



MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES



TECHNOLOGICAL FORECASTING MODEL: A CASE STUDY IN THE MOBILE TELECOMMUNICATION INDUSTRY

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Ph.D. THESIS

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TABLE OF CONTENTS

ÖZET	vii
ABSTRACT.....	vi
CLAIM FOR ORIGINALITY	vii
ABBREVIATIONS	viii
LIST OF FIGURES	xi
LIST OF TABLES.....	xiii
1. INTRODUCTION	1
1.1. Background.....	1
1.2. Thesis Objective.....	2
1.3. Thesis Organization	3
2. LITERATURE REVIEW	5
2.1. Mobile Telecommunication Industry.....	5
2.1.1. Evolution of technologies in the mobile telecommunication	5
2.1.2. 5G ecosystem and technology drivers	24
2.1.3. Beyond 5G technologies	36
2.2. Technological Forecasting	39
2.2.1. Definition	39
2.2.2. Technological forecasting techniques.....	41
2.2.2.1. Monitoring	43
2.2.2.2. Expert opinion.....	43
2.2.2.3. Trend analysis	46
2.2.2.4. Modeling.....	47
2.2.2.5. Scenario construction.....	47

2.2.3. Technological forecasting applications in the telecommunication industry	49
2.2.3.1. Mobile telephony and subscription	54
2.2.3.2. Mobile broadband and services	60
2.2.3.3. Mobile telecommunication technologies	61
2.3. Technology Life Cycle	63
2.3.1. Definition	63
2.3.2. Stages of technology life cycle	64
2.3.3. Technology life cycle in mobile telecommunications	68
3. CASE STUDY	73
3.1. Research Methodology	75
3.1.1. Forecast parameters and collecting data	77
3.1.2. Application of the Delphi method.....	78
3.1.3. Application of quantitative forecasting method.....	79
3.2. Results of the Analyses	82
3.2.1. Delphi results	82
3.2.2. Combination with the time series forecasting results	83
3.2.3. Demonstration of the forecasting results	83
3.2.4. Final results	90
4. CONCLUSION.....	91
4.1. Managerial Implications of the Research	92
4.2. Limitations of the Research	92
4.3. Future Work	93
REFERENCES	95
APPENDICES	113

APPENDIX A.....	113
APPENDIX B.....	118
APPENDIX C.....	123
APPENDIX D.....	127
CURRICULUM VITAE.....	130



ÖZET

TEKNOLOJİ TAHMİNLEME MODELİ: MOBİL TELEKOMÜNİKASYON ENDÜSTRİSİNDE BİR VAKA ÇALIŞMASI

Mobil telekomünikasyon endüstrisinde 3G ve LTE (diğer adıyla 4G) teknolojilerinin evrimi, çeşitli ihtiyaçları olan çok sayıda kullanıcıya her yerde internet hizmeti sağlayarak mobilite tabanlı dijital çözümler alanında dikkate değer bir avantaj sağladı. Günümüzde akıllı cihazların çarpıcı bir şekilde benimsenmesi ve mobil internet tüketiminin ciddi şekilde artışı, mobil teknoloji geliştirme faaliyetlerini de 5G ekosistemi yönünde ivmelendirmektedir. Bu nedenle, mobil telekomünikasyon endüstrisi oyuncularının yönetsel karar mekanizmalarını ve stratejilerini 5G teknoloji lansmanına ilişkin tahminlere dayalı olarak yapmaları gerekmektedir. Bu tezin amacı, önerilen bir araştırma metodolojisine dayanarak, mobil telekomünikasyon endüstrisindeki teknoloji tahminleme ve teknoloji yaşam döngüsü kavramlarının daha iyi anlaşılmasını sağlamaktır. Telekomünikasyon endüstrisindeki teknoloji tahminleme, tanımı, teknikleri ve uygulamaları hakkında literatür incelemesi yapılarak detaylı şekilde irdelenmektedir. Bu doğrultuda, Türkiye'de bu konudaki mühendislik yönetimi alanına katkı sağlamak amacıyla vaka çalışması yapılmıştır. Bu katkı, mobil şebekesine sürekli olarak yeni mobil haberleşme teknolojilerini entegre eden ve mevcut şebeke yatırımlarını da son yıllarda dikkate değer oranda yoğunlaştıran, pazardaki lider bir telekomünikasyon şirketi için 5G hizmetlerinin ideal lansman süresinin tahminlemesi yapılarak gerçekleştirilmektedir. Tezin sonucunda elde edilen bulgular, Türkiye'de 5G mobil telekomünikasyon hizmetlerinin devreye alınması ve piyasaya sürülmesi için en uygun zamanın Ağustos 2020 olabileceğini göstermektedir. Mobil şebeke yatırımlarında karar verme amacıyla kullanılan tahmin parametrelerinin bu tarihte olgunluğa ulaşması beklenmektedir.

Anahtar Kelimeler: Mobil Telekomünikasyon Endüstrisi, 5G Ekosistemi, Teknoloji Tahminleme Metodolojileri, Teknoloji Yaşam Döngüsü, Delphi Metodu, Zaman Serisi Tahmini.

ABSTRACT

TECHNOLOGICAL FORECASTING MODEL: A CASE STUDY IN THE MOBILE TELECOMMUNICATION INDUSTRY

The evolution of 3G and Long Term Evolution (LTE, i.e. 4G) has brought a remarkable advantage to mobility-based digital solutions by providing ubiquitous Internet services to a plethora of users with various needs. Nowadays, the dramatic adoption of smart devices and increasing consumption of mobile Internet have been accelerating mobile technology development activities towards a 5G ecosystem. Therefore, industry players need to make managerial decisions and design strategies based on forecasts related to the introduction of 5G technology. The aim of this thesis is to enhance the understanding of technological forecasting and technology life cycle in the mobile telecommunication industry, based on a proposed research methodology. First of all, a literature review on the definition, techniques and applications of technological forecasting in the telecommunication industry was performed. Then, a case study was carried out in Turkey to contribute to the engineering management field on this topic. The outcome of this study is the forecasting of the ideal launch time of 5G services for a leading telecommunication company in the market, which has been integrating new mobile technologies and densifying its existing network at an unprecedented rate in recent years. Our findings reveal that the most appropriate time for the 5G deployment and launch of mobile telecommunication services in Turkey would be August 2020. This is the time when most of the forecast parameters used for making decisions on network investments are predicted to reach maturity.

Keywords: Mobile Telecommunication Industry, 5G Ecosystem, Technological Forecasting Methodologies, Technology Life Cycle, Delphi Method, Time Series Forecasting.

CLAIM FOR ORIGINALITY

The advent of mobile Internet has played a substantial role in terms of magnitude in the technology world and thus, the mobile telecommunication industry has become the fuel for global economic growth, where in particular the high diffusion of 3G and LTE has provided a remarkable advantage to the mobility of individuals and businesses.

Companies need to make their investments efficiently to be able to struggle with the fierce competition and hence, stay robust throughout the technological advances and changes in the local and global environment. Nowadays, mobile technologies have been rapidly evolving to 5G and accordingly, industry players, especially mobile network operators as researched in this thesis, require a systematic approach to determine the appropriate launch time of this new technology in the market. Technological forecasting tools and techniques look very convenient and useful to satisfy this need.

This thesis aims at extending the comprehension of technological forecasting and technology life cycle in the mobile telecommunication industry with the help of research methodology. The proposed methodology is primarily built on the combination of both quantitative and qualitative forecasting methodologies for the case study, which is conducted by exploiting the original data of a leading telecommunication company warming up for the launch of 5G in Turkey.

Even though the technology life cycle, expert opinion based Delphi and time series forecasting are well-known methods in the literature, those have not never been utilized in such a hybrid methodology for technological forecasting purposes. Besides, the literature review on the relevant topics supports this thesis to understand the study framework with regards to technical and historical background.

In short, practicing engineering managers can use the findings of this thesis to make better-informed decisions when drawing risk mitigation strategies for their 5G launch projects in the industry. Following this, the methodology proposed in the thesis can also generate accurate results for other mobile network operators and service providers positioned in a similar condition from technical aspects.

ABBREVIATIONS

5GAA: Fifth Generation Automotive Association

AI: Artificial Intelligence

AMPS: Advanced Mobile Phone System

AR/VR: Augmented/Virtual Reality

ARIMA: Autoregressive Integrated Moving Average

ARMA: Autoregressive Moving Average

CDMA: Code Division Multiple Access

CPE: Customer Premises Equipment

EDGE: Enhanced Data rates for GSM Evolution

eMBB: Enhanced Mobile Broadband

FWA: Fixed Wireless Access

GPRS: General Packet Radio Service

GSM: Global System for Mobile Communications

GSMA: GSM Association

HSDPA: High Speed Downlink Packet Access

HSUPA: High Speed Uplink Packet Access

ICT: Information and Communication Technologies

IIoT: Industrial Internet of Things

ILC: Industry Life cycle

IMS: IP Multimedia Subsystem

iOS: iPhone/iPad/iPod Operating System

IoT: Internet of Things

ITS: Intelligent Transport Systems

ITU: International Telecommunications Union

LTE: Long Term Evolution

M2M: Machine-to-Machine

MEC: Mobile Edge Computing

mMTC: Massive Machine Type Communications

MNO: Mobile Network Operator

MWC: Mobile World Congress

NARX: Nonlinear Auto-Regressive Network with Exogenous Inputs

NFV: Network Function Virtualization

nG: nth Generation of Mobile Telecommunications (n: 1, 2, 3, ...)

NGMN: Next Generation Mobile Networks

NMT: Nordic Mobile Telephone

ODM: Original Design Manufacturer

OECD: Organization for Economic Cooperation and Development

OEM: Original Equipment Manufacturers

OTT: Over the Top

PDA: Personal Digital Assistant

PLC: Product Life Cycle

PSAP: Product Specific Adoption Potential

RCS: Rich Communication Services

SDN: Software Defined Networking

TACS: Total Access Communication System

TFDEA: Technology Forecasting using Data Envelopment Analysis

TLC: Technology Life Cycle

UE: User Equipment

URLLC: Ultra Reliable Low Latency Communication

V2X: Vehicle-to-Everything

VoLTE: Voice over LTE

ViLTE: Video over LTE

VLC: Visible Light Communication

VoWiFi: Voice over Wi-Fi

WAP: Wireless Application Protocol

WCDMA: Wideband Code Division Multiple Access

LIST OF FIGURES

Figure 2.1. Nokia 8810

Figure 2.2. The mobile phone ecosystem

Figure 2.3. Number of mobile phone models introduced per year: regular phones vs. smartphones

Figure 2.4. Worldwide smartphone market shares by operating system

Figure 2.5. Convergence of mobile technologies

Figure 2.6. VoLTE subscriptions by region in billion

Figure 2.7. Mobile network evolution

Figure 2.8. Mobile phone evolution

Figure 2.9. Global market share of smartphone vendors

Figure 2.10. Evolution of mobile telecommunications across generations

Figure 2.11. Global 5G coverage and adoption

Figure 2.12. Performance weights of sub-criteria of 5G technology

Figure 2.13. Total mobile data traffic (EB/month)

Figure 2.14. Main use cases of 5G

Figure 2.15. The basic FWA architecture in 5G

Figure 2.16. Proposed 6G roadmap

Figure 2.17. Sample illustration of trend analysis

Figure 2.18. Forecasting mobile phone subscriptions per 100 inhabitants by analogy

Figure 2.19. The procedure of diffusion analysis

Figure 2.20. Out-of-sample forecasts and 90% confidence intervals

Figure 2.21. Logistic based forecast for mobile technologies (3G+4G) adoption in India

Figure 2.22. Technology performance and adoption curves

Figure 2.23. The S-Curve concept of technology life cycle

Figure 2.24. Dynamics of Innovation Model reflecting the TLC

Figure 2.25. Evolution of mobile telecommunication technologies

Figure 2.26. 3G and 4G adoption forecasts in India between 2016–2026

Figure 3.1. Diagram of the research process

Figure 3.2. LTE Mobile Data Ratio

Figure 3.3. Number of LTE Users

Figure 3.4. LTE Average Download Throughput

Figure 3.5. Smartphone Penetration

Figure 3.6. Mobile Video Data Ratio

LIST OF TABLES

Table 2.1. Mobile phone vendors' market share ranking in the 1G telephony

Table 2.2. Some of the mobile phone technologies introduced by the vendors

Table 2.3. The key factors in the evolution of OEM's mobile phone and technology innovation

Table 2.4. LTE categories with regard to maximum downlink and uplink throughputs

Table 2.5. Key performance indicators associated with 5G technology use cases

Table 2.6. Categorization of technological forecasting methods

Table 2.7. Methodological families in the technology forecasting techniques

Table 2.8. The summary of the review in the technological forecasting in telecommunications

Table 2.9. The summary of the review

Table 3.1. Time series forecasting of forecast parameters

Table 3.2. Summary results from the Delphi method

Table 3.3. Summary results



1. INTRODUCTION

1.1. Background

Telecommunication has always been a popular research area in the academic environment since Alexander Graham Bell invented the telephone and made his first call in 1876. Then scientists tried to get rid of the cable to provide mobility for communication purposes. Particularly the developments during the Second World War have pushed the industry to progress faster in parallel to military equipment and tools. The first generation of mobile systems (1G) can be regarded as the ancestor of mobile telecommunication though it was only a local solution in some countries rather than being a global technology. The world has witnessed lots of advances in the information and communication technologies after the first mobile dialog over Global System for Mobile Communications (GSM), also known as 2G, in 1991. Mobile telecommunication, where the customer focus is the main issue, has been one of the major industries leading the global economy. With the help of the convergence of information and communication technologies, smart devices have come out of its box to become a part of our daily lives in a rush.

Especially the development of Third Generation of Mobile Telecommunications (3G) profoundly contributed to the mobility with the help of the information over the Internet everywhere and every time. In addition, the iPhone introduced by Steve Jobs in 2007 was one of the most influential triggers in this direction. Soon afterward, the Fourth Generation of Mobile Telecommunications (4G) has been developed and implemented in a fast way, then started to dominate the mobile telecommunication sector in the mid-2010s. It is also known as Long Term Evolution (LTE) and mostly this term is preferred throughout the thesis. Taking this into consideration, it can be expected that LTE is not just defined one technology or standard, but a compatible combination of technologies and protocols to enable the highest speed with the lowest cost. Primarily Chinese telecommunication manufacturers have played a major role to decrease the cost in the term of LTE globally (Gao, 2018). In addition, fiber optic technologies and advanced transmission capabilities have provided a significant contribution to the enhancement of mobile telecommunications when going through LTE. Besides, the mobile telecommunication has been called as “the fastest growing ICT in human history” (ITU, 2016). All these advances have created a giant industry including smart devices such as smartphones, tablets, modems, and

Internet of Things (IoT) devices varying in thousands of types.

Mobile Network Operators (MNOs), infrastructure suppliers, Original Equipment Manufacturers (OEMs), regulative authority, and Over the Tops (OTTs) including mobile application developers, content providers, and social media companies are outstanding as the main players in this industry. It is clear that a broader industry exists than that on the first day of mobile telecommunications in the world. In fact, voice communication was the main function of GSM technology in the 1990s and early 2000s whereas currently, data-centric communication has been dominating 3G and LTE which are packet-based technologies. Video and social media applications such as YouTube, Instagram, Facebook, and Twitter are leading actors playing a major role in the mobile application platform making customers follow the latest technologies all the time. In recent years, the dramatic adoption of smart devices and increasing consumption of mobile Internet have been accelerating mobile technology development activities towards a 5G ecosystem.

1.2. Thesis Objective

Nowadays, the industry players need a systematic approach much more than ever to respond to customer needs and technological advances under high competition and digital transformation throughout the pacing mobile era. In particular, mobile network operators have to make their managerial decisions and draw their strategies based on the foresight and predictions on this area. Technological forecasting is getting much more significant and coming through the issue at this point. Nevertheless, forecasting the next steps of technological advances correctly requires a well-defined forecasting model to handle the complexity and dynamism of the sector. Moreover, the extreme change rate in the mobile telecommunication industry makes the forecasting process harder in comparison to other high-tech industries indeed.

Finally, the main purpose of this thesis is to fill the gap regarding launch time of 5G technology in a market by broadening the perspective, in terms of the technological evolution of the mobile telecommunications and technological forecasting, and developing a research methodology based on the combination of quantitative forecasting technique with the expert opinion based forecasts in a leading telecommunication company in Turkey. Besides, the study aims at contributing to the engineering management field on the topic.

1.3. Thesis Organization

The structure of the thesis, fundamentally based on literature review and a case study built on a proposed method, is presented as follows. First of all, the thesis looks closer to the evolution of technologies in the mobile telecommunications, 5G ecosystem, technology drivers and the emerging technologies beyond 5G by including new trends and technological advances in the industry. Secondly, the literature review on the definition, techniques, and applications of technological forecasting in the telecommunication industry is scrutinized in detail respectively. Thereafter, the technology life cycle is explained and illustrated together with its description, stages, and practices encountered during the review of mobile telecommunications. Then, the case study is initially introduced as a means of motivation, statement of purpose, and information about the company. Further, research methodology is given with the forecast parameters, and applications of Delphi as well as quantitative forecasting methodologies comprehensively. When coming to the end, the results of the analyses are exhibited with the help of Delphi results, combination with the time series forecasting results, and the demonstrations of forecasts. In conclusion, the thesis is finalized with the general remarks about the findings, managerial implications, limitations of the study, and future work by discussing further.



