic consequences for humankind. Understanding how innovation emerges in such a context is critical so that EWS can evolve and iterate, improving its efficiency as an essential tool for planning and preventing events such as a pandemic.

In brief, the innovation process and expertise typically consist of non-predictive control heuristics, organized under the concept of effectuation [54]. Expert entrepreneurs and innovators apply the effectual principles while addressing the uncertainties faced in creating a new product and service. As detailed in chapter 2, such principles can be summarized as follows:

1. Bird-in-hand principle: they build a new venture not necessarily with a goal in mind, but with the most basic resources and means they have at hand, who they are, what they know, and whom they know. From that starting point, they start imagining possibilities.

2. Affordable loss principle: they do not place large bets with the expectation of high returns. Instead, they limit risks by understanding what they can afford to lose at each step in creating a new venture. By adopting this approach, they select actions and goals with upsides even if downsides occur in the outcome.

3. Crazy quilt principle: they reduce uncertainty by partnering with self-selecting stakeholders. These partners and stakeholders join the venture creation process without any specific predetermined goal. Instead, they make initial commitments to shape the goals of the new venture and co-create a new market for it.

4. Lemonade principle: they embrace and leverage contingencies and surprises instead of rejecting them. By doing so, they interpret potential bad outcomes

as clues and insights to iterate and create new products, services, and markets. They make lemonade when life throws them lemons.

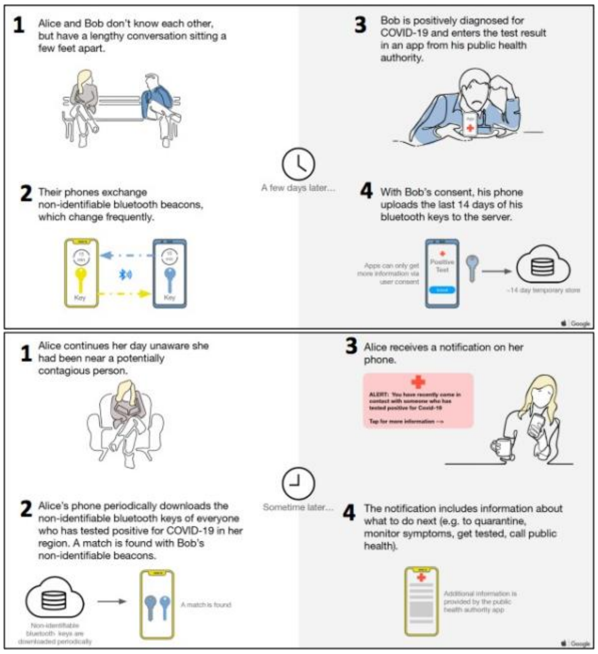
5. Pilot in the plane: they focus on actions within their control instead of relying on trends or inevitable outcomes. They assume the future is not found or predicted, butit is made through human action.

These principles imply a high likelihood of innovation while keeping potential losses under control and undermine the socially accepted relationship between risk and reward. Initiatives such as Operation Warp Speed and COVID-19 Smart Management System are examples of these principles in action in the process of creating new products (vaccines, antivirals) and services (contact tracing) under uncertainty (during a pandemic). Conversely, it is worth noting the early efforts of governments and organizations worldwide during the initial phases of the COVID-19 crisis in creating effective mobile contact tracing apps, with limited if not inexistent results.

A case in point of early attempts to innovate by creating a global solution for COVID-19 contact tracing is the joint venture between Apple and Google that together created an Exposure Notification System [139], [140] based on Bluetooth Low Energy (BLE) technology. Since both companies have combined more than 99% of the mobile operating system market share worldwide, a mobile-first solution to track, trace, and communicate positive COVID-19 cases would have immediate global coverage if adopted early [141], [142]. The system uses the mobile phone's BLE technology, allowing the exchange of non-identifiable Bluetooth beacons to collect and notify anonymous data of diagnosed COVID-19 individuals, helping governments and health agencies effectively monitor outbreaks while allowing individuals to self-monitor their personal exposure risks.

The system shown in Figure 22 operates as following. Let us assume that Alice and Bob carry a smartphone. They do not know each other, but they remain close to each other when talking. During this time, while they remain close (a few feet apart), their phones will exchange non-identifiable beacons. Afterward, if Bob is COVID- 19 positive, he will communicate his positive status to the corresponding public health authority and with his consent, his phone will upload the last 14 days of beacons to a server. Meanwhile, Alice's phone periodically receives the beacons of positive cases from the server, looking for a match with the beacons stored in her phone (e.g., Bob's beacons). Because Bob has advised of his positive status, Alice's phone will find a match and she will receive a notification.

Several countries adopted the Apple and Google proposed methodology and deployed their own national notification applications. An example of such an app is Radar Covid, launched in Spain in August 2020 (Figure 22) with European-wide interoperability amongst other apps using the same technological approach and sharing the same European accepted privacy standards.



(a)

(b)

Figure 22. (a) Apple and Google COVID-19 exposure notification system framework (credit: Google/ Apple Exposure Notification FAQ, p. 4, https://www.google.com/covid19/exposurenotifications/ (accessed on 26 April 2022)); (b) Radar Covid public campaign (Spain's official Covid contact-tracing app) (Credit: [144]).

Table 13. Statistics of Radar Covid usage; Radar Covid App downloads and positive cases confirmed in Radar Covid are obtained [145], [146]; COVID-19 positive cases in Spain were obtained from [147]

	COVID-19 Positive Cases	Radar Covid App Downloads			Positive Cases Confirmed in the Radar Covid App	% Of Positive Cases Confirmed in the Radar Covid App/ COVID-19 Positive Cases
		Android	iOS	Total		
2020 total	1,381,751	4,745,431	1,531,838	6,277,269	28,213	2.04%
3rd Quarter	281,751	3,256,486	1,208,870	4,465,356	2399	0.85%
4th Quarter	1,100,000	1,488,945	322,968	1,811,913	25,814	2.35%
2021 total	4,719,958	1,577,905	404,495	1,982,400	67,469	1.43%
1st Quarter	1,328,649	826,809	76,153	902,962	27,950	2.10%
2nd Quarter	525,408	218,445	75,643	294,088	8879	1.69%
3rd Quarter	1,126,797	285,023	108,128	393,151	10,802	0.96%
4th Quarter	1,739,104	247,628	144,571	392,199	19,838	1.14%
2022 total	2,690,710	64,515	31,715	96,230	16,150	0.60%
1st Quarter	2,690,710	64,515	31,715	96,230	16,150	0.60%
Total	8,792,419	6,387,851	1,968,048	8,355,899	111,832	1.27%

Nevertheless, a succession of failed communication efforts, an increasing mistrust of the population about data privacy, and a non-intuitive code certification process to make the app effective eventually undermined its use. By March 2021, Radar Covid hit a bottom in its adoption after topping seven million downloads, as seen in Table 13, covering less than 20% of the population, with an average ratio of COVID-19 cases effectively detected through the app averaging 1.14% by December 2021 (see Table 13). By January 2022, the Spanish government stopped the active tracing of close contacts of COVID-19 infected individuals. While still keeping Radar Covid functional, the app stopped being effectively used after 14 months of its implementation [143].

Radar Covid can be seen as a case in point of how IoT services (and the IoT market) came into existence in the context of uncertainty and a pre-existing market (an explicit demand to detect and report Covid infected individuals). Nevertheless, despite significant government efforts and clear benefits at the individual and collective levels, the failure in its adoption can open a broader discussion about the more extensive IoT adoption by industries and individuals. The illustrative case of a failure in the adoption of Radar Covid and other contact tracing apps worldwide [148]–[150] should not inhibit further innovation in creating effective early warning systems to prevent future pandemics.

As explained in section 3.1., the author participated in constructing "Lemur," a proof of concept and MVP of intelligent transportation systems focused on reducing pollution and improving key traffic performance indicators (e.g., travel time, congestion) by using smart algorithms. Some of the results demonstrated the importance of considering the behavior of pedestrians when making traffic control decisions [151]–[153].

