Estimating the socio-economic impact of 5G use cases: a conceptual framework

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1 Abstract (English)

5G networks represent a breakthrough innovation because they are the first wireless technology whose standards are capable to satisfy a new set of performance requirements necessary to enable innovative services and applications. More than enhanced mobile broadband, this set of performances includes ultra-high reliability and low latency communication and massive machine-type communication. In this case, the setup of the 5G network is the result of an optimisation of all the parameters according to each different application.

European Commission defined the vision for the development of new generation mobile networks which are meant to drive Europe’s economic growth with a direct impact on the society itself.

The Italian Ministry of Economic Development (MiSE) promoted several pre-commercial experimentations of 5G technology, aiming to identify and seize the potential socio-economic benefits arising from the trials in the most strategic vertical sectors of application.

This thesis provides an analytical framework for the evaluation of the potential socio-economic benefits of 5G that can be unlocked by the roll out of the business applications tested in the trials. The proposed model maps the causal relationship between the wireless technology and the social impacts, by identifying and quantifying the gaps between current state-of-the-art processes and new 5G-enabled processes.

The framework was applied and tested on different use cases in the Healthcare and Automotive vertical sectors, which are part of the trials that took place in the Milan area.
2 Abstract (Italian)

Le reti 5G rappresentano un’innovazione rivoluzionaria perché costituiscono la prima tecnologia wireless i cui standard siano in grado di soddisfare una nuova serie di requisiti prestazionali necessari per consentire servizi e applicazioni innovative. Oltre che una banda larga mobile potenziata, questo insieme di prestazioni include una comunicazione ad altissima affidabilità e bassa latenza e la gestione di un numero massivo di dispositivi connessi alla rete. In questo caso, la configurazione della rete 5G è il risultato di un'ottimizzazione di tutti i parametri in base alle diverse applicazioni.

La Commissione Europea ha definito le linee guida per lo sviluppo di reti mobili di nuova generazione che hanno lo scopo di guidare la crescita economica europea che avranno un impatto diretto sulla società stessa.

Il Ministero dello Sviluppo Economico italiano (MiSE) ha promosso diverse sperimentazioni pre-commerciali della tecnologia 5G, con l'obiettivo di individuare e cogliere i potenziali benefici socio-economici derivanti dalle sperimentazioni nei settori verticali maggiormente strategici.

Questa tesi fornisce un framework analitico per la valutazione dei potenziali benefici socio-economici del 5G che possono essere ottenuti dall'implementazione dei nuovi modelli di business testati sul campo. Il modello proposto mappa le relazioni causali tra la tecnologia 5G e gli impatti sociali, identificando e quantificando gli scostamenti di performance tra gli attuali processi allo stato dell'arte e i nuovi processi abilitati dal 5G.

Il framework è stato applicato e testato su diversi casi d'uso nei settori verticali di Sanità e Auto e Trasporti, che fanno parte delle sperimentazioni svolte nell'area milanese.
4 Executive summary

This study aims at evaluating the expected socio-economic impact of innovative applications that are supported by the deployment of 5G technology and to evaluate the worthiness of government-backed pre-commercial projects. This study focuses, among the ongoing initiatives, on the experimental trials promoted by the Italian Ministry of Economic Development (MiSE) in the Milan area, which is one of the selected cities for the field tests.

The study comprises:

- An overview of 5G technology and ongoing pre-commercial initiatives;
- The review of the methodologies for the evaluation of socio-economic benefits;
- The presentation of the framework adopted for this research;
- The methodology adopted for the use case analysis;
- The application of the model to use cases in the healthcare and automotive sectors;
- Conclusions and main findings on the analysed use cases and on the application of the model.

In the following sections the main findings for each chapter are presented.

Overview of 5G technology and ongoing pre-commercial initiatives (Chapter 3)

5G technology is expected to have unprecedented impacts on the business because of the variety of cutting-edge solutions it will enable because it pledges to deliver performance improvements not only in terms of broadband enhancement, but also in terms of ultra-low latency and management of massive amounts of connections to support the exponential growth of IoT devices.

Wireless technology is supposed to be the backbone of the digital transformation, one of the key goals in the European digital agenda to support economic growth and competitiveness at a global level. To this extent, European commission promoted several
initiatives to accelerate the development and a timely adoption of the technology, among the most relevant there are the 5G Action Plan and 5G Public Private Partnership (5GPPP).

The definition of a roadmap to 5G comprises the launch of pre-commercial pilot projects throughout Europe supported by national initiatives such as the one promoted by MiSE in Italy.

This study focuses on the 41 experimental projects that took place in the Milan: these pilots are split among 7 vertical sectors and involved more than 40 partners among which Vodafone, industrial partners, public entities and research centres.

**Review of the methodologies for the evaluation of socio-economic benefits** *(Chapter 4)*

Many papers analysed the potential value that will be unlocked after the full deployment of new generation networks, but few of them focused on the quantification of the socio-economic impacts with direct analysis of the shreds of evidences emerged from field tests.

The methodologies for a structured approach lack of a standardized approach that will help the comparison of the outcomes in different sectors of analysis and the evaluation of the worthiness of government initiatives.

Literature review followed a goal-oriented approach in order to target the following main elements:

- **5G technology and future scenarios**
  
  For the correct framing of the 5G context and to be able to have a comprehensive view on the topic that is addressed in this thesis it has been important the overview over three very important papers. Next Generation Mobile Network (NGMN), Boston Consulting Group (BCG) and McKinsey Global Institute (MGI) investigated the 5G context, this has been useful for the sake of this thesis to understand the boundary of topics to be addressed and generally have an overview on the 5G
environment. In the papers analysed has been highlighted that 5G has huge impact on the quality of life in urban centres, particularly on the Healthcare sector and in terms of Intelligent transport systems. But in order to support these applications, 4G is not enough anymore because of projected network capacity saturation and lack of adequate performances.

- **Methods for use case categorisation**

  The International Telecommunication Union (ITU) and Ericsson formulated two complimentary strategies for the categorisation of the use cases: the first one is used to describe the balancing of the performances of 5G networks required to enable the use case according to the three main characteristics of enhanced mobile broadband (eMBB), ultra-reliable and low-latency communication (URLLC) and massive IoT (M-IoT); the second method proposed by Ericsson focuses on the possible final applications of 5G technology and therefore it defines 9 main application-based clusters.

  The two types of classification proved to be complimentary because they allow to understand which technological performance are considered and which are the most relevant functionalities enabled by the new generation networks.

- **Framework for the conceptualisation of key benefits**

  The studies promoted by the European Commission in order to assess the socio-economic impact of 5G networks provide valid conceptual frameworks that identify the targets of the expected benefits.

  However, the literature lacks models that link technological performance and achievement of benefits, which is one of the main needs of this research.

  To dive deeper into this topic, Ericsson suggests a framework aimed at tracking the evolution of 5G features in order to assess possible future developments of each application-based cluster.

- **Methods for the quantification of socio-economic benefits**
The available researches rely on static methods based on statistical and mathematical tools for the quantification of socio-economic benefits. The most widely used are input-output analysis and regression analysis: the first one is used to evaluate the multiplicative effect that investments in broadband deployment will have in different industrial sectors thanks to the exchange of goods and services, while the secondo tries to understand the relationship between a set of dependent indicators and a target variable. In both the cases, the final output are usually macro-economic indicators such as GDP and employment rates. Although the estimation produced with these methods proved to be valid, they are not suited for a deep evaluation of single and specific use cases. These methodologies can be precious for further researches and for the validation of benefits emerged from the use cases.

- References for the use cases

Most use cases must be treated singularly, even if many cases belong to the same vertical, they show peculiarities that make it impossible to group them together. For this reason, on top of every analysis it has been added a small chapter regarding its key references.

The presentation of the framework adopted for this research (Chapter 5)

Elaborating on existing frameworks used for this kind of researches, a new conceptual framework has been developed considering: the technology, the use cases and the socio-economic benefits as shown in Figure 1.
A three-levels framework has been developed in order to understand the relationships between the three core elements. It comprises:

- **Level 1: Technology**
  According to the categorisation proposed by ITU, the performances of 5G networks are summarised as eMBB, URRLC and M-IoT. The construction of the model starts from the identification of the key performance required by the 5G network in order to enable the use case.

- **Level 2: Application-based cluster & Use Case**
  The intermediate level describes the use case in analysis in terms of application-based clusters and use case features. Each use case is assigned to one or more application-based clusters according to the functionalities required; these functionalities enable specific features of the use cases which drive the realisation of socio-economic benefits.

- **Level 3: Socio-economic benefits**
The benefits are grouped into three main categories: people, planet and profit. People and planet refer to the expected impacts on the society and on the environment, while the profit category reflects the translation of the impacts of the new processes in monetary terms.

The structure of the framework serves to identify the links and the correlations between each level for a deeper understanding of the root causes of the benefits. The performances of the processes are measured by a set of indicators that describe the processes of each use case.

**Methodology adopted for the use case analysis (Chapter 6)**

The framework underpins the analysis of each use case because it maps the chain of consequences that links technology to the achievement of the benefits. Each use case has been assigned to one or more application-based cluster prior the construction of the framework.

The conceptual map of each use case is then tested on the scenarios proposed by the trials and the performances are measured by benchmarking current state-of-the-art processes with the ones enabled by 5G.

Therefore, the analysis of each use case requires two main elements:

1) The collection of the technological requirements of the 5G network which are used to understand the role of wireless connectivity;
2) The mapping of the process flow following an activity-based methodology in order to benchmark current processes and 5G-enabled ones.

**Application of the model on use cases in the healthcare and automotive sectors (Chapter 7-8)**
The methodology described in Chapter 5 and Chapter 6 is tested on 2 out of the 7 vertical sectors that comprise the trials in the Milan area: healthcare and automotive.

These two sectors are forecasted to record most of the expected benefits because of the strong socio-economic implications. Some use cases present similarities and synergies that were leveraged to have more sizeable opportunities of analysis and they are listed in Table 1.

<table>
<thead>
<tr>
<th>HEALTHCARE</th>
<th>AUTOMOTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Connected ambulance</td>
<td>Cooperative urban cross traffic</td>
</tr>
<tr>
<td>2) Remote surgery</td>
<td>Assisted driving</td>
</tr>
<tr>
<td>3) IoT for telemedicine and remote medical</td>
<td>Automated systems for driving</td>
</tr>
<tr>
<td>consultation</td>
<td>Intelligent speed adaptation and control</td>
</tr>
<tr>
<td>4) Rehabilitation robot</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: List of the analysed use cases

From our analysis, in the healthcare the main beneficiaries of the implementation of 5G-enabled solutions will be the society and the healthcare system itself. While the environmental improvements resulted to be negligible for this kind of trials, the reduction of mortality rates, the greater accessibility to healthcare services and enablement of remote consultation solutions are expected to boost efficiency and effectiveness of the healthcare system. The improvements in efficiency, calculated in optimal-case scenarios, were quantified in the order of hundreds of million € per year, and in most of the cases the perimeter of the analysis was limited to the Lombardy region alone.
On the other hand, the automotive sector is expected to provide a wide range of benefit that comprises the whole three categories of people, planet and profit. The implementation of Vehicle-to-X (V2X) communication is forecasted to drastically reduce the number of road accidents and to provide a practical solution to the issues of traffic congestion and CO₂ emissions thanks to the cooperation between vehicles, road infrastructures and users.

Conclusions and main findings on the analysed use cases and on the application of the model (Chapter 9 & 10)

From the analysis of the field tests, the main bottlenecks were identified in order to assess the time sequences in which the benefits will take place.

From a technological perspective, 5G technology presented two main pain points that delay the realization of the benefits:

1) Network slicing is fundamental to grant the high reliability of the service, especially with mission critical applications as the ones designed for the healthcare sector. The technological standards for this feature are still in the developing phase, therefore the roll out of the solutions that need near 100% of reliability are delayed.

2) At the moment, network coverage is limited to selected urban centers. The availability of enhanced mobile services only in urban areas, cutting off a portion of the sub-urban and rural areas. Hence, the attainable benefits are reduced.

The analysis conducted on the trials allowed further considerations on the worthiness of government initiatives in anticipating commercial deployment of 5G with local trials, while also provided some recommendation on how to accelerate the development:

1) Trials served as testing ground for innovative application that must be developed and adapted to solve local problems. The early test of new business models helped the validation of performance standards, the enhancement of the relationships among the diverse working groups and the mitigation of investment risks.
2) The quantification of the socio-economic impacts is limited by the bottlenecks that emerged from the analysis. The realisation of the expected benefits is subject to the overcoming of organisational bottlenecks due to the high interaction between different stakeholders, the adaptation of infrastructure and vehicles to the new technologies to enable V2X communication and the maturity of the technologies applied on top of the 5G networks (such as the robots used for surgeries).

3) Pre-commercial testing business models resulted to be a catalyst for new investments by public and private entities, thus accelerating the development and adoption of the next generation networks.
5 Overview of 5G technology and pre-commercial initiatives

This chapter is aimed at introducing the fundamental concepts at the basis of fifth generation networks and at presenting the ongoing pre-commercial initiatives that are taking place all over Europe, with a focus on the ones promoted by the Italian Ministry of Economic development (MiSE) in Italy.

5.1 5G technology

The evolution of the standards adopted by the telecommunication industry has seen a rapid development over the years, from the delivery of voice-only solutions with 2G connectivity to the third and fourth generation of mobile communications that support internet access and video experience.

All of these performances are included in the 5G capabilities and they are furtherly pushed to the edge: 5G pledges a 100 times faster data transfer and a close to zero latency of the signal, manages up to one million connected devices per km$^2$, ensures a greater battery longevity and enables the development of innovative services with the usage of a wider spectrum of frequencies.

The implication of the diversity of all the above-mentioned features of the new-born networks is that the performances needs to be optimised according to each specific solution, with the creation and setup of a dedicated “slice” of network.

Network slicing allows operators to offer differentiated services using a single physical infrastructure. This makes it possible to target economic or industrial sectors and multiple markets. It is thus expected that 5G will be capable of better meeting the unique needs of different players (in terms of capacity, speed, latency and, what it is more important, availability), opening new opportunities for both the so-called verticals and Mobile Virtual Network Operators (MVNO). A visual representation of network slicing concept is provided in Figure 2.
Furthermore, the introduction of computing capabilities on the edge of the network supports mission-critical applications which require ultra-low latency and ultra-reliable communications.

The categorisation of the 5G capabilities proposed by the International Telecommunication Union (ITU) is summarises the features explained, and it is described in Figure 3:

1) Enhanced Mobile Broadband (EMBB)
2) Ultra-Reliable and Low Latency Communication (URLLC)
3) Massive machine-type communication (M-IoT)
5.2 5G trials

5G infrastructure is the backbone of the transformation from a Megabit to a Gigabit society as its goal is to enable a ubiquitous access to advanced digital applications for consumers, businesses and the public administration.

In the Gigabit society, Information and Communication Technology (ICT) represents no longer a stand-alone sector, but it constitutes the foundation of modern digital economic systems because of the tight interaction with other verticals. The development of advanced ICT infrastructure is considered the key enabler of the digital single market, which is at the core of Europe’s growth strategies because of the fundamental role it covers in terms of the economic competitiveness of the continent. The importance of connectivity is measured with indicators like the Digital Economy and Society Index (DESI), which dedicates one of the five main metrics to this subject.

To support this strategic issue, European initiatives such as Horizon 2020 (H2020) and 5G Public Private Partnership (5GPPP) are leading the creation of joint international efforts for the development of the technology, the infrastructures and new solutions.

To unlock the full potential of the new infrastructure in line with the vision set by the EU Commission with the “5G Action Plan”, the interoperability of the technology must be granted. In this regard, the 5G trials Roadmap is put in place by 5GPPP and its main objectives are to:

▪ Support global European leadership in 5G technology, networks deployment and profitable business;
▪ Validate benefits of 5G to vertical sectors including public sector, businesses and consumers;
▪ Stimulate a clear path to successful and timely 5G deployment in Europe.
These trials are integrated with national initiatives that contributes to meeting the challenge of making 5G a reality for all citizens and businesses in Europe such as the government bids promoted by the Italian Ministry of Economic Development (MiSE).

### 5.3 5G trials in Milan

The Italian Ministry of Economic Development (MiSE) launched a series of pilot projects over a 4-year horizon in three major areas:

- Area 1: Milan and its metropolitan area
- Area 2: Prato and L’Aquila
- Area 3: Bari and Matera

These experimentations have the goal to foster the collaboration between telco operators and the other industrial sectors to translate the technology advancements into new feasible and sustainable business models with high social impact.

Experimental projects are built upon ecosystems of stakeholders working together to develop better technological features and to define the requirements of each possible application.