2. LITERATURE REVIEW

2.1. Mobile Telecommunication Industry

Nowadays mobile telecommunication has a major role in the world with the help of mobile Internet and the convergence of various industries running on mobile platforms such as applications and services (Basole and Karla, 2011).

No doubt that the industry of mobile telecommunication has passed through lots of stages when coming to today. The mobile phone invented firstly in AT&T's Bell laboratory in the 1970s has eventually evolved into a mini-computer. The following part tries to explain these evolution phases step by step as well as taking all stakeholders and milestones into consideration with their contribution to the industry. In the meantime, the mobile phone is also called 'cellular phone' in British English. 'Mobile phone' is preferred in the thesis. Similarly, 'mobile network' is mostly used instead of 'cellular network'.

2.1.1. Evolution of technologies in the mobile telecommunication

In general, the evolution of mobile telecommunication technologies can mainly be clarified in the five stages extending from 1G to 5G in this journey. 1G seems the beginning phase of the industry as the first mobile telephony system developed over the analog signal. It was basically providing only voice communication through too big, heavy, and costly equipment used in specific business areas. So, mobile communication was never widened in that phase because of these difficulties (Giachetti and Marchi, 2010).

1G telephony systems such as Advanced Mobile Phone System (AMPS) in the US, Total Access Communication System (TACS) in the UK, Nordic Mobile Telephone (NMT) in Scandinavia, Nippon Telegraph and Telephone (NTT) in Japan were completely incompatible with each other and definitely unstandardized among the systems (Funk and Methe, 2001). The mobile phone market was mostly penetrated by Motorola with a high ratio especially in the US market during the 1980s and early 1990s (Steinbock, 2002). The primary competitors were Ericsson from Sweden and Nokia from Finland to challenge with Motorola toughly in the European market through the achievement of NMT telephony system. Thereafter, the Japanese manufacturers Matsushita (Panasonic), Mitsubishi, and Toshiba obtained strong market shares via AMPS-

supported phones in the US market as indicated in Table 2.1 below.

Table 2.1. Mobile phone vendors' market share ranking in the 1G telephony (Funk, 2002)

	Analog standards			
	US AMPS		NMT	TACS
	1989	1996	1991	1994
Motorola	1	1	1	1
Nokia	10	2	2	2
Ericsson	9	8	3	3
Matsushita	2	6	5	
Mitsubishi	3	5		
Philips			4	
Toshiba	4	9		

On the other hand, the quality of voice communication was really inferior due to the high interference of analog signal in the first generation of the mobile phone system and more, it was not adequate to handle the increasing number of subscribers. To overcome such limitations of 1G systems, Global System for Mobile Communication was developed by the Groupe Speciale Mobile that consists of European regulators and leading telecommunication companies. The second generation of cellular communication was depending on digital technology in opposition to the first generation. 2G technology launched firstly in Europe in 1991 offered globalization of the mobile telecommunication services. Then it entered the US in 1995 and lived together with AMPS for a while.

The following items were the most prominent capabilities of GSM (Giachetti and Marchi, 2017):

- Introducing roaming service initially in Europe and then throughout the world,
- Digital centric new mobile services such as Short Message Service (SMS) and Multimedia Message Service (MMS),
- Giving a chance to develop more portable handsets because of highly integrated electronic boards in a smaller device platform,
- Cost efficiency with the help of increasing diffusion of technology in a short time.

When deeply looked into technical aspects of the second generation of mobile telecommunication, enhanced voice quality, encryption of subscriber data, and improvement on

the transmission speed are also remarkable benefits for the industry (Ashiho, 2003). In particular, the miniaturization of mobile phones pushed the widespread adoption of GSM technology immediately amongst individual consumers in several years after the commercial launch of the system and rapid penetration enabled valuable advantage on the cost by the scale of economy in the manufacturer side. All these fostering factors made GSM the dominant technology in all continents by the end of the 1990s. The diffusion of GSM in the world market was much higher compared to the alternative standards in 2005. GSM covered approximately 75% of all mobile subscribers globally (Giachetti and Marchi, 2017).

In addition, Code Division Multiple Access (CDMA) technology was deployed based on synchronous transfer technology with the leadership of the US operators in parallel to GSM deployments in Europe. However, currently, it has been replaced commonly with the upper technologies even in the US (Yeo et al., 2015).

When the usage of 2G mobile phones were getting much wider acceptance among the mobile customers, the quick adoption of the novel mobile product technologies was required to keep the position in terms of competition (Giachetti and Lanzolla, 2016). In this direction, pocket-sized phones were enriched with some superior technical capabilities such as games, downloadable ringtones, infra-red connection, larger capacity in memory size, longer talk time and standby duration with respect to analog mobile devices (Fuentelsaz et al., 2008).

Furthermore, the design was getting more significant so as to diversify in the market. Nokia and Ericsson were the main players in this area as giant telecommunication companies at the end of the 1990s. When Ericsson's focus was on innovation, rather Nokia's focus was on customers. Nokia was the first producer to introduce replacement parts for mobile phones to the customers. Ericsson also wanted to increase its customer focus and A1018s was the first step to serve this intention (Cerit et al., 2014).

Table 2.2. Some of the mobile phone technologies introduced by the vendors (Giachetti and Marchi, 2017)

Product technology	Firms introducing the technology ^a	Year of introduction
SMS	Nokia	1992
Composer	Ericsson	1997
Infrared	Nokia	1997
Games	Nokia	1997
Voice recorder	Sony	1997
Touchscreen	Alcatel	1998
Email client	Nokia	1998
Radio	Sagem	1998
WAP	Nokia	1999
MP3 player	Samsung and Siemens	2000
Color screen ^b	Nokia and Ericsson	2000-2001
Bluetooth	Ericsson	2001
Photo camera	Sharp	2001
Video camera	Nec and Panasonic	2003
iTunes	Motorola	2005
Multi-touch display	Apple	2007
Android OS	T-Mobile	2008

In 1998, Nokia 8810 was announced as the first mobile phone without an external antenna. This model rapidly became popular with an aesthetically appealing design with its sliding keypad cover (Koski and Kretschmer, 2007). Nokia completely extended its product line in order to present a larger variety of product choices in comparison to its competitors.



Figure 2.1. Nokia 8810

Wireless Application Protocol (WAP), General Packet Radio Service (GPRS), and Enhanced Data rates for GSM Evolution (EDGE) were developed at the beginning of the 2000s before moving towards the third generation of mobile telecommunication. With the introduction of the WAP technology, mobile subscribers could reach some basic web pages and WAP-based services using the primitive browsers of their mobile phones. To enrich phones, the mobile

phone manufacturers used the new features shown in Table 2.2 widely.

GSM networks, upgraded with GPRS and EDGE technologies, contained both circuit-switched and packet-switched networks (Farooq et al., 2013). It can comfortably be claimed that the initiation of mobile Internet was started by these enhanced services constructed over GSM infrastructure with a revolutionary step. GPRS and EDGE are called 2.5G and 2.75G respectively because of filling a substantial gap between 2nd and 3rd generation technologies in the industry. Thus, both GPRS and EDGE technologies provided an important transition in this way.

In this period, Personal Digital Assistant (PDA) phones were also launched to enable consumers to reach their e-mail accounts using the QWERTY keyboard with the integrated voice and data capabilities in mobility. Then the first mobile operating systems came up with Blackberry and then Microsoft's Windows phones in the same time window. Additionally, Nokia developed its own operating system Symbian while the mobile phones were transforming into smarter ones day by day. Mobile phone vendors had to enhance device capabilities and architectural competencies that need software integration which is the key differentiation component to catch a competitive advantage in the global market (Suarez and Kirtley, 2012).

One of the milestones during the evolution of mobile phones is surely the meeting of the camera with the phones. This embedded feature acted a major role afterward to open a path by increasing demand for future technologies and device specifications in the industry. The early seeds were spread at that time and eventually, sharing photo and video content has enormously increased data consumption in the mobile networks in recent years.

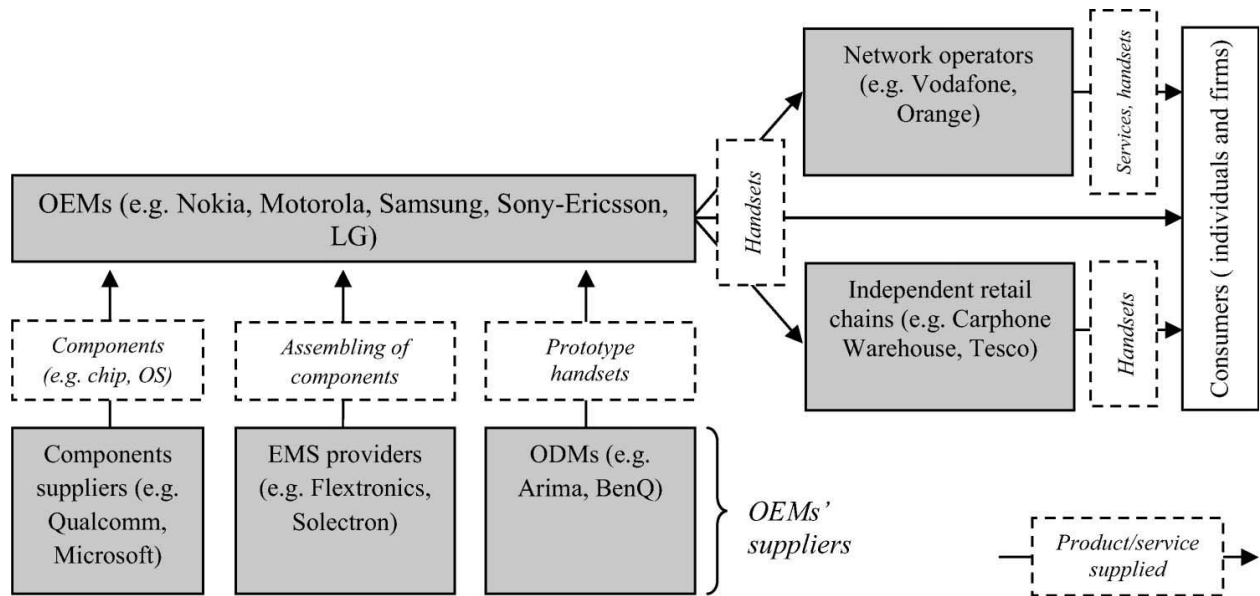


Figure 2.2. The mobile phone ecosystem (Giachetti and Marchi, 2010)

Figure 2.2 shows us a structure of the mobile phone ecosystem in terms of the supply chain while reaching the end user (mobile subscribers). It can be indicated that four main groups exist in the industry; mobile network operators, original equipment manufacturers (mobile phone manufacturers), OEM's suppliers, and independent retailers. Mobile handsets are sold to consumers by the operators, independent retailers, and manufacturers directly. Globally, the consumers mostly prefer to buy mobile phones from operators' retail channels together with a contract to get an advantage for the total cost of tariff and handset used in the operator network (Giachetti and Marchi, 2010).

OEMs also utilize lots of third-party companies to supply hardware and software-based components such as chipsets, operating systems, electronic boards, antenna, battery etc. In fact, the supply chain of a mobile phone was much simpler in the 1990s. Increasing complexity in the mobile communication technologies and devices has also expanded the chain in the course of time. Moreover, Table 2.3 successfully makes a brief overview to indicate the key factors for the evolution of mobile phones until this stage.

Table 2.3. The key factors during the evolution of mobile phone and technology innovation (Giachetti and Marchi, 2010)

Mobile phone industry variables	1980s	First half 1990s	Second half 1990s	First half 2000s	Second half 2000s
Key offering for consumers	Availability	Portability	Design in line with the consumer lifestyle	Service/experience (multi-tasking)	Service/experience (multi-tasking) Status
Main product technologies introduced into the market	Analogue system	GSM digital systems SMS (still in the infant stage)	WAP Games Diffusion of SMS	Colour display, MMS, camera, MP3 player UMTS technologies	Smartphone features (e.g. advanced OS, fast Internet connection, touch screen)
Main elements of product differentiation	None: OEMs offer many different versions of mobile phones; most of them are mounted in cars	Portability: smaller and lighter handsets GSM digital system SMS	Games, WAP Segmentation based on the product design/aesthetic Wide product range	Multi-tasking products Wide product range	Aesthetic, design, fashion; OEMs' brand image
Dominant design (product features widely diffused among OEMs)	None	Portable handsets	Miniaturisation	Dominant design not well defined ('device diversity'): basic phones vs. multi-tasking devices	Multi-tasking: camera, colour display, MP3, etc.
Technical standard	Analogue system	Discontinuities: analogue and digital systems	GSM digital system SMS	GSM digital system SMS	GSM digital system SMS, MMS
Product scope	Voice capabilities	Mainly voice capabilities (SMS introduction and very slow diffusion)	Voice + text capabilities (SMS fast diffusion)	Mainly voice + text capabilities (camera, MP3 and Internet mobile were emerging)	Voice + text capabilities + camera + MP3 + Internet mobile

Going back to technology evolution, 2G technology could not satisfy the customer requirements especially in data transfer even though EDGE was developed and implemented into many handsets without wasting time. Thus, 3G was imperative technology to move the industry to the next generation in this way by offering a variety of advanced services. Wideband Code Division Multiple Access (WCDMA) and CDMA 2000 were presented by the service providers in Europe and the USA, respectively (Fuentelsaz et al., 2008).

The growing mobility demands encouraged the development of the Universal Mobile Telecommunications Systems (UMTS) in 2001, but it failed to be commercialized due to the limitations in transmission infrastructures at the beginning and so, GSM was the dominant technology until 2005 (Yeo et al., 2015). For this reason, the deployment of 3G was broadened amongst mobile network operators particularly after the development of High Speed Downlink Packet Access (HSDPA) in 2006. This technology is also called 3.5G since it was launched between 3G and 4G services. Then, High Speed Uplink Packet Access (HSUPA) technology was announced by the infrastructure suppliers to increase the upload data transfer rate. HSDPA provided download speeds up to 43.2 Mbps with the advanced feature of Dual Carrier (DC) merging two separate radio sources of mobile network whilst HSUPA supported upload speeds up to 5.76 Mbps.

3G was generally presented in the markets by means of featuring video calls in smartphones whereas the main benefit was the high speeds given in download and upload connection in the network as mentioned above. Such higher speeds and lower latencies in the mobility ignited an incontrovertible transformation in the mobile telecommunication industry from voice towards data. Samsung's CEO was saying "In the analog era, it was difficult for a latecomer to catch up. But in the digital era, if you are two months late, you are dead. So, speed and intelligence are what matter, and the winners have not yet been determined." in his interview with Businessweek in 2003 (Edwards et al., 2003). When he was talking about the digitalization in the telecom industry, Samsung had already started to follow Nokia and Motorola closely in the global market with the help of its extended product line.

As the next step of 3G, the advent of HSPA technologies pushed the mobile phone market to unveil smartphones having a mobile operating system and application stores. Perhaps the most

significant milestone throughout the evolution of smartphones was the launch of the iPhone in 2007 by Apple Inc. which was the giant company of the computer industry till that time. That was one of the most remarkable actions for the mobile phone and telecommunication industries (Kalem and Cobanoglu, 2016). Steve Jobs, who was co-founder and Chief Executive Officer of the company, made a visionary announcement when he was showing iPhone to the audience and defining it as an “Internet phone” providing real Internet to the customers. The iPhone, as a smart device merging various functionalities, offered a bigger and multi-touch display which is capable of access to thousands of mobile applications running on the iPhone Operating System (iOS). When making these novel and stylish smartphones, Apple was remarkably focusing on design innovation besides developing an operating system for the iPhone, iPad, and iPod product family. The advent of iOS remarkably changed the direction of the smartphone market (Ozkan and Kalem, 2015). When coming out as a game changer in the industry, Apple rapidly obtained a noteworthy market share with iOS based smartphones while spurring widespread adoption of mobile Internet in a short time (West and Mace, 2010). Although it was not the initial smartphone model in the global market, it was admitted as a reference for whole OEMs (Original Equipment Manufacturer) in the coming years with regards to the design and user interface (Cecere et al., 2015).

In parallel, Research in Motion (RIM) was another OEM focusing on the manufacturing of these high-price high-profit devices because of their well-drawn design and advanced technologies. The company sold millions of Blackberry models with costly prices until Apple products occupied the target markets of RIM in the US and European countries. The first instant messaging application Blackberry Messenger (BBM) were highlighted in Blackberry phones when the other dominant applications like WhatsApp, Skype, Line, Viber, and Facebook Messenger were not launched yet.

Eventually, as seen in Figure 2.3, smartphones have become the dominant design in a few years thanks to the technical convergence of different functionalities.