Applying effectuation and embracing the effectual approach, we decided to use our acquired knowledge in pedestrians and vehicular management to create an EWS tool to monitor people’s behavior in indoor or outdoor areas during the COVID-19 pandemic. The new early warning system, as described later, was not only designed but also implemented, deployed, and tested in a real testbed using the authors’ experience with early tested innovations using sensors and IoT systems in vehicular traffic monitoring and control. The team was composed of two graduate students, one senior member with extensive business experience in strategy consulting and product development, and one senior member with solid research experience in intelligent systems. A sensor data fusion-first approach was followed, combining multiple sensor data sources, artificial intelligence algorithms, and Application Program Interfaces (APIs) to create a robust real-time early warning system for pandemic control in specific areas. From the author's view, this approach allows for efficient, cost-effective event prevention policy implementation and community warning while avoiding many of the pitfalls in cases such as Radar Covid.

Regarding previous works in effectuation and its role in innovation, to the author's knowledge, there is a lack of contributions from an engineering perspective in the context of information asymmetry and uncertainty. In [153], the authors carried out a study to avail decision-making mechanisms when creating a new product using a game console as an example. In the light of their conclusions, there was a clear linkage between business models, causation processes, and effectuation, with the former being the focus of their research. In [154], the authors explored the role of individual business founders presenting a qualitative analysis when effectuation and causation were employed as decision-making logics. Finally, in [155], [156] it was shown how effectual logic and principles were embraced during the development of new products.

3.2.2. State-of-the-Art in Warning Systems Based on Radio Frequency Technologies

In this application, the study of people's behavior in indoor and outdoor areas was addressed from three different perspectives, namely, using sensors [157]–[161], image processing [162], or historical data and applying predictive models [163]. In this section, a review of the works carried out to estimate people's behavior using sensors and wireless technologies is presented.

One of the first works to derive the number of people from the imprint left on Radio Frequency (RF) signals was conducted in [164]. The proposal was based on the use of Received Signal Strength (RSS) and a Link Quality Indicator (LQI) to obtain an estimation of crowd density. They assumed that there was a linear relationship between the number of people between two nodes (transmitter and receiver of RF signals) and both the RSS amplitude (decreasing) and the RSS variance (increasing). They also assumed that the LQI replicated this behavior. Experimentally, they demonstrated that their hypothesis was true. Indoor tests were conducted in two scenarios, namely a Zigbee wireless sensor network and a WiFi 802.11b network. In the latter, only RSS was measured. As the authors indicated in their work, the accuracy of the system should be improved. In [165], an improvement to [164] was introduced. The new method was based on using successive signal cancellation in an iterative manner to count people in indoor scenarios. The procedure was as follows: first, the testing scenario was empty, and they measured the ambient RSS in this condition. Then, a person walked randomly, and they measured the RSS, so by subtracting the obtained measurement from the ambient RSS, the authors quantified the impact of one person on the RSS values. However, they were aware that the relationship between the number of people and the RSS variation was not linear. They therefore proposed a consecutive iterative cancellation method, selecting at each iteration the strongest signal to be subtracted from the RSS until no further presence was detected (i.e., sequential counting). The authors obtained good results, although limited to a very low number of people. The reason is that their proposal cannot yet deal with a severe multipath effect.

Aiming to improve the accuracy of previous proposals and following the same device-free trend, two methods were proposed in [166] to estimate the number of people in an indoor environment. The two proposals were based on linear regression and vector regression using the RSS of WiFi signals as the physical descriptor. For the evaluation, they used dedicated wireless devices (Raspberry Pi). The suggested method was as follows: the wireless devices calculated the RSS of the signal received from the WiFi Access Point (AP). These values were then collected by a computer, which estimated the number of people in the room. For the estimation, linear regression or vector regression—non-linear regression based on Support Vector Machine (SVM)—was employed. The coefficients of the regression formula were previously calculated with historical real data obtained from the experiments. One of the main findings of this work is the corroboration that there was no linear relationship between RSS variations and the number of people in the room.

In [167], the effect of moving people on the received RSS was studied from two different perspectives: the blocking of the Line of Sight (LoS) and the multipath effect. Once characterized, they combined both to obtain the probability distribution of the received signal amplitude as a function of the number of people in the scene. Then, the Kullback–Leibler divergence was applied to match the experimental measurements with the previously assessed analytical expression. The parameter that minimized the divergence between both was interpreted as the resulting people estimation. One possible limitation of this work is that they first modeled the pedestrian movement from the experiments. Given the limited conditions of this test (i.e., few people, perhaps of the same age and thus with a similar walking profile, walking alone, etc.), it would be necessary to verify the results with more random groups of people, in higher numbers, etc. This is because, for instance, the probability of blocking the LoS was obtained by applying the previously defined motion model. Results were very robust with an estimated error of less than two people (out of 9) with directional antennas. With omnidirectional antennas results were worse, although still good compared with other proposals.

Another interesting proposal was suggested in [168]. The method was based on Channel State Information (CSI) measurements. The authors attempted to obtain a relationship between CSI and the number of moving people. A new metric was introduced, namely Percentage of non-zero EleMent (PEM), which represents the number of non-zero elements of the dilated CSI matrix. This metric is directly proportional to the crowd size, giving a saturation value for a specific number of people. Its performance is more accurate than [165]. Similarly, a novel system was proposed in [169] also based on CSI measurements, which did not need to be trained in the same environment where the tool was to be used. The proposal was based on analyzing the Doppler spectrum obtained via the CSI in a WiFi network, but without employing a reference signal (i.e., it cannot be classified as a radar-like approach). The idea lies in the fact that the Doppler spectrum varies according to the number of people in an indoor environment. Particularly, the authors observed the time variations of the Channel Frequency Response (CFR) represented in the Doppler. The selected feature for people estimation was the spectral kurtosis of the Doppler spectrum. They used a device as processing equipment. This device sends a ping to the WiFi AP and the WiFi AP replies. The response is then used to obtain the CSI and CFR. Experiments in different rooms and with the same number of freely moving people (limited to seven) were carried out. Good accuracy of more than 92% was obtained in the performed tests.

In [170], the performance of CSI-based and RSS-based crowd-counting systems in the same indoor scenarios was compared. In addition to the relatively good accuracy in counting people that both approaches offered, the authors discovered two interesting facts. First, the RSS-based proposal presented good results when blocking the LoS was the main signal impairment. Second, the CSI-based solution was less dependent on the indoor scenario (e.g., room size) compared to the RSS-based solution.

From a totally different perspective, Wi-Counter was introduced in [171]. This method used RSS as the physical layer input data, but the proposal falls into a device-based category, that is, using data that are generated by people's own wireless devices (e.g., smartphones). The proposal operated as follows. There was a preprocessing step to eliminate noise and disturbances; specifically, using the Wiener filter and Newton interpolation. Then, there was a learning/training phase employing neural networks to learn the relationship between WiFi signals and number of people. There were also two sub-phases. One offline sub-phase to assess the eigenvalues relating RSS and people from captured data. Then, eigenvalues were introduced into the model and trained using a sigmoid activation function. Afterward, another online sub-phase, where real WiFi signals were captured, the eigenvalues were calculated and used as input to the already trained model to obtain the estimated number of people. A notable accuracy of 93% was achieved, but tests were only carried out in indoor environments. More importantly, the method required user cooperation for data gathering, which was later used in offline training.

Another crowd-counting device-based system that also used the WiFi-enabled signals from the users' mobile phones was presented in [172]. Unlike [171], that proposal was not anonymous. An OpenWrt device captured all WiFi frames from the defined area of interest (i.e., not only probe request frames sent by mobile devices, but all existing frames). To do so, they employed the promiscuous listening mode. Each Medium Access Control (MAC) address was associated with a unique IDentifier (ID). Other information such as RSS was also stored. An RSS threshold was set to avoid observers that did not participate in the event but were temporarily within the region of interest. The number of people was obtained simply by eliminating those IDs with RSS values that were below the set threshold and by adding the remaining unique IDs. The robustness of this system was assessed in an indoor scenario. The accuracy achieved was 83% compared with visual accuracy. Nevertheless, the proposal presents some limitations. First, privacy concerns arise due to the use and storing of unique information from mobile devices. Second, the crowd estimation is obtained after the end of the event. In other words, it is not useful for real-time estimations. As stated by the authors, further improvement is needed, for instance, it is not clear whether it could be used with a moving crowd since a RSS threshold should be defined in advanced, among other concerns.