In the specific pilots in Milan, the ecosystem is divided as follows:

- Telco partner (1)
- University and research centres (3)
- Endorsers and public institutions (10)
- Industrial partners (28)

The use cases that are being studied in Milan are 41, split among 7 vertical sectors as shown in Table 2.
<table>
<thead>
<tr>
<th>Verticals</th>
<th>Number of Use Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive and transports</td>
<td>4</td>
</tr>
<tr>
<td>Digital divide</td>
<td>1</td>
</tr>
<tr>
<td>Education, learning, entertainment</td>
<td>7</td>
</tr>
<tr>
<td>Energy, smart city and smart grid</td>
<td>3</td>
</tr>
<tr>
<td>Healthcare</td>
<td>9</td>
</tr>
<tr>
<td>Manufacturing &amp; industry 4.0</td>
<td>12</td>
</tr>
<tr>
<td>Security and surveillance</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7</strong></td>
</tr>
</tbody>
</table>

Table 2: Verticals analysed in 5G trials in Milan and number of use cases

5G technology presents itself as the necessary infrastructure to target the ambitions of the Italian digital agenda in terms of stimulation of the ICT sector in shaping the digital innovation of local economies in different verticals of application.

In this sense, the pre-commercial trials enhance the relationships between mobile network operators and the economic fabric from the early design of new business models to the full implementation of the services. On these premises, the experimentations embrace the technological revolution in a wider sense and explore the natural development of telecommunication infrastructure along with its local impacts on the society.
6 Literature review

Several papers analysed the potential value that will be unleashed after the full deployment of new generation networks, but few of them focused on the quantification of the socio-economic impacts with direct analysis of the shreds of evidences emerged from field tests.

This section includes a review of the literature analysed to develop a model for the quantification of the socio-economic impacts of the pre-commercial trials of 5G technology. The overall aim of this study is to define, starting from the observations of the pilot projects, the relationship between the performances of wireless technology and the processes they are linked with, in order to predict the impacts of innovative business models on the main beneficiaries. The variety of the fields of application in our perimeter of analysis requires a structured framework applicable to different scenarios that provides strong evidence of the goodness of government initiatives for the local economy.

As a result, the proposed framework wishes to suggest meaningful insights on more convenient and impactful investment directions as well as recommendations on how to overcome bottlenecks and barriers encountered during the assessment of the trials.

The literature review of this study followed a goal-directed investigation of institutional and commercial papers that examined the socio-economic impact of wireless broadband technologies and they can be summarised in three main categories:

- 5G technology and future scenarios;
- Methods for use cases categorisation;
- Framework for the conceptualisation of key benefits;
- Methods for the quantification of socio-economic impact;
- Reference for the use cases.

On top of the literature analysed for the creation of the model, we researched specific papers for each use case depending on the discussed topic. The main reference used for the analysis of each use case are listed at the beginning of every use case analysis.
6.1 5G technology and future scenarios

Given the breadth of the subject dealt with in this thesis, it has been fundamental the review of many papers regarding the technology, the implications for mobile industry and smart applications that will be relevant with the new technology.

For this purpose, the main references took into consideration are the following:


The first paper provided by NGMN presents the general overview on 5G technology. It is stated that 5G will enable a fully mobile and connected society and can empower socio-economic transformations which are unimagined today. A fully mobile and connected society is characterized by tremendous growth in connectivity and density of traffic. 5G will operate in a highly heterogeneous environment characterised by the existence of multiple types of access technologies, multi-layer networks, multiple types of devices and user interactions. In such environment there is the fundamental need for 5G to achieve seamless and consistent user experience across time and space. It is also highlighted that business orientation and economic incentives with foundational shift in cost, energy and operational efficiency should make 5G feasible and sustainable.

The second reference provided by BCG presents challenges that mobile network operators, policymakers, consumers and businesses must face for the correct deployment of 5G in Europe. Current networks cannot support enormous data growth without increasing the number of cell towers and antennas in heavy traffic areas, which could drive up costs and this is not generally acceptable by city governments and residents. They estimate that 4G capacity will be capacity for a typical large European city will be exhausted by 2021. Therefore, see 5G as a solution to this problem, that has the ability to expand network
capacity and lower its costs, but in order to do so and make it viable from a financial perspective it requires the full engagement of all stakeholders. This means that operators need to optimise network deployment lowering the cost base. While policy makers and regulators can help stimulating and incentivising investments. Increasing confidence in the potential of 5G business cases, stimulate innovation and provide 5G leadership in Europe.

On the other hand, the third report, provided by MGI has the purpose to analyse the smart city of the future, with many technological considerations also on healthcare and mobility, which are the verticals considered in this thesis. A topic of great importance addressed in the report is undoubtedly the one of traffic mitigation, where it is highlighted the way digitalisation and new technology will help to address this problem in cities of the future. In this paper it is also investigated how cities can be catalysts for better health, the sheer density of cities makes them critical for addressing health.

6.2 Methods for use cases categorisation

The variety of application fields of the 41 use cases in 5G trials in the Milan area implied the research of clustering methods to provide robustness to this research and comparability of the results.

The wireless technology is at the core of the research, therefore we analysed possible aggregation rationales able to capture the maximum amount of variability of the applications of 5G.

The most meaningful references in this case are the following:

- ITU. Setting the Scene for 5G: Opportunities & Challenges
- Ericsson. The guide to capturing the 5G industry digitalization potential

The first reference provided by ITU suggest a categorisation based on the technological performances adopted and it is characterised by three main dimensions:

1) Enhanced mobile broadband (eMBB)
2) Massive machine-type communications (M-IoT)

3) Ultra-reliable and low-latency communications (URLLC)

The technological requirements of each use case can be summarised as a combination of these three features, thus providing a solid reference for the assessment of the technical progresses emerged from the trials.

This method suits in this analysis because gives a simplified, but complete, view of the usage of 5G networks and it allows the assessment of the technological maturity thanks to the aggregation of data coming from different application scenarios.

The second reference provided by Ericsson suggests an application-based clustering. In this case, a cluster is identified as a group of use cases that is enabled by a common technological application in terms physical requirements and user experience.

The nine clusters identified by Ericsson are the following:

- Augmented reality
- Autonomous robotics
- Connected vehicle
- Enhanced video services
- Hazard and maintenance sensing
- Monitoring and tracking
- Real time automation
- Remote operations
- Smart surveillance

The application-centric aggregation gives a more precise overview of the functionalities adopted in each vertical sector and provides a more sizeable opportunity for the quantification of benefits than the analysis of stand-alone use cases.
Furthermore, it constitutes a solid basis for the analysis that bridges the gap between connectivity and the processes concerned, thanks to the definition of technological requirements needed to enable the use cases.

As a conclusion, both the investigated methodologies suit for the purpose of this research because the categorisation proposed by ITU helps to highlight the technological features utilised in each use case, while the second proposed by Ericsson provides a more detailed classification of the final applications supported by the network.

6.3 Framework for the conceptualisation of key benefits

The research of a conceptual framework for the analysis constitutes an important milestone for this study because it provides the essential guidelines to conduct the analysis, highlighting the directions in which the socio-economic impacts are investigated.

The literature review for this topic followed the goal-oriented approach because of the specific need of this project: to link the technological improvements to the processes of the use cases in order to understand the how the technology is generating benefits for the society.

The relevant literature references in this case are the following:

- Trinity College, Tech4i2, & Real Wireless and InterDigital. (s.d.). *Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe*. European Commission
- Ericsson. *The guide to capturing the 5G industry digitalization potential*

Benefits modelling in the first reference is conducted as in Figure 4.
Figure 4: Benefits and impacts modelling (Source: Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe. European Commission)

The framework provides a comprehensive overview of the key areas impacted by the scenarios forecasted for 5G utilization. The first and most relevant segmentation of these key areas is represented by the focus on four main verticals and the distinction among strategic, operational and user benefits.

The model encompasses all the key areas impacted by 5G as well as the main beneficiaries, providing a thorough estimation of the maximum attainable outcome Europe can get.

On the other hand, the framework provided by Ericsson examines in depth the role and the evolution of 5G features in each application field. An example is showed in Figure 5.
This framework suggests analysing the development of 5G network and the evolution of its performance for each application cluster.

Despite it does not address the socio-economic value unlocked by each application cluster, this framework suggests a more precise dive deep into the processes supported by 5G and how they will be changed according to the maturity of the technology.

Both the aforementioned frameworks provide useful approaches to the analysis of the use cases and the definition of the key areas to target the benefits.

### 6.4 Methods for the quantification of socio-economic impact

We reviewed the most relevant papers issued by the European Commission focused on the impacts of broadband:

- Trinity College, Tech4i2, & Real Wireless and InterDigital. (s.d.). *Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe*. European Commission
- Analysis Mason, Tech4i2. *The socio-economic impact of bandwidth*. European Commission
Starting from these two main references, we examined in depth the most widely use methodologies behind the quantification of the impacts to evaluate their fit for our purpose.

The key findings in terms of quantification methods can be summarised in two relevant models: input-output and regression analysis.

**Input-output analysis**

Input-Output analysis is used to investigate the relationship between investments in broadband development and the socio-economic value created by trickle down effects.

As shown in Figure 6, the impact of broadband deployment is measured by means of four main effects: the direct economic value created by the construction of the physical infrastructure, the productivity improvement of the factors used by enterprises, the household’s income and the consumer surplus deriving from residential adoption.

![Figure 6: Economic impact of broadband (Source: Katz and Suter (2009))](image)

The studies on the correlation between economic growth and broadband investments highlighted also the complex relationships existing between different industries because of the exchange of goods and services triggered by the availability of new technology.
The spill-over of benefits from the mere investments in broadband deployment are measured with multipliers that capture the magnitude of inter sectorial trades and the consequent employment change throughout the economy caused by the variation on the input side.

Therefore, the type of expected impacts can be classified in three levels:

- **Direct impact**: these effects captures the benefits generated by the investment on 5G infrastructure and services;

- **Indirect impact**: these effects measures the exchange of goods and services across the supply chain generated by the direct investments. The magnitude of this spill-over is measured by a multiplier defined as *Type I Multiplier*, which is calculated as follows:

  \[
  \text{Type I Multiplier} = \frac{\text{Direct effect} + \text{Indirect effect}}{\text{Direct effect}}
  \]

- **Induced impact**: these effects represent the reflection of the increase in household’s income related to the deployment of broadband. Higher incomes translate into changes in consumes’ spending and consumption of goods. The magnitude of this spill-over is measured by another multiplier defined as *Type II Multiplier*, which is calculated as follows:

  \[
  \text{Type II Multiplier} = \frac{\text{Direct effect} + \text{Indirect effect} + \text{Induced effect}}{\text{Direct effect}}
  \]

The effects of this classification of impacts is better visualised in Figure 7: Direct, Indirect, and Induced effects of 5G Investment [Source: European Commission]Figure 7.
A quantitative representation of the interdependencies involving different vertical sectors can be provided by input-output tables, which set the basis for the calculation of the above-mentioned multipliers.

To come up with Type I and II Multipliers, the input-output tables should be reformatted in order to obtain the Total Requirement table, also known as Leontief-Inverse matrix, which is the result of the following calculation:

\[ L = (I - A)^{-1} \]

Where:

- \( L \) is the Leontief-Inverse matrix (Total requirement table);
- \( I \) is the identity matrix;
- A is the matrix of the technical coefficients, obtained as the division of the domestic supply of goods and services by the total amount of industry supply.

The results of this analysis are robust especially in the short-term because they are based on proven inter-sectorial linkages.

However, the output of this model is strictly related to macroeconomic indicators such as GDP and employment.

**Regression analysis**

Regression analysis is a statistical method that looks for the relationship between a set of explanatory variables and dependent variables, usually set as GDP or employment rate. In this case, the regression analysis needs to contain an estimate of broadband penetration to evaluate its impact on economic growth.

Previous studies that applied this technique tried to understand the impact of broadband penetration on the macro-economic indicators. Therefore, the variables should be set as follows:

- **Dependent variables**: macro-economic indicators such as GDP, employment or number of enterprises;
- **Independent variable**: rate of change of broadband penetration;
- **Control variables**: set of explanatory variables that influence the final value of the dependent variables such as education, urbanisation, industry concentration and so on.

Keeping the control variables constant, it is possible to observe the change in the dependent variables according to different values of the broadband penetration.
The objective of a regression analysis is to break down the macro-economic indicator to assess the importance of the independent and control variables in determining such indicator.

Furthermore, the regression analysis requires a modest amount of structured data over a long enough time span for the investigation of the role of broadband deployment, including data concerning 5G deployment.

All the mentioned models rely on static methods to assess the cross impact of investment in broadband infrastructure and the reflected effects on macro-economic indicators such as GDP and employment.

6.5 References for the use cases

As it is previously mentioned, in order to understand the topics covered in each individual use case, it has been necessary to review multiple reports, papers and websites regarding topics treated in every pilot project. This has been fundamental to provide a general boundary to the analysis and to get deeper with numerical analysis as well.

Every pilot project requires specific knowledge about a particular field of application, for example in Connected Ambulance it is required a deep understanding of emergency medical practices and in our specific case requires knowledge, even if at a general level, of the pathologies that depend on time. Then, once identified the main activities and mapped the process in case of emergency medical service, it has been fundamental to dive deep with numbers in order to make benefit estimation. Specifically, to build the framework, the information needed were competence based and numerical based.

The process applied in Connected Ambulance use case has been subsequently applied to every other use case analysed.

For this reason, we believe that it is logic to insert the reference, which is different for each use case treated, at the beginning of the analysis of the use case itself. Thereby, at the
beginning of the analysis, a complete list of the main references that helped in drawing up, identifying and measuring the benefits has been included.

6.6 Conclusions and research question

The presented methodologies for the categorisation of the use cases provide an exhaustive array of possible configurations in order to cluster the pilot projects according to both the technological features and the final applications.

However, the scope of this research needs an underlining framework that can capture the variety of the use cases and their application field with a deep focus on the technological aspects. Therefore, the existing frameworks cannot suit for this context because they do not provide a clear link between the wireless connectivity and the achievement of socio-economic benefits.

In order to assess the goodness of government bids for 5G trials and to identify the most promising investment directions, the couple of presented models fall short.

For what concerns the quantification of the socio-economic benefits, the most widely used approaches consist in static mathematical methods that provide results at macro level. In our case, the assessment of the contribution of each pilot project towards 5G-oriented scenarios must be prioritised. Input-Output and regression analysis proved to be valid tools for macro-economic considerations, but they are not suited for a deep evaluation of single and specific use cases. These tools can be used in further researches on this topic.

Therefore, an approach that identifies and captures the value unlocked by each innovative feature offered by 5G is needed.

Because of these reasons, the research question guiding this study is the following:

**RQ** How can use cases be modelled to understand the role of 5G connectivity towards the achievement of socio-economic benefits?
7 Methodology

This research is focused on the pilot projects that are taking place in Milan area and aims to creating a new tool for assessing the socio-economic impacts deriving from 5G technology in the proposed area of interest.

The framework should be used as input to address three main high-level objectives:

1) Discuss the results of the ongoing pilot projects;
2) Evaluate the expected socio-economic benefits of the deployment of the technology;
3) Identify the most promising investment directions.

The foundation of the framework is constituted by a combination of the approaches proposed by Ericsson and ITU for the categorisation of the use cases, while the identification of the socio-economic impacts and their beneficiaries is the result of a rework of the methodology adopted in the 5G reports of the European Commission.

This section is intended to present the framework adopted for this study starting from the methodology by which the use cases are analysed.
7.1 The framework

![Diagram of the framework](source: Authors)

In order to evaluate the benefits deriving from each use case, a new framework has been introduced (Figure 8).

The scope of the Model is to give a replicable multi-level framework of analysis, the meaning is that it is possible to build a logical pathway where all the major connections are explaining one level in function of the characteristics of the previous level.

The main role of this framework is of supporting and guiding in the construction of the logical chain that has the impact generated at its end. Thereby, the model is built to be applicable to every use case, and this characteristic enables to run this analysis not only for the use cases of the 5G trials in Milan but can be extended to all the pilot studies for this technology. For a complete overview of the 5G experiments, it is essential to build this flow for every use case. The objective is to aggregate the information arising from lower levels and link them step by step to draw conclusions for higher level benefits, thus providing a
visual tool to identify the major features in each use case and to accurately target the beneficiaries of the improvements.

The construction of the model followed a bottom-up approach, in the sense that we consider the 5G technology as the fundamental basis of the use cases, and we gradually rise in a scheme divided into three levels.

The three levels composing the model are presented in detail in the subsequent section.