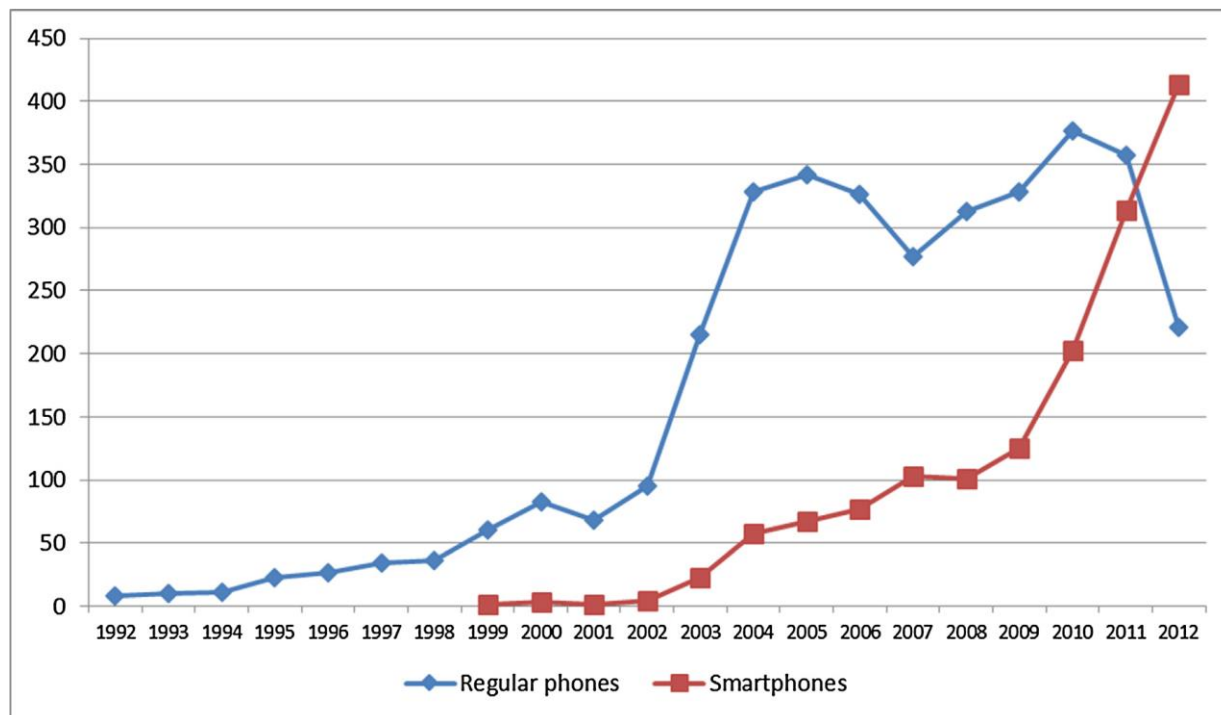


Figure 2.3. Number of new mobile phone models introduced per year: regular phones vs. smartphones (Giachetti and Marchi, 2017)

Google also contributed to this phase of mobile telecommunication by announcing the Android operating system in 2008. Thereby, the first decade of the 21st century witnessed substantial progress with the help of both Apple and Google companies' focuses on mobile devices and application platforms. In 2011, Google's Android operating system obtained the highest ratio of penetration amongst mobile operating systems, primarily driven by the achievement of Samsung branded smartphones. The Android operating system was delivered to the device vendors as an open source and free of charge. Actually, that was the main method to make it the dominant OS in the market in a few years. Google enriched the Android platform with Google Play Store and its own branded applications including the search engine.

The increasing diffusion of these advanced mobile handsets and software products were indeed accelerated by the mobile Internet speed of developing 3G technologies and services (Kurt et al., 2016). Further, smartphone penetration also contributed to the diversification of the mobile applications such as social networks, mobile games, banking, traveling, location-based services, and video content platforms. Facebook, Instagram, Twitter, and YouTube have obviously

become the most effective ones in this area today.

Besides all this progress in the industry, as the market leader, Nokia tried to give a response by developing the Symbian operating system and multi-touch interface on its new mobile phones, but it could not sell as expected at all. Apple's own mobile OS was coming to the forefront with a user-friendly and custom-built interface in iPhones. Symbian also failed in terms of its stability performance on the devices.

Especially iOS and Android-based smartphones radically changed the user experiences on mobile phones. Both Apple and Google have led to a radical change in the telecommunications industry. In addition, Microsoft was another important player from the computer and software industry developing a mobile operating system for smartphones. However, Microsoft's OS Windows Mobile could not compete with Apple and Google later on in this area because its application store was so limited in comparison to iOS and Android platforms. In 2011, Apple's App Store included more than 333.000 applications, and Google's Android Store obtained more than 200.000 apps. On the other hand, Windows Mobile Market place had less than 12.000 (Giachetti and Marchi, 2017). Further, the low penetration of Windows Mobile based smartphones in the market prevented the progressing of the operating system even though Microsoft launched the smartphones with its own brand after purchasing the mobile handset division of Nokia in 2013. Thus, Microsoft Windows Mobile was never able to obtain momentum in the market.

The Android operating system was rapidly adopted by many OEMs and ODMs in the first half of the 2010s. First Nokia and then Microsoft resisted against this obvious tendency in the smartphone industry by insisting on using Symbian and Windows Mobile operating systems on their devices during the smartphone revolution. Disappointing selling results of Nokia and Microsoft smartphones caused a major market share loss against Android-based device manufacturers (Suarez and Kirtley, 2012). As a result, the market share of Nokia was melting though it was trying to adopt Windows Mobile operating system in its high-end smartphones.

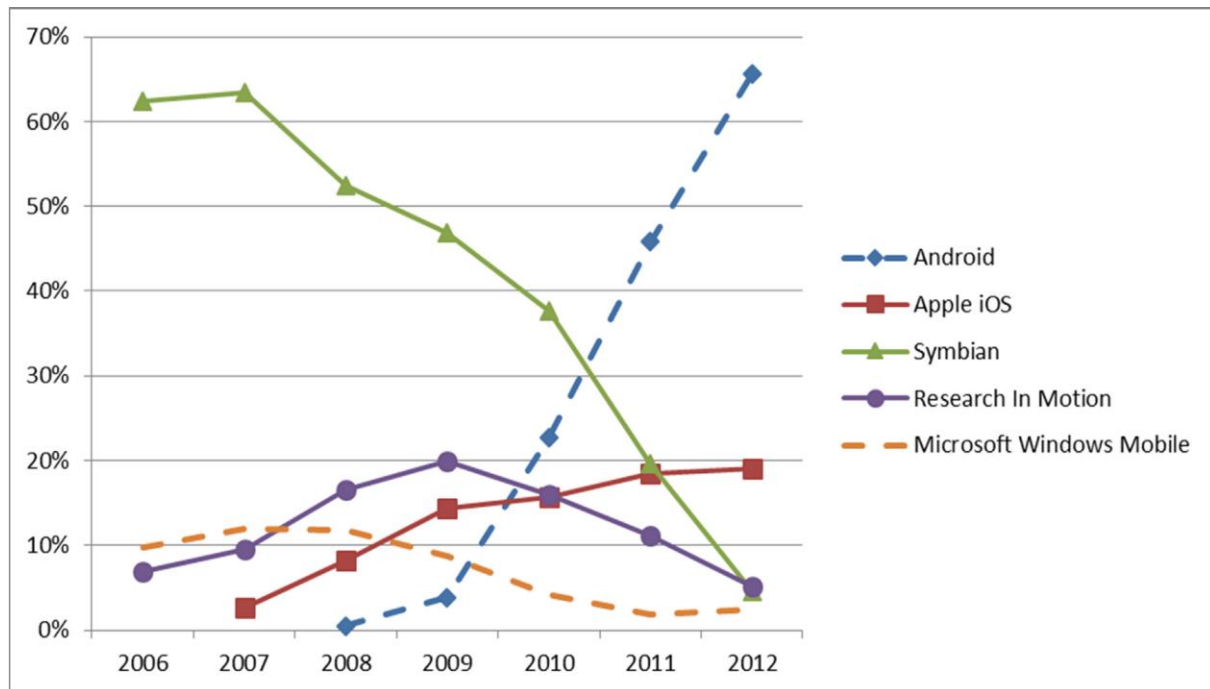


Figure 2.4. Worldwide smartphone market shares by operating system (Giachetti and Marchi, 2017)

It is really weird to state that, when approaching to 2010, Nokia's R&D budget for mobile phones was three times more than Samsung's and double that of RIM. The Finnish vendor was investing more and more indeed. Notwithstanding, Nokia's product innovation strategy was not robust enough to take advantage of the opportunities and dynamicity in the market affected by the iOS and Android ecosystems (Srivastava and Ben-Aaron, 2011). The trend is clearly indicated in Figure 2.4. Google's Android succeeded to catch up with Symbian in late 2010 and quickly left it behind as seen in this figure.

What is more, mobile network operators were popularly announcing their own branded smartphones produced by the Original Design Manufacturers (ODM) with the cost advantage in the industry. Most of these companies are from China and Taiwan such as Huawei, ZTE, TCL, BenQ, HTC, Compal, and Quanta. The outsourcing in the manufacturing of mobile handsets was the fundamental factor to face the low prices in the market. ODMs were educated by the OEMs at the beginning and then they provided higher and quicker penetration of smartphones in the global market. On the other hand, there were some exceptional companies from South Korea such as Samsung and LG which were not utilizing ODMs to manufacture their handsets

(Hu and Hsu, 2008). Particularly Samsung was using vertical integration structure by manufacturing displays, memories, processor units, and various mobile phone components. This made the firm flexible with regard to dynamic and efficient production in the changing market requirements (Grobart, 2013).

As mentioned earlier, smartphones started to provide real Internet experience through the development of the Third Generation in mobile technologies. Thus, it is worth saying that without the broad availability of mobile Internet in the industry, the rise of smartphone penetration would have been dramatically slower and their usability much more limited. The outstanding capabilities of 3G technology were really notable, but researchers surely did not give up improving the mobile telecommunication systems so as to handle the increasing demand (Kammoun et al., 2016). Further, mobile operating systems and application platforms developed by Apple, Google, and Microsoft have remarkably contributed to the growth of technological penetration throughout the 3G era (Campbell-Kelly et al., 2015; Garcia-Swartz and Garcia-Vicente, 2015).

The tremendous consumption in data transfer and the higher throughput requirement because of enriched video content and social networking in the mobile applications needed the Fourth Generation in the mobile telecommunication. Moreover, customers getting more and more used to advanced mobile technologies increased their expectations in terms of having higher data rates and lower latency. These necessities were partially satisfied by the evolution of HSPA, but it was not adequate in general. In this direction, the Long Term Evolution standard was firstly published in March 2009 as part of the Third Generation Partnership Project (3GPP) Release 8 specifications (Bjerke, 2011). LTE, which was evolved from WCDMA and HSPA technologies, was commercially deployed in the Scandinavian capitals Oslo and Stockholm by the Swedish-Finnish network operator TeliaSonera in late 2009, but the first LTE-compatible mobile devices were launched by HTC and Samsung in 2011 (Hossain et al., 2014).

LTE has presented a completely IP-based communication technology as well as data-centric communication system just like the Third Generation. However, LTE has gathered voice and data communication in a wholly IP integrated platform whereas 3G was serving only data in the packet-switched network, and still voice in the circuit-switched network (Astley et al., 2013). A new core architecture, named Enhanced Packet Core (EPC), was also developed for LTE in

order to enhance the previous core structure used by 2G and 3G. Perhaps the most significant specification of LTE is having the acceptance by the whole telecom industry in the world, unlike previous generations for which several competing technologies existed. LTE, as a single and universally accepted technology, has speeded up the development of new mobile services and diminished the cost for both customers and service providers (Dahlman et al., 2016). Moreover, with the start of LTE, the spectrum became technology-independent which simply refers to the fact that mobile operators are able to have more flexibility for their frequency policies within the spectrum they commercially have (David and Berndt, 2018).

As of the end of 2017, LTE has become the leading mobile technology in the industry. The number of LTE connections has been ascending dramatically, and it is predicted to catch up with 5.4 billion at the end of 2024 while reaching higher than 60% of the total mobile subscriptions globally (Ericsson, 2019).

In brief, Figure 2.5 shows the convergence of mobile technologies that have been developed so far.

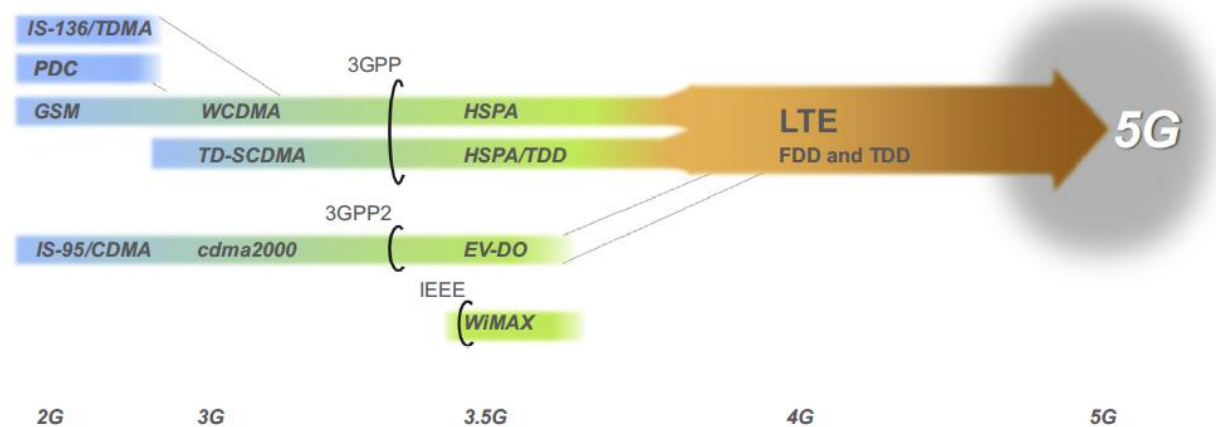


Figure 2.5. Convergence of mobile technologies (Dahlman et al., 2016)

In addition to enhancements in the mobile broadband, Voice over LTE (VoLTE) as the new voice transmission technology has also been developed since the circuit-switched voice was not supported by the network architecture of LTE. VoLTE has come up with its substantial advantages such as superior voice quality which is called HD Voice, and shorter call setup durations throughout the call initiations in the network. Besides VoLTE, Video over LTE (ViLTE) technology has also been developed to improve video call quality and enrich call

experience.

Furthermore, the evolution of voice and video services to IP-based systems has rapidly increased spectrum efficiency in the LTE network. Mobile network operators have rolled out these services by deploying an IP Multimedia Subsystem (IMS) nodes at their core networks. Then, device manufacturers have rapidly implemented these services into smartphones. From the point of view of end users, there are more than 2400 VoLTE-enabled smartphone models today (GSA, 2019).

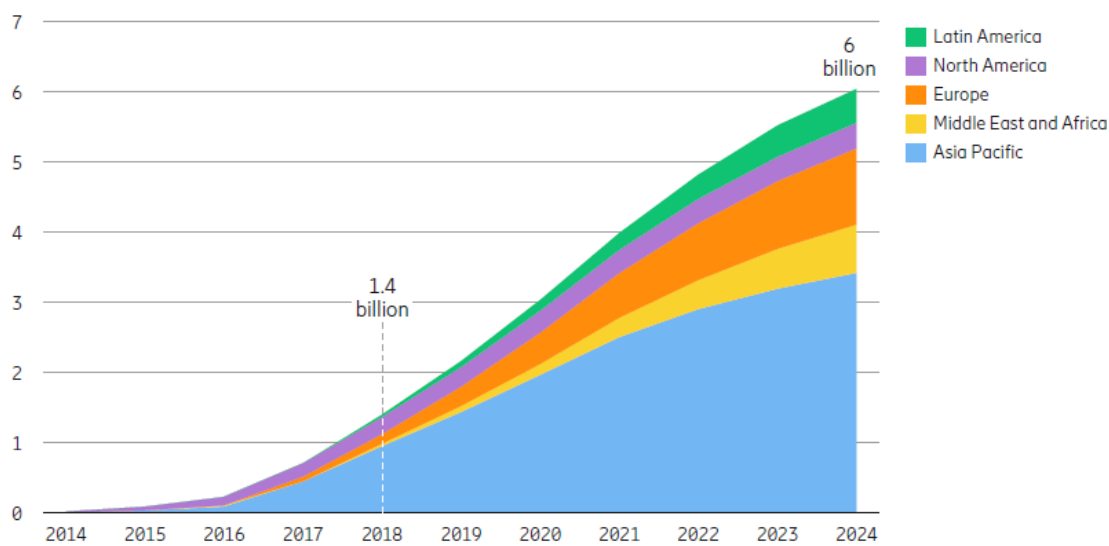


Figure 2.6. VoLTE subscriptions by region in billion (Ericsson, 2019)

As of the end of 2018, VoLTE has been introduced by more than 155 mobile operators in 75 countries globally, and the number of VoLTE subscriptions reached about 1.4 billion globally. At the end of 2024, the VoLTE subscriptions are expected to extend up to 6 billion as clearly seen in Figure 2.6 (Ericsson, 2019).

As stated above, LTE has evolved remarkably in terms of data rates, capacity, spectrum, and application range since its initial deployment in late 2009. Eventually, LTE is capable of providing up to 100 Mbps beyond 42 Mbps of the 3G era. Later on, LTE Advanced (LTE-A) has been developed to obtain more and more higher throughput and massive capacity in the existing frequency spectrum of LTE networks. In 2014, it was possible to reach up to 300 Mbps thanks to this advanced technology by merging contiguous or non-contiguous carriers, which

are frequency channels used for packet data transfer. In summary, the major purpose of evolution of LTE-A was to enhance the data services support through increased capacity, higher data rates, and lower latency (Khan et al., 2009).

Figure 2.7 shows the mobile network evolution in terms of throughput in downlink and uplink.