Following the same approach, a crowd estimation system based on capturing the probe request frames from the users' mobile devices was proposed in [173]. The most remarkable particularity of this proposal is that it was designed and tested on a bus, thus providing a novel scenario with interesting insights for Intelligent Transportation Systems. The algorithm only used timestamps and RSS measurements for its operation, leaving the use of other available information from the probe request frames (e.g., MAC, Service Set Identifier - SSID, WiFi card driver, channel frequency) for future work. Each bus was equipped with a scanner node, the goal of which was to gather the probe request frames. All captured frames were then sent to a central server that processed them. Two intervals were defined, namely, the active interval and present interval. The present interval was the time that elapsed since the first probe request frame from device A was received until device A was considered to be within the bus. Active interval was the maximum allowed time between consecutive probe request frames from the same device. By using these two intervals and a RSS threshold, the system was expected to estimate the number of passengers on the bus. The values for these parameters were heuristically obtained based on two bus trips with only one scanner node and without implementing communications with the central server. Although the proposal was simple, the accuracy was very low, given its very incipient state.

3.2.3. Smart IoT-Based Early Warning System

In this section, the proposal is described. It has been designed as an Artificial Intelligence (AI)-powered solution that analyzes people flow and predicts their next move, generating strategic and tactical insights at the operational level. The key performance indicators that our system generated were the number of people in a specific location in a given time, the average time spent in particular areas, and the number and density of people that interacted over a particular period, among others.

As depicted in Figure 23, our proposal (called “Dolphin”) followed a sensor fusion approach, specifically operating as a data level fusion algorithm, merging sensor data from different sources in a way that less uncertainty is present in the output information than would be obtained if raw data were processed separately [174]. Thus, at the first level, the low-cost IoT devices were selected and deployed. Off-the-shelf IoT devices were selected to accelerate the implementation phase. These devices (e.g., Raspberry Pi 3 and Raspberry Pi Zero W) incorporate both BLE and WiFi communication modules. People carrying any portable device compatible with BLE and/or WiFi would then be detected by our solution. It is important to note that all processes included in our system are secure-by-design (i.e., no personal identifiable information (PII) is stored at any time, and temporal non-recoverable virtual identifiers are created from BLE and WiFi device information using hash functions and temporal keys).

These anonymized data from detected devices are then transmitted to the edge nodes using the MQTT protocol. MQTT is a standard messaging protocol for the IoT with numerous advantages [175], [176]. One of them is its design as a lightweight messaging transportation, which makes it a much more energy efficient option compared to other alternatives such as Hypertext Transfer Protocol (HTTP). MQTT follows a topic-based publish–subscribe operation mode. Its header size is small, so it optimizes network bandwidth. MQTT messages can be sent in both directions, from IoT nodes to the edge devices or the cloud and vice versa, hence allowing more versatility in the system design. Finally, it is possible to enable encryption for the exchanged MQTT messages and different levels of QoS can be configured. Consequently, it has been used in some interesting previous works related to IoT-based monitoring [177].

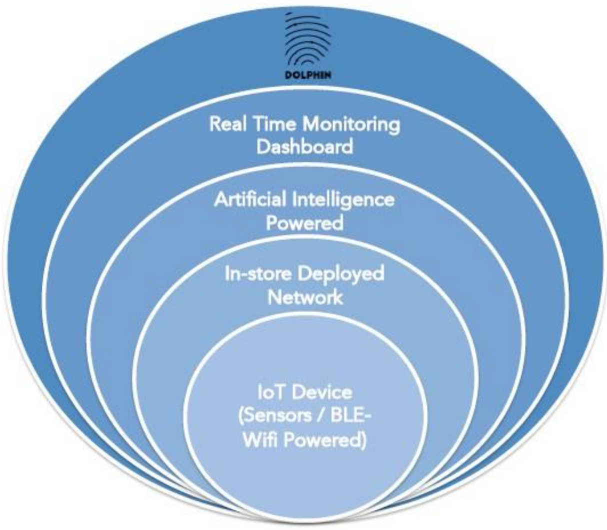
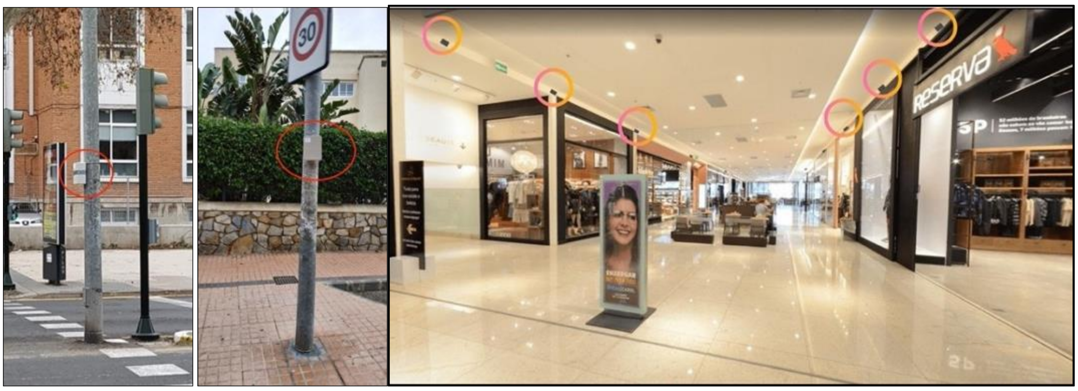


Figure 23. Sensor fusion approach with combined technologies: BLE, WiFi, and 4G.

Edge nodes are also IoT devices whose function is not to capture data but to apply the first level of processing by applying a Machine Learning (ML) algorithm that locates the anonymized device's carrier with an estimated error smaller than one meter in indoor areas. The error estimation as well as the initial configurations were calculated by carrying out extensive experimental tests in two control testbeds, one indoor and one outdoor (see Figure 24). Figure 25 illustrates the initial results in terms of pedestrian flows in the outdoor real scenario. The supervised ML algorithm for indoor geolocation was based on a convolutional neural network and is currently under an intellectual property process. Then, the output of the algorithm, composed of the x and y coordinates of all located virtual identifiers within the geographical area under monitoring, is then sent by the edge nodes to the central servers at the cloud. In our experiments, only one server was needed to deal with the amount of data generated (approximately 1.8 GB of data per month). Table 14 includes the characteristics of the cloud server and an example of the CPU usage of the server is depicted in Figure 26. The central server is in charge of the second level of processing, with two main goals, namely forecasting and visualization. The forecasting procedure, also under IP, permits us to estimate the evolution of the Key Performance Indicators (KPI) for the next hour and/or days, depending on the amount of data already stored by the platform. For visualization, a graphical user interface was implemented as depicted in Figure 27.



(a) (b)

Figure 24. Example of the experimental tests before deployment; (a) outdoor; (b) indoor.