7.2 Level 1: Technology

As the foundation of the model, it is the backbone of the analysis because here are included the technological requirements to enable the case in question. The network requirements of each use case are evaluated on the basis of the three main characteristics of 5G technology identified by the ITU (International Telecommunication Union):

![ITU 5G Triangle](image)

The goal is to identify the technological requirements that satisfy the requisites of the selected use case, so 5G performances are considered as enablers of upper levels. The
connections between level one and level two are treated as Boolean variables (a Boolean variable is a variable that assumes binary values, typically True-False 1-0): benchmarking the performances of previous wireless technologies with the ones of 5G, it is possible to highlight which requirements of the application clusters are met also with previous technologies and which features can only be enabled by new generation networks.

To define the level of technological requirement of a specific use case, it is important to define the source of the threshold. The technological data will be taken from the experiments themselves, as the data collected in the field explain the requirements that enable the functions of the use case itself.

7.3 Level 2: Application-based cluster & use case

This intermediate layer is the one dedicated to the explanation of the features of the use case in analysis.

Each scenario involves one or more application-based clusters that summarise the different applications of 5G utilised in the use case. Each application cluster has the role of enabling new features and processes considered in the pilot projects.

The features of the use cases are explained by those of the application cluster, hence the correct attribution of the clusters to the use cases plays a key role in the analysis.

The link between the two classes of features explains how the technology is enabling new and enhanced functionalities in the proposed cases and sets the basis for the detection of the primary sources of benefits.

7.4 Level 3: Socio-economic benefits

The last step of the analysis is the identification of the benefits enabled by the use cases. In order to easily identify them, the idea is to divide into three categories: People, Planet and Profit.
This analysis is based on the so-called ‘Triple Bottom Line’ (TBL), (Hammer & Pivo, 2017). It refers to social, environmental and economic value and it is mainly used to analyse the impact of an organisation in order to account on these three levels the full cost of doing business, but in recent years this framework is gaining importance in all the economic development related fields. For this reason, it is a suitable framework to identify the targets of the socio-economic benefits arising from the 5G experimentations.

*People:* refers to the human capital of the bottom line, interested in the welfare of stakeholders, evaluating how much the use case application of 5G will benefit society. Furthermore, the performance indicators are not case specific but pretend to be as generic as possible in order to have the same indicators for an entire vertical. This is done in order to evaluate the contribution of every use case to the vertical.

*Planet:* is the environmental bottom line. Here it is crucial to identify the impact of the use case characteristics in terms of resources consumption or emissions in order to size as much as possible the ecological footprint of the use case, highlighting the difference form the actual state of the art.

*Profit:* usually refers to the financial profitability of a project or a company business, but in this case, it is intended as the economical evaluation of benefits arising from the use cases or from the *People* and *Planet* bottom lines. Hence, for each case the savings coming from the exploitation of the new technology will be calculated.

The link and connection between level 2 and level 3 of the framework is based on strong assumptions deriving from literature and studies. The idea is to aggregate information of studies, concerning one or more performance dimension, to the benefit enabled by that dimension on the three categories (*People, Planet and Profit*).
The above-mentioned links are built by means of key performance indicators that belong to one of the categories listed below:

- **Time**
  The aspect to be addressed in this dimension is to check whether the new technology allows or not an improvement in efficiency of the service.

- **Quality**
  This dimension is focused on the advantages that the technology would allow in terms of knowledge and skills, as well as focused on outcome of the service

- **Flexibility**
  It is a concept that is often used in the manufacturing systems field. Flexibility is a multidimensional concept based on the change that a manufacturing system can accommodate, such as volume flexibility, product flexibility, operation flexibility, and process flexibility. Technology can also affect flexibility through the relationship between the technological process organization and the business process owners, change request processing, and other response characteristics.

- **Cost**
  This dimension is particularly relevant in the search of *profit benefits*, for which an assessment is made to find possible savings for the system or the user of the technology itself.

### 7.5 Interpretation

As a result, each use case feature is described as a precise concatenation of drivers coming from different application clusters. The combination of different application clusters sets the basis for the simulation of different scenarios that can be assessed at the same time, identifying and anticipating possible developments of the use cases.
Figure 10: Technology evaluation model in a connected ambulance (use case #8)

Linking the technological performances to the processes the use case helps to track which feature of 5G connectivity is enabling the achievement of the identified socio-economic benefits. The investigation of the maturity of the technology is used to evaluate the time-to-market of each solution and it indicates how and when the benefits will be realised.

This model helps also to track the sources of the benefits in each vertical sector and tries to quantify them, as it aims to provide meaningful insights that can make the decision-making process more informed over future investment and research directions.
8 Use case analysis

Each use case is analysed in a two-fold way:

1) Technological requirements enabling the applications;
2) Process flow of the scenario proposed.

This double perspective is needed to understand the role and the importance of connectivity as a primary enabler along with the identification of the activities that are directly impacted by the technological improvements.

8.1 Use case final classification and selection

The perimeter of this analysis is delimited by the 41 use cases, split among 7 vertical sectors, that constitute the pilot projects promoted by MiSE in the Milan area.

The vertical called Digital Divide, referring to the homonymous topic, is expected to be one of the pillars in the 5G deployment, it is constituted by 1 use case and it differs from the other trials because it deals with granting rural areas the access to the new network. It deserves other assessment methodologies because it is not presenting a new application supported by the technology, hence it is not considered in this analysis. The final number of addressable use cases is 40, which are split among 6 verticals.

The applications in each vertical sector, as presented in the introduction of this study, are heterogeneous in terms of partners involved, technical requirements and final beneficiaries, therefore a further level of aggregation according to the application-based clusters is necessary for the sake of the robustness of the results of this analysis.

Following the categorisation proposed by Ericsson, each use case has been assigned to one or more application clusters based on the functionalities adopted in each pilot.

After the final categorisation, only 7 out of the 9 application-based clusters were used to describe the use cases: in fact, the two clusters “Autonomous robotics” and “Hazard maintenance & Sensing” did not find a match among the trials in the perimeter of this study.
The result of this aggregation is a new classification matrix that contains both the information of the vertical sector of belonging and the application clusters involved. In Table 3 an example of the final classification for the Healthcare sector: each use case has been assigned to one or more application clusters, thus highlighting the most common applications in the use cases in analysis.

<table>
<thead>
<tr>
<th>USE CASE</th>
<th>MONITORING &amp; TRACKING</th>
<th>REMOTE OPERATION</th>
<th>SMART SURVEILLANCE</th>
<th>AUGMENTED REALITY</th>
<th>CONNECTED VEHICLE</th>
<th>ENHANCED VIDEO SERVICES</th>
<th>AUTONOMOUS ROBOTICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Medical cognitive tutor</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Rehabilitation robots</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Service robotics</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4 IoT for telemedicine</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Remote patient monitoring</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Wearables in sports</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>7 Analysis and remote medical consultation</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Connected ambulance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Remote surgery</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td>X</td>
</tr>
</tbody>
</table>

*Table 3: Classification of the use cases in the Healthcare sector*

The complete classification of the 6 verticals and the 40 use cases can be found in the Table 16 in the Annex.

### 8.2 Technological requirements

Technology remains the core element in this type of evaluation of innovative applications, therefore the it is fundamental to dive deep into the technical requirements emerged from the experimental projects.
Following the approach proposed with the technology evaluation model, the first requirements collected concern the pure characteristics of the wireless network on which the use case is based on according to the ITU triangle.

From each use case the information about data rates, latency of communication, reliability and the specific network configuration needed are collected (e.g. mobile edge computing, slicing).

Quantifying connectivity needs and correctly assigning them to one of the 3 categories proposed by ITU is necessary to build the first layer of the technology evaluation model and to step up the applications level.

The application-based clusters assigned to each use case are associated with different level of requirements and their aggregation constitutes the final set of desired performance that the mobile network should be able to deliver to enable the use case.

The discussion over these performances allows to understand which role 5G will play when the pilot solutions will be deployed on a larger scale.

### 8.3 Process flow

The pathway to the final benefit achievement is case specific and the definition of the key features should be addressed analytically.

The first step concerns the identification of the state-of-the-art processes that are being carried on without 5G technology: benchmarking actual service delivery with forecasted future performances sets the basis for understanding where the performance gaps lie.

Mapping the identified process following an activity-based methodology is useful to get an analytical support for the analysis and to give a complete and simplified overview of the problem.

The flow chart is meant to be complimentary to the technology evaluation model explained in the previous paragraph, as the first one is needed to map the activities in the specific
process to be improved, while the second one represents the role of technology and its expected impact on the target stakeholders (people, planet, profit).

It is important to highlight three kind of flows:

1. Activities: logical sequence of tasks carried on in the use case;
2. Information: typology and quantity of data exchanged in each task;
3. Physical flows: documental and material flows that are directly impacted by the new technology.

5G implementation can impact all the above-mentioned flows, enabling new methods to enhance operations, to accelerate the exchange of information or optimize the consumption of materials.

For this reason, the high level KPIs are the ones set for the people, planet and profit categories which determine the final target of the evaluation. The process mapping aims to highlighting which activities of the process are impacting the selected KPIs and how those activities are improving or worsening the performances.
9 Applications in healthcare

The speed and the reliability of 5G networks are expected to bring significant efficiency benefits in the whole healthcare sector. Delivering healthcare services in a smarter way will have waterfall effects on the both the perceived quality of the National Healthcare System and its cost structure.

The next generation of connectivity is meant to accentuate the interaction between hospital, doctors and patients through digital means that optimise and enhance the information flows that allow decision-makers to better manage people, procedures and assets. In the following paragraphs different phases of the Healthcare services are analysed: from faster response to emergency situations with connected ambulances to robotic surgeries managed by specialist doctors from remote, and finally to the post-operative assistance from remote of patient in need with telemedicine applications and robotic rehabilitation.

9.1 Connected Ambulance

As one of the most popular use cases in 5G pilot projects, connected ambulance is expected to have a significant impact on the emergency medical services. Thanks to on-board connectivity, the Connected Ambulance will be able to exchange seamless flows of information with all the actors involved in the emergency processes.

The data collected in this use case are an integration of patient’s vital parameters and video information coming from high definition cameras installed on board. The aggregated information is shared with specialized medical personnel that supports the operations on-site and facilitates the reception of the patient in the designed hospital.

The remote interaction between the first responders and the specialized medical personnel is further enhanced with the use smart glasses that support augmented reality applications, which are meant to guide the responders in critical situations.
Lastly, the connected ambulance is also equipped with sensors that allow the communication with surrounding vehicles and road infrastructures, so that the designed route from and to the hospital can be prioritized with a direct impact on intervention time.

The above-mentioned characteristics are aimed at improving the quality of the patient outcome in critical situations such as time dependent diseases, while providing the emergency services with a more efficient utilization of resources. The reference pathology considered for this analysis is the out-of-hospital cardiac arrest (OHCA) as it constitutes a good proxy of the time dependent diseases.

9.1.1 References

This use case tries to understand the link between a more efficient first aid service and the related mortality rate. For the investigation of this type of relationship, several medical papers were consulted. The essential reference papers are:


To test the use case in the region of the analysis, Lombardy, the data concerning the first aid missions, the assets involved, and the organisation of the regional healthcare system were taken from the main sources of open data provided by the institutions. The essential references are listed below:
9.1.2 Use case setup

For the quantification of the benefits of the connected ambulance, the expected improvements are calculated with respect to a typical emergency managed by the authorities in charge of this service in Lombardy: AREU. Furthermore, the generalisation of benefits is limited to the expected impact on Lombardy region.

Figure 11 presents a scenario in which a basic means of rescue, that is an ambulance with volunteers on board and no medical personnel, gets a call from the central station and start the rescue mission. The proposed scenario tracks the macro activities from the alarm to the time in which the patient undergoes the specialized treatment inside the hospital structure.

The times considered for each activity are collected from papers published by AREU and from interviews to experts working on the connected ambulance project and they are listed below:

- Transport (Alarm-to-target) = 11’
- On site treatment = 20’
- Transport (target-to-hospital) = 5’
- Intervention = 60’
9.1.3 Application-Based Clustering

In the proposed scenario, four main application-based clusters are identified with different types of network requirements:

1) **Enhanced video services**: the presence of high-definition cameras on board provides mobility streaming services that require high broadband capacity along with high service reliability that minimizes downtimes;

2) **Monitoring and tracking**: the continuous exchange of vital parameters from on board instrumentation has very high requirements of network availability;

3) **Augmented reality**: this type of application requires high broadband capacity to support video analysis and low latency to ensure an efficient use of the smart glasses by the responders;

4) **Connected vehicle**: Vehicle-to-X (V2X) communication needs ultra-low latency connectivity to ensure an efficient and safe prioritized routing in mobility conditions. The realisation of the full potential of V2X communication implies a huge number of objects connected to the network, hence the capability to support a massive number IoT devices is required.

The quantification of network requirements for the designed application-based clusters derives directly from field tests of the use case and they are summarised in Table 4. Enhanced video services, monitoring and tracking and augmented reality constitute the
whole on board instrumentation of the connected ambulance, so the requirements are grouped together.

<table>
<thead>
<tr>
<th>TECHNOLOGICAL CHARACTERISTIC</th>
<th>ENHANCED VIDEO SERVICES, MONITORING AND TRACKING AUGMENTED REALITY</th>
<th>CONNECTED VEHICLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBB</td>
<td>DL: 1 Gbps</td>
<td>DL: 5 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL: 500 Mbps</td>
<td>UL: 5 Mbps</td>
</tr>
<tr>
<td>URLLC</td>
<td>Latency: 10 mS</td>
<td>Latency: 1 mS</td>
</tr>
<tr>
<td></td>
<td>Reliability: 99.99%</td>
<td>Reliability: 99.99%</td>
</tr>
<tr>
<td>M-IoT</td>
<td>Not relevant</td>
<td>Elevated</td>
</tr>
</tbody>
</table>

*Table 4: Network requirements for connected ambulance*

The required network performances cannot be satisfied with current technologies: on one hand, on board instrumentation requires very demanding download and upload rates; on the other hand, V2X communication is subject to a very low-latency requirement to operate in safety conditions. In both cases, the reliability of the network plays a key role given that the service can be defined as mission-critical: in case of downtimes of the connection, the whole process could be compromised.

9.1.4 Socio-economic benefits

From the above-mentioned application-based clusters, three main use case features are enabled.

1) **Assisted decision-making**: augmented reality applications help the decision-making processes of the volunteers and facilitates the application of life saving protocols;

2) **Remote medical assistance**: video streaming in mobility and real time data processing are available for remote medical consultation. Enhanced quality of the available information allows specialized medical personnel to support the volunteers and to make more accurate and early diagnosis of the patient status.
These characteristics influence the patient’s pathway and speeds up the in-hospital operations;

3) **Route prioritization**: the communication between the vehicle and road infrastructures (e.g. traffic lights optimisation) has the potential to reduce travel times for a quicker response to emergencies.

In Figure 12 the technology evaluation model represents the interactions between technological requirements, application-based clusters and use case features.

![Technology evaluation model in a connected ambulance](image)

*Figure 12: Technology evaluation model in a connected ambulance*

To further explain how the features enabled by the use case are changing or improving the processes, a second activity-based mapping has been carried out on identifying where and when those features come to action as shown in Figure 13.
Each macro activity is expected to be more efficient with the connected ambulance and the resulting final gain (red zone in Figure 13) is the total amount of time on which the mortality rate improvement is measured.

The enhanced capabilities of the ambulance and the responders are expected to improve space and time coverage of the intervention of specialists in critical situations.

The final set of benefits and the related beneficiaries are summarised in Table 5, while the methodology used to forecast the values of the indicators in Lombardy is presented in the next paragraph.

<table>
<thead>
<tr>
<th>BENEFICIARY</th>
<th>BENEFITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEOPLE</td>
<td>In-hospital mortality rate reduction</td>
<td>-2.1%</td>
</tr>
<tr>
<td>PLANET</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>PROFIT</td>
<td>Emergency medical services cost reduction</td>
<td>-26.5 Million €/Year</td>
</tr>
</tbody>
</table>

Table 5: Summary of connected ambulance socio-economic benefits in Lombardy

The communication between on board instrumentation and medical personnel boosts the efficiency of the operations in terms of time reduction: transport, diagnosis, protocol execution and idle times can be improved, leading to a faster and better-quality service.
Effectiveness benefits are measured as mortality rate reduction, thus the main category impacted by this first order of benefits is People.

As a second order of benefits, HD video quality and real time monitoring can support decision making processes when it comes to the dispatch of advanced medical equipment (e.g. medicalized ambulances). It is reasonable to assume that smart dispatch of emergency teams can reduce the unnecessary deployment of advanced medical equipment, leading to savings in both the categories of Planet and Profit by reducing emissions and operative costs of unnecessary deployments.