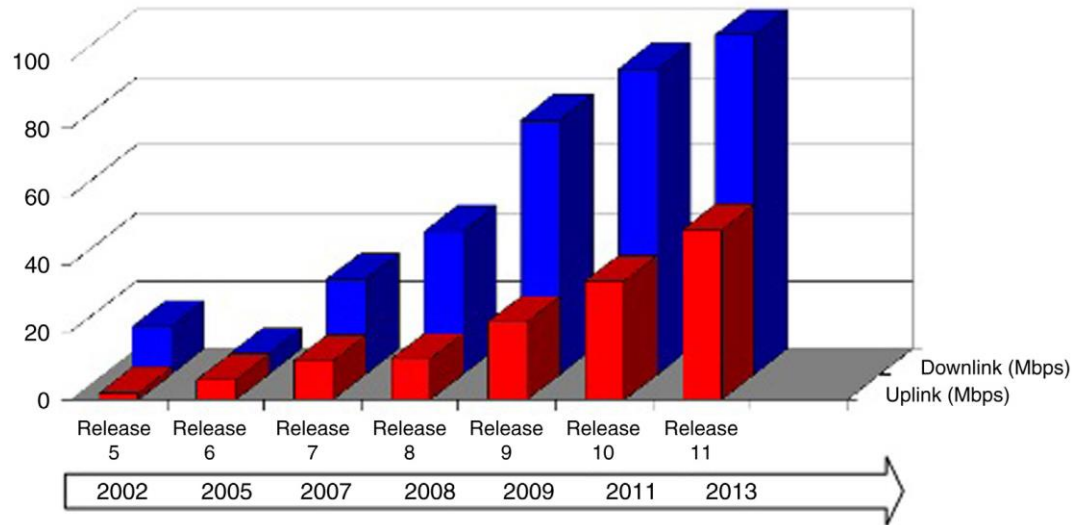


Figure 2.7. Mobile network evolution (Kammoun et al., 2016)

Nowadays, max 2 Gbps (Gigabit per second) throughput has become reachable in downlink if both network and device support Category 20. Table 2.4 simply shows all the category levels including both downlink and uplink peak throughputs reached in LTE technology. LTE-A has made it possible to download a gigabyte sized video content in a few seconds. Therefore, LTE-A technology has significantly postponed the launch of the Fifth Generation in the industry by enabling Gigabit LTE and shortening latency durations (Kammoun et al., 2016). Currently, the number of Gigabit LTE networks launched commercially has already reached 25 in the world (Ericsson, 2019).

Table 2.4. LTE Categories with regard to maximum downlink and uplink throughputs

LTE Category	Downlink (Mbps)	Uplink (Mbps)
3	100	50
4	150	50
5	300	75
6	300	50
7	300	100
9	450	50
11	600	50
12	600	100
13	400	150
15	800	150
16	1000	150
18	1200	200
19	1600	300
20	2000	300

Back to mobile phone evolution, LTE profoundly affected the advanced specifications of smartphones in a positive direction. Higher throughputs have diversified video content and online gaming applications with an offering of higher resolution and have also enabled a smooth Internet connectivity. This effect caused an extension of smartphone displays to provide an enhanced user experience with Full HD screens. The screen-body ratio has exceedingly been enlarged as shown in Figure 2.8.

What is more, camera performance has been improved enormously with regard to software and hardware, and high-end smartphones have also been equipped with 4K video resolution and highly talented cameras. Fingerprint scanning and then face recognition features have been implemented into smartphones quickly. Navigation and location-based applications have advanced in the same period as well.



Figure 2.8. Mobile phone evolution

In 2012 Samsung became the market leader by surpassing Nokia which was keeping the leadership in its hand since 1997 in the global market. The success of Galaxy smartphones, positioned as a sub-brand of Samsung Mobile, played a major role in this way with the help of big-screen sized Note series in particular. In parallel, Apple achieved a strong success story by selling a record number of iPhone 5 and 5S models. Thus, these two giant mobile device manufacturers have totally obtained more than 50 percent of the global market share speedily in this time interval.

Figure 2.9 indicates the global market share held by leading smartphone vendors between 2009 and 2018.

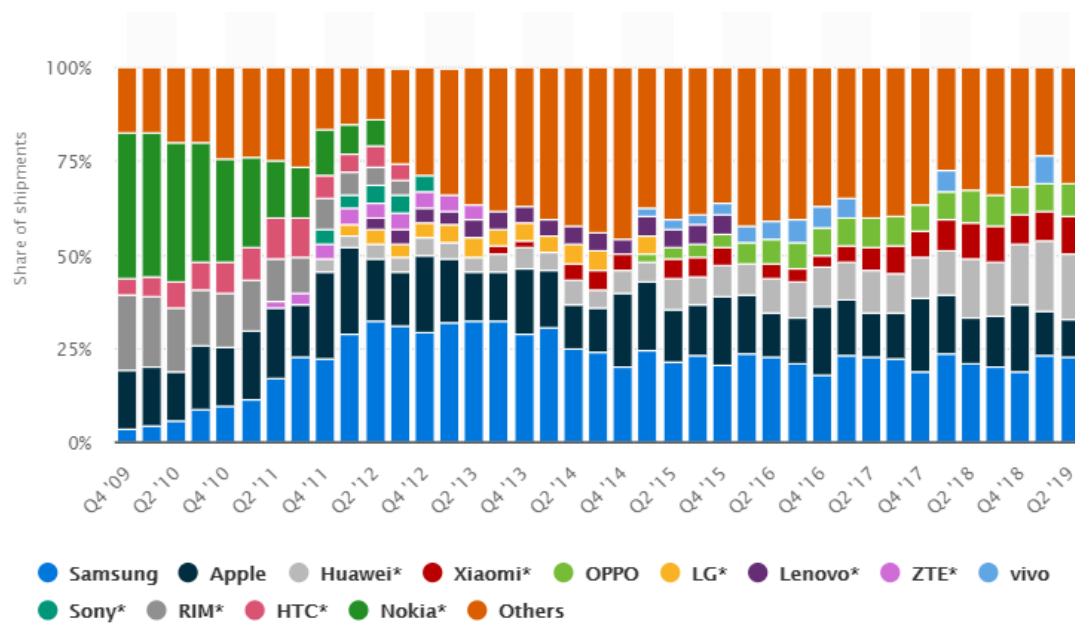


Figure 2.9. Global market share of smartphone vendors (Statista, 2019)

In 2017, Apple marked ten years in the smartphone era with the full-screen iPhone X and removed the physical home button for the first time. Then this change has been followed by the other vendors in the same year. Samsung and other Android-based smartphone manufacturers have speedily developed their new products with full-screen and notch design including front (selfie) camera and various sensors.

In particular, Chinese vendors such as Huawei, Xiaomi, and Oppo have started to come up with their robust and unique smartphone designs in recent years. Thus, it is surely not hard to estimate that Apple and Samsung will have to struggle in a higher competitive environment in comparison to the past era of smartphones. Chinese manufacturers have obtained some substantial advantages such as unit cost, the economy of scale, technological know-how, ODM experience, and globalization until today when moving step by step in the global industry.

At the beginning of 2019, foldable smartphones have enthusiastically been introduced by Samsung and Huawei companies during the Mobile World Congress (MWC) in February 2019, which is an event organized annually by the GSM Association (GSMA). These foldable phones are expected to come into the market by the end of this year, 2020. Apple and Google have not introduced any product regarding this trend so far. As the latest generation in the evolution history, 5G was commercially introduced at the beginning of 2019 in a few developed countries

such as the USA, South Korea, and Switzerland. 5G networks and future technologies will be explained in detail in the next section.

2.1.2. 5G ecosystem and technology drivers

Nowadays mobile telecommunication is not only between humans but also between systems and machines. Therefore, the dramatic growth of smart devices, skyrocketing demand for mobile data, and the new drivers in the market have been accelerating mobile telecommunication technologies towards 5G quicker than ever (Lemstra, 2018). Thus, 5G can be adequately regarded as an emerging and also promising technology in terms of technological advances (Noh et al., 2016; Fettweis and Alamouti, 2014).

As indicated in Figure 2.10, each generation in mobile telecommunications has come up with novel and revolutionary technologies targeting a superior user experience so far (Nawaz et al., 2019). What is more, the emerging technologies have always obtained a positive acceleration in the ecosystem and required a successful plan prepared with a systematic approach so as to respond to customer demands and expectations. Especially mobile network operators have to make their managerial decisions and draw strategies based on their foresight and predictions under fierce competition in this pacing mobile transformation era.

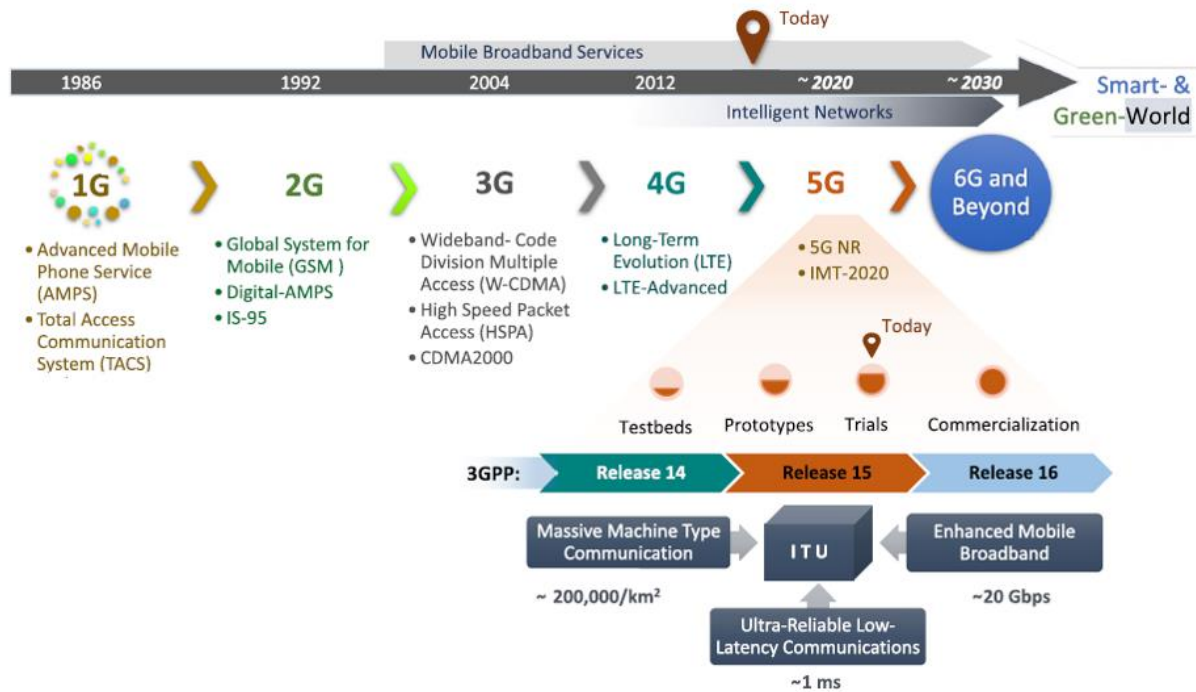


Figure 2.10. Evolution of mobile telecommunications across generations (Nawaz et al., 2019)

Mobile transformation is expected to reach a peak point together with 5G whereas it was slightly started in the 3G era by means of the data-centric communication services. So far, the digital transformation has affected whole shareholders operating in this ecosystem from OEMs to the MNOs in the market. This transformation requires an evolution of connected devices as well because customer preferences and behaviors show remarkable variations when compared to previous years. For instance, video content applications were not as effective as many years ago. They have actually affected lots of variables from the size of the smartphones to the Internet packages promoted by the telecommunication companies to the market. Moreover, advanced video contents with 4K/8K resolution, 360-degree recordings, and Augmented/Virtual Reality applications are expected to be much more widespread in the near future of the industry. The newly announced foldable phones are expected to help blow up mobile data traffic coming from video applications (GSMA, 2019).

Initially mobile network operators and then the other companies in the industry are presently trying to plan their investments for the 5G rollout to make their infrastructure ready for the upcoming technologies and new business cases as of second half of 2019 (Kumar and Gupta, 2018). 5G is generally thought of as a set of novel various technologies, since it needs ultrafast mobile data rates as well as lower latencies that the previous technologies cannot deliver

(Boccardi et al., 2014; Chen and Zhao, 2014). Additionally, 5G is not a single technology but an aggregation of technology types that consist of earlier generations of mobile technologies ineluctably (Oughton et al., 2018). According to a demand-driven analysis undertaken for the Netherlands, it is also found that 5G spectrum bands provide a remarkable improvement of user traffic capacity approximately in comparison with the existing LTE network (Oughton et al. 2019). Similarly, market-driven strategies are investigated for 5G deployments in Finland to stimulate investment in line with population density, which can be interpreted as demand and capacity (Benseny et al., 2019). Based on the forecast results of Ericsson Research, it is projected that 5G technology will achieve 40% population coverage and also 1.5 billion subscriptions in 2024 as the most promising generation in the history of mobile telecommunication on a global scale (Ericsson, 2019). On the other hand, Figure 2.11 indicates global 5G coverage and adoption between 2020 and 2025. By 2025 it is forecast that the number of 5G mobile broadband subscriptions will go up to 1.1 billion in the world (GSMA Intelligence, 2017). As seen in the forecast results, GSMA's forecast is more provident in comparison to Ericsson's.

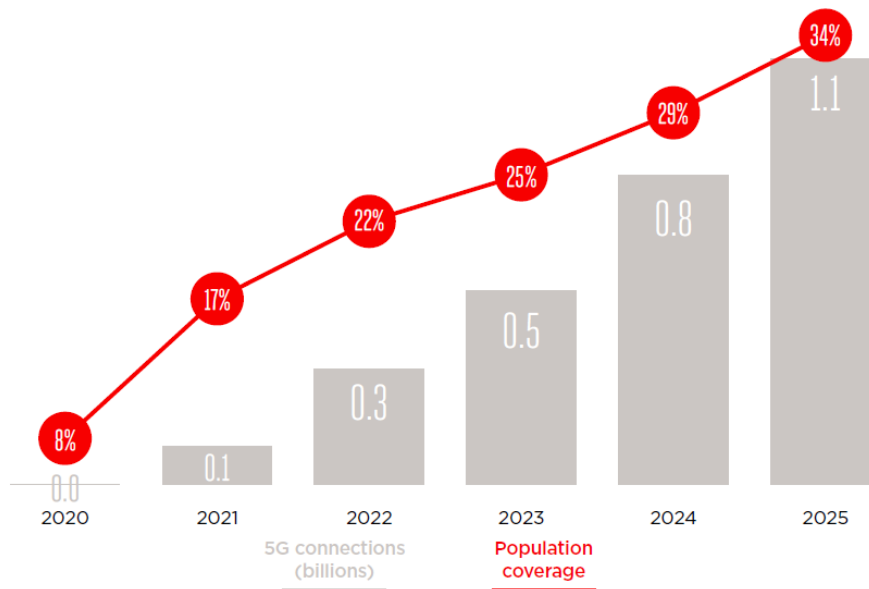


Figure 2.11. Global 5G coverage and adoption (Zhang, 2017)

The increasing consumption of mobile data and the ascending number of connected things in the world require more capacity, higher speed, and shorter latency time from the mobile broadband networks due to the high performance need. Furthermore, lots of new business cases

are expected to come out with the new mobile telecommunication technology. The on-going development of Fifth Generation technology is regarded as the cornerstone for applying information technologies to the various fields. Internet of Things (IoT), smart cities, autonomous and connected vehicles, smart health care systems, advanced sensors are the most remarkable ones (Kim et al., 2017). These enhancements and new services will surely help mobile service providers generate more revenue for 5G technology to be widely deployed.

To begin with, the following 5G capabilities are considered primary advantages in terms of functionality and features when compared to its predecessor technology, 4G (NGMN Alliance, 2015; Osseiran et al., 2016):

- Higher data rates,
- Higher traffic density,
- Higher reliability,
- Support of higher mobility speeds (km/h),
- Lower latency,
- Connectivity for many more devices,
- Lower power in support of the Internet-of-Things.

According to the Next Generation Mobile Networks (NGMN) report, 5G networks are designed to be elastic to create smart infrastructures called network slices capable of meeting these requirements on-demand. Therefore, a network slice can be consisting of 5G network capabilities and technology settings customized for the various business use cases (NGMN Alliance, 2015). A prior stage to enable network slicing and the flexibility needed in 5G networks is the transition to virtualized networks. This seems an important part of digital transformation in the mobile telecommunication networks (Schneir et al., 2019). What is more, virtualization is seen as an internal driver for operators to deploy 5G and as based on a survey of 50 operators globally it is expected to have a virtualized core network before 5G deployments (Ericsson, 2016). With regards to 5G's implication, the impact on the radio access, backhaul, and core networks is considered limited, however, then its effect on digital transformation is much more extensive. Moreover, telecommunication companies need to establish a long-range

mobile network to provide availability that is dependent on the wider roll-out of 5G networks capable of adapting to subsequent levels of digital transformation (Cave, 2018).

As illustrated in Figure 2.12, among the whole set of sub-criteria examined by experts, low latency stands out as the most important performance criterion for 5G technology while high data rate and high reliability are the second most significant factors in this set. 5G promises mobile data rates up to 10 Gigabit/s and latencies as low as 1ms, which are unachievable today. High reliability is also seen as a key necessity for 5G networks particularly because of the heterogeneous structure of 5G networks. Next comes low energy consumption, which is of utmost importance for end user devices as well as the network equipment. Increased coverage has the lowest weight among the whole criteria due probably to the matching between coverage and existing bandwidth (Neokosmidis et al., 2017).