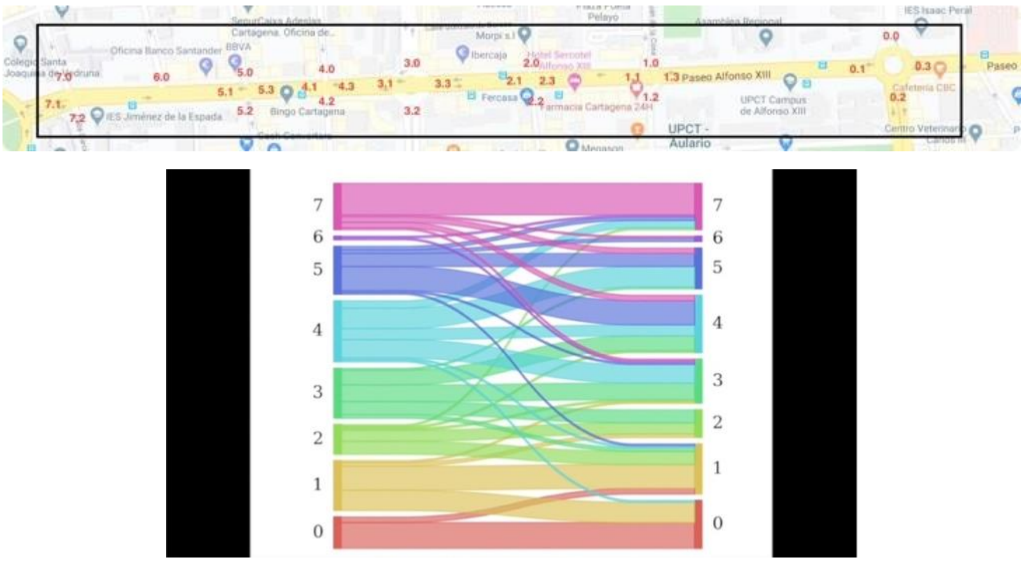


Figure 25. Example of pedestrian flows from the data obtained in the outdoor experimental tests. The image/video shows the number of pedestrians that moved from location *x* to location *y* in periods of time equal to 15 min. Note that the number indicates the street crossroads from crossroads 0 on the right to crossroads 7 on the left, as shown in the map above, and the sub-index at each crossroad designates the street; for instance, 7.2 means street 2 in crossroad 7.

Table 14. Features of the cloud server used in the real deployment

Type	Description
Server	Cloud L Ionos
CPU	2vCores
RAM	4GB
SSD	80 GB
OS	Linux Ubuntu 18.04

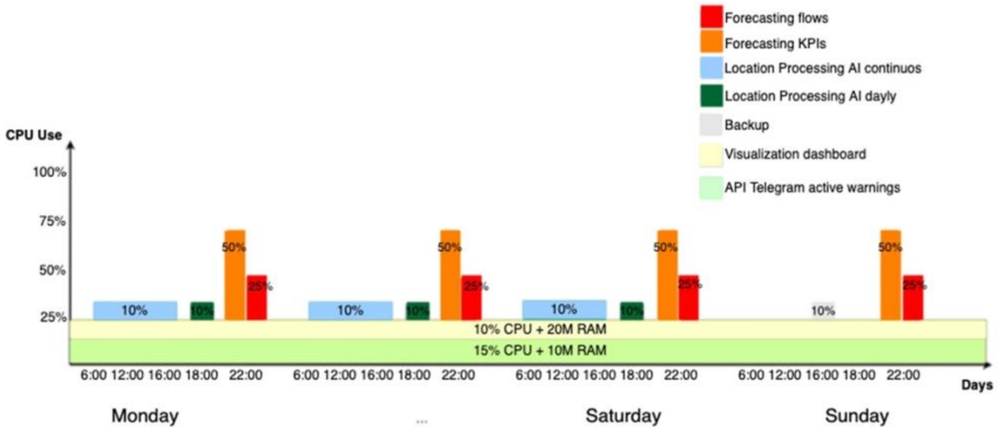


Figure 26. CPU usage of the server in real deployment.

Figure 27. Graphical interface for the user showing the KPI of one day during the real deployment in an indoor environment. Upper left: overview panel of the developed EWS platform; Upper right: people flows, starting from the entrance of the building and showing two levels of depth, first the top three visited locations from the entrance (i.e., where do people go once has entered the building?), and second, the next top three visited locations from the previous three places; Lower center: heatmap with people density in the two floors of the monitored area.

As indicated in Figure 28, the platform shows the number of people in real time (in Figure 28, it can be observed that the current capacity was 2%). This information is configurable, so it is possible to show the capacity of the complete monitored building or a specific area within. Therefore, it can be used to control indoor capacity either for a complete area or for smaller specific zones (e.g., rooms, offices, store sections). Another important feature shown in Figure 27 (lower center) is the heatmap, highlighting people density in the monitored zone. To facilitate the warning process, a chat bot was also developed using the commercial application Telegram [178] using APIs (see Figure 28, Left). In this case, the warning system is bidirectional, being possible to automatically notify the subscribers of specific events (e.g., capacity above a given limit, people proximity exceeded for a given time, and so on) or to answer specific questions made by the users about the KPIs. The complete EWS was built in six months, deployed in real indoor scenario in two weeks, and was run for six months without incurring any problem, successfully confirming the initial two hypotheses.

One question that arises after successfully deploying this EWS is, what determines the adoption (or rejection) of technology in demanding situations? One initial hypothesis could be that the more accustomed companies and society are, even if in a totally different context (e.g., in an industrial environment), the faster the technology adoption in daily life. A preliminary reasoning is that those countries with higher usage of Quick Response (QR) codes have better assimilated the use of QR applications for COVID-19 track and trace as could be the case in South Korea or Japan. This hypothesis requires a deeper study that will be addressed in future works.

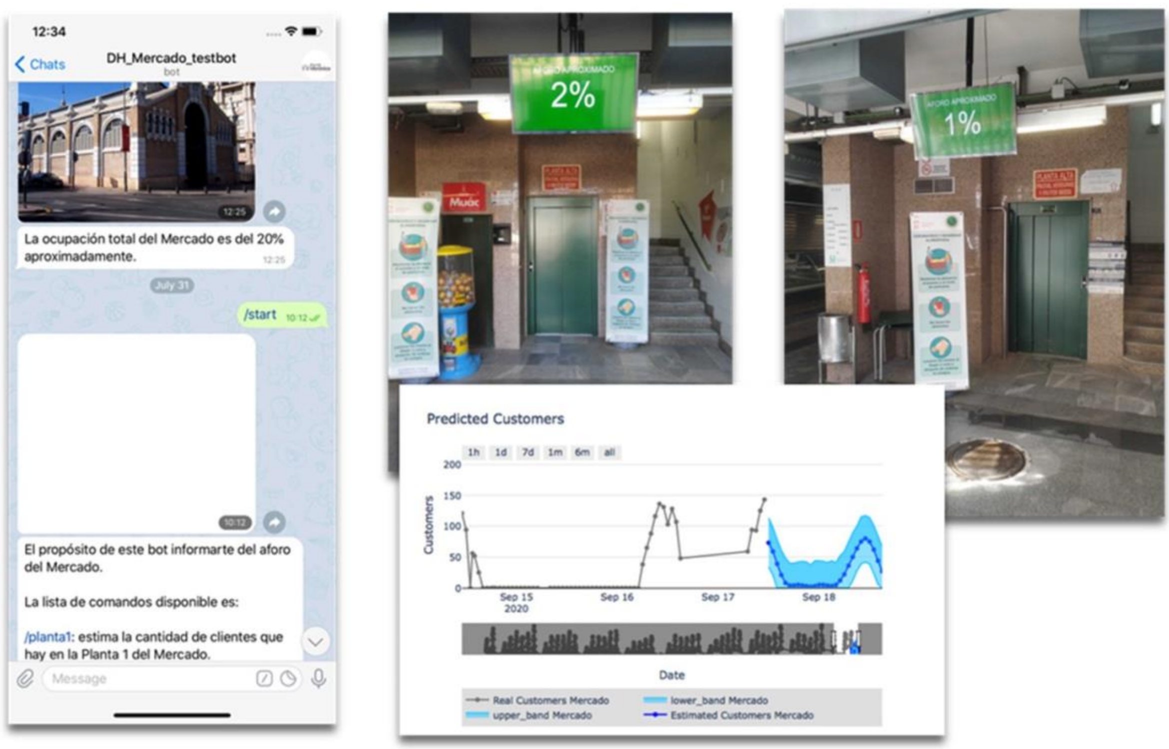


Figure 28. Example of the results obtained in the real indoor deployment; Left: example of the instructions and information shown through the Telegram bot (active warning); Right: physical screens to warn clients about the current capacity at different times, limiting if necessary, the entrance to the monitored space; Lower: forecasting the number of clients for the next 24 hours.