Lastly, route prioritization reduces transport times, and this leads to greater utilization of the ambulances: the increasing number of trips per unit of time made by a single ambulance may reduce the number of vehicles necessary to cope with the required service rate.

9.1.5 Quantification of socio-economic benefits

The quantification of the socio-economic benefits is subjected to previous evaluation of the expected impact of each use case feature on the process.

1) Assisted decision-making: the help of augmented reality technologies can reduce significantly the time needed to take decisions in critical situations and it can also speed up the execution of life saving protocols. The expected time reduction can be quantified as the 20% of total time spent on-site.

2) Remote medical assistance: early diagnosis and availability of patient’s data can streamline in-hospital operations in preparation to surgical intervention. The expected time reduction can be quantified as the 5% of the time between the reception of the patient and the moment it undergoes surgical intervention.

3) Route prioritization: communication with road infrastructure can clear the path of the ambulance to the target zone and to the hospital, increasing the average speed of the trip. The expected time reduction can be quantified as the 19% of the travel time.

Overall, the total time saving is presented in Table 6.
<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>TIME (AS IS)</th>
<th>IMPROVEMENT</th>
<th>TIME (TO BE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSPORT (ALARM-TO-TARGET)</td>
<td>11’</td>
<td>19%</td>
<td>9’</td>
</tr>
<tr>
<td>ON-SITE TREATMENT</td>
<td>20’</td>
<td>20%</td>
<td>16’</td>
</tr>
<tr>
<td>TRANSPORT (TARGET-TO-HOSPITAL)</td>
<td>5’</td>
<td>19%</td>
<td>4’</td>
</tr>
<tr>
<td>INTERVENTION</td>
<td>60’</td>
<td>5%</td>
<td>57’</td>
</tr>
<tr>
<td>TOTAL</td>
<td>96’</td>
<td>10%</td>
<td>86’</td>
</tr>
</tbody>
</table>

*Table 6: Time improvements in connected ambulance*

Connected ambulance can save up to 10% of the time for a single rescue mission and on top of this gain it is reasonable to calculate the expected benefits for people, planet and profit categories.

- **People**: in every 10’ saved in case of OHCA, the mortality rate decreases by roughly 2.1%;
- **Planet**: the expected reduction in CO2 emissions has been calculated because of the expected reduction in number of unnecessary trips thanks to a more informed dispatch of means of rescue. However, the impact on emissions is not the core of this specific use cases and after the calculation of the results we considered them negligible.

The methodology that we followed for the calculation of planet benefits is the following: in Lombardy, the sum of the dispatch of intermediate and advanced medical equipment is 109.500 times/year (advanced: 64.970, intermediate: 44.530). The dispatch of these two types of equipment can be reduced by 5% and 15% respectively thanks to a more accurate identification of unnecessary intervention and better efficiency of basic means of rescue.

With this assumption, 9.928 trips/year with an average trip length of 13.3 km can be avoided resulting in the saving of 33.4 tons of CO2 every year since it has been assumed that each ambulance emits into the atmosphere 252.7 grams of CO2 every kilometre;

- **Profit**: considering the average time in which an ambulance will be employed in a rescue mission from the alarm to the reach of the hospital which is equal to 29’ plus 15’ to be reset in working condition after the rescue, an ambulance will be employed
for an average of 44’. A connected ambulance available 24/7 will be capable of 1,36 trips/h versus 1,18 trips/h for a normal one, resulting in a productivity improvement of 15.9%. This improvement would be precious in the Italian context, because nowadays most of the ambulances have volunteers on board, an increase of productivity would increase the percentage of ambulances that have professional personnel on-board.

In monetary terms, if the total cost of basic means of rescue is 160 million €/year, the expected savings are roughly 25.6 million €/year.

In addition, the savings from the avoided unnecessary trips previously discussed amount to 873.437 €/year, calculated considering the cost per hour of an advanced means of 134.40 €/h and for the intermediate of 65.40 €/h. The final impact on Profit benefit would be a reduction of 26.6 million €/year for emergency medical services expense.

9.1.6 Critical analysis

The identification of the impact of 5G technology and its applications in the use case is highly dependent on the selected scenario of analysis. In this case, the choice to dive deep into time dependent diseases is due to the clear link between intervention time and probability of successful outcome. The impact of 5G capabilities in a connected ambulance is better observed when comparing the time of operations before and after the introduction of enhanced applications that aim to make the whole process more efficient.

The perimeter of analysis took into consideration is just a small portion of the overall potential benefits of connected ambulance (the blue area represented in Figure 14). In Figure 14 it is possible to see the considered perimeter and possible directions of expansion in order to identify the potential attainable benefits. For this purpose, there are two main dimensions to describe the perimeter of action considered.
The x-axis represents the number of time dependant diseases addressed, cardiac arrest account for the 26,6% of the whole domain of diseases (infarction, stroke and trauma). While the y-axis represents the geographical extension of the analysis, the benefits arisen has been considered only in Lombardy, that account for the 16,6% of population in Italy. Therefore, the idea is to represents the actual research and the potential domain of future studies on this topic.

For better proxies of the socio-economic benefits of the connected ambulance, the model can be replicated considering different scenarios and different time-dependent diseases such as traumas, stroke and heart attacks. The replication of the model would follow the same logic adopted for cardiac arrest, while the weights of the benefits should be adapted to the new circumstances.

The model can be adapted to various scenarios and use case, thus producing different outcomes because of the possible combination of interaction between application-based clusters and use case features.
In this case, the validation of the causal relations from the technological characteristics until the realization of the benefits was constantly reviewed and validated by a team that are participating to the pilot projects in Milan area.

The quantification of socio-economic benefits presents several criticalities that can produce high variability on the final values of the indicators. The most relevant criticality is given by the specificity of the application fields of the use case: emergency services are managed in a very complex way, but in this analysis the processes were purposefully simplified for the sake of modelling. Furthermore, understanding the emergency practices and assessing potential improvements require a deep knowledge of medical subjects that is out of the scope of this research.

To overcome this knowledge gap, two experts in charge of connected ambulance pilot project were interviewed and consulted to better identify where the impact are more likely to be observed. Nonetheless, some improvements are assessed using educated guesses that follow a conservative approach not to overestimate the calculated benefits.

An important point to address is the overall deployment of V2X application. For the proper functioning of connected ambulance, it is required that most of the cars have connectivity (V2V) and that the road infrastructure should be able to communicate with emergency vehicles (V2I). Since the automotive market is mainly represented by private cars, in order to exploit the full potential of 5G in in this peculiar application, cars need to be able to connect, and therefore at present is not possible to achieve benefits. In the next years the number of cars with level of driving automation and embedded connectivity is going to grow exponentially. Hence, in this case time benefits are achievable in the medium-long term rather than in the short-term.

The last criticality is represented by the lack of precise data. The information about the process itself can be recorded with dedicated field test, while system data regarding the number of rescue missions, the number of ambulances and the costs can be more precise
with a stronger interaction with the organisations in charge of emergency services in Lombardy.
9.2 Remote Surgery

Remote surgery (or Telesurgery) indicates an intervention performed from distance. This process requires having a robot (slave) that runs the operation on the patient and a console where the surgeon (master) controls the movements of the robot. Furthermore, it is required a third element to implement the connection between robot and surgeon: the telecommunication system that is required to transmit commands, video and other data between the slave and master component of the system.

Remote surgery is expected to have a huge potential among the surgery of the future. Nowadays, many hospitals in the world run every day many robotic surgery interventions, but this procedure with current technologies is limited to just few meters distance, with the surgeon sitting in a master-pilot console, located in the same room where the robot is operating. This pilot project is placed within an ongoing revolution in surgical field, in the latest years robotic surgery is continuously growing, showing the potential of mini-invasive surgery compared to the actual standards. Advantages of minimally invasive surgery compared to open surgery, include:

- Few small cuts versus a large incision
- Less trauma to the muscles, nerves and tissues
- Less bleeding
- Less scarring
- Less trauma to organs
- Less pain and reduced use of narcotics
- Less hospital times
- Less effect on the immune system

The 5G proves to have the requirements to make it possible to control complex operations remotely via a robot that is potentially located in any hospital in the world.
Thanks to enhanced connectivity the surgeon will be able to give real time commands to the robot, and through enhanced video services he will be able to follow the procedure step by step for a seamless surgical intervention in a safe environment.

9.2.1 References

In order to deeply investigate the potential benefits arising from remote surgery, there is one paper regarding how robotic surgery, considered by most as an emerging and exciting technology, was born and developed in the last 20 years with the aim of increasing the benefits and results of minimally invasive and video-assisted surgery and to improve and simplify the work of the surgeon.


Then, many other information regarding healthcare migration, overall robotic surgery numbers, surgical KPIs and processes insights have been researched in the following references:


- abmedica.it. «ab medica». Consultato 7 novembre 2019. 
9.2.2 Use case setup

In order to quantify the benefits arising from the remote surgery pilot project, the improvements have been calculated using as a starting point the current standard for many robotic surgeries: the DaVinci robot. The DaVinci robot is the most advanced robotic system for minimally invasive surgery. Its technical characteristics allow it to find different applications, from urology to gynaecology, from thoracic surgery to general surgery.

In Figure 15 is visually explained the concept of health mobility. Which is the movement on the territory of a user, compared to his residence, to obtain cure and care. A phenomenon
that can be classified in various ways in relation to the specific treatment service required: diagnostics, surgery, rehabilitation, transplantation or treatment of rare diseases.

The scenario proposed is summarized in the activity-based mapping represented in Figure 16, the patient recognises the need of cure and goes to the closest hospital, there after a first treatment, what can happen is that the patient has to migrate in another facility, eventually in another Italian region to seek better care. Patients move mainly for healthcare quality reasons and in this case also for lack of adequate robotic surgery. The DaVinci robot installed in the closer hospital in the region is not supported by the right medical team for the disease of the patient.

![Figure 16 As Is process mapping for remote surgery](image)

9.2.3 Application-Based Clustering

For the proposed scenario, two main application clusters have been identified, both with their specific network requirement to be satisfied:

1) **Enhanced video services**: the seamless transmission of stereoscopic images and video at high resolution require high broadband capacity along with high service reliability because continuous service is a critical element for remote surgery;
2) **Remote operations**: thanks to the robot the surgeon is ‘teleported’ in the operating room, but in order to do so, the system require ultra-low latency and reliability of the service. This has been the main obstacle to the deployment of remote surgery at long distances so far.

The quantification of network requirements for the pilot project in question derive directly from the testing of the ongoing experimentations. The technological requirements are summarized in Table 7.

<table>
<thead>
<tr>
<th>TECHNOLOGICAL CHARACTERISTICS</th>
<th>ENHANCED VIDEO SERVICES AND REMOTE OPERATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EMBB</strong></td>
<td>DL: 100 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL: 100 Mbps</td>
</tr>
<tr>
<td><strong>URLLC</strong></td>
<td>Latency: 1 mS</td>
</tr>
<tr>
<td></td>
<td>Reliability: 99,99%</td>
</tr>
<tr>
<td><strong>M-IOT</strong></td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

*Table 7: Network requirement for remote surgery*

The required network performances mentioned in Table 7, cannot be satisfied with current telecommunication infrastructure and technologies (optic fiber and 4G). The bidirectional transmission of video streaming together with audio signals coming from the console room and the operating room require high downloads and upload rates; furthermore, remote control of the robot is subject to very low latency requirement to help the surgeon to operate in a safe environment. In both applications the reliability of the network plays a central role, in fact a surgery is a critical medical operation and even very small downtime of the network would compromise its whole success and effectiveness.
9.2.4 Socio-economic benefits

From the application clusters mentioned above, it is possible to say that both converge in a unique feature of the use case:

- **Remotely guided robots**: real time medical video and audio streaming and robot assistance are both crucial for the deployment of remote guided robots. The timely control and exchange of information allow the surgeon to support and run a proper intervention without complications. 5G would be an enhancement of the current robotic surgery, eliminating geographical barriers and allowing the interchange of medical competences among different hospitals in the world.

In Figure 17 it is illustrated the technology evaluation model, applied for remote surgery. It represents the interactions between technological requirements, application-based clusters and use case feature, along with achievable benefit.
In order to explain how the new technology will change the current practice, a second activity-based mapping has been carried out on identifying where the feature of the use case plays its role. Figure 18 shows the current process mapping for remote surgery.

![Figure 18 To Be process mapping for remote surgery](image)

Basically, the macro activities are not changing, but in remote surgery pilot project, the 5G technology acts as an enabler of flexibility, both for the patient and eventually the physician. The main concept is that the patient will not move anymore in an hospital far from his home to seek better care, but if in the region where the patient is living there is an hospital with the DaVinci robot installed then the problem would be the lack of medical competences; and it is here that 5G plays its role eliminating this sort of geographical barrier. The system is therefore more flexible, first by improving spatial coverage of medical skills, then later, enabling the other benefits deriving from an increase of availability of medical competences.

The final set of benefits and the related beneficiaries are summarized in Table 8, while the methodology used to forecast the values of the indicators for the national health care service is presented in the next paragraph.
<table>
<thead>
<tr>
<th>BENEFICIARY</th>
<th>BENEFITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEOPLE</td>
<td>1) Coverage of medical skills</td>
<td>1) 1,66 robots/million inhabitant</td>
</tr>
<tr>
<td></td>
<td>2) Healthcare migration reduction</td>
<td>2) -1,64%</td>
</tr>
<tr>
<td>PLANET</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>PROFIT</td>
<td>Households savings</td>
<td>Between 60,8 million € and 127,6 million € every year</td>
</tr>
</tbody>
</table>

Table 8: Summary of socio-economic benefits for remote surgery in Italy

All the benefits measured are intended as the direct consequence of the coverage of medical skills benefit. In fact, an increase of coverage would directly affect the reduction of interregional healthcare migration; subsequently, this is strongly impacting the costs the households incur when migrating for healthcare reasons (mainly travel, board and lodging expenses). In a minor way it could even impact the air pollution caused by travels, but since the environmental dimension is not the main one in healthcare will not be taken into consideration.

9.2.5 Quantification of socio-economic benefits

The quantification of all the socio-economic benefits is subjected to the main unique feature of this pilot project. Which has an enormous impact on the process.

- Remotely guided robots:

  Once verified that using real-time audio and video streaming and robot assistance surgeons will be able to provide cure and perform surgery from distance, it is very important to bring these components into the Italian context.

Italy has been one of the pioneers in robot surgery and is the first country in Europe for number of DaVinci robot installed in hospitals, sharing this leadership in robotic with France. Nowadays there are 100 robots operating and are they are divided in the Italian regions as shown in Table 9.
<table>
<thead>
<tr>
<th>ITALIAN REGIONS</th>
<th>DA VINCI ROBOT INSTALLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALLE D’AOSTA</td>
<td>1</td>
</tr>
<tr>
<td>PIEMONTE</td>
<td>8</td>
</tr>
<tr>
<td>LOMBARDIA</td>
<td>22</td>
</tr>
<tr>
<td>LIGURIA</td>
<td>2</td>
</tr>
<tr>
<td>VENETO</td>
<td>12</td>
</tr>
<tr>
<td>FRIULI-VENEZIA GIULIA</td>
<td>2</td>
</tr>
<tr>
<td>TRENTINO ALTO-ADIGE</td>
<td>1</td>
</tr>
<tr>
<td>EMILIA-ROMAGNA</td>
<td>3</td>
</tr>
<tr>
<td>MARCHE</td>
<td>3</td>
</tr>
<tr>
<td>UMBRIA</td>
<td>3</td>
</tr>
<tr>
<td>ABRUZZO</td>
<td>3</td>
</tr>
<tr>
<td>LAZIO</td>
<td>8</td>
</tr>
<tr>
<td>TOSCANA</td>
<td>13</td>
</tr>
<tr>
<td>CAMPANIA</td>
<td>6</td>
</tr>
<tr>
<td>MOLISE</td>
<td>0</td>
</tr>
<tr>
<td>PUGLIA</td>
<td>6</td>
</tr>
<tr>
<td>CALABRIA</td>
<td>1</td>
</tr>
<tr>
<td>BASILICATA</td>
<td>1</td>
</tr>
<tr>
<td>SICILIA</td>
<td>3</td>
</tr>
<tr>
<td>SARDEGNA</td>
<td>2</td>
</tr>
</tbody>
</table>

*Table 9: Geographical distribution of DaVinci Robot installed in Italian regions*

From Table 9 is clear the potential that remote robotic surgery could have in the Italian healthcare context, thanks to the fact that every region, besides Molise, has at least one DaVinci robot installed.