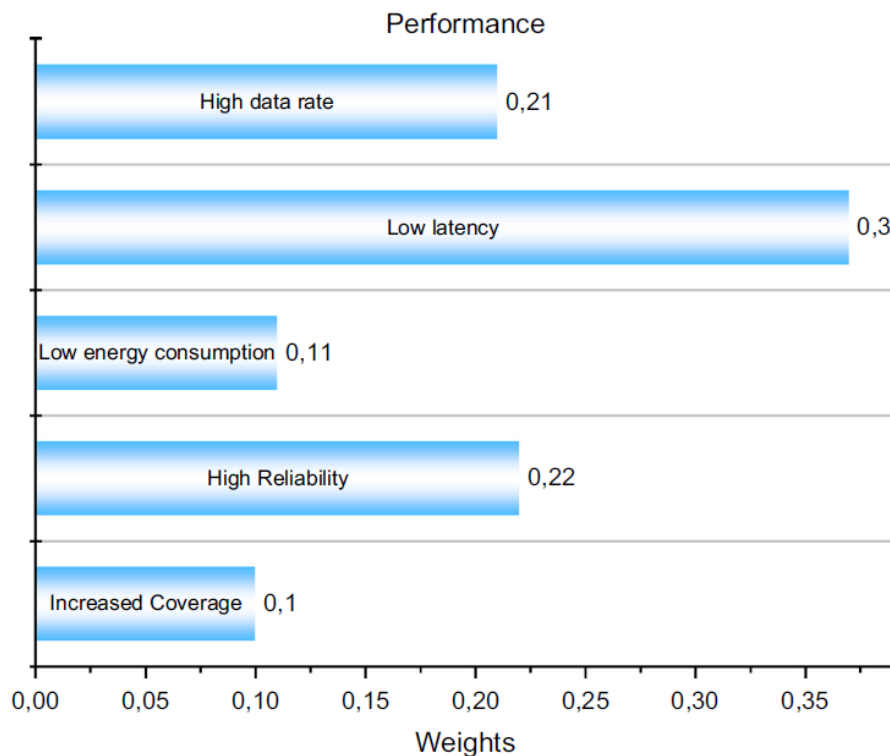


Figure 2.12. Performance weights of sub-criteria of 5G technology (Neokosmidis et al., 2017)

As mentioned earlier, the skyrocketing usage of mobile data and the increasing number of connected things require more capacity, higher speed, and shorter latency duration from the mobile broadband networks due to the high performance needs technically. Furthermore, Figure 2.13 indicates that the mobile data consumption goes on growing on a global scale and it is

forecast to catch 131 Exabyte (EB) per month until the end of 2024. This corresponds to 30% annual growth rate averaged between 2018 - 2024. In this time interval, only novel smartphone based mobile services might have the capability of influencing the growth curve of the global mobile data traffic (Ericsson, 2019). In short, it can be claimed that the increase of 3D (Device, Data volume, and Data transfer rate) encourages the immediate development of 5G networks (Panwar et al., 2016). Moreover, a wide range of new business cases is expected to come out with new companies that never existed before in the mobile ecosystem (Pujol et al., 2016). Based on the HIS Economic Impact Analysis, 5G era is expected to produce approximately 12.3 trillion US dollars in 2035 as the global economic output (Campbell et al., 2017).

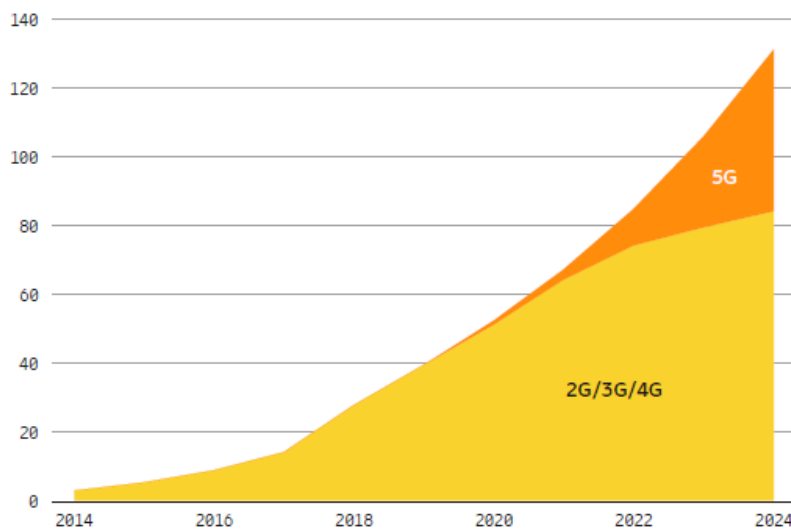


Figure 2.13. Total mobile data traffic (EB/month) (Ericsson, 2019)

5G technology represents a major breakthrough with respect to previous generations and targets producing an ecosystem to meet technical requirements from the so-called ‘vertical industries’ (Frias and Martinez, 2018; Lemstra, 2018). Hence, 5G network architecture is anticipated to host a plenty of business cases with its enhanced capabilities, particularly with regard to latency, resilience, coverage, and bandwidth. Enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC), ultra-Reliable Low Latency Communication (URLLC) services, Vehicle-to-Everything (V2X), Industrial IoT and Fixed Wireless Access (FWA) are the most highlighted ones in the 5G ecosystem.

In the literature, there are various classifications in terms of use cases of 5G technology. The 5G

Infrastructure Public Private Partnership (PPP) is trying to determine and propose uses cases and application areas on the vertical industries, e.g. production factories, automotive, e-health, energy, as well as media and entertainment. As a global authority, International Telecommunications Union (ITU) identified eMBB, mMTC, and URLLC as the three main pillars of 5G (Liu et al., 2018) to incorporate the things, machines and in more general terms various vertical sectors into the picture. Figure 2.14 simply shows these three broad use case families coming with 5G technology. More, a lot of new business cases targeting industrial players as potential users of 5G are expected to come up with this novel mobile technology and it is forecast that 31 billion IoT devices will be deployed all over the world by 2020 (Sadique et al., 2018).

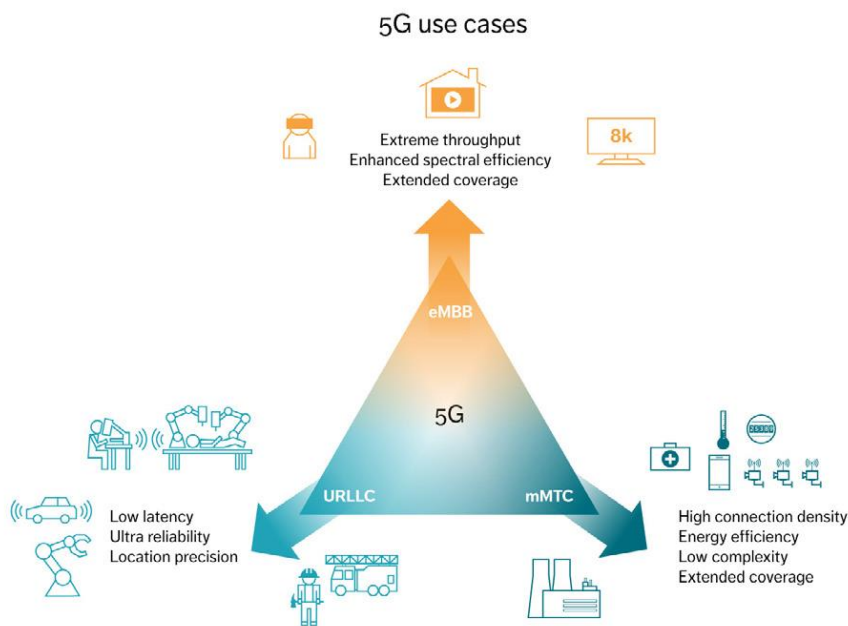


Figure 2.14. Main use cases of 5G (Zaidi et al., 2017)

Firstly, eMBB is expected to make it possible to reach Gigabit level speeds in mobility. When 5G technology then becomes mature, eMBB will be able to extend peak data rates up to 20 Gbps (Morgado et al., 2018). LTE can also provide speeds up to 1 Gbps in the specific environments such as a laboratory or under excellent radio conditions in the stationary, but it is not possible practically to give such high-level speeds to the mobile Internet users during mobility. What is more, eMBB will most probably become the leading element in especially early announcements of 5G, and will prominently drive improved performance, efficiency, and functionality of the

advanced mobile network. Therefore, it seems to be an obvious 5G use case by enabling the reach of ultra-high-resolution video (e.g. TV and gaming), 3D communication (e.g. video calling and AR/VR) and smart city services. In this context, the force for eMBB in 5G service is a progressing stage of 4G mobile transformation indeed. The focus on the enhanced mobile broadband will be able to trigger the 5G business cases and lead network investments during the lack of new use cases. Thus, 5G definitely looks a promising technology with this feature in fact. Furthermore, 5G will be able to leverage the mobile service experience in almost all conditions: at cell borders, stadiums, airports, concert/congress halls, shopping malls, on trains, subways, etc. Next, the 5G network is expected to provide a seamless network experience regardless of the user device.

Second, MTC is a communication paradigm where a number of devices or things are attached to the Internet or directly connected and communicate with each other. In the 5G era, new applications for MTC are developed to serve a huge number of things, introducing the so-called massive MTC (mMTC), or massive IoT (mIoT). mMTC provides connection density capable of connecting around 1 million devices per km² and it can be considered a massive IoT as well. Beyond its technical potential, mMTC technology primarily supports the 5G use cases by enabling many vertical services; those are indeed expected to be a major contributor to the added value of 5G in comparison to previous generation networks (Dutkiewicz et al, 2017). The challenge of complexity and magnitude has resulted in the breakthrough of new mobile technologies, particularly in the M2M area. The fundamental purpose is the development of mobile massive technologies that can enable connectivity to a giant number of affordable devices located in a wide geographical area. Therefore, Machine-to-Machine (M2M) communication is anticipated to evolve into mMTC technology in the upcoming years (Pratas et al., 2017).

Thanks to URLLC, 5G will have the capability to serve in 1 millisecond (ms) as the one-way time measured considering a single user and an IP packet with the 0-bit payload. It also enables superior service in terms of reliability with the help of a minimum packet error rate of 99.999% (Morgado et al., 2018). A round-trip latency of 1 ms can potentially move the world from enjoying today's mobile systems into the new world of enhanced mobile control systems. It will profoundly change daily life by affecting all aspects of application areas such as health, safety,

traffic, education, sports, games, and energy (Fettweis, 2014). For instance, this technology makes it possible to manage a surgery operation or drive a truck from thousands of kilometers. Moreover, traffic safety and control in the smart cities will become available via the URLLC technology. Accordingly, manufacturing is one of the most demanding industry in terms of 5G networking support requiring ultra-high reliability and latencies down to 1 ms (for real-time process control), and densities of more than 10 to 100 machine sensor streams per square meter. Furthermore, low latency and high reliability are critical in several real-time applications, e.g. message transmission by robots monitoring patients, life safety systems, cloud-based gaming, nuclear reactors, sensors, cellular drones, and connected transportation systems (Panwar et al., 2016). To illustrate, the significant advances in URLLC will move the current AR/VR experience to the next level by enabling immersive interconnected AR/VR, where participants can virtually interact across vast distances, thanks to 5G connectivity (Vega et al., 2020). Namely, it is not difficult to find numerous examples and diversifying business cases in this way.

To give more detail on these fundamental use cases expected from 5G, according to the ITU report on “Minimum requirements related to technical performance for IMT-2020 radio interfaces”, the key performance indicators, indicated in Table 2.5, have to be accomplished in these 5G use cases; eMBB, URLLC and mMTC (ITU-R, 2017).

Table 2.5. Key performance indicators associated with 5G technology use cases (Morgado et al., 2018)

#	Technical performance requirement	Indoor hotspot		Dense urban		Rural	
		UL	DL	UL	DL	UL	DL
eMBB usage scenario							
1	Peak data rate (Gbit/s) NOTE: all resources allocated to a single user	10	20	10	20	10	20
2	Peak spectral efficiency (bit/s/Hz) NOTE: these values assume 8×8 MIMO in DL and 4×4 MIMO in UL, but this is not mandatory	15	30	15	30	15	30
3	User experienced data rate (Mbit/s) NOTE: 5% point of the CDF of the user throughput	–	–	50	100	–	–
4	5 th percentile user spectral efficiency (bit/s/Hz)	0.21	0.3	0.15	0.225	0.045	0.12
5	Average spectral efficiency (bit/s/Hz/TXRX) NOTE: aggregate throughput of all users divided by channel bandwidth divided by number of TX-RX points	6.75	9	5.4	7.8	3.3	1.6
6	Area traffic capacity (Mbit/s/m ²)	10		–	–	–	–
7	User plane Latency NOTE: one-way time measured above layer 3, considering single user and IP packet with 0 bit payload	4 ms					
8	Control plane latency NOTE: idle to active transition	20 ms					
9	Energy efficiency	Support high sleep ratio (network) and long sleep duration (terminal). Other mechanisms can be proposed.					
10	Mobility (bit/s/Hz)	1.5 (10 km/h)	–	1.12 (30 km/h)	–	0.8 (120 km/h) 0.45 (500 km/h)	–
11	Mobile interruption time	0 ms					
12	Bandwidth NOTE: maximum aggregated system bandwidth	At least 100 MHz (In bands above 6 GHz, this should be higher, e.g. 1 GHz)					
uRLLC usage scenario							
1	User plane Latency NOTE: one-way time measured above layer 3, considering single user and IP packet with 0 bit payload	1 ms					
2	Control plane latency NOTE: idle to active transition	20 ms					
3	Reliability NOTE: probability of successful transmission of layer-2 Packet Data Unit (PDU) with 32 bytes, within 1 ms, considering cell- Edge channel quality	99.999% (Packet error rate less than 10^{-5})					
4	Mobile interruption time	0 ms					
5	Bandwidth NOTE: maximum aggregated system bandwidth	At least 100 MHz (In bands above 6 GHz, this should be higher, e.g., 1 GHz)					
mMTC usage scenario							
1	Connection density	1 000 000 devices/km ²					
2	Bandwidth NOTE: maximum aggregated system bandwidth	At least 100 MHz (In bands above 6 GHz, this should be higher, e.g., 1 GHz)					

Fourth, the conception of Vehicle-to-Everything is mostly positioned in the automotive industry and simply V2X provides the instantaneous sharing of safety-relevant information between vehicles to enable obstacle detection, collision avoidance, and cooperative mobility. In fact, mobile network operators have globally started to talk about the automotive slices of the 5G network to provide the required QoS (Quality of Service) in latency, bandwidth, and security (Mavrakis, 2018). With the help of V2X systems, unsafe and risky road conditions can be quickly detected, and then surrounding vehicles and pedestrians can be informed promptly in order to improve road safety and provide a more comfortable drive experience. Besides, the instantaneous information regarding traffic conditions can remarkably reduce the time spent in congested traffic as well as the additional benefit of decreasing the energy consumption and vehicle emissions (Campolo et al., 2018). To do this, primary automobile manufacturers and network operators joined the Fifth Generation Automotive Association (5GAA) by aiming at producing interoperable applications for the V2X technology (Nguyen et al., 2017). Further, 5G will also come up with long-range low latency connectivity besides short-range V2X communication. In MWC 2019, notice was attracted to the significance of the highly increased capacity, which is connecting up to 1.2 billion vehicles in the near future (ABI Research, 2019).

What is more, 5G is expected to be the heart of Industrial IoT (IIoT) where the giant amounts of data produced will promote productivity enhancements as well as lead to entrepreneurial activities over the global economy (Schneir et al., 2018; Ammar et al., 2018). According to Cisco IBSG, it is forecast that more than 50 billion things to be connected to the Internet by 2020, with around 20% of the industry (Palattella et al., 2018). Especially smart manufacturing, as an important part of Industry 4.0, will be the pioneer in 5G based IIoT that depends on mMTC, URLLC, and eMBB technologies (Cheng et al., 2018; Kusiak, 2017). Smart metering, asset management, fleet management, collaborative robotics, advanced automation, and control will be the most probable use cases in this context. Moreover, IIoT targets to complete ubiquity of 5G networks in industrial environments based on the technologies of reliable sensing, computer network, real-time communication, and big data. IIoT also helps to get the significant production process parameters with lower cost, more appropriate applicability, which cannot be achieved in the traditional industrial production line, to optimize production management (Li et al., 2018).

Lastly, Fixed Wireless Access is clearly standing out as another significant business case for 5G

since it provides fiber-like gigabit level speeds in the spectrum exhaust areas where fixed fiber-optic is not ubiquitous or costly to deploy. Some leading operators have already launched this service by utilizing LTE Advanced technology in the existing frequencies. In this direction, Fixed Wireless Access contributes to accelerate the return on investments from the LTE Advanced technology as well as having a significant role as a forerunner to the upcoming 5G FWA service. This means a notable opportunity to provide a high-quality FWA service before the launch of 5G technology (Ericsson, 2019). In 5G, FWA is technically operated on the mmWave spectrum defined at a high-frequency spectrum such as 26 GHz, 28 GHz, and 39 GHz in different regions and countries. Even though mmWave signals have much higher path-loss than the microwave signals used in the legacy mobile networks, it is capable of offering multi-Gbps data rates with a lower cost when compared to the previous technologies thanks to its opportunity of providing broader bandwidth at these high frequencies (Oughton et al., 2018; Murdock et al., 2012). Owing to these path-loss constraints, mmWave is well appropriate for the usage in indoor hotspots and outdoor small cell scenarios (Ayach et al., 2014).