3.2.4. Conclusions

When faced with uncertain decisions, it is paramount for individuals and decision-makers to have as much trusted information and knowledge as possible, deciding on the best strategies to avoid drastic consequences such as those produced by a pandemic such as COVID-19. In this thesis, an innovative early warning system was proposed. The system encompasses several technologies, particularly WiFi and BLE, as an example of a sensor data fusion approach.

It has been shown that this solution can show real-time information about an indoor or outdoor area in terms of capacity (i.e., estimation of the number of people, people flow, time spent in specific areas, and indoor geolocation with an estimated error smaller than one meter). All this information allows one to generate notifications and alarms as required. In addition, the system was based on an IoT-edge-cloud architecture, using APIs and providing a graphical interface and a chatbot for human interaction. In addition, it can be concluded that crisis-like situations can spark innovation, especially if decision-makers act like entrepreneurs and innovators by applying effectual principles when assembling resources to build new products and services. Early warning systems in such a context can serve as perfect examples of innovation, leveraging a crisis (contingencies) to make overall pandemic preparedness more robust and sustainable in the long term.

This logic has been successfully tested in the solution presented by constructing an innovative early warning system, creating a robust real-time EWS for pandemic control in specific areas, allowing for efficient, cost-effective event prevention policy implementation and community warning. In future works, we plan to incorporate additional sensor data sources such as video capture and the containerization of the system to optimize its performance at scale.

3.3. Crypto Degrees – Blockchain Verified University Degrees

The third application leverages the know-how in innovating by applying and testing the effectual principles and agile methods accumulated by the author and the team that built the two solutions presented in sections 3.1 and 3.2 and guided by the theory described in chapter 2.

Following and testing the same principles, we created "Crypto Degrees," a system that leverages blockchain technology to verify the degrees issued by a university quickly and securely. It allows any student or company to verify any of the degrees a university-issued from a web browser. With this solution, any student has a secure, certified, and fast access (web-based) to the information of the academic degree achieved and monitor (trace) any changes that may occur in their academic information (e.g., more degrees, dates)

This solution also aimed to create a real-world innovation in the spirit that guided this thesis. In this case, it assumed that democratizing the use of blockchain to the next level of the value chain is possible.

It requires working with multiple stakeholders of different nature (e.g., academia, private and public organizations) with the ability to bring the digitization of the physical environment and the accessibility of information from data to all its customers and suppliers in an agile, straightforward way and resulting in a direct impact on their business and society. In this sense, we initially developed it as a minimum viable product converting it later into an actual service.

Specifically, Crypto Degrees was effectively launched at the Universidad Politécnica de Cartagena (UPCT) and at the time of this writing, it is offered as a free service to UPCT students and alumni at https://www.crypto.upct.es/.

3.3.1. Blockchain technology

Blockchain-based authentication systems are generally based on identity verification through digital signatures using public-key cryptography. For example, when an identity is authenticated on the blockchain, in many instances, the only verification performed is to determine whether the appropriate private key signed the transaction. Although this technology has many potential applications, there are several challenges, such as its computational costs (e.g., mining) or security risks (e.g., attacks such as content theft or denial of service).

In short, a blockchain is a database and a network of nodes that collaborate for the same purpose. In this case, the database comprises data structures called blocks, which are chained together. It is a shared, distributed, fault-tolerant database that only allows data aggregation (no modification or deletion actions can be executed). In this way, records are maintained in the blocks, while all blockchain users can access the blocks without the possibility to delete or modify them.

The blocks are connected, forming a chain as each block has a hash value of its predecessor that acts as a linking element. Each block usually contains several verified transactions. In addition, each block includes a timestamp indicating the instant of creation of that block and a random number (nonce) for cryptographic operations. On the other hand, the blockchain network consists of nodes (devices with connectivity between them through a communication network) that maintain the blockchain in a distributed peer-to-peer manner. All nodes have access to the blocks and the blockchain but cannot control them completely. In this way, blockchain allows communicating parties to interact without a trusted third party. The interactions are recorded on the blockchain providing the desired security requirements.

When a blockchain user needs to interact with another user, they transmit their transaction to the blockchain network. Several nodes in the network then check if the interactions are valid and build a new block of valid transactions through a mining process. If the new block is deemed valid, it is attached to the blockchain (added) without the possibility of being removed or modified later. If the interactions are not validated, that block is removed and not added to the chain. Both transactions and blocks are signed; therefore, they cannot be reversed or denied in the future (offering non-repudiation).

Depending on the different levels of access permission, blockchains can be categorized into 1) public blockchains (e.g., Bitcoin, Ethereum), 2) consortium blockchains (e.g., Hyperledger, Ripple), and 3) private blockchains.

So far, three generations of blockchain have emerged.

The first one corresponds to the release of Satoshi Nakamoto's paper in 2009 [3]. The application of this generation was restricted to monetary transactions and implemented as part of the Bitcoin cryptocurrency, which became the first application to use the blockchain concept.

The second generation of blockchain technology had broader use cases, exchanging assets instead of only currency. In this generation, users own "assets" that can be exchanged. In the third generation of blockchain, smart contracts were introduced.

The role of smart contracts is essential for future developments and new generations of blockchain. They are computer programs that run through the blockchain network and can express triggers, conditions, and business logic to enable complex and programmable transactions. According to the operational mechanism of smart contracts, their life cycle is summarized in five stages: 1) negotiation; 2) development; 3) deployment; 4) maintenance; and 5) learning and self-destruction. The decentralization, enforceability, and verifiability characteristics of smart contracts allow contract terms to be executed between untrusted parties without the involvement of a trusted authority or central server. Thus, smart contracts are expected to revolutionize best practices in supply chain management, such as Service Level Agreements SLA, and new applications in telecommunications (e.g., 5G, IoT), finance, management, and health).

Based on the first analysis of state-of-the-art [179]–[184], clear challenges are limiting the practical application of this technology:

1) Privacy.

- Linked transactions: Although users of public blockchains can create new public addresses independently, the ledger tracks their entire history in blockchain transaction graphs that link all independent public key addresses to the user.

- Private key management and recovery: private keys are used to sign each transaction on the blockchain; therefore, they are critical for user security and privacy. In such cases, appropriate key management systems should be implemented. If compromised, it can leak privacy and allow for identity theft.

- Malicious smart contracts: The execution of smart contracts can lead to vulnerabilities such as intellectual property theft. Validation nodes execute smart contracts, and the ledger records the code, input, and outputs. A node could access the data processed in the transaction compromising the user's privacy.

- IoT: the data collected is publicly accessible and available to all users. This can be a point of evasion and privacy concerns. In addition, pervasive sensing systems in IoT continuously collect consumers' personal and confidential data. Entering this data into open ledgers could lead to privacy concerns. Recently proposed methods can guarantee the anonymity of data sources (e.g., e-health patients) while simultaneously guaranteeing data authentication [184].

2) Scalability and Side Chains.

- Scalability is one of the main concerns of current blockchain technology. For cryptocurrency platforms like Bitcoin, the blockchain can perform an average of four transactions per second, while Ethereum can perform an average of 12 transactions per second. This performance is much lower when compared to the performance of other distributed systems and services, such as Facebook, which handles millions of transactions per second.

- Side chains, also known as auxiliary channels, are used to accelerate the performance of blockchains; their operation is based on the fact that transactions are resolved between parties quickly outside the main chain and are established on it only once a day. In addition, some new blockchain approaches significantly improve the consensus algorithms of mining nodes. For example, platforms such as Algorand and IoTA can provide substantially better performance than blockchains implemented with Ethereum and Hyperledger. Additional research is still required to improve scalability, current communication overhead, and the yet-to-be-established quality requirements in terms of QoS and Quality of User Experience (QoE), such as latency, storage, network losses, and power consumption, to become comparable to highly efficient distributed systems.

3) Blockchain security. The power of decentralization provided by blockchains becomes a double-edged sword, making them a target for abuse and misuse. Despite the security measures to prevent attacks, blockchains are vulnerable to cyberattacks. As the consensus mechanism depends on the power of miners to obtain hashes, the decentralized platform sometimes becomes centralized in a few miner farms that control the consensus of the entire blockchain. This problem affects public blockchains like Ethereum and Bitcoin and, less severely, private/consortium blockchains like Hyperledger. In addition, the execution environment of the mining nodes is not protected, especially in private blockchains, where the results can be manipulated. These vulnerabilities must be protected to avoid misuse.