- **People:** in 2011 there were 46 hospitals with da Vinci installed, but just 1 out of 46 had a medical team trained to perform paediatric surgery. Nowadays, the system is
more widely used, and it is possible to suppose, thanks to the increase of knowledge on this type of surgery, that five hospitals can perform paediatric surgery. In this case medical coverage for paediatric surgery would increase from 0.08 robots for one million inhabitants to 1.66 robots for one million inhabitants. Enlarging this concept to every kind of disease, is possible to expand the benefit to the problem of healthcare migration. In Italy there is a total of 20,450 hospitalization for robot surgery; the interregional mobility for surgery is 45% of the total number of surgeries but is possible to assume this percentage to be more in case of robotic surgery due to the novelty of this kind of cure (suppose 60%). Therefore, the number of mobility hospitalisations is 12,270, remote surgery has the potential to set to zero this number. The total interregional mobility in Italy amount for 750,000 hospitalisations circa, this means that it is possible to cut 1.64% of total mobility.

- **Planet:** the effects of this use case on consumption of resources and emissions can be considered negligible and not particularly differential compared to the current situation.

- **Profit:** To the 12,270 hospitalisation in one hospital avoided with remote surgery need to be added the relatives travelling with the patient. For the profit benefit have been considered two scenarios: one lower bound with 0.7 relatives for each patient hospitalised and an upper bound of 1.5 relatives for each patient.

### 9.2.6 Critical analysis

The impact the 5G would bring to robotic surgery and its applications is dependent on the scenario selected for this analysis. In this pilot project there are several criticalities that prevent the full potential of remote surgery. The impact of 5G capabilities is observed in the increase of flexibility that an enhanced medical robot would allow. This is creating many advantages for the potential patient, decreasing the number of interregional travels caused by healthcare migration.
Therefore, for a better understanding of the potentiality offered by remote surgery, a further investigation is needed, particularly in the sense that this specific scenario has given proxies at national level considering only interregional travels. The problem of healthcare migration is wider, considering that there are many Italian citizens seeking better care abroad.

To better describe the perimeter of analysis, in Figure 19 it is provided a graphical representation of the perimeter considered. The perimeter of analysis took into consideration is just a small portion of the overall potential benefits of remote surgery (the blue area represented in Figure 19). In Figure 19 it is possible to see the considered perimeter and possible directions of expansion in order to identify the potential attainable benefits. For this purpose, there are two main dimensions to describe the perimeter of action considered.

![Figure 19: Visual representation of the socio-economic potential benefits of Remote Surgery](image)

The x-axis represents the potential that robotic surgery can have in the future years with the number of robotic surgeries. The benefits arisen from remote surgery are constrained from the field of application, which is the robotic surgery. Even if Italy is the European leader in robotic surgery, it is still at its infancy, every year the number of diseases curable with a robot are exponentially increasing (15% increase year by year), likely in future years the
robotic field follow the same growth pattern, and this would mean that in the next 10 years can quadruple current numbers of surgical operations. While y-axis represents the geographical dimension in terms of healthcare migration, interregional migration accounts for 68.8% of Italian healthcare mobility (interregional plus international).

Another criticality arises from the fact that robotic surgery is very costly, and only few countries and hospitals can afford surgical robots, so it is not a solution for developing countries’ lack of medical competences.

Lastly, there is a lack of precise data and a deep understanding of medical practices is needed. To overcome this problem could be useful to have contact with expert in surgical and robotic field. Hence, a stronger analysis can be carried out analysing first the pathologies cured with robots in Italy, sorting the peculiarities in care for each hospital with robot installed.
9.3 IoT for telemedicine and remote medical consultation

Telemedicine is expected to bring several benefits to both the healthcare system and the patients thanks to fast and reliable exchange of vital parameters and documentation that allows specialised medical equips to provide remote assistance, diagnosis and intervention.

The creation of a network constituted by hospitals, doctors and patients can significantly boost the efficiency of post-operative treatment, monitor chronic diseases and predict the occurrence of critical events. These targets, if managed with telemedicine, are expected to bring major savings in the National Healthcare Systems while improving the effectiveness of the treatments because of the shift of recovery activities from inside the hospital to the patient’s house.

The increased reliability of wearable devices along with the enhanced computing capabilities of big data and the support of the medical personnel will grant the patients the same, if not superior, level of post-operative assistance without the need of being hospitalised.

Furthermore, a second order of benefits concern the quality of life of patients and caregivers that can better assist their relatives directly at home.

In case of cardiovascular diseases, especially with chronic ones, the benefits of telemedicine can be easily recognized, because the treatment is tightly linked to the constant monitoring of vital parameters. These diseases have also the highest mortality incidence over chronic diseases, indicating the potential social impact of the improvements.

9.3.1 References

- The research for the impacts of Telemedicine in the Italian territory followed the consultation of the references listed below:


Telemedicine can have plenty of applications to various types of pathologies and patients, with a consequent different impact on its expected outcomes.

For the quantification of the benefits, the main sources of data used to frame the perimeter of analysis were provided by available documentation published by the Italian authorities and institutes of statistics, and they are listed below:

- ISTAT, 2016, Mortalità per territorio di evento
- ISTAT, 2017, Aspetti della vita quotidiana: Stato di salute - regioni e tipo di comune

9.3.2 Use case setup

Considering a patient who suffered a heart failure, it is possible to distinguish two different phases in the treatment of the pathology: the first is represented by the acute occurrence of the heart failure, which needs the medical intervention at the hospital and a consequent hospital stay the following days; the second phase is the permanent monitoring of the pathology that is fundamental to prevent future crisis that can entail severe outcomes for the patient.

These two phases occur in two different moments and embed different shares of the expected benefits; therefore, they are distinguished in the following analysis.

Starting from post-operative treatment, it is important to identify the place where the patient is nursed: right after the operation, hospitals grant a period of convalescence under
strict control of the medical personnel until the diagnosis allows the de-hospitalisation. The simplified activity-based mapping is showed in Figure 20.

![Figure 20: As is process mapping in post-operative treatment of heart-diseases](image)

The second phase refers to the discharge of the patient and the continuation of the treatment at the patient’s house with periodic medical checks. When dealing with cardiovascular pathologies, the likelihood of sudden heart crisis for the patient grows and the prevention of these unexpected event can significantly reduce negative outcomes.

The activity-based mapping of this second phase is shown in Figure 21.

![Figure 21: As is process mapping in post-operative home stay](image)

Once more, the relevant axis of analysis is the time of detection and intervention following possible relapse of the pathology. When these events happen, the patient is rescued with emergency procedures involving the first aid service.
Both the figures illustrated above are a qualitative representation of the activities that are being carried on and their function is only to highlight where potential improvements may lie and not to precisely track the duration of each activity. For sake of clarity, the dimension of the box does not reflect the effective duration of each phase, but it is used for the identification of the causal relationships between events and for understanding where the new technology comes kicks in.

9.3.3 Application-based clustering

The fundamental pillars of a telemedicine systems are basically two:

1) **Monitoring and Tracking**: chronic diseases, especially with serious cardiovascular pathologies, need constant monitoring of vital parameters to track the effectiveness of the treatment and the health status of the patient. The sensitivity of the data exchanged requires high reliability standards;

2) **Enhanced video services**: the discharge of the patient from the hospital is subjected to the maintenance of the quality of the assistance from medical personnel even if the patient is not physically at the hospital. To create an effective interaction between doctors and patients, high quality video streaming comes to fill the gap and it requires high and reliable broadband capacity.
The above-mentioned requirements are summarised in Table 10.

<table>
<thead>
<tr>
<th>TECHNOLOGICAL CHARACTERISTIC</th>
<th>ENHANCED VIDEO SERVICES MONITORING AND TRACKING</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBB</td>
<td>DL: 1 Gbps&lt;br&gt;UL: 500 Mbps</td>
</tr>
<tr>
<td>URLLC</td>
<td>Latency: 10 mS&lt;br&gt;Reliability: 99.99%</td>
</tr>
<tr>
<td>M-IoT</td>
<td>Millions of devices</td>
</tr>
</tbody>
</table>

Table 10: Network requirements for telemedicine

While this application may not have stringent requirements in terms of latency of the communication, the most important 5G feature is the reliability of the connection. Given the sensitivity of the information exchanged and the involvement of people’s life, the continuity of the service is crucial to scale the solution to an always greater number of patients.

9.3.4 Socio-economic benefits

The selected application-based cluster enable two main features of the use case:

1) **Remote medical support**: high quality video streaming and real time data processing are available for remote medical consultation. Doctors can visit the patients from remote, control the effectiveness of the treatment and eventually adjust the therapy or opt for hospitalisation in case of deterioration of patients’ conditions;

2) **Automatic detection of emergencies**: constant monitoring produces enormous quantities of structured data that, with the help of artificial intelligence application, can prevent the occurrence of crisis and detect them earlier. Thanks to this level of monitoring, emergencies can be automatically detected, hence the intervention of emergency systems can be limited or reduced.
The interaction between the technology, the use case features, and the prospected benefits is shown in Figure 22.

![Technology Evaluation Model in Telemedicine](image)

*Figure 22: Technology evaluation model in telemedicine*

The technology evaluation model, in this case, comprehends both the two phases of the scenario illustrated above because on one hand the remote medical support affects the number of days of hospital stay needed for the patient as in Figure 23; on the other hand, the automatic detection of emergencies impacts the effectiveness of the remote management of the therapy as in Figure 24.
The benefits of the first phase of the scenario impact directly the society, because treating the patients with serious diseases at their homeplaces comes with a long list of intangible benefits for the patient itself and her caregivers in terms of quality of life. In monetary terms, the de-hospitalisation represents a great source of savings for the National Healthcare System because of the high costs sustained by hospitals for convalescent patients.

The second phase deals with the likelihood of positive outcomes in case of crisis, which is significantly higher if the monitoring can effectively anticipate possible relapses. The
connection between the patients’ house and the hospital may avoid the first aid service to intervene in emergency conditions thank to the anticipation of deterioration of patient’s health. In case of severe diseases this benefit reflects in the reduction of the mortality rates associated with cardiovascular diseases.

The summary of the socio-economic benefits obtainable in Lombardy is summarized in Table 11.

<table>
<thead>
<tr>
<th>BENEFICIARY</th>
<th>BENEFITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEOPLE</td>
<td>Reduction in supply of days of hospital stay</td>
<td>-26%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-309.616 days)</td>
</tr>
<tr>
<td></td>
<td>Reduction of mortality rate in chronic cardiovascular diseases</td>
<td>-15%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-1.537 deaths)</td>
</tr>
<tr>
<td>PLANET</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>PROFIT</td>
<td>Saving thanks to days of hospital stay reduction</td>
<td>-208,7 Million</td>
</tr>
<tr>
<td></td>
<td></td>
<td>€/Year</td>
</tr>
</tbody>
</table>

Table 11: Summary of telemedicine socio-economic benefits in Lombardy

It is reasonable to assume that modern technologies can benefit the patients affected by chronic diseases thanks to precise and advanced monitoring of the therapies even if they are not taking place inside the hospital.

The economic impact of this shift is perceived by the National Healthcare System as a more restrained supply of days of hospital stay that constitute a relevant burden on healthcare budget.

The expected saving can be obtained while also improving the quality of service in terms of effectiveness of the therapies and reduction of negative outcomes due to critical events. In terms of efficiency, the first aid service will be able to take more informed decision thanks
to the availability of data regarding patients’ clinical history, health status and early diagnosis.

9.3.5 Quantification of socio-economic benefits

The quantification of the improvements coming from the features of this use case is derived as follows:

1) Remote medical support: the supply of days of hospital stays can be reduced up to 26% compared to actual supply thanks to the great reliability of the instrumentation that can be installed at the patient’s homeplace.

2) Automatic detection of emergencies: the mortality rate associated with crisis derived from chronic cardiovascular diseases can be reduced up to 15% thanks to the anticipation of irreversible relapses.

These expected impacts are identified for the Lombardy region considering the best proxies available.

- **People**: the starting point for the calculation of the reduction of the supply of days of hospital stay is the number of days supplied in 2019 for the acute pathologies in Lombardy, which is equal to 7,938,886 days. This number is equivalent to the sum of all the days of convalescence spent by the patients in private and public hospitals. Chronic cardiovascular diseases are about the 15% of all the chronic diseases and this percentage is used as proxy to calculate the number of days of hospital stay for this specific type of chronic patients which is equal to 1,190,832 days per year. Assuming a potential reduction of 26% of these days of hospital stay, the saving accounts for 309,616 days per year.

Concerning the reduction of mortality rates, telemedicine is expected to increase survival rates up to 15%. The deaths for cardiovascular pathologies in Lombardy amount to 30,737 per year and the 33% of these deaths derive from chronic pathologies. Therefore, telemedicine is expected to save 1,521 lives per year.
- **Planet**: the effects of this use case on consumption of resources and emissions can be considered negligible and not differential compared to the current situation.
- **Profit**: Each day of convalescence inside the hospital costs 674 € to the National Healthcare System. Therefore, the yearly savings coming from the reduction of 309,616 days of hospital stay are equal to 208,6 Million €.

### 9.3.6 Critical analysis

In this use case, the role of 5G connectivity as an enabling technology is not as straightforward as it is for other use cases such as connected ambulance and remote surgery. With current 4G connectivity, the implementation of a telemedicine system would be possible because of not-so-stringent requirements over bandwidth, latency and traffic density.

However, the reliability of the communication plays a key role in strategic sectors such as the healthcare one. In many cases, the lives of the people are at stake, thus the related costs and consequences of eventual downtimes or service failure may outweigh the potential benefits that telemedicine can bring.

Other than the reliability of the connection, 5G is expected to manage sensitive patient data that require the security that new generation networks are expected to deliver.

Concerning the outcome of this analysis, only one potential field of application is analysed: chronic cardiovascular diseases. In addition to the high level of incidence of these pathologies on mortality rates, chronic cardiovascular diseases were the designed pathology to test the technology in the pilot projects.

To fully grasp the potential impact of telemedicine, the same analysis should be conducted on other relevant pathologies such as diabetes, cerebrovascular and respiratory diseases. The quantification of the improvements is case-specific, and it may significantly differ from one disease to another.

To highlight this problem, in Figure 25 it is provided a graphical representation of the perimeter considered. The perimeter of analysis took into consideration is just a small
portion of the overall potential benefits of IoT for telemedicine and remote medical consultation (the blue area represented in Figure 25). In Figure 25 it is possible to see the considered perimeter and possible directions of expansion in order to identify the potential attainable benefits. For this purpose, there are two main dimensions to describe the perimeter of action considered.

Figure 25: Visual representation of the socio-economic potential benefits for IoT for telemedicine and remote medical consultation

The x-axis type of acute disease considered, chronic cardiovascular disease accounts for the 15% of all acute chronic problems. While the y-axis describes the geographical expansion of the analysis made, where Lombardy accounts for the 16.6% of Italian population.

The model remains replicable and the adaptation to other types of pathologies is limited to the change of the parameters used as input for the final values. Despite the model demonstrate a solid framework for the analysis even in diverse circumstances and diseases, the value of the benefit indicators is highly dependent on the accuracy of the system data used to produce the estimations.

The numbers used to estimate the reduction of number of days of hospital stay and the reduction of mortality rates come from the best proxies available to describe the hospital
stay for cardiovascular chronic diseases in Lombardy and the exact number of deaths due to such pathology.
9.4 Rehabilitation Robot

In the recent years there has been a rapid evolution and growth in the sector of rehabilitation technologies. Robotic is expected to be one of the biggest revolutions in the healthcare sector, as already seen in remote surgery the application of robotics in healthcare cover a wide number of different diseases. In this case robotic is intended to be used in rehabilitation. Thanks to the enhanced connectivity, the physician can remotely follow a rehabilitation session enabled by a seamless flow of information.

Robotic rehabilitation is gaining more and more acceptance in the clinical field. Many experimental studies show its effectiveness in specific fields of intervention, among which the neurological field is the most significant. Robotic technology is becoming increasingly popular and there are numerous studies in the literature that attest to its effectiveness. Few are, for the moment, the centres that use these technologies in rehabilitation courses, but robotic rehabilitation is destined to play an increasingly important role in the future.

This pilot project has been developed around the Hunova robot (developed by Movendo Technology that is a partner start-up in the 5G trials in Milan), interconnecting it in a system in order to collect data for recognition and transmission of total body biomechanical parameters of the patient. It allows physicians and physiotherapist to treat, measure and prevent many pathologies in orthopaedic, neurology and geriatric field.

Therefore, thanks to the enhanced connectivity between the remote workstation where the physician is located and the remote system, it is going to be possible to have seamless flow of real time data of training programs and evaluation of parameters by the clinician; as well as real time bio-feedbacks generated by the robot during the rehabilitation session and eventually a video stream between operator and patient.

9.4.1 References

In order to build the framework for rehabilitation robot, it has been analysed a various number of references. Basically, the information needed were competence based and
numerical based, in the sense that it has been fundamental to get in touch deeper with the arguments treated in the use case and make the right estimations for achievable benefits.