Moreover, FWA is remarkably able to influence the whole 5G data consumption based on market conditions because it is one of the initial usage areas considered for 5G networks. In especially developing countries, only 20% of households have access to fixed broadband networks. FWA can be a good choice of the broadband connection for the remaining 80% of households (Wei, 2018). Figure 2.15 illustrates a basic FWA architecture including 5G base station (gNB) and Customer Premises Equipment (CPE) deployed in the subscriber location.

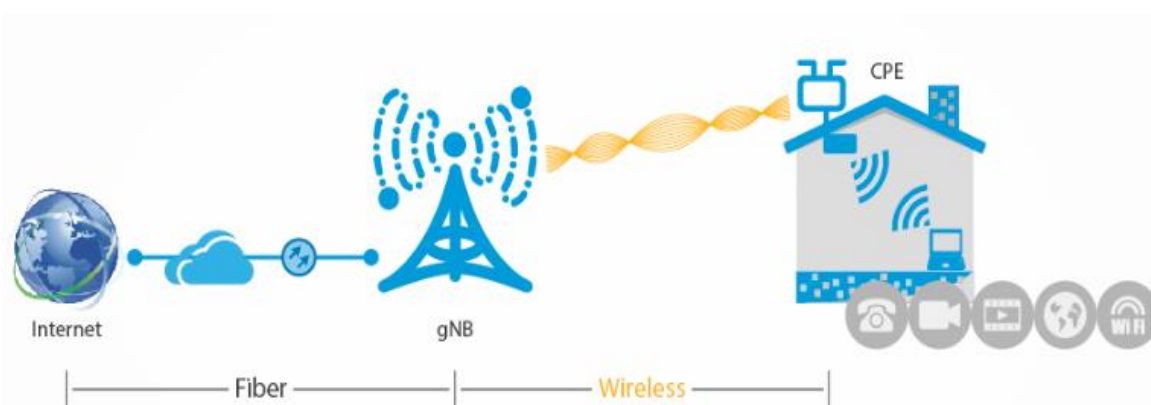


Figure 2.15. The basic FWA architecture in 5G (ZTE, 2018)

Besides new business cases and features coming with 5G technology, 5G is expected to be backward compatible with the legacy telecommunication networks for both data and voice communication services. As mentioned before, data-centric communication was started with 3G technology and progressed with LTE later on. As concerns voice, this legacy capability for mobile services was missing at the beginning of LTE. The industry players worked a lot to handle this and most of LTE operators have already launched Voice over LTE, Video over LTE, Voice over Wireless Fidelity (VoWiFi), and Rich Communication Services (RCS). 5G networks need to be enriched to provide these voice services as of first day. It is significant that 5G will enable seamless compatibility with existing heterogeneous networks to satisfy the high demand for real-time data traffic so that mobile subscribers will have smooth connectivity to the network (Mitra and Agrawal, 2015). Hence, mobile network operators should flawlessly keep on supporting this global range for telecommunication services in the 5G as it was in the previous mobile technology generations in the past.

As emphasized before, the 5G ecosystem seems to be a key solution to address increasing mobile requirements while the mobile connectivity demand is getting more extensive than ever. However, some issues are still kept under investigation by the academic environment and research departments of industry players in the world. Most probably, such work items will be handled in the next generation of mobile telecommunication.

2.1.3. Beyond 5G technologies

In 1926, genius scientist Nikola Tesla stated: “When wireless is perfectly applied, the whole Earth will be converted into a huge brain”. Today 5G technology has many advanced technological capabilities mentioned earlier to make Tesla’s prophecy reality and it promises far-reaching changes and appears a unique solution of all these needs when the mobile connectivity demand is much more extensive than ever. Even if 5G seems an ultimate mobile technology for the needs in the world, the mobile telecommunication ecosystem will likely call for a more enhanced mobile communication system with a new architecture incorporating new services and technologies. In this direction, it is surely an early stage to define definitely what 6G will become, but Sixth Generation (6G) technology is anticipated to be rolled out gradually at the end of 2020s as indicated in Figure 2.16 apparently (Strinati et al., 2019). According to this figure, 6G key technology components are expected to be functional till 2026, and the

product is finally predicted just before the new decade, in conjunction with the readiness of full 6G PoC and services.

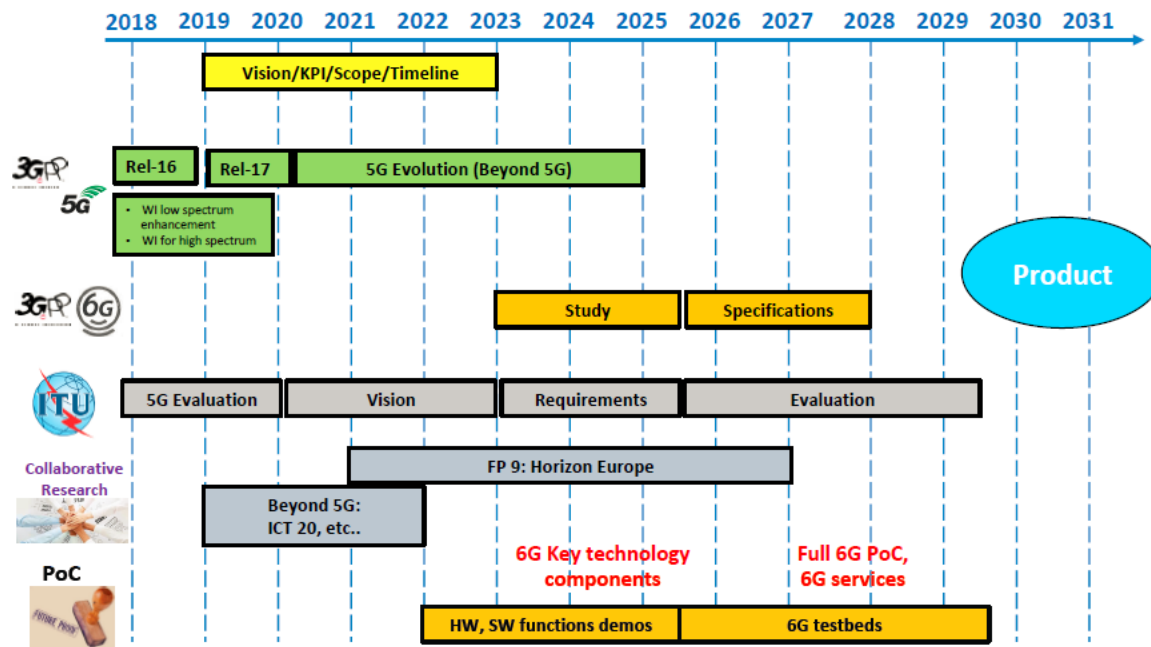


Figure 2.16. Proposed 6G roadmap (Strinati et al., 2019)

Research activities regarding the future mobile technologies are continuously performed by the industry, academic environment, and research communities, and such groups have already started to work on the definition and identification of relevant key enabling technologies that might be called ‘beyond 5G’ (B5G) or shortly “6G” (David and Berndt, 2018; Li, 2018). In 2018, ITU-T (International Telecommunications Union Telecommunication Standardization Sector) established a focus group called FG-NET 2030 to research over the requirements of networks for 2030 and beyond, forecasting time in order to ensure new use cases such as holographic communications, ultra-fast response, and high-precision communications. After the introduction of holographic telepresence applications in the industry, the bandwidth needs will probably jump to Terabit levels when these applications are capable of strong precision and best-guaranteed services (Yastrebova et al., 2018).

Additionally, researchers from the University of Oulu started a research program to conceptualize 6G by naming that ‘6G Enabled Smart Society and Ecosystem, 6Genesis’ in the same year (Katz et al., 2018). There are also some other groups studying on ultra-dense network

technologies such as Network Function Virtualization (NFV), Software Defined Networking (SDN), and Mobile Edge Computing (MEC) to offload the network and enhance resource allocation and optimization in the future networks (Barritt and Cerf, 2018; Gao et al., 2018; Siddique et al., 2015).

As newly experienced in the 5G era, different vertical sectors will be complicatedly involved in the 6G development phase along with the increasing need to provide mobile connectivity solutions focused on the vertical industry (Mahmood et al., 2019). Most of the use cases in 6G will evolve from the emerging 5G system based applications. Nevertheless, there are some key expectations from 6G such as ultra-long battery lifetime, ultra-high bit rates reaching ~1Tbps, wireless charging via radio waves or laser beams, optical free-space indoor communications, extensive use of machine learning in the mobile networks (David and Berndt, 2018).

Furthermore, sub-TeraHertz (THz) communications and Visible Light Communication (VLC) for short-range are most likely predicted techniques as regards 6G technologies (Strinati et al., 2018). Artificial Intelligence (AI) will be a substantial part of 6G technology in almost all levels, from network orchestration to coding and signal processing in the physical layer, and to data mining at the network and device level for service-based communications, etc. (Tariq et al., 2019; Letaief et al., 2019). In short, it can be estimated that AI will seriously dive into the whole layers and be the signature for 6G for smarter and more powerful networks (Zheng et al., 2018).

In 6G, charging mobile devices via radio waves is another research topic, integrated with energy producing techniques such as generating the energy from motion and solar cells. Here the research question is whether we will still need to separately charge the mobile devices together with other enhancements such as enhanced display techniques and more powerful processors etc. (Liu et al., 2016).

Furthermore, another flashing technology is Quantum communication that tends to contribute remarkably to two fundamental criteria of 6G, such as extremely high data rate and link security (Nawaz et al., 2019; Hosseinidehaj and Malaney, 2017). Additionally, every generation of mobile communications has been defined by the UE capability. This will be more so for 6G since AI is expected to play a significant role that helps the UE make access decisions in the fog networking (Tariq et al., 2019).

2.2. Technological Forecasting

In recent years, technology related topics have been considered major areas to make forecasting and use different decision making and selection algorithms to see the horizon in the industry. In particular, the evolution of societies and technologies has played an important role at this point. Especially, the last three decades have witnessed numerous developments in mobile telecommunications. Hence, technological forecasting has obtained a quite substantial position in the mobile telecommunication industry as it sets light to the strategic management and investment decisions by showing emerging technological areas where it should be invested in and also time to get involved.

2.2.1. Definition

Firstly, technology forecasting is defined as “anticipation of technological change” (Schon, 1967). After that, while technology forecasting is defined as the attempt to project technological capabilities and to predict the inventions and spread of technological innovations in (Ascher, 1978), according to Porter, technology forecasting is “anticipation of the character, intensity and timing of changes in technology” (Coates et al., 2001). In the traditional context, it was also described as “prediction of the future characteristics of useful machines, procedures, and techniques” (Martino, 1993). In other words, technology forecasting refers to “the systematic process of describing the emergence, performance, features, or impacts of technology at some time in the future” (Porter et al., 2004).

All these definitions of technological forecasting allow us to look at, as independent variables, not only the evolution of the understanding of technological change but also its management in both government and industry (Coates et al., 2001). Essentially, technology forecasting gives infrastructure and methodology to foresee the future trends of technologies for the following societies, products, and services. Thus, it is a fact that technology forecasting has a big impact on the design of new technologies. Undoubtedly, technologies are affected by these forecasting studies and investment plans can be changed by companies based on forecasting results.

In general, technology forecasting performs a systematic approach to read and understand the likely direction, characteristics, and influences of technological changes, innovation, adoption, and use. However, technological forecasting is much harder than weather forecasting on the

basis since meteorologists at least have past data of observing weather patterns to help them. Technology forecasters have to deal with new concepts and approach with little historical data to build upon (Roper et al., 2011). Moreover, good forecasts reflect a range of possible futures, of which some might be more likely than others. To handle that successfully, a good technological forecast should be quantitative, qualitative, or a mixture of both.

Successful forecasting is one that maximizes the future gain and minimizes the future loss of companies, which employ these forecasts to make resource allocations. The aim of almost all organizations in the industry is to come up with an accurate technological forecast to be able to optimally deploy their resources to some particular purposes and directions over time as dictated by the forecast. The main motivations underlying technology forecasting are given below (Coates et al., 2001):

- Planning new product developments,
- Prioritizing research & development activities,
- Improving existing products,
- Making strategic decisions on technology licensing and joint ventures,
- Keeping on a competitive environment,
- Timing for the new technologies and investments,
- Guidance for future projects,
- Roadmapping.

Besides those primary drivers of technological forecasting, the main attributes of technologies to be forecast are mostly as followed (Roper et al., 2011):

- Growth in functional capability,
- Rate of replacement of old technology by a newer one,
- Market penetration,
- Diffusion,
- Likelihood and timing of technological breakthroughs.

Please note that no distinction is intended between “technological forecasting” and “technology forecasting” throughout this dissertation. So, both statements are widely used for the same meaning and purpose.

2.2.2. Technological forecasting techniques

It is possible to encounter various classifications for the forecasting methodologies in the literature. These classifications might be complicated with the point of view of the planning or decision making activity that the technological forecast is planned. To understand better, these methods can be categorized in the following three parts; direct, correlative, and structural, and can be found in Table 2.6 together with their corresponding categories inline.

Table 2.6. Categorization of technological forecasting methods (Roper et al., 2011)

Category	Definition	Methods
<i>Direct</i>	Direct forecast of parameters that measure an aspect of the technology	Expert opinion, Delphi surveys, nominal group technique, time series analysis, trend extrapolation, growth curves, substitution curves, life cycle analyses
<i>Correlative</i>	Correlates parameters that measure the technology with parameters of other technologies or other background forecast parameters	Scenarios, lead-lag indicators, cross-impact analyses, technology progress functions, analogy
<i>Structural</i>	Explicit consideration of cause-and-effect relationships that affect growth	Causal models, regression analyses, simulation models, gaming, relevance trees, mission flow diagrams, morphology

Direct methods mostly forecast technology parameters that are related to functional capacity or some other relevant specification of the technology. Direct methods are not interested in the correlations with technological, economic, social, and political contexts apparently. On the other hand, expert opinion methods also deal with subjective consideration of contextual change through the implicit mental model that each expert has internalized about the nature and likelihood of change.

Correlative methods consider the relations of technology development with the growth or change of one or more elements in its context. Scenario construction is usually utilized to forecast major parts of the context and technology. Similarly, forecasting by analogy claims that the development of the technology will follow a specific pattern structured by earlier technology.

Whole correlative methods generate formal or informal assumptions regarding the relationship between the forecasting technology and elements of its context.

Structural methods normally pay regard to the interaction between technology and context. In this direction, they must be explicit about the structural relationships between the technology and the elements. For instance, simulation models should handle the relationships among elements. Likewise, regression analyses search to build those relationships. Without considering their complexity, all of the structural models facilitate reality to make problems processable.

Table 2.7 indicates a broader and more advanced classification in order to explain whole methodological families in the context of technological forecasting (Porter, 2010).

Table 2.7. Methodological families in the technology forecasting techniques (Porter, 2010)

<i>Methods families</i>	<i>Sample methods</i>
Creativity approaches	TRIZ, future workshops, visioning
Monitoring and intelligence	Technology watch, tech mining
Descriptive	Bibliometrics, impact checklists, state of the future index, multiple perspectives assessment
Matrices	Analogies, morphological analysis, cross-impact analyses,
Statistical analyses	Risk analysis, correlations
Trend analyses	Growth curve modelling, leading indicators, envelope curves, long wave models
Expert opinion	Survey, delphi, focus groups, participatory approaches
Modelling and simulation	Innovation systems descriptions, complex adaptive systems modelling, chaotic regimes modelling, technology diffusion or substitution analyses, input-output modelling, agent-based modelling
Logical/Causal analyses	Requirements analysis, institutional analyses, stakeholder analyses, social impact assessment, mitigation strategising, sustainability analyses, action analyses (policy assessment), relevance trees, futures wheel
Roadmapping	Backcasting, technology/product roadmapping, science mapping
Scenarios	Scenario Management, Quantitatively based scenarios
Valuing/Decision-aiding/economic analyses	Cost-Benefit Analysis (CBA), Analytical Hierarchy Process (AHP), Data Envelopment Analysis (DEA), Multicriteria Decision Analyses
Combinations	Scenario-simulation (gaming), Trend impact analysis

In general, the most frequently used forecasting methods are classified into five groups: Monitoring, expert opinion, trend analysis, modeling, and scenario construction (Porter and Rossini, 1987):

2.2.2.1. Monitoring

Monitoring is a fundamental initial step for almost all forecasts. It refers to monitoring the technological environment and collecting the information from a wide range of sources to utilize in forecasting, which is easy today with the help of the Internet and its capability to allow enhanced access to information. Hence, monitoring is so important in times of quick social and technological changes. Such changes in the information, telecommunication, energy, and other rapid technologies require that technology managers should be conscious and farseeing to make sensible investments and decisions. It is much more crucial for the organizations and companies running in supremely competitive environments as well.