4) Smart contracts vulnerabilities. To ensure a good implementation of smart contracts, it is essential that the code and network information is protected and not accessible, as they can be vulnerable to cyber-attacks. These vulnerabilities appear mainly due to poor and negligent programming practices in the languages in which smart contracts are written. Malicious miners and users can exploit these vulnerabilities and profit in return, usually in the form of cryptocurrencies provided by exchanges. Typical cases include:

- Changes in the order of transactions. The miners themselves are in charge of choosing the transaction order. In the case of dependent transactions invoked through the same smart contract, this can generate problems in the system.

- Timestamp changes. Miners set the block timestamp according to their local system time, providing a miner to advance the block timestamp a few seconds for other miners to accept his block. The problem comes from the fact that some transactions need some time to occur, as in money transfers.

- Attacks on smart contracts. When failures occur in calls between contracts, exceptions are thrown and must be properly timed. If this is not the case, these contracts can carry out attacks. The same happens if, during the waiting time between these calls, successive calls occur again, collapsing the correct contract functioning.

- Limitations of the blockchain itself. Due to blockchain's invariant nature, irreversible bugs can occur, such as limitations due to network performance, lack of Oracles (reliable data sources), or non-existence of regulations and standards. In conclusion, it is crucial to test smart contracts' vulnerabilities and develop tools that allow users to maintain their code's highest level of security.

5) Integration with AI. Blockchains and smart contracts are the base infrastructure to implement parallel organizations/societies based on the Cyber-Physical-Social Systems (CPSS) concept because they provide efficient decentralized data structures and an interaction mechanism for distributed social systems and distributed AI. It should be noted that nodes running smart contracts can be considered software agents that understand the external environment and act on it. Since different nodes represent the interests of different individuals in an organization/society, they deploy and execute contracts through autonomous negotiation, thus forming several Decentralized Autonomous Organizations (DAO) / Decentralized Autonomous Corporations (DAC) / Decentralized Autonomous Societies (DAS). Beyond traditional organizations/societies that are organized in a hierarchical structure and top-down commands, DAOs/DACs/DASs can help solve several persisting problems in organizational management, such as communications management. However, as described before, there are several limitations and challenges. For example, the execution time of smart contracts on a blockchain is always deterministic and cannot be probabilistic. This makes it predictable and vulnerable to attacks. Instead, random, unpredictable, and approximate execution could be chosen by applying decision algorithms based on artificial intelligence and machine learning. This provides a novel

solution for developing consensus protocols for mining nodes in which the results would be accepted with a particular degree of precision or certainty, as they would not be exact.

3.3.2. Crypto Degrees at UPCT

The purpose of Crypto Degrees (https://www.crypto.upct.es/) is to create a system capable of verifying the university's degrees quickly and securely. It allows any student or company to verify (from a web browser) any degree issued by the Universidad Politécnica de Cartagena.

The blockchain stores in each block a register of the university degree with the student's data and the necessary information to validate it. Its security depends on the size of the chain, i.e., the more blocks added to the chain, the more difficult it will be to carry out malicious attacks against it.

This form of digital certification provides many advantages. University students are the primary beneficiaries of this service. At any time and from any network or device, the service allows them to view the information that certifies their university degrees in the network. In addition, students can publish their information through a link in any social or business network so that companies can verify it. This simple process to verify one's background can have multiple benefits for students and organizations, e.g., reducing barriers to hiring qualified remote workers. In addition, it avoids significant problems and limitations of current schemes such as identity theft or document forgery.

Crypto Degrees is a private blockchain, i.e., any user or organization cannot perform transactions or be a node in the chain unless authorized (which would be the case of other universities, for example). This restriction increases the security of the chain and the system. Nevertheless, the data of the securities registered in the chain are still public, i.e., visible to any unauthorized user. In order to prevent any user from being able to view the titles in any way, he must know the title identifier or its Uniform Resource Locator (URL). In case of not knowing it, obtaining an identifier that corresponds to one of the degrees, although not impossible, is computationally challenging.

As shown in Figure 29, the UPCT is the only node in the business network and contains a replica of the chain. This node can perform and validate all types of transactions. On the other hand, external companies and students can read all the chain's data to verify the titles, but without being able to perform any action on them (after receiving the information from the degree owner).

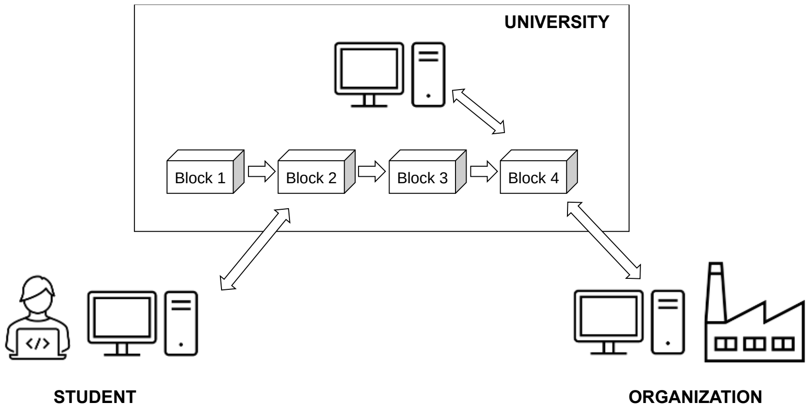


Figure 29. Crypto Degrees service.

In Figure 30, we can see the internal structure of a blockchain service using the Hyperledger Fabric framework. As a starting point, users access the service through any device via a web browser. The browser, in turn, accesses the web server that contains the application that allows the user to interact with the service. This application interacts with the REpresentational State Transfer (REST) server through its API to execute the queries made by the user. Finally, the REST server executes the requests on the peer through the Hyperledger Fabric framework. Once the process is finished, the response is returned following the reverse process until it reaches the client again.

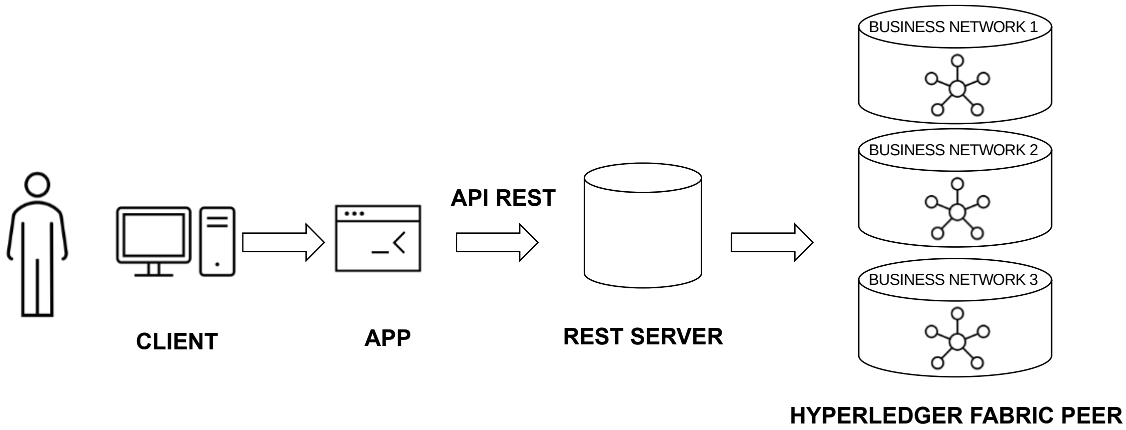


Figure 30. Service structure.

Any student can apply to have her/his official UPCT degree at Crypto Degree in two steps:

- Give her/his consent to use this service (Figure 31), following the General Data Protection Regulation (GDPR).

- Then, as soon as the student completes the number of credits required in one of the official university degrees offered at the UPCT, her/his degree will be automatically added to the blockchain.

Collecting students' consent is also incorporated into the web platform. It only requires the student to authenticate with her/his university credentials and accept the terms of use.