The main reference consulted is a report made by the Ministry of Health:


In this report is presented a comprehensive analysis of hospitalisation activity in Italy, with the full list of key performance indicators needed for the analysis for rehabilitation diseases.

Apart from that, many reports and information coming from websites of technology provider helped in the drafting of rehabilitation robot use case. Research has been focused on understanding the role of robots and telemedicine applied for rehabilitation diseases, as well as better understanding the functionalities of Hunova robot, which is a robotic system designed in response to a clinical need for objective evaluation and rehabilitation treatment tools that support doctors, physiotherapists, and patients throughout the course of treatment and recovery. The information was consulted from the following references:

- ISTAT, Il sistema dei conti della sanità per l’Italia», 2017, 22.
- Demurtas, Giorgio, Silvia Dari, e Rosella Bonifazi. «Stima del fabbisogno del personale della riabilitazione nella ASL di Viterbo». TEME - TECNICA E METODOLOGIA
9.4.2 Use case setup

The quantification of the benefits arising from the rehabilitation robot use case, the improvements, as previously mentioned, have been calculated using the current standard for rehabilitation session (rehabilitation centres) comparing it with a hypothetical introduction of practices performed remotely via robot.

Hunova is a robotic system designed in response to a clinical need for objective evaluation and rehabilitation treatment tools that support doctors, physiotherapists, and patients throughout the course of treatment and recovery. It is dedicated to rehabilitation in orthopaedics, neurology and geriatrics. In the analysis of robotic rehabilitation, the perimeter of analysis considered, is focused on neurological rehabilitation in Lombardy.

This use case cannot be summarized in just one scenario, but in order to evaluate all the main benefits, is needed to divide it into two main scenarios. In the first one the patient in need is undergoing rehabilitation hospitalisation after an intervention.

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**Figure 26 As Is process mapping for rehabilitation robot, scenario 1**
In Figure 26 are shown, for the first scenario, the main macro activities the patient is undergoing until the end of rehabilitation treatment. Here, the patient has a problem and goes to the hospital to undertake the intervention, after there is the period of hospitalisation (post-operative recovery and rehabilitation). Subsequently, the patient is de-hospitalised and for a period will have to go to a rehabilitation centre periodically to complete the treatment.

Different is the second scenario, illustrated in Figure 27, where the patient needs a medical examination for rehabilitation, the patient takes the appointment for the examination and has to wait his turn (time between $T_0$ and $T_1$) on the waiting list before receiving care from the rehabilitation centre physicians.

![Figure 27 As Is process mapping for rehabilitation robot, scenario 2](image)

For sake of clarity, the dimension of the box does not reflect the effective duration of each phase, but it is used for the identification of the causal relationships between events and for understanding where the new technology kicks in.

9.4.3 Application-based clustering

In order to analyse these two scenarios presented above, three main application clusters have been identified, all with their specific network requirement to be satisfied:
1) **Enhanced video services:** high resolution video streaming between medical operator and remote robot location require broadband capacity along with high service reliability. This is a critical element for a fluid remote integration between patient and physician;

2) **Monitoring and tracking:** the continuous real-time exchange of biofeedback generated by the Hunova robot has high requirements of network availability;

3) **Remote operations:** thanks to the robot the physician will be able to perform a rehabilitation session, but to do so the system require ultra-low latency and reliability of the service. This is useful for eventual feedback actions.

The quantification of network requirements for the rehabilitation robot use case come from the testing Vodafone is performing. The technological requirements are summarized in Table 12.

<table>
<thead>
<tr>
<th>TECHNOLOGICAL CHARACTERISTICS</th>
<th>ENHANCED VIDEO SERVICES, REMOTE OPERATIONS AND MONITORING &amp; TRACKING</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBB</td>
<td>DL: 5 Mbps</td>
</tr>
<tr>
<td></td>
<td>UL: 5 Mbps</td>
</tr>
<tr>
<td>URLLC</td>
<td>Latency: 2ms</td>
</tr>
<tr>
<td></td>
<td>Reliability: medium/ high (99.99%)</td>
</tr>
<tr>
<td>M-IOT</td>
<td>Not relevant</td>
</tr>
</tbody>
</table>

*Table 12: Network requirement for rehabilitation robot*

The required technological performances mentioned in Table 12, cannot be all satisfied with the current telecommunication infrastructure (4G and optic fiber). In this use case the application scenario of the robot is that it is installed remotely, therefore wireless connection is mandatory. Furthermore, the case requires high transmission speed that allows the transmission of measurements made by the sensor network of Hunova and
transmit those real-time together with video and audio streaming to the medical operator if necessary. For these reasons 5G technology is considered essential for the realistic deployment of rehabilitative robots.

9.4.4 Socio-economic benefits

From the three application clusters mentioned in the previous chapter, the use case shows the possibility to be described mainly by two features:

- **Remote medical support**: real-time video (and audio) streaming and remote continuous monitoring are the two building blocks of any remote medical support. Indeed, also in this use case they are crucial for the deployment of remote support. The data and biofeedback from the robot allow the physician to carry out a remote examination without complications. 5G is showing the possibility to eliminate competence geographical barriers in medical field.

- **Robotic rehabilitation**: robot assistance is the enabling application of 5G technology that makes remote rehabilitation feasible. The advances made by technology and robotics have enabled rehabilitation medicine in recent years to apply new and more effective treatment systems. System reliability and low latency play a central role in this use case feature.

In Figure 28 it is illustrated the technology evaluation model, applied for the Hunova rehabilitation robot, the model represents the interactions between technological requirements, application-based clusters and use case features, along with measurable benefits.
Figure 28 Technology evaluation model for rehabilitation robot

Subsequently, in order to illustrate how the 5G technology will change the current process, for both scenarios have been drafted a second activity-based mapping (to-be), focused on identifying where the use case characteristics play their role.

For the first scenario the to-be process mapping is shown in Figure 29.
In Figure 29 is possible to notice that the macro activities are not changing, but in this case 5G acts as a flexibility enabler for the patient, bringing advantages in productivity also for the physician. The main concept is that the physician is going to be able to perform remotely many protocols he could only do face to face with the patient, allowing earlier de-hospitalisation and in this case the patient can go in a place very close to his home or in some cases even stay at home to undertake the medical examination. This system compared to the actual standard is enabling more flexibility, improving doctor’s efficiency as well.

In the second scenario, illustrated in Figure 30, has been highlighted the time benefit, the increase of medical productivity could have for the national healthcare system and indeed for the patient, reducing the overall time of waiting lists (time between T₀’ and T₁’).
The final set of benefits and the related three beneficiaries are summarized in Table 13, then the methodology used to forecast and measure the impact of the indicators for patient and national health care service is presented in the next paragraph.

<table>
<thead>
<tr>
<th>BENEFICIARY</th>
<th>BENEFITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEOPLE</td>
<td>1) Hospitalisation</td>
<td>-131.982 days</td>
</tr>
<tr>
<td></td>
<td>2) Optimisation of resources</td>
<td>x1.5 more productivity</td>
</tr>
<tr>
<td></td>
<td>3) Waiting list reduction</td>
<td>33%</td>
</tr>
<tr>
<td>PLANET</td>
<td>Negligible</td>
<td></td>
</tr>
<tr>
<td>PROFIT</td>
<td>- NHS savings</td>
<td>88.9 million €</td>
</tr>
</tbody>
</table>

Table 13: Summary of socio-economic benefit for rehabilitation robot in Italy

As previously explained the benefits arise from two different scenarios, remote support and robotic medicine are enablers for all the social benefits. They contribute to earlier de-hospitalisation with as a result the reduced need of hospital stays. This is going to make an impact on savings for healthcare system reducing the cost for hospitalisation. Another important aspect is that thanks to this new technology medical operators can perform more than one examination at same time thanks to enhanced capabilities of remote
rehabilitation, increasing their productivity and subsequently reducing hospital waiting lists, which is a big problem in Italian healthcare nowadays.

9.4.5 Quantification of socio-economic benefits

In order to quantify all the socio-economic benefit has been carried out a deep research on the enabling features of this pilot project.

1) Remote medical support: thanks to the real-time video streaming and remote continuous monitoring is possible to state that the doctor can perform many tasks from remote location. For this reason, what can be performed with Hunova when patient and physician are together, could be in future performed remotely without complications.

2) Robotic rehabilitation: remote communication of medical competences is not the only peculiarity of this use case, without the robot, remote rehabilitation cannot express its full potential. Nowadays robotic rehabilitation is already changing the rehabilitation world, and particularly Hunova can help in many rehabilitation cases. As previously said Hunova can perform many clinical protocols in orthopaedics (rehabilitation of ankles, knees, hips, and the lumbar region of the spine), neurology (functional retraining, postural control, balance, proprioception, rehabilitation following stroke, degenerative diseases of the central nervous system, and injury to the peripheral nervous system) and geriatrics (fall risk assessment, postural control, proprioception and balance, joint mobilization, rehabilitation following prosthetic implant).

Due to the lack of specific clinical record, it has been assumed in a conservative manner that Hunova robot is able to perform 30% of the overall neurological rehabilitations for degenerative diseases of the central nervous system.

The information above allow the full explanation of the final step of the analysis for this use case. The benefits:

- **People:** the first benefit to be highlighted is the number of days saved by the healthcare system and patients in terms of hospitalisation. In 2016 in Lombardy there have been 95,891 hospitalisations for rehabilitation, and degenerative
diseases of the central nervous system account for the 11.3% of this number (10,836 hospitalisations), the average hospitalization for this kind of rehabilitation is 40.6 days per person (higher than the average mean hospitalisation for rehabilitation in Lombardy: 23.2 days), summing is a total of 439,942 days of hospital stay. If only 30% of degenerative diseases of the central nervous system rehabilitations can be performed with robot, there would be 131,982 fewer hospitalisation days.

The second improvement come from physician productivity; the robot is allowing faster treatment because similar examinations can be performed together, assuming a 50% of productivity gained. Given that an average examination is one hour long, the waiting lists in Lombardy are 34 days long for rehabilitation and that one operator works in a medical ward 36 hours a week, the application of 5G technology and Hunova robot would bring, thanks to the increased productivity, a reduction of 33.3% in waiting lists length for the 30% of neurological rehabilitation patients.

- **Planet:** in this case the environment is not the main beneficiary of the analysis. As many of the healthcare pilot projects, the focus of action is the patient. In healthcare providing better care and allowing savings for the system are the critical points of the analysis. Nonetheless, the reduced need of travel allowed by rehabilitation provided by remote can have an impact on the pollutant emissions of patients travel.

- **Profit:** combining the application of robotic rehabilitation and remote medical support there could be huge savings for the healthcare system. In Italy the average cost of a day of hospitalisation is 674 € and considering the fewer days of hospitalisation, would bring to 88.9 million € of savings for the Lombardy healthcare system.

### 9.4.6 Critical analysis

The impact that 5G will have for the indicators measured in this use case is highly dependent on the scenarios selected for the analysis.
To highlight this scenario, in Figure 31 it is provided a graphical representation of the perimeter considered. The perimeter of analysis took into consideration is just a small portion of the overall potential benefits of rehabilitation robot (the blue area represented in Figure 31). In Figure 31 it is possible to see the considered perimeter and possible directions of expansion in order to identify the potential attainable benefits. For this purpose, there are two main dimensions to describe the perimeter of action considered.

![Diagram](image)

*Figure 31: Visual representation of the socio-economic potential benefits for Rehabilitation Robot*

The x-axis describes the type of rehabilitation disease, the analysis focused on rehabilitation of degenerative diseases of the central nervous system, that account for the 11,3% of the total rehabilitation diseases. While the y-axis represents the geographical extension of the analysis, considering that Lombardy accounts for the 16,6% of total Italian population. Therefore, the potential of rehabilitation robot is huge compared to the actual numbers considered.

Another important point is that Hunova robot is not the only technology allowing remote rehabilitation, the current robotic devices include exoskeletons for aiding limb or hand movement such as the Tibion Bionic Leg, the Myomo Neuro-robotic System, MRISAR’s STRAC (Symbiotic Terrain Robotic Assist Chair) and the Berkeley Bionics eLegs; enhanced
treadmills such as Hocoma's Lokomat; robotic arms to retrain motor movement of the limb such as the MIT-MANUS, and finger rehabilitation devices such as tyromotion's AMADEO. Some devices are meant to aid strength development of specific motor movements, while others seek to aid these movements directly. Often robotic technologies attempt to leverage the principles of neuroplasticity by improving quality of movement, and increasing the intensity and repetition of the task.

In this use case there are several criticalities that prevent the full deployment of remote rehabilitation. The main problem arisen during the analysis is the cost that the full deployment of robots would have in the healthcare system, bringing to huge investment in terms of money and reorganisation of medical processes. Another critical point is the lack of precise data, as well as a deep understanding of rehabilitation techniques. In order to overcome this problem could be useful to make interviews with experts in neurology and rehabilitation to understand feasibility of the system.

Therefore, for a better understanding of potential benefits for remote rehabilitation a further investigation is needed and some of the hypothesis made must be falsified by reality, mainly in terms of medical willingness for change in processes of this magnitude. Nevertheless, the field of application is growing over the years and it presents itself as a solution to overloaded and scarce healthcare system. In the next decades Italian healthcare system will face an increasing demand for rehabilitation of elderly people, forecast say that in Italy by 2040 there will be 18,8 million citizens aged 65 or more, according to ISTAT data (at least 5 million more than today). Hence, all the applications in remote medicine can be the solution for a collapsing healthcare system.

Lastly, the benefits arisen from remote rehabilitation are constrained to the analysis that has been performed, robotic applications are not the only solution for many cases, but many systems are currently under study, such as smart sensor devices for rehabilitation and connected health project are focused on introducing wearable sensor systems among elderly communities to support their rehabilitation.
10 Applications in automotive

All the main components of ITU 5G triangle (latency, reliability, network density and capacity) are expected to bring significant benefits in the whole automotive sector. Providing transportation with smarter vehicles and infrastructure will have huge effects of transportation systems and the importance of achievable benefits is emphasized by the size the automotive sector and its importance in modern economies.

In the next future vehicles are meant to exchange digital data one another, accelerating the flow of information and even change the data interchange pattern. Digitalising such a strategic sector will allow to address some of the national major criticalities, such as traffic jams, road safety and pollutant emission reduction. In the following paragraph different applications of 5G technology in future mobility are analysed: from urban environment, where smarter vehicles and infrastructure allow better management of urban intersections and non-urban environment where 5G enables the development of automated safety systems, with clear repercussions also on the environmental side.

10.1 Intelligent Transportation Systems

As one of the most important domains of the 5G technology, the automotive sector of the future is forecasted to make huge changes in everyday life. Thanks to enhanced capabilities, connected vehicles will be able to exchange seamless flow of information with other vehicles, road infrastructure, pedestrian and cyclists.

The following analysis has been carried out considering the four use cases of automotive vertical into one single use case with two different application scenarios:

- **Urban:**
  - Cooperative urban cross traffic
  - Intelligent speed adaptation and control

- **Non-Urban:**
  - Assisted driving
Automated systems for safe driving (Highway Chauffeur)

The analysis has been carried out grouping these four different scenarios because all of them show to have the same technological requirements and share one another many of the benefits arisen. Vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) data transmission is going to help and support driver advisories, driver warnings and vehicle or infrastructure controls.

It is envisioned that vehicles will be able to communicate and that this rich set of data will support new generation of active safety applications and systems, along with effects on pollutant emissions. The following analysis takes into consideration the effects that 5G technology has on light vehicles (i.e., passenger cars, van, minivan, sport utility vehicles, or pickup trucks) addressing the most critical crash scenarios.

The uses cases grouped show to cover most of the safety applications enabled by connected vehicles combining effects of existing safety technologies enhanced by further application of 5G V2X.

In literature it has been analysed that there are many technologies working together in order to obtain the maximum benefit out of V2X systems, where enhanced connectivity works complementarily with current advanced driver assistance systems (ADAS), the full list of technologies is listed below:

- Forward collision warning (FCW)
- Cooperative adaptive cruise control (CACC)
- Control lost warning (CLW)
- Cooperative intersection collision avoidance system (CICAS)
- Road departure crash warning (RDCW)
- Lane keeping assist (LKA)
- Automatic emergency breaking (AEB)
- Electronic stability control (ESC)
- V2Pedestrian
- V2Pedalcyclist
- Backup collision intervention (BCI)
- Blind spot warning (BSW)
- Lane changing warning (LCW)
- Do not pass warning (DNPW)

The above-mentioned characteristics are aimed at improving safety of drivers in case of crash scenarios.