What is more, monitoring is described as “to watch, observe, check, and keep up with developments, usually in a well-defined area for a specific purpose” (Coates and Coates, 1986). This description covers the meaning of monitoring which is the most widely practiced forecasting method. Monitoring provides most of the information to be shaped for the forecast by using suitable information resources. Within this context, it can be considered the backbone of technological forecasting indeed. In addition, the Internet has become an essential information source by means of advantages of Google and other search engines to extract the required information from extensive databases and news sources. This practice is defined as “tech mining” when technology is the main topic (Porter and Cunningham, 2005; Morris et al., 2002).

2.2.2.2. Expert opinion

Expert opinion is the collection of opinions of experts in a specific field for further analysis. It becomes a more substantial and necessary technique when the data is insufficient, and a data model does not exist. It is strongly recommended to work with a group of experts in a forecast study rather than working with an individual expert. A number of experts who are ready to share information and feedback on multiple aspects of the forecast can provide remarkable value.

Gustafson et al. (1973) divided expert opinions into three processes: feedback, interaction, and estimates. Nelms and Porter (1985) thought schemes for unifying these processes and came up

with the following six factors in adjusting expert opinion techniques:

1. Logistics: Resources and time available may constrain the options.
2. Feedback: Long delays are possible in multistage processes; it may be sought to balance consideration of outlier positions.
3. Communication medium: In-person or electronic; real-time or “whenever” participation.
4. Sample size: Particularly for interactive modes. Group processes are valuable, but their value declines as groups grow beyond five or six.
5. Stopping rule: In multi-stage processes, time and tolerance favor two or three rounds.
6. Interaction: More is needed for complex tasks and where serious disagreements arise.

Commonly, expert opinion techniques are focus groups, brainstorming, nominal group process, survey, Delphi, Shang Inquiry, and participatory approaches. Expert opinion methods usually result in merely, so it is strongly recommended to combine with another empirical approach to help integrate and interpret forecast (Glenn and Gordon, 2002). Amongst all expert opinion approaches applied in the literature, the most popular technique in this group is the Delphi (Fowler, 2008).

Delphi technique

At the beginning of the 1950s, it was developed by the Rand Corporation and has rapidly become one of the main characters of technological forecasting. The main idea of this method has been structured on the proverb “two heads are better than one”. The use of multiple experts is superior to an individual’s knowledge and so, removes any probable personal mistakes (Hill and Fowler, 1975). The Delphi technique is a structure of survey planned to give attendant anonymousness, controlled feedback, iterative replies, prediction of the probabilities and timing of technological advances. Delphi method for obtaining expert opinion has been conducted to obtain strategic information about the development of emerging technologies covering their foreseen launch date and features (Gerdri, 2005).

Delphi survey is systematically applied as an interactive forecasting technique that depends on a group of experts. The process is completed at the end of two rounds of the questioning stage. Participants are asked a set of questions and later, those same questions are asked to them again after initial feedback from the first round. This iteration is mostly ended in the second or third

tour based on the responses' and feedbacks' consistency generally (Winkler et al., 2015). Then, the results of the Delphi study are statistically evaluated to make a decision on whether a group consensus exists regarding emerging technologies and the time of their introduction. More, the stability is checked between subsequent Delphi rounds to determine when it is proper to end up the study (Gerdri, 2005). Its advantages and disadvantages are regardfully listed in the following.

Advantages:

- Allows a gathering of the views of an expert group,
- Appropriate for looking long-term into the future for emerging technologies having no historical data,
- The anonymity is important in a strict environment in which individuals might feel limited in stating their own opinions,
- The chance to collect replies without bringing the participants together is a really cost-effective way to get rid of physical limitations.

Disadvantages:

- Selection of experts might be problematic,
- Some misunderstandings may exist if questionnaires are poorly created and not clarified clear enough,
- Consistency, certainty, and reliability are hard to decide.

When compared to other expert opinion methods, the Delphi process has an important advantage and favor with the help of anonymous feedback and the absence of interpersonal exchanges in which some experts might be dominant in the group sessions (Linstone and Turoff, 2002). Delphi based surveys also outperform statistical groups and standard interacting groups (Rowe and Wright, 1999). Further, the Delphi survey can be easily integrated with another forecasting method since it is an efficient instrument to acquire foresight for an uncertain future (Wright et al., 2013; Lee et al., 2016; Chen et al., 2012).

The Delphi method also works well for structuring the information flow and iteratively obtaining

feedback in mobile technologies (Chuang, 2015). Delphi's expanded range of applications and variations in the industry will be clarified in the following sections.

2.2.2.3. Trend analysis

Trend analysis consists of mathematical and statistical techniques to extend a time series data to the future. It enables analysts to obtain a significant databased forecast of quantifiable parameters in order to analyze the adoption and substitution of emerging technologies. It provides well-aimed results particularly over short time periods. Growth cycle, S-shaped projection, Logistic curve, Fisher-Pry, Gompertz curve, Box Jenkins (ARIMA) method, Eyeball fitting, and Linear Regression are well-known trend analysis techniques frequently applied in the technological forecasting problems (Roper et al., 2011). As indicated in Figure 2.17, these leading forecast techniques might have so different results based on their methodological and statistical approach on a given historical data. Further, an important diffusion model, the Bass model can be also considered among trend analysis methods. This model will be explained in-depth with various use cases in the section 2.2.3.

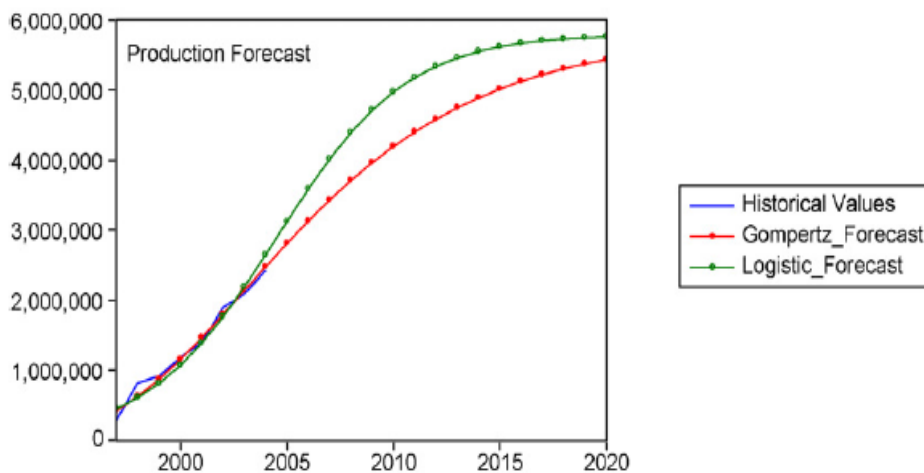


Figure 2.17. Sample illustration of a trend analysis (Moon and Jeon, 2009)

In the trend analysis, the main assumption is that past conditions and trends will be continuous in the future more or less unchanged with an almost stable manner. It mostly needs plenty of data to be more influential and accurate and works only for quantifiable parameters. In case of the absence of adequate data, trend analysis techniques must be ruled out and another method

should be considered properly in this context. Additionally, it is not robust against complexity and discontinuities in the technological environment. Thus, forecast results might be misleading especially for long time periods whereas it gives successful output for the short time frames in the technological progress.

2.2.2.4. Modeling

Modeling is a simple figuration of the structure that is a part of real life. It needs a deep understanding of interactions between the forecasts and underlying variables. These models can be flow diagrams, equations, physical models, computer based simulations, and so on. Ordinary forecasting models are either computer based (simulations) or judgment based. Quantitative parameters typically are utilized in the computer based simulations. Judgment-based models build on the forecast analyst's talent to generate well assumptions and to make logical decisions about how they affect the forecast. When a model is available that includes the essential features of a forecast topic, and the forecast analyst feels safe about the assumptions that drive them, it is clearly that modeling is applicable.

The modeling can help forecast analysts to build insights by structuring the real world conditions simply and reducing the complexity of systems to convert complex systems to the handleable representations. Models are able to demonstrate future characteristics of complex systems basically by eliminating remarkable system specifications from insignificant detail. The modeling or simulation technique can enable brilliant insight into the complex system structure. Therefore, advanced simulation methods are often preferred in the latest technological changes and development phases. However, most of the models use quantifiable over nonquantifiable parameters by ignoring probably substantial aspects. Models that are not based on a strong data-set might be misleading for forecast analysts. In recent years, technology forecasters frequently resort to this methodology. In particular, technology diffusion models are commonly preferred to be able to forecast the growth of a technological advance in the information, telecommunication, or energy technologies areas.

2.2.2.5. Scenario construction

Scenario analysis or in other words, scenario construction can be seen as the portrayal of some parts of the future or paths extending into the future. It generally offers different conceptions of

future technologies providing integration of lots of quantitative and qualitative information acquired by other forecasting methods. A set of scenarios can surround the probable range of chances for some aspect of the future. Scenarios are able to produce valuable projections of probable futures and cover a broad range of quantitative and qualitative information generated by other forecasting methods. They are widely used in order to merge both quantitative and qualitative information and to unify forecast results from plenty of sources and techniques into an appropriate portrayal. Moreover, it is used to provide a forecast when data-set is not enough or reliable to utilize another method.

There are five stages in establishing a scenario as follows (Roper et al., 2011):

1. Describing variables,
2. Developing levels of measurement,
3. Characterizing important variables,
4. Designing scenarios,
5. Creating the story.

Scenario construction is the most favorable technique in forecasting complicated and uncertain cases. Amongst major families of technological forecasting techniques, scenarios are actually more powerful and persuasive tools to communicate with decision makers who are not so familiar with forecasting techniques as well (Van der Heijden, 2005). In the past, SWOT (Strength-Weakness-Opportunities-Threats) analysis was primitive and initial technique when coming to modern scenario analysis approaches (Spies, 1994). Today, it is pretty widespread to present a set of three scenarios that the forecast analyst believes to be one of the most possible futures: no surprise projection (neutral), the worst case projection (pessimistic), and the best case projection (optimistic).

As seen above, diverse methods have evolved for technological forecasting in recent years, but the quality of such forecast results profoundly depends on the appropriate selection and practice of proper techniques on a specific technology (Kalem et al., 2018b). The next section investigates these forecasting applications and use cases encountered in the telecommunication industry.

2.2.3. Technological forecasting applications in the telecommunication industry

The mobile telecommunication industry can be regarded as both a market-driven and technology-driven industry based on the point of view. Therefore, technological progress and market development are coupled with a high rate of change. As stated earlier, it is literally required in order to invest correctly and continue being a competitive player by keeping the company robust throughout the advances and changes in the local and also global environment. Hence, these factors make technological forecasting more crucial in this industry.

When researched thoroughly, application areas of technological forecasting techniques in mobile telecommunications can be separated into the three subclasses; mobile telephony and subscription, mobile broadband (internet) and services, and mobile telecommunication technologies. In the following three parts, lots of significant applications and research examples from the telecommunication industry will be pointed out based on the literature review in detail. Table 2.8 exhibits a summary of the literature review for this section. As an important note at this point, forecasting studies conducted in only the mobile telecommunication industry are investigated in this thesis.

Table 2.8. The summary of the review in the technological forecasting in telecommunications

Title	Year	Methodology	Result
A conjoint model of enhanced voice mail services. Implications for new service development and forecasting	1997	Conjoint model	The results demonstrate that conjoint analysis yields: (1) accurate identification of consumer priorities and price sensitivities; (2) underlying benefits-based market segmentation; and (3) realistic, efficient demand forecasts for multiple market scenarios.
Models of technology diffusion	2000	S-curve models	The paper obtains the models in which the initial choice between different variants of the new technology affects the subsequent diffusion speed of the chosen technology.
The diffusion of mobile telecommunications services in the European Union	2001	Logistic and Gompertz models	The results show that the evolution during the next 10 years, when the industry will have reached a stage closer to maturity, will yield an interesting new data against which the results of this paper can be confronted.

A genetic algorithms approach to growth phase forecasting of wireless subscribers	2002	Bass diffusion model, genetic algorithm	It is found that the predictions from GA (Genetic Algorithm) are robust across many datasets and are better than OLS and NLS with respect to both Relative Absolute Error (RAE) and predictions of time to peak sales.
An analysis of the determinants and effects of ICT diffusion in developing countries	2003	Gompertz model	The results show that income and government trade policies influence ICT diffusion. However, freedom indices may or may not affect ICT diffusion. Contrary to expectations, ICT diffusion is not associated with education.
Long-term technological forecasting	2004	Delphi method, identifying precursor events, trend-curve fitting, and forecasting by analogy	The paper reviews possible methods of technology forecasting and predicts Chinese cellular phone use per 100 inhabitants by analogy using comparable data from Korea, Japan, and the US.
The diffusion of cellular phones in Portugal	2004	S-curves (the Gompertz and the Logistic models)	It is shown that the pattern of diffusion is S-shaped and is consistent with a logistic function, which describes a symmetrical growth process. Furthermore, it is found that the leveling-off process in the diffusion of mobile phones has already begun.
The diffusion of mobile telephony in Italy and the UK: An empirical investigation	2004	Logistic, Gompertz models	The paper utilizes Logistic and Gompertz models of innovation diffusion to evaluate the impacts due to economic variables on the diffusion speed and market potential (i.e., saturation level), of mobile telephony adoption in the UK and Italy.
An analysis of the effect of the economic situation on modeling and forecasting the diffusion of wireless communications in Finland	2004	Logistic model	The forecast shows that the final penetration rate will be 91.7% in 2009. The model predicts the actual figures for the year 1999 very accurately.
The pattern and externality effect of diffusion of mobile telecommunications: The case of the OECD and Taiwan	2005	S-shaped curve, Ordinary Least Squares (OLS) method	The paper finds that the pattern of diffusion of mobile telecommunications for all the sample countries is generally characterized by an S-shaped curve; nevertheless, significant differences exist in the spread of the S curve.
Diffusion of digital mobile telephony: are developing countries different?	2006	Gompertz model	With the help of the Gompertz model, the importance of having a large potential user base in a developing country, and the effects on diffusion speed due to the late introduction of innovation in the developing world, is highlighted in the study.

The future of the mobile phone business	2007	S-curve, Logistic curve, Natural growth	Active mobile accounts around the globe are expected to grow from 1.7 billion in 2004 to approximately 2 billion in 2008, reaching a peak penetration of 29.2%.
The diffusion of mobile telecommunications services in Korea	2007	Logistic, Time-series, and the Autoregressive moving average model (ARIMA)	The work compares the performance of the Logistic model of diffusion with that of an ARIMA model for diffusion of mobile telecommunications in Korea. The factors affecting the diffusion process are also evaluated.
Demand forecasting of high-speed Internet access service considering unknown time-varying covariates	2008	Diffusion model, the growth curve model	The proposed model achieved high accuracy in the case of Internet services.
Diffusion models of mobile telephony in Greece	2008	Bass model, Gompertz, Fisher–Pry, and Logistic models	Gompertz model is considered as the most appropriate, based on the lowest values of MAPE over the data corresponding to the withheld period (HB) as well as the data that correspond to the take-off dataset (TO).
Technology forecasting for wireless communication	2008	DEA	This forecast predicts that in order for successors to the CDMA based technologies (CDMA 2000 and WCDMA) to be technologically state-of-the-art in 2011.
The diffusion of mobile phones in India	2008	Logistic and Gompertz models	It is found that mobile density in India will increase from 8.1 in 2005–2006 to 36.5 in 2010–2011 and 71 in 2015–2016. Consequently, the mobile subscriber base is projected to increase from 90 million in 2005–2006 to 433 million in 2010–2011 and nearly 900 million in 2015–2016.
The forecasting of the mobile Internet in Taiwan by diffusion model	2008	Bass, Norton-Bass (NB) and Combined-diffusion model	The work introduces a “multi-product” diffusion model, to forecast the diffusion of mobile internet; the technologies included are 2G, GPRS/2.5G, and 3G in Taiwan.
An estimation of the pattern of diffusion of mobile phones: The case of Colombia	2009	Gompertz, Logistic models	The findings suggest that in recent years the rate of growth of mobile phone subscribers has started to slow down, there still appears to be room for further expansion as the saturation level is expected to be reached in 2013.
Diffusion models of mobile telephony	2010	Diffusion models and ARMA	Empirical results demonstrate that the Gompertz model outperforms the other models for the period prior to diffusion take-off, whereas the Logistic model is superior after diffusion inflection.