Once the student graduates, the system sends an email to the student's email address with a link to her/his blockchain-verified degree. This link can be accessed from any device and browser. Figure 32 shows an example of a university degree registered in the Crypto Degrees service.

Solicitud

Marque la siguiente casilla para expresar su consentimiento:

☐**AUTORIZO** a la UPCT a tratar mis datos de carácter personal mediante el uso de tecnología de cadena de bloques (blockchain), con la finalidad de prestar un servicio de acreditación de títulos universitarios por medios electrónicos. Este servicio de acreditación permite a las personas y entidades con las que interactúe el Usuario, el acceso al registro de acreditación de títulos con base en la información obtenida directamente de la UPCT, siendo por tanto verificables de forma pública los siguientes datos del Usuario: nombre, apellidos, cuatro dígitos del DNI, titulaciones obtenidas en la UPCT y fecha de obtención de las mismas.

Correo electrónico:

alumno@mail.com

Aceptar

De conformidad con lo que dispone la legislación vigente en materia de protección de datos personales aplicable a la Universidad Politécnica de Cartagena (en adelante UPCT) y publicada en el buscador de normativa UPCTlex (https://lex.upct.es) dentro del área temática Protección de datos, se le comunica que la UPCT, con CIF Q8050013E y con domicilio fiscal en la Plaza del Cronista Isidoro Valverde s/n - Edificio Rectorado - 30202 Cartagena, tratará sus datos personales, obtenidos a partir de la información facilitada en la matriculación y en su expediente académico de esta Universidad, sin que sean tratados datos especialmente protegidos y correspondientes a las categorías identificativas y de carácter académico, con la finalidad de prestar un servicio de acreditación de títulos universitarios por medios electrónicos. Puede ejercitar los derechos generales de acceso, rectificación, cancelación, oposición, limitación y portabilidad mediante comunicación escrita y adjuntando fotocopia del DNI, dirigida al Registro General en la misma dirección del domicilio fiscal de la UPCT o bien a través del Registro telemático accesible en la Sede Electrónica de la UPCT, https://sede.upct.es/. Puede consultar la información adicional y detallada sobre Protección de datos, sus derechos y la Política de Privacidad de la UPCT en el siguiente enlace, donde también podrá consultar información ampliada sobre este tratamiento bajo la denominación Titulación Académica en Blockchain. https://www.upct.es/contenido/universidad/proteccion_datos_personal/ . Para la realización de cualquier consulta sobre el tratamiento de datos personales realizado por la UPCT, además del Registro telemático, ya mencionado, puede enviar un correo electrónico a la dirección dpd@upct.es.

Salir

Figure 31. Consent to comply with GDPR.

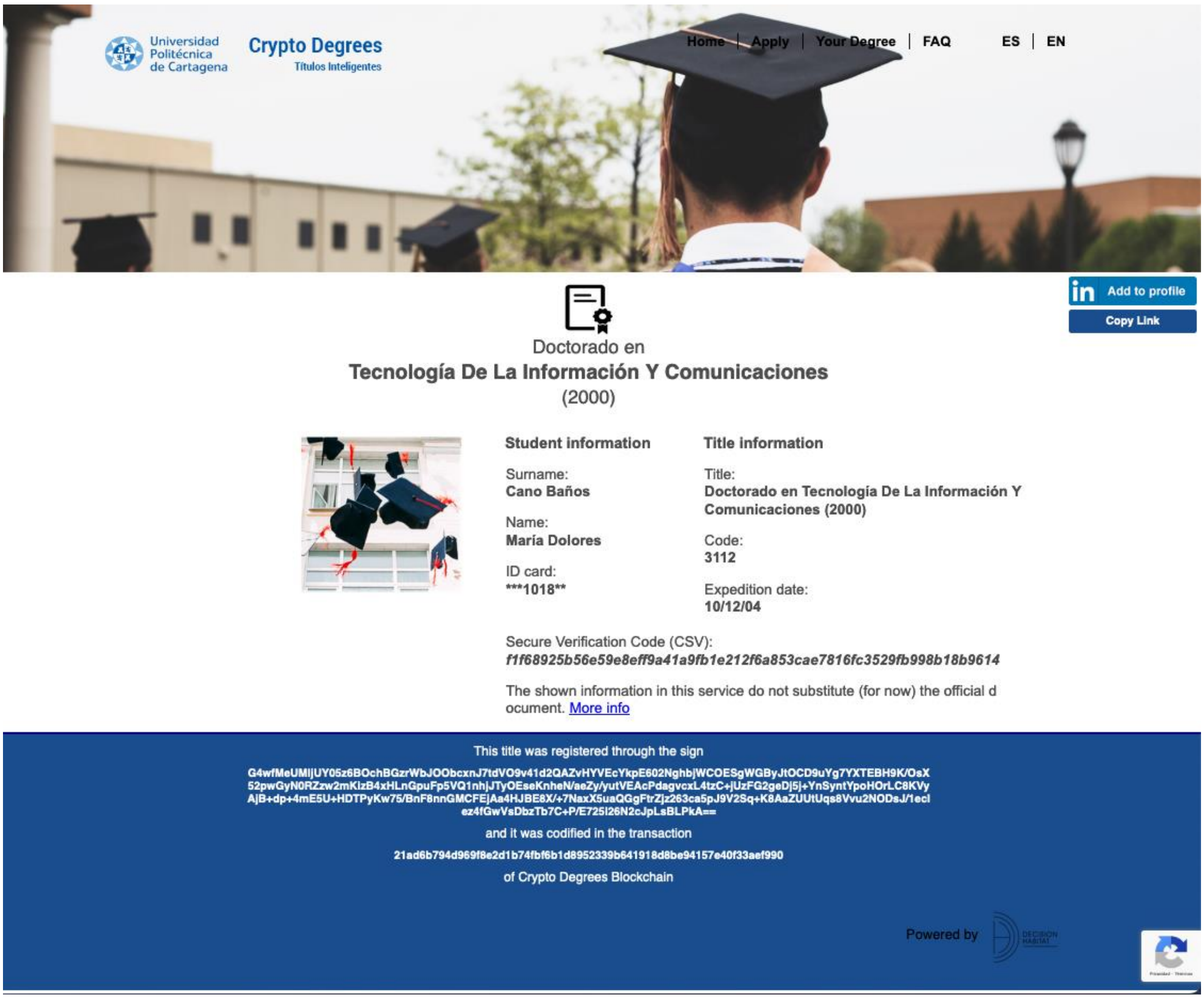


Figure 32. Example of a degree verified by Crypto Degrees (https://www.crypto.upct.es/titulo.php?id=f1f68925b56e59e8eff9a41a9fb1e212f6a853cae7816fc3529fb998b18b9614).

3.3.3. Results

Several technological macro trends have converged in the last decade: cloud computing, artificial intelligence, the Internet of things, cybersecurity, and blockchain.

The team's deep experience in the telecommunications sector and global business environments makes us optimistic about this convergence of trends and the opportunities arising from new ways of working and interacting with our environments.

The research focus on the blockchain topic has two key factors:

1) Cost-effectiveness: We believe products should be affordable and "plug & play ready" (easy installation) for a wide range of use cases so that more companies can be impacted.

2) Platform-oriented: We seek to collaborate to build robust solutions, leveraging the industry and technical expertise of our partners, future partners, and customers to connect and expand the impact of our products.

As a result, to the best of the author's knowledge, we developed the world's first blockchain application for university degrees with government/institutional support (validated by Spain's Murcia Region Government), marking the path to be followed by other universities in the Region of Murcia. It is a smart degree verification system based on blockchain technology.

This prototype has achieved initial indications of product-market fit, with the official launch of the MVP and traction of real users - Landing Page MVP (https://crypto.upct.es/) and with a continuous number of increasing users since 2020:

- Institutional validation from both UPCT and the Region of Murcia, making the MVP the first "Smart Degrees" blockchain application in the world to have regional implementation support (despite the lack of legislation on the subject globally). Example of impact: https://www.upct.es/destacados/cdestacados.php?c=28&ubicacion=general&id_buscar=11933

- Positive initial traction of the first users: https://www.youtube.com/watch?v=eDT7Hu4zz2M

4. Conclusion

This thesis examined the innovation and new venture creation phenomenon by applying the effectuation principles and accelerated methods.