In the urban environment it is proposed to investigate the possibility to send and receive, from other vehicles while approaching road junctions about, information regarding position, speed and drive commands. The sensorised cars communicate one another thanks to 5G network with vehicle to vehicle (V2V) communication and in a more futuristic scenario cars will be able to communicate with the surrounding road infrastructure (V2I), allowing even more advanced road safety.

Increase in safety applications has consequences even in other fields of application, an example I given by the application of 5G to highways, where increased string stability impacts on safety application with better performances also in platooning systems, that has environmental impact too.

10.1.1 References

In order to build the framework, it has been analysed a various number of references. Basically, the information needed were competence based and numerical based, in the sense that it has been fundamental to get in touch deeper with the arguments treated in the use case.

In intelligent transportation systems the main reference considered in the analysis is a paper of the University of Texas at Austin:

Given the complexities of technology interactions and crash details, the overall safety impacts of multiple connected vehicle technologies have not yet been estimated. The authors provide a research that seeks to fill the gap that by using the most current U.S. General Estimates System crash records to estimate the economic and functional-years crash-related savings from each connected and automated vehicle application.

To better understand the topic other side papers have been analysed, they provide many information on vehicle to vehicle applications and potential benefits. In some cases, they provide empirical studies and related numbers that have been reused in this analysis; the references are listed below:

For the numerical analysis, it is often required more specific data for the system analysed and for the variables affected by intelligent transportation system. For this reason, many local reports have been analysed:

- Antognazza. «Rapporto sulla qualità dell’aria della città metropolitana di Milano», 2016, 86.

10.1.2 Use case setup

For the quantification of the benefits of Intelligent Transportation Systems, the expected improvements are calculated with respect to Italian macro data for incidents, adapting results derived from a study about US data. Previously, has been mentioned the fact that there are four different use cases divided in urban and non-urban environment scenarios. Two different scenarios have been analysed.

Figure 32 represents the urban scenario, in which a light vehicle is approaching a road junction. The macro activities mapped are the same for many different pre-crash scenarios for crossing paths:

- Running red light
- Running stop sign
- Left turn across path of opposite direction at signalised Junctions
- Vehicle turning right at signalized Junctions
- Left turn across path of opposite direction at non-signalised Junctions
- Straight crossing paths at non-signalised Junctions
- Vehicle(s) turning at non-signalised Junctions

Figure 32 aims at simplifying the scenario in which a vehicle is going straight, and while crossing an intersection collides with another straight crossing vehicle from a lateral direction.

![Process Diagram](image)

**Figure 32: As is process mapping in urban scenario**

The second scenario process mapping illustrated in Figure 33 aims at identifying the main macro activities of rear-end and opposite direction crashing type in non-urban environment.
For this kind of crash type, there are many similar pre-crash scenarios that characterise the analysis, taking into consideration the assisted driving pre-crash scenario avoided and highway chauffeur:

- Following vehicle making a manoeuvre – rear-end
- Lead vehicle accelerating– rear-end
- Lead vehicle moving at lower constant speed– rear-end
- Lead vehicle decelerating– rear-end
- Lead vehicle stopped– rear-end

The main problem identified is the lag between the time difference between the pre-crash event and the first corrective manoeuvres by the following vehicles. The main cause for this type of incidents is human error.

10.1.3 Application-Based Clustering

For connected and autonomous vehicles have been identified two application-based clusters. Both have their network requirement to be satisfied:
5) **Monitoring and tracking**: the continuous exchange of vital parameters from on board instrumentation has very high requirements of network availability. The information coming from a fusion of different sensors information is the backbone for the deployment of connected vehicle application with 5G technology. The realisation of the full potential of smart sensor communication implies a huge number of objects connected to the network, hence the capability to support a massive number IoT devices is required;

6) **Connected vehicle**: Vehicle-to-X (V2X) communication needs ultra-low latency (maximum 2 mS end to end) connectivity to ensure an efficient and safe data exchange in mobility conditions, along with high broadband capacity for the exchange of high amount of data if needed.

The quantification of network requirements for the designed application-based clusters derives from test run by Vodafone for automotive pilot projects and they are summarized in Table 14.

<table>
<thead>
<tr>
<th>TECHNOLOGICAL CHARACTERISTIC</th>
<th>MONITORING AND TRACKING AND CONNECTED VEHICLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMBB</td>
<td>DL: 5 Mbps&lt;br&gt;UL: 5 Mbps</td>
</tr>
<tr>
<td>URLLC</td>
<td>Latency: 1 mS&lt;br&gt;Reliability: 99.99%</td>
</tr>
<tr>
<td>M-IoT</td>
<td>Elevated</td>
</tr>
</tbody>
</table>

*Table 14: Network requirements for Intelligent Transportation Systems*

The implementation of 5G wireless technology is a fundamental element that enable the proper functioning of control systems for vehicles safety. Particularly, some of the characteristics of 5G technology are necessary. The experimentations are focused on active
safety, for this reason is necessary to grant the accuracy of information exchanged and the absence of delays in the transmission and 5G satisfies these requisites. Moreover, another important element is the need to protect the information allowed by the functionalities of network slicing, aiming at securing future IoT networks.

Lastly, 5G technology allows to share one single physical infrastructure between different service models, therefore providing different levels of latency, reliability and safety for different information according to specific needs. This specific group of cases require to be able to establish a connection vehicle to vehicle and vehicle to road infrastructure.

10.1.4 Socio-economic benefits

From the above-mentioned application clusters, for intelligent transportation systems have been identified three main features:

1) **Collision helper**: sensor application and the communication of information with the surrounding environment, combined with current safety technologies embedded in cars allow enhanced collision avoidance systems. This specific feature is suitable for urban and non-urban scenarios, being the centre of gravity of vehicles of the future;

2) **Traffic flow optimisation**: vehicle to X does not mean just mere communication, but it is useful in traffic congestion too. V2V involves direct connection between vehicles to communicate relative position, speed and intended movements. This feature is therefore suitable in urban environments, where traffic congestion is one of the main problems.

3) **String Stability**: Cooperative Adaptive Cruise Control (CACC) system, regulates intervehicle distances in a vehicle string, for achieving improved traffic flow stability and throughput. Improved performance can be achieved by utilizing data interchange between vehicles through wireless communication. An increase in string stability in non-urban environments has the potential to reduce fuel consumed through platooning. Platooning refers to the practice of multiple vehicles
following one another closely, leading to reductions in aerodynamic drag for all the vehicles, but particularly for the vehicles in the middle of the pack.

In Figure 34 the technology evaluation model represents the interactions between the technological requirements, application-based clusters, use case features and potential benefit that could be achieved for the proposed scenarios.

![Technology Evaluation Model in Intelligent Transportation Systems](image)

*Figure 34: Technology evaluation model in Intelligent Transportation Systems*

To further explain how the features enabled by intelligent transportation systems are changing or improving the process, a second activity-based mapping has been carried out for both urban and non-urban environments on identifying where and when those features come to action.
Figure 35: To be process mapping in urban scenario

The to-be process mapping for urban scenarios is shown in Figure 35; in this case each macro activity is expected to be more efficient in the sense that enhanced communication and safety applications work together in order to reduce the reaction time in case of pre-crash scenario.

In Figure 36, it is illustrated the non-urban scenario. The increase of string stability along with collision helping systems have the potential to increase road safety and decrease air pollution. Compared to the as-is flow of information, the augmented safety systems allow the transmission of information in the platoon directly from the leading vehicle, cutting enormously the response time of following vehicles. Information flow in not anymore from one car to the other, but all cars are able to connect one another and follow the information coming from the leading vehicle.
Thanks to these new capabilities, cars are expected to be safer, along with environmental benefits deriving from optimisation of traffic and reducing forward resistance (platooning).

The final set of benefits and the related beneficiaries are summarised in Table 15, while the methodology used to forecast the values is presented in the next paragraph.
<table>
<thead>
<tr>
<th>BENEFICIARY</th>
<th>BENEFITS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEOPLE</td>
<td>Incident reduction Urban (Milan)</td>
<td>38.8%</td>
</tr>
<tr>
<td></td>
<td>Incident reduction non-Urban (Italy)</td>
<td>47.1%</td>
</tr>
<tr>
<td></td>
<td>Road deaths and injuries (Urban)</td>
<td>-41 deaths and -7.051 injuries</td>
</tr>
<tr>
<td></td>
<td>Road deaths and injuries (non-Urban)</td>
<td>-139 deaths and -7462 injuries</td>
</tr>
<tr>
<td>PLANET</td>
<td>Emissions:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Highway (Italy)</td>
<td>- 212 million tons CO₂/year</td>
</tr>
<tr>
<td></td>
<td>- Urban (Milan)</td>
<td>- 959.33 kilotons CO₂/year</td>
</tr>
<tr>
<td>PROFIT</td>
<td>- Social costs Urban (Milan)</td>
<td>-418.5 million €/year</td>
</tr>
<tr>
<td></td>
<td>- Social costs Highway (Italy)</td>
<td>-572.2 million €/year</td>
</tr>
</tbody>
</table>

Table 15: Summary of Intelligent Transportation Systems socio-economic benefits

All three categories of benefits are fundamental, with economic benefits deriving from societal advantages brought by the application of 5G technology in the automotive sector.

Benefits arisen are summarised in one single table, but they come from two different scenarios. Both urban and non-urban environment show the potentiality reduce considerably road incidents, but they differ in terms of environmental benefits. In the urban scenario V2I and V2N (vehicle to network) involve vehicles sending data to a wider network, which is then aggregated by a traffic management system. The traffic management system analyses inputs and communicates with the connected devices (other vehicles, traffic lights, etc.) to optimize traffic flows. Different is non-urban where the reduced latency in information and data communication allow cars reduce or even zero the string instability, making it possible to form platoons of cars at medium and high speeds.
10.1.5 Quantification of socio-economic benefits

In order to quantify the socio-economic implications of intelligent transportation systems, has been carried out an analysis on every single use case that makes up the automotive sector in the 5G trials, taking into consideration all the enabling features.

1) Collision helper: communication system enhances the capabilities of ADAS (advanced driver-assistance systems), adapting and enhancing vehicle systems for safety and better driving. V2V and V2I applications enrich the set of data and vehicles will be able to undertake corrective manoeuvres without the need to wait for human intervention, eliminating the first cause of incident that is human error.

2) Traffic flow optimisation: In relation to V2X, V2N (Vehicle-to-Network) enables both broadcast and unicast communications to take place between vehicles and the V2X management system and the V2X Application Server (AS). Vehicles are able receive broadcasted alerts regarding accidents further down the road or warnings of congestion or queues on the planned route.

3) String Stability: compared with human drivers, an automatic car platoon control system has the advantages of decreasing intervehicle distance (i.e., tight formation), and is thus considered a promising solution for reducing, aerodynamic drag, and fuel consumption.

The information above allow the explanation of final benefits of the analysis:

- **People**: the first benefit to be highlighted is the number of incidents saved for the pre-crash scenarios took into consideration. Crossing path incidents account for 50,7% of the total. In 2017 in Milan metropolitan area there have been 13.904 incidents, this means that around 7.049 incidents are accountable to crossing paths pre-crash scenarios. Under a conservative effectiveness scenario V2X would decrease this number by 76,5%, with 5.392 incidents saved in Milan metropolitan area (38,8%). Rear-end incidents on highways account for 50% of total highway incidents, that in 2017 have been 9.395. This means that around 4.697 incidents are
accountable to rear-end pre-crash scenarios. Under a conservative effectiveness scenario V2X would decrease this number by 94.3%, with 4.429 incidents saved on highways in Italy (47.1%).

The second order benefit arising from a social point of view, is the measure of potential reduction of road deaths and injuries. From simulation under conservative scenario, results show that for the decrease of number of incidents in the pre-crash scenario considered, there would be 41 fewer deaths and 7.051 less injuries in Milan area; while there would be 139 fewer deaths and 7.462 less injuries in Italian highways. The results have been calculated assuming proportional the number of deaths and injuries with the number of incidents reduction.

- **Planet**: in non-urban scenario, has been estimated a reduction of 10% in fuel consumption. The estimates are valid for the lower bound of effectiveness assuming that all V2V and V2N can perform platooning. Given an average of 252.7 grams of CO2 emission per kilometre and 84 billion kilometres travelled in Italian highways from two axis vehicles (light), this would bring to a reduction of 212 million tons of CO2 emission every year.

  Different is urban scenario, it has been estimated using intersection management systems there would be the saving of 23% of CO2 emissions under traffic conditions (there is no reduction in case of low traffic density). In Milanese area the CO2 emissions coming from road transport into the atmosphere account for 4.171 kilotons, this means that the expected saving account for 959.33 kilotons of CO2 every year.

- **Profit**: in order to translate the social benefit in monetary terms, must be considered the formula suggested by ISTAT:

  \[
  TC = (Ci \times Ninj) + (Cd \times Nd) + (GC \times Ninc)
  \]

  - TC = total social cost of incident;
- \(Ci =\) social cost of injury (42.219 €);
- \(Ninj =\) number of injuries;
- \(Cd =\) social cost of death (1,5 million €);
- \(Nd =\) number of deaths;
- \(GC =\) general cost of incident (10.989 €);
- \(Ninc =\) number of incidents.

Taking into consideration the number of incidents saved mentioned above and related deaths and injuries reduction, there would be 418,5 million € of social savings in Milan area and around 572,2 million € of social savings for the non-urban scenario considered. This is just a small portion of overall social cost of incidents in Italy, that accounted for 19,3 billion € in 2017.

10.1.6 Critical analysis

In this use case, the role of 5G wireless connectivity as enabling technology is straightforward. 5G will be critical to communications and is likely to contribute to the development of connected and autonomous cars and may in fact become integral to their functioning. Current 4G technology cannot provide the needed technological requisites, in terms of latency and data rate, but mostly in network density, which is the maximum number of vehicles per unit area under which the specified reliability should be achieved. The impact of V2X capabilities, summed to current ADAS (advanced driver assistance systems), is expected to decrease the response time for safety purpose and, specifically V2N can manage traffic flows in order to have more efficient urban transports. This is going to create a big set of benefits for drivers, public administration, and more generally the entire community.

The numbers provided in this analysis are strongly impacted by the scenarios took into consideration. For this reason, is important to highlight the perimeter of analysis considered. In Figure 37 it is provided a graphical representation of the perimeter
considered for non-urban environment. The perimeter of analysis took into consideration is just a small portion of the overall potential benefits of intelligent transportation systems in non-urban environments (the blue area represented in Figure 37). In Figure 37 it is possible to see the considered perimeter and possible directions of expansion in order to identify the potential attainable benefits. For this purpose, there are two main dimensions to describe the perimeter of action considered.

**Figure 37: Visual representation of the socio-economic potential benefits for Intelligent Transportation System – non-urban**

The x-axis shows the number of pre-crash scenario considered for non-urban environments, that accounts for the 13,5% of all the pre-crash scenario considered in literature. On the other hand, on the y-axis is described the geographical extension of the analysis, here has been taken into consideration the numbers coming from Italian highways that account for the 4,6% of total non-urban roads in Italy (7.150 kilometres out of 154.166).

Different is the urban scenario represented in Figure 38. In Figure 38 it is provided a graphical representation of the perimeter considered for urban environment.
What has been previously described for non-urban environment is still valid in this case. The perimeter of action considered in the analysis of urban environment is the blue area in Figure 38, the x-axis represents the pre-crash scenario considered (the 18,9%) and on the y-axis is shown the geographical expansion of the analysis for the urban scenario, the Milan area that accounts for the 14,9% of overall metropolitan population in Italy (3,25 million people out of 21,9 million people living in metropolitan areas in Italy).

In addition to what is previously written, in the analysis have been considered only some of the benefits achievable with V2X application in the automotive industry, therefore for a more comprehensive analysis further investigation is needed, the analysis could be widened taking into consideration several benefits that original equipment manufacturers (OEM) may encounter, like the impact of predictive maintenance. Users are encountering many other benefits not considered in the analysis like the time spent in queues and money saved in insurance policies.

The benefits arisen for intelligent transportation system are constrained from the field application of the four use cases implemented by Vodafone. They do not cover all the pre-crash scenarios, therefore the real impact of V2X in automotive industry is wider than the impact expected in previous paragraphs. Another critical point is represented by the
adoption curve of V2X application in the real world. 5G infrastructure only one of the two main points for its adoption. Since the automotive market is mainly represented by private cars, in order to exploit the full potential of 5G in automotive cars need to be able to connect, and therefore at present is not possible to achieve benefits. In the next years the number of cars with level of driving automation and embedded connectivity is going to grow exponentially. This pattern is shown in Figure 39: Passenger cars with embedded cellular connectivity in EU, 2015-2025 [Source: Analysys Mason, 2017] Figure 39, where it is forecasted the increase of cars with embedded connectivity in the European market.

![Figure 39: Passenger cars with embedded cellular connectivity in EU, 2015-2025 [Source: Analysys Mason, 2017]](image)

The last point to be discussed is the transformation of business models and evolution of business role around 5G and automotive industries, with standardisation issues and regulatory barriers to the introduction of 5G in the automotive domain. Therefore, the need for rolling investments to improve, evolve and optimise networks on IoT services is relevant in case of intelligent transportation systems.
11 Findings on the trials

Through the analysis carried out, it has been possible to identify the main benefits arising from the potential systemic implementation of use cases. Consequently, it is possible to draw the main conclusions on benefits identified for both the vertical sectors analysed.

With regard to the Healthcare vertical the main Social benefits arisen are the reduction of mortality in case of clinical pilot projects, the reduction of hospitalisation rate among patients (this is valid for all the use cases concerning remote medical intervention and support) and the reduction of healthcare migration for both patients and relatives in case of robotic surgery intervention. On the other hand, Planet benefits in case of healthcare, even if it is present, the focus of 5G applications is not into this dimension, therefore it is possible to assume that it is a minor benefit and negligible. As regards the economic aspect, because of improved performances in social terms, there would be significant reduction in healthcare system expenses and in case of healthcare migration a reduction of costs incurred by households.

The same type of analysis can be applied to the other vertical studied: Automotive vertical. In this case the Social value of the pilot projects is well expressed by its safety applications reducing number of incidents and related injuries and deaths. Despite healthcare vertical, Planet benefits play a central role, where the optimisation and increased string stability lead to a significant reduction in pollutant emissions. Economically speaking, the reduction of incidents allowed by V2X applications brings with it a remarkable reduction in social costs.

Verified the goodness of the applications analysed, during the analysis of the two verticals considered in this thesis, even though the 5G wireless technology seems to be mature enough for its implementation, many problems and limitations have come to light.

The criticalities can be summarized in two dimensions, which represent the main technological constraints to make scalable the solutions proposed in the use cases. The constraints arisen are:
1) **Network slicing:**

The key to the evolution of 5G networks is network slicing, which is mandatory for supporting diversified 5G services. The problem arisen is that technically the latest version of 5G network is still not capable of this feature in a complete manner, and operators must figure out how to do it quickly if they want to monetize vertical 5G markets.

2) **Network coverage**

Telco companies are economic actors; therefore, profit is guiding them in the deployment in 5G antennas; for this reason, in the short term the full coverage (urban and rural) of 5G network is just utopia and companies cannot provide this type of service in a reasonable time frame. Even though, enormous efforts are going to be made to activate the coverage of major urban areas. For example, it is forecasted the expansion of 5G in 50 Italian cities within 2022.

Both dimensions above mentioned are going to affect the potential benefits of verticals analysed.

Starting from **Healthcare vertical**, for the use cases analysed there is huge impact of *network slicing* in mission critical services. Connected ambulance and remote surgery are two perfect examples where network availability is too important, therefore until network slicing is not a reality, would be difficult to reach scalability for these use cases and obtaining benefits imagined. *Network coverage* affects the full deployment of all use cases where 5G plays the role of enabling technology. 5G will be a reality only in some urban areas, rural areas will enjoy 5G capabilities only in the long term, as a result the magnitude of benefits is drastically reduced for all the application in healthcare that require rural deployment.

The same criticalities have been encountered in **Automotive vertical**. V2X applications have network availability as one of the key elements. Without continuous on-line systems this solution would never be achievable because of the safety implications encountered in the use cases. Therefore, *network slicing* is the real enabler of 5G incredible performances that
would allow V2X scalability in urban and non-urban environments. Without slicing there would be dangerous downtimes of the network availability and the achievement of social, environmental and economic benefits would be unattainable. On the other hand, the other problem encountered is network coverage, only urban environments would be suitable for V2X applications, with a reduction of overall expected benefits because solutions imagined for non-urban environments would stand-by until full network coverage would be attained. One specific example is the deployment of highway solutions, here platooning requires full availability of the service otherwise there would be dangerous implications for driver safety.

11.1 Comments & recommendations

Each analysis we conducted in this research considers 5G fully deployed and with optimal performance standards to better assess the magnitude of the socio-economic benefits unlocked by the roll-out of the innovative solutions.

5G is going to make an enormous impact on our economy, shaping new business models and requiring the reprocessing of many strategic sectors of Italian economy. Tests and experimentations on this new technological wave are not important just for mere scientific reasons, but they are the only way to test the impact on specific sectors and predict future scenarios.

From the evidence of the analysis presented, there are three main points to summarise the reasons why the trials were beneficial:

1) Pre-commercial test on business models:
   - Technology enhancement: the fast deployment and study of 5G trials is a huge opportunity for the entire system of economic actors to validate the technology. To be among the first to develop the experimentations is without a doubt an opportunity to gain international visibility, making the country a testing ground for telco companies and research centres would allow an acceleration of technological development. This is producing clear benefits from a technological
point of view, but it is important to mention the possibility to create new competences on key technological and digital sectors.

- **Workgroups:** regarding the 5G trials in Milan it has been very important the identification and selection of the stakeholders, the creation of collaborative working groups has been fundamental to proceed with trials. These groups of work involve partners that come from very different industries, unlikely they would have shared information and competences without the opportunity provided by the trials. An example in healthcare sector is the connected ambulance use case where partners coming from different industries share information and knowledge to build new competences. Here the involved partners are Qualcomm, Nokia, Ospedale San Raffaele and Vodafone. Another example is from automotive vertical is the use case on intelligent speed adaptation and control where the round table is composed of a wide group of actors: Politecnico di Milano, FCA, Vodafone, Vodafone automotive, Magneti Marelli, Altran, Pirelli and ENI Fuel S.p.A.

Apart from that, the deployment of 5G trials is also an enormous opportunity for many start-ups involved, could be the springboard for many innovative realities in Italy.

- **Reduced risk:** since 5G is going to change many practices in the economy, the investments to be undertaken are huge, therefore it is important to forecast the outcomes at wider level. Trials give the possibility to investigate and improve the predictability of the outcome in order to understand from an economical point of view the directions and priorities for future investments.

2) **Quantify socio-economic benefits and temporal perspective:**

The full realisation of the benefits calculated under optimal-case scenarios is prior to the overcoming of the bottlenecks that limit the expected impact. The main typologies of bottleneck are listed below:
Organisational bottlenecks: the early identification of the criticalities that are interposed between the trials and the full deployment of the solutions are fundamental to speed up the transformation process. They can be divided into three main dimensions:

1- **Organisational integration** between different actors and responsibility allocation are key topics for a successful deployment of the applications in analysis. The new solutions rely on strong and efficient partnerships among all the stakeholders due to the variety of competences needed to operate.

2- **Legal problems.** Political effort is needed to provide updated policies in order to implement new systems and gain the related benefits; an example in this case can be the intelligent transportation system environment, where safety problems need new policies to address legal issues such as liability and privacy of the exchanged data.

3- **System digitalisation,** currently Italy is lagging behind the rest of EU countries in terms of digitalisation and 5G applications require a shared digital architecture to be deployed.

System bottlenecks: system intended as the set of external variables influencing the achievement of benefits, it is possible to divide into two main dimensions:

1- **Infrastructural problems.** In order to achieve potential benefits, the external infrastructure on which the 5G application is based must be adapted to be able to work with the new applications. Taking as reference the V2X communication, the solutions provides the expected level of benefits only if it reaches approximately the 80% of penetration rate among vehicles and road infrastructures.

2- **Related technologies** can constrain the full potential of 5G in many applications. The perfect example in this case is remote surgery where 5G potential is constrained by the advancements in medical robotics that must reach a certain level of performance and reliability that is subject to medical
certification. For this reason, the real bottleneck is represented by the technological developments of the technology on which the 5G functions are based.

3) **Catalyse investments:**

- **Address sectorial issues:** each trial is developed based on real sectorial issues that are strictly related to the region in which the solutions will be applied. The identification of promising amount of benefits attracts investments by public and private sectors aimed at the creation of ad hoc solutions to be integrated with the local socio-economic fabric.

- **New opportunities:** testing projects is a big opportunity to test potential business models, to see applicability and economic potential for partner companies and start-ups.

- **Industrial partnerships:** this point is an appendix of workgroups point, instead of sharing competences, here the main point is the economic potential of pilot projects. Many companies that before were not interacting with each other are given the opportunity to test business models and build connections for future business relationships.
12 Conclusions

This study addressed the gap between the existing researches on the socio-economic benefits expected by the deployment of 5G and the methodologies for a deeper understanding of the root causes of the awaited results.

The construction of the maps of each analysed use case was supported by input provided by experts in the field of telecommunication and by interviews to professionals in charge of the trials in Milan.

12.1 Answer to Research question

The scenarios proposed by the trials show a high complexity in terms of actors, processes and applications that can have an impact on the expected outcome. Therefore, modelling the use cases is a first a fundamental step for the quantification of the socio-economic benefits arising from 5G technology because it allows to simplify the number of variables by finding and selecting the most relevant for each process.

The categorisation proposed by ITU is exhaustive enough to be able to describe the technological requirements of each of the 40 use cases and the parameters adopted allow the benchmarking with existing wireless connectivity solutions. The comparison with current technological standards highlights the role of 5G as an enabling factor for the use case or as a catalyst for the improvement of already-working solutions.

The creation of the bridge between technological performances and the attainable benefits needed the integration of an intermediate layer that connects 5G to the processes of the use cases: the insertion of the application-based clusters fills this gap by giving a simplified, but complete view of the relevant features that are put in place.

Lastly, connecting the features of each use case to the forecasted socio-economic implications closes the loop. The individuation of causal relationships between features and socio-economic benefits sets the ground for the quantification of the impacts, which is completed by collecting the relevant data to support the identified relationships.
The combination of the above-mentioned characteristics of the layers by means of understanding the correlations between them brought to the creation of a new model for the investigation of the root causes of the benefits and the related beneficiaries.

12.2 Theoretical and managerial implications

The majority of current research is focusing on technological developments and protocols to enable 5G to operate effectively and provide beneficial outcomes, while the studies on the strategic implications of this technology are mostly targeting the analysis of future scenarios to evaluate the maximum attainable benefits.

This research provides a new element for the investigation of the criticalities emerged from trial projects and the most remunerative investment direction for a selection of stakeholders. The proposed framework gathers most of the relevant information starting from the technological performance and proved to be useful for the identification of the critical bottlenecks for the realization of the scenarios in analysis.

From a managerial perspective, the framework has one more implication: it can be adopted for the evaluation of the worthiness of investments in pre-commercial pilot projects because it helps to accelerate the innovation process by leading decision-makers to more informed judgment of the trials.

12.3 Work limitations and future developments

The flexibility required by the extent of the 40 pre-commercial trials guided this research. In fact, for the sake of comparability of the results, the study was purposefully focused on finding a new tool to generalise the approach to different use cases as much as possible.

The proposed framework worked on use cases associated to different applications, contexts and verticals. Furthermore, it proved to be a solid methodology for the investigation of the most promising scenarios in terms of impact on the socio-economic fabric.
The main limitation of this study can be found in the lack of accuracy of the predicted values and they derive from three main reasons:

- The structure of the framework;
- The specific knowledge required for the analysis of each use case;
- Data availability.

Modelling a wide variety of 5G use cases required the rationalisation of the variables and the selection of the most relevant parameters according to the evidence observed during this study. For the purpose of building a unique tool for the strategic assessment of a complete set of trials, the framework is not suited for a deep evaluation of the use cases in all their aspects. The simplification of the perimeter of analysis aims to provide the order of magnitude of the impacts, more than an accurate estimation of the numbers.

The variety of application fields has another implication related to the specific knowledge required to tackle the use cases. The impact of time on mortality rates, the types of intervention that can be performed by a robot surgeon and the likelihood of accident reduction thanks to V2X communication are examples of the specificity of each application field, which of course requires dedicated studies to come up with accurate results.

The third cause impacting the accuracy of the results is the availability of data. As confirmed by the multiple links identified with the mapping of the use cases, the achievement of a benefit is the result of multiple parameters interacting with each other. Finding the right data to be used as input of the model is the result of the consultation of the major sources and databases available, but the lack of the desired granularity of the information brought us to use educated guesses and assumptions in several cases.

Future researches and developments of this study may involve a greater number of experts for each specific application in order to improve the accuracy of the predictions.

Due to time limitations, the analysis of the pre-commercial trials in the Milan Area was limited to a couple of vertical sectors out of six. For a complete analysis of the results of the
pilot projects, the analysis should be extended to the remaining four verticals and this would be beneficial also to check one more time the robustness and the scalability of the framework.
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| Annex | \begin{tabular}{|c|c|c|c|c|c|}
| \hline
| \textbf{Healthcare} | \textbf{Monitoring & Tracking} & \textbf{Remote Operation} & \textbf{Smart Surveillance} & \textbf{Augmented Reality} & \textbf{Connected Vehicle} & \textbf{Enhanced Video Services} & \textbf{Autonomous Robotics} \\
| \hline
| 1 Medical cognitive tutor | X | | | | | | \\
| 2 Rehabilitation robots | X | | | | | | \\
| 3 Service robotics | | X | | | | | \\
| 4 IoT for telemedicine | X | X | | | | | \\
| 5 Remote patient monitoring | X | X | | | | | \\
| 6 Wearables in sports | | | | | | | X \\
| 7 Analysis and remote medical consultation | | | | | | X | X \\
| 8 Connected ambulance | X | X | X | X | | | \\
| 9 Remote surgery | X | X | X | X | | | \\
| \hline
| \textbf{Security & Surveillance} | \textbf{Monitoring & Tracking} & \textbf{Remote Operation} & \textbf{Smart Surveillance} & \textbf{Augmented Reality} & \textbf{Connected Vehicle} & \textbf{Enhanced Video Services} & \textbf{Autonomous Robotics} \\
| \hline
| 10 Disaster Recovery | X | | | | | | \\
| 11 Drones for security shooting | X | X | | | | | \\
| 12 Advanced services for public security and emergency | | | | | | | X \\
| 13 Urban and passenger security in train stations | | | X | | | | \\
| 14 Mobile cameras for videosurveillance | | X | X | | | | \\
| \hline
| \textbf{Smart City} | \textbf{Monitoring & Tracking} & \textbf{Remote Operation} & \textbf{Smart Surveillance} & \textbf{Augmented Reality} & \textbf{Connected Vehicle} & \textbf{Enhanced Video Services} & \textbf{Autonomous Robotics} \\
| \hline
| 15 Smart city and smart campus | X | | | | | | \\
| 16 Smart energy | X | | | | | | \\
| 17 Citizen 4.0 | | X | | | | | \\
| \hline
| \textbf{Automotive} | \textbf{Monitoring & Tracking} & \textbf{Remote Operation} & \textbf{Smart Surveillance} & \textbf{Augmented Reality} & \textbf{Connected Vehicle} & \textbf{Enhanced Video Services} & \textbf{Autonomous Robotics} \\
| \hline
| 18 Cooperative urban cross traffic | X | X | | | | | \\
| 19 Assisted Driving | X | | | | | | \\
| 20 Automated systems for driving | X | | | | | | \\
| 21 Intelligent speed adaptation and control | X | | | | | | \\
| \hline
| \textbf{Manufacturing & Industry 4.0} | \textbf{Monitoring & Tracking} & \textbf{Remote Operation} & \textbf{Smart Surveillance} & \textbf{Augmented Reality} & \textbf{Connected Vehicle} & \textbf{Enhanced Video Services} & \textbf{Autonomous Robotics} \\
| \hline
| 22 Smart station and advertising | X | | | | | | \\
| 23 Assisted maintenance with AR | X | | | | | | \\
| 24 Purchasing experience support with AR | X | | | | | | \\
| 25 Attendance to events in VR | X | | | | | | \\
| 26 Robot for precision agriculture | X | X | | | | | \\
| 27 Collaborative robots for industry 4.0 | | X | | | | | \\
| 28 Last-mile Logistic | X | | | | | | \\
| 29 Drones for industrial inspections | X | | | | | | \\
| 30 Drones for last mile delivery with collision helper | X | | | | | | \\
| 31 Industrial process automation and remote control | X | | | | | | \\
| 32 Smart Agriculture | X | | | | | | \\
| 33 Health food recognition | X | | | | | | \\
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<th>REMOTE OPERATION</th>
<th>SMART SURVEILLANCE</th>
<th>AUGMENTED REALITY</th>
<th>CONNECTED VEHICLE</th>
<th>ENHANCED VIDEO SERVICES</th>
<th>AUTONOMOUS ROBOTICS</th>
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*Table 16: Final categorization of the use case of the 5G trials in Milan*