Using a case study approach and effectively creating and launching three innovative technology applications in the real world, this thesis sought to understand the use of the effectual rationality in the decision events that allowed its creation and implementation.

As presented in chapter 2, the entrepreneur is not independent of the context in which his decisions are made. He is part of a dynamic environment involving multiple decisions, which are interdependent and simultaneous. In this sense, several stakeholders and decision-makers refine the entrepreneur's aspirations until they crystallize into goals and real-world innovations.

The creation of the three applications systematically leveraged the principles and methods of a non-predictive logic. From the definition and refining of specific technologies to engaging with several stakeholders for its actual implementation, it was evident that innovation is a continuous, multidisciplinary, and multi-stakeholder endeavor.

Similar to what the author faced in this thesis, entrepreneurs focus on how much they can bear to lose and experiment with as many strategies and resource combinations as possible, given the resources already under their control. When innovating and creating a new venture, the goal is not necessarily to maximize potential financial returns but rather to reduce the uncertainty of specific strategies and resource combinations. Through actions and "getting things done," entrepreneurs innovate, co-creating possible futures from these resource combinations and constant engagement with early pre-committed partners while reducing uncertainties around the innovation / new venture.

By leveraging the effectuation theory and the operational methods used in acceleration programs, this thesis had the ambition not to characterize what would be the innovation and entrepreneurial process but, instead, to give alternative clues of analysis, as well as to explore the ideas inherent to the decision to innovate and create new ventures under uncertainty and ambiguity of objectives

In general terms, aspects of how the researcher dealt with a series of uncertainties while implementing the three applications presented were highlighted and discussed, many of which could be qualified as "true" uncertainties in Knight's [83] terms.

As observed in chapter 3, the creation of every solution (from design to implementation) indicates that several decisions were made without clarity of objectives of what the final product would be, who could be the initial customers, and if an actual result/impact would be achieved. By systematically applying accelerated/agile methods operationalizing the five effectuation principles, it was possible to reduce the uncertainty along the way while expanding resources and converging goals around each application.

Contrasting the cases described in chapter 3 with the effectuation theory presented in chapter 2, one can observe:

- Uncertainty has always been seen as a resource to be exploited and a process upon which decision-making occurs. On the contrary, as the example of "Dolphin" adapted as an early warning system for pandemic control during the Covid-19 crisis illustrates, uncertainty is not perceived as a disadvantage when building an innovative solution.

- The initial ambiguity and lack of clarity of objectives was usually a factor of creativity and generated opportunities for improvement. As all applications required multiple iterations and prototype designs, it was by embracing this ambiguity and engaging with feedback received that clarity about the value of each solution could be seen.

- As the adaptations in the prototypes on the way up to the creation of minimum viable products demonstrate, the allocation of resources brought more resources (e.g., additional cycles of feedback and iterations) by focusing on the "feasible" aspects of each project and not due to a precise calculation that maximized returns—ideas and improvements through experiences with customers and partners rather than from deliberate search efforts. An example of this reality, the team did not conduct market research or elaborate planning at the beginning of the project. Even in the case of "Lemur," when the team did a market scan, it was used more as directional validation of a market opportunity and not as a prescription to develop product features.

- The team always preferred to work with partners/stakeholders that were truly committed and engaged in the process of creating the products rather than seeking the "best" partner/stakeholder. From finding a partner for 3D printing to allowing the initial clients to self-select and support the implementation of each project. This strategy provided the team with more resources to work with and allowed the partners to understand their goals better and crystallize a vision about the value of each solution over time.

- In several moments, the team showed a remarkable orientation for action (enactment) in building each solution, but also on the market (e.g., when engaging with prospect customers) and on the environment around them (e.g., when engaging with a partner), eliminating one of the basic premises of causal logic, the objectivist notion of markets and the passivity of the entrepreneur when facing the environment and contingencies.

- The benefits of controlling what could be done with the resources instead of elaborating market forecasts and consequently losing time to market was clear from the beginning. Such benefits were present even when the team had to discharge/substitute a member or write off a resource. Control over those decisions proved beneficial because it accelerated the learning process toward creating a valuable solution (i.e., something others want).

In summary, all applications achieved an impact and added value to a group of customers, but uncountable iterations were required, taking advantage of the surprises that arose and exploiting the resources we could control. This seems to be the core of innovation and new venture creation.

Despite the lack of parameters to analyze what "success" is and the inability to define precise goals for a business model for each application, the team, at all moments, decided to continue and, ultimately, create innovative solutions, from designs to prototypes to effective minimum viable products.

In many ways, the act of creating the "new" resembles the act of creating art. As Clarice Lispector beautifully writes:

"The work of art is a madness of its creator. ... The madness of the creators is different from the madness of those who are mentally ill. These, among other reasons unknown to me, have made a mistake on the path of the search. They are cases for doctors, while the creators are fulfilled by the very act of madness."

4.1. Scientific Contributions Derived from this Thesis

I. Tasic, M.-D. Cano, “Sparking innovation in a crisis: An IoT Sensor Location-Based Early Warning System for Pandemic Control”, *Applied Sciences*, 12(9), 4407, 2022. DOI: https://doi.org/10.3390/app12094407. IF: 2,474 Q2 (32/91 Engineering, Multidisciplinary)

Member of the research team in the project “*Prueba de Concepto - Sistemas inteligentes para la optimización del tráfico urbano*” funded by Fundación Séneca, Región de Murcia (20539/PDC/18). Number of researchers: 3. From 01/01/2019 to 31/12/2019. Principal researcher (entity): María Dolores Cano Baños (UPCT).

Member of the research team in the project “*Programa +Spinoff*” funded by Universidad Politécnica de Cartagena. Number of researchers: 3. From 01/01/2020 to 31/03/2021. Principal researcher (entity): María Dolores Cano Baños (UPCT).

Other relevant publications from the author:

I. Tasic, A. Montoro-Sánchez, and M.-D. Cano, "*Startup accelerators: an overview of the current state of the acceleration phenomenon,*" in Proc. XVIII Congreso AECA "Innovación e Internacionalización: factores de éxito para la Pyme", pp.1-23 (130C), Cartagena, Spain, October 2015. ISBN 978-84-16286-14-0

I. Tasic and A. Montoro-Sánchez, "*The Startup Acceleration Phenomena: Premisses, Processes, and Performance of Business Accelerators*," In Proc. Doctoral Consortium, IE Business School, Madrid, Spain, April 24th, 2015.

D. Alonso, J. Pastor, B. Álvarez, T. Suarez, and **I. Tasic**, "*Improving the learning experience and outcomes in entrepreneurial courses*," in Proc. IEEE 26th International Symposium on Industrial Electronics (ISIE), 2017, pp. 1581-1586, DOI: 10.1109/ISIE.2017.8001482.

I. Tasic, "Startup Ecosystems and Effectuation: Impact analysis of new ventures creation processes, " in Proc. V Jornadas Doctorales, Escuela de Doctorado de la Universidad de Murcia, Murcia, Spain, May 31st, 2019

I. Tasic, "Teaching and Practice Case: Startup Europe Week" in Proc. 2019 Effectuation Conference, Jean-Baptiste Say Institute for Entrepreneurship of ESCP Europe, Berlin, Germany, November 26th, 2019

C. Musso-Gutierrez, **I. Tasic**, M.-D. Cano, J. Ochoa-Rego, P. Gómez Di Marco, J. A. Fernandez, C. Egea-Gilabert, and M.-D. De Miguel-Gomez, "*Estudio de seguimiento y trazabilidad de productos en agricultura urbana con tecnologías blockchain,*" In Proc. III Symposium Ibérico de Ingeniería Hortícola 2022 Smart Farming, pp. 1-4, Cartagena, Spain, April, 2022. (Selected for Special Issue "Applications, Challenges and Potential of Intelligent Equipment in Agriculture" in Agronomy, IF 3.417).

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