A look into the future of wireless mobile communication technologies	2010	Trend extrapolation method, regression analysis	A combination of technical parameters (channel bandwidth, channel bit rate, and data capacity) can explain heterogeneous wireless mobile communication technologies.
On the combination of exponential smoothing and diffusion forecasts: An application to broadband diffusion in the OECD area	2011	Gompertz, Fisher-Pry models	According to the results, the forecasting obtained after the application of the exponential smoothing is found to be more accurate as compared to the diffusion models (Gompertz, Fisher-Pry).
A computational intelligence-based forecasting system for telecommunications time series	2012	Takagi–Sugeno–Kang fuzzy neural system, time series forecasting	The ability of the proposed system to forecast telecommunication time series has been evaluated by applying it to real-world data.
Bass model estimates for broadband diffusion in European countries	2012	Bass diffusion model, the Digital divide analysis	The analysis shows that if the present trends continue broadband services will not reach the 100% penetration rate in the near future.
Diffusion of mobile telephony in China: drivers and forecasts	2012	Gompertz, Logistic, Bass models	In the paper, model comparisons using data from eight representative countries (Brazil, China, France, Germany, India, Russia, the U.K., and the U.S.) provide a valuable reference for model selection for mobile telephony diffusion.
The diffusion of mobile telephones: An empirical analysis for Peru	2013	Gompertz and Logistic models	The empirical results indicate that the Gompertz model is the most appropriate.
A two-stage fuzzy piecewise logistic model for penetration forecasting	2014	Fuzzy piecewise regression, Multiple objective programming, Delphi method	A comparison of the results shows that the proposed model outperforms the technology substitution model and the Norton and Bass diffusion model.
An integrated model for analyzing the development of 4G telecommunications market in Taiwan	2014	Conjoint analysis, Delphi method, and diffusion model	Suggestions are provided for policy making and strategic actions for 4G stakeholders.
Analysis of mobile broadband service penetration in Korea	2015	Diffusion of innovation and Porter's diamond model	The results show that Korea's success in mobile broadband deployment is characterized in terms of government support and coordination, supply side and demand-side conditions, and competition in the market. Several implications for policy makers are provided from the analysis of this study.
The diffusion of mobile telephony in Kazakhstan: An empirical analysis	2016	Logistic, Gompertz and Bass models	It was found that the best fit model of the diffusion process for mobile telephony in Kazakhstan is Gompertz.

The effect of service rollout on demand forecasting: The application of modified Bass model to the step growing markets	2016	Bass diffusion model	The resulting plan is a network deployment strategy that defines the temporal sequence of network layouts.
The effects of price, popularity, and technological sophistication on mobile handset replacement and unit lifetime	2016	Rayleigh, Weibull, and Gamma distribution and regression analysis	The results show that the median unit lifetimes decreased during the second half of the study period, indicating a structural change in the mobile handset market.
Forecasting mobile broadband traffic: Application of scenario analysis and Delphi method	2016	Scenario Analysis and Delphi Method	The research findings indicate that mobile traffic will increase rapidly, and the patterns of use for mobile devices will change to some extent.
Evolution and determinants of digital divide in Brazil (2005–2013)	2017	Logistic and multi-linear regression models	Results indicate that the digital divide among individuals is decreasing quite fast among Brazilians over time.
Diffusion of mobile telephony: Analysis of determinants in Cameroon	2018	S-shaped growth curve, Logistic model	Forecasts indicate an increase of almost 70% in the demand by 2026 as far as mobile phone use in Cameroon is concerned.
Determinants of mobile phone ownership in Nigeria	2019	Logistic model	The results show that factors such as geographic location and income may not strongly influence mobile phone ownership, in contrast to what was previously thought.
A business case for 5G mobile broadband in a dense urban area	2019	Traffic forecasting via growth model	The results show that the business case for a 5G network providing mobile broadband services alone is positive over the time period 2020–2030.
Forecasting and analyzing the characteristics of 3G and 4G mobile broadband diffusion in India: A comparative evaluation of Bass, Gompertz, and Logistic growth models	2020	Norton-Bass, Gompertz, and Logistic growth models	The paper results show that 4G is diffusing at 6.1 times the speed of 3G diffusion in India when the total mobile broadband services subscription in India is likely to reach 410 million by 2026.

2.2.3.1. Mobile telephony and subscription

Initially, mobile subscriber number is one of the crucial forecast parameters in the mobile telecommunication industry because most of the projections are drawn based on the number of mobile subscribers to utilize during developing strategies and making important decisions. S-curve is taking a fundamental part in the forecasting of the diffusion of mobile technologies in a market since it reflects the natural growth of emerging technology. The literature on the expansion of an emerging technology discloses that the spread of a new technology follows an S-shaped growth curve. The main idea underlying the S-curve description as follows. In the beginning, penetration speed is really slow in the market. After that, an accelerated period pursues as the result of the adoption of new technology by the majority, and the growth rate decreases again. Finally, the penetration of new technology comes towards an obvious saturation level (Geroski, 2000). The cumulative diffusion shapes of technologies are usually denoted by sigmoid patterns, namely S-shaped growth models (Mahajan et al., 1990).

The S-shaped growth model (or natural growth model) provides numerical estimates and remarkably develops the basic trends for the markets. Natural growth models enable valuable information regarding the general trend which the population follows even though they do not exactly forecast the size of the population. In these models, mostly Loglet Lab software is widely used and active mobile accounts data is exploited as the actual data to produce forecasting for a mobile subscription (Boretos, 2007; Hamoudia and Islam, 2004). Moreover, a negative exponential growth curve is often utilized to create a demand forecasting model by including time-varying covariates to show the cumulative number of subscribers in the telecommunications (Sohn et al., 2008).

In the forecasting of mobile telephony and subscriptions in the industry, the analogy is another efficient method to forecast based on the comparable data from a number of mobile telephony markets such as the US, Japan, Korea, and China. As mentioned previously, the analogy methods attempt to compare historical patterns with existing methods situations in order to model and forecast future evolutions. For instance, when considering a forecasting study in the Japanese and Korean markets, the U.S. seems a sensible analogy since it has already experienced an identical period in the mobile phone development and more, has a grand population covering a broad geographical area. By analogy, Figure 2.18 indicates the mobile phone usages predicted

by using the experience from three advanced countries; the USA, Korea, and Japan (Jeon et al., 2004). Nevertheless, the analogy method was not often preferred in the mobile telecommunication industry because dynamic conditions, characteristics, and competitive environment in the markets differ in many aspects indeed, whereas it still has many application areas in other industries.

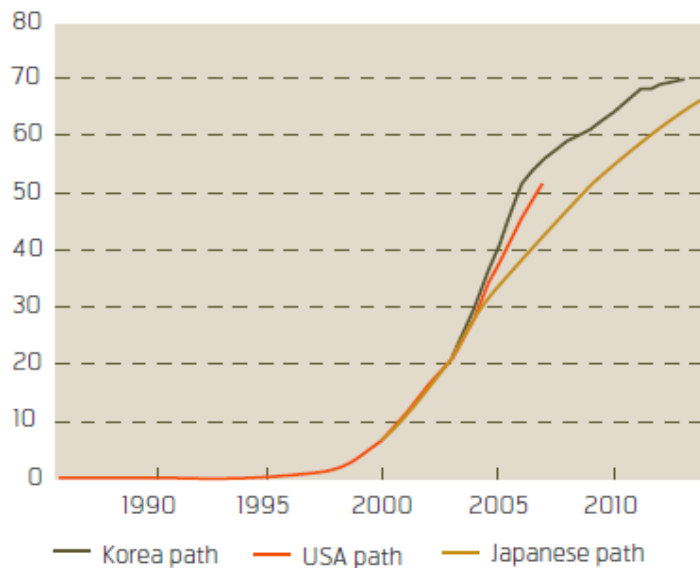


Figure 2.18. Forecasting mobile phone subscriptions per 100 inhabitants by analogy (Jeon et al., 2004)

Furthermore, the number of mobile phones is frequently forecast by means of various diffusion models encountered in the literature. Literally, the well-known diffusion models employed for the technological forecasting aims are essentially Bass (Bass, 1969), Fisher–Pry (Fisher and Pry, 1971), Logistic (Bewley and Fiebig, 1988), as well as the Gompertz (Rai, 1999) models. In fact, these models are completely structured on an S-shaped growth curve referring technology adoption and penetration amongst particular populations.

Bass model was firstly used to describe the process of how new products get adopted in a population (Norton and Bass, 1987). It makes forecasters see the future penetration of emerging technology and so, numerous Bass model studies can be easily found in the telecommunication industry.

Next to the Bass model, both Gompertz and Logistic methods are commonly utilized so as to

investigate diffusion of mobile telephony. Most of the forecast studies exploit these models by comparing or integrating with each other to improve the forecast results. In the last two decades, cross-national or cross-sectional studies have been often performed based on model comparisons (Sultanov et al., 2016; Turk and Trkman, 2012; Liu et al., 2012; Gupta and Jain, 2012).

The Gompertz model of technology diffusion is widely utilized to research the dissemination of information and communication technologies (Balliamoune-Lutz, 2003). In particular, it attracts notice to see the numerous applications of Logistic and Gompertz models applied for emerging technologies in the developed and developing countries (Rouvinen, 2006). Forecasting the diffusion in mobile telecommunications especially in African countries by integrating them into panels of developing countries is problematic. Logistic models perform well to study on such tough forecasting problems in this way. To start with, the Logistic (or logit) model is utilized to understand mobile phone distribution in Nigeria as well as identifying the implementation of the country's telecommunication roadmap between 2017 and 2020 and creating Vision 2020 (Forenbacher et al., 2019). Similarly, a productive study in Cameroon is applied based on a logistic model to analyze the adoption trend of mobile phone ownership. The diffusion of mobile telephony is also analyzed with the help of S-Curve. The findings reveal that the Logistic model sufficiently pursues the diffusion curve of mobile telephony in Cameroon (Honore, 2019). In addition, diffusion analysis based on Logistic model is proven as reliable in the other mobile telephony studies applied in various developing countries from different continents such as Brazil (Nishijima et al., 2017), Bangladesh (Tran et al., 2015) and Gabon (Penard et al., 2012).

In another study, the diffusion rate of mobile telephony subscriptions in Greece is investigated and displayed by comparing Bass, Fisher-Pry, Gompertz, and Logistic diffusion models. In the light of this study, upcoming trends and the existing circumstances in Greece are anticipated to be likewise the other European countries in which mobile technologies have obtained a remarkable rise in spreading and adoption (Michalakelis et al., 2008). In Kazakhstan, one of the fastest developing countries in middle Asia, when predicting the distribution rate of mobile telephony with the three most popular diffusion models; Bass, Logistic and Gompertz, it is discovered that the most appropriate model for the empirical analysis of mobile telephony is Gompertz (Sultanov et al., 2016). The diffusion analysis executed for Peru has similar results showing that the Gompertz model is more suitable (Yamakawa et al., 2013). However, it should

be known that the best fit model might be different for each country in such studies. Thus, a certain model that is mostly superior in many markets might be falling behind other models in another market having different characteristics. For instance, the Logistic model is chosen as the most convenient model in Taiwan when analyzing the accelerated diffusion of mobile telephony in terms of growth model (Chu et al., 2009).

Next to Bass, Logistic, and Gompertz diffusion models, Fisher and Pry hypothesized that most technological progress can be regarded as competitive substitutions of one method to assure the requirements of another method when analyzing these technological progress (Fisher and Pry, 1971). Fisher-Pry model, which refer to the linear-logistic model as well, mainly arises based on the approach that the progressing level of the technology can be defined as the time function (t) and the inherent upper limit (S) to that advance. In an application to the broadband diffusion in the Organization for Economic Cooperation and Development (OECD) area, the results indicate improved forecasts in a 48-month forecasting horizon when compared to two well-known models, Gompertz and the Fisher-Pry model (Christodoulos et al., 2011).

Figure 2.19 simply shows the stages of diffusion analysis in Kazakhstan (Sultanov et al., 2016). This procedure can be also considered valid for most of the diffusion modeling studies in the mobile telecommunication industry.

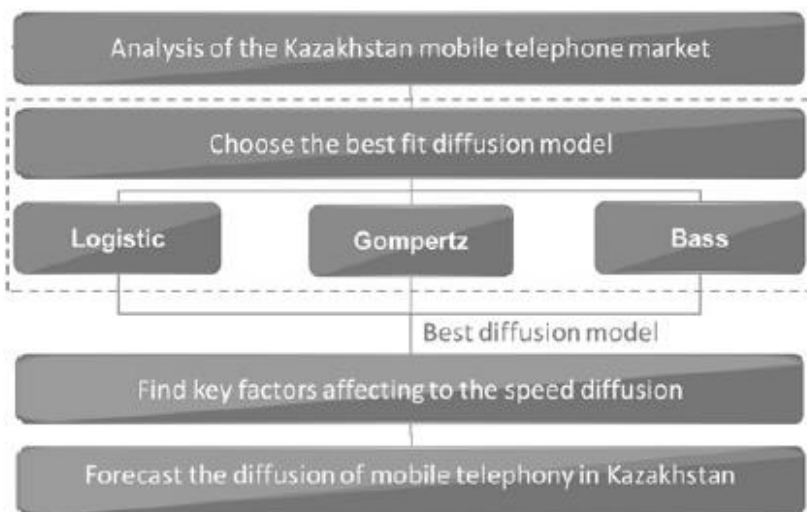


Figure 2.19. The procedure of diffusion analysis (Sultanov et al., 2016)

In another market, time series data over the number of subscribers is employed to investigate

the diffusion pattern of mobile phones in the case of Portugal. As known, the theory of technology diffusion suggests an S-shaped curve for the diffusion path in an emerging technology. In this study, even though both the Logistic and Gompertz models define an S-shaped (or sigmoid) diffusion curve, only the Logistic model sufficiently draws the diffusion path of mobile phones in Portugal (Botelho and Pinto, 2004). Similarly, the Logistic model is used in the case of Finland in order to forecast the diffusion of mobile telecommunications during the 2G stage. Then the velocity and acceleration of the diffusion of mobile communications are figured out in the study. Such time derivatives of the diffusion process are successfully examined to identify the influence of economic situation on the technology diffusion (Frank, 2004).

Figure 2.20 illustrates the notable values for the number of mobile phone subscribers in Colombia, the forecasts for 20 quarters ahead (from 2008 Q3 till 2013), and the 90% confidence intervals for the forecasts based on Gompertz and Logistic models. After executing a statistical test to select the appropriate functional form, the results reveal that the pattern of diffusion can be well characterized by means of a Logistic model (Gamboa and Otero, 2009). In addition to this observation, Hwang et al. (2009) notice that the Gompertz function delivers better performance for modeling diffusion of consumer durable goods, which are different from high technology products such as mobile phones. Further, the Gompertz model is superior defined in the diffusion process of mobile telephony in India when scrutinizing the social, technological, economic, and political factors affecting particularly the diffusion speed of mobile telephony in the country (Gupta and Jain, 2012). In this direction, the Gompertz model is best chosen when the penetration of the mobile phone and mobility in India is investigated using S-shaped growth curve models. According to the results of this study, the number of mobile phones will surpass the total population of the country by 2022–2023 (Singh, 2008).

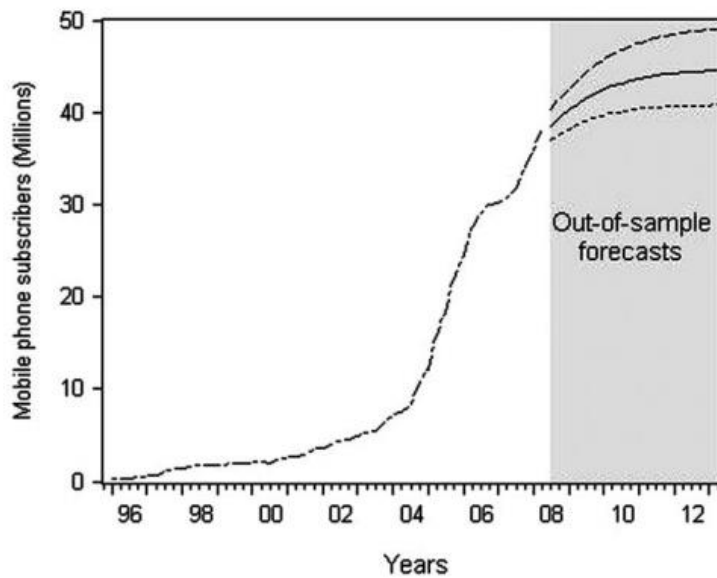


Figure 2.20. Out-of-sample forecasts and 90% confidence intervals (Gamboa and Otero, 2009)

In the majority of the studies remarked over the diffusion of mobile telephony and subscriptions, three popular growth models (Bass, Logistic, and Gompertz) are exploited for every country in order to make fitting the historical data of mobile adoption. Besides those, the literature also has lots of publications comparing these diffusion models with the time series forecasting models such as autoregressive moving average (ARMA) technique. For instance, a study is conducted to examine the Logistic and ARMA models in contrast in order to describe the factors that identify the diffusion adoption process in Korea (Lee and Cho, 2007). More, mobile subscriber data between 1988–2007 in Taiwan is analyzed to compare the performance of these well-known diffusion models and time-series forecasting methods, ARMA. Gompertz model here outperforms the other models in the study as well (Wu and Chu, 2010).

To get back to the examples of comparative cross-national studies, one is for OECD countries and Taiwan (Jang et al., 2005); the other one is for the 15 member states of the European Union (Gruber and Verboven, 2001). Then, the Bass diffusion model is exploited to examine the adoption of 25 countries with the help of regression with descriptive variables that represent these three categories; country, culture, and timing. The results reveal that the country's richness and cultural analogy to the innovation topics certainly affect the country's early adoption in a positive direction (Sundqvist et al., 2005). In another study, with the assistance of the Gompertz

model, the aspects that identify the penetration of mobile telephony are evaluated when analyzing 78 developed and 123 developing countries (Rouvinen, 2006).

2.2.3.2. Mobile broadband and services

The initial mobile telephony system, GSM has mainly provided voice-centric service over the global mobile system. However, it has been dramatically surpassed by the new mobile technologies 3G and subsequently 4G technologies. In terms of mobile broadband, 3G and 4G technologies correspond to the radical changes in mobile network architectures, resulting in higher data bandwidth in mobile telecommunications. The diffusion models play an important role in the forecasting of mobile telephony in the industry as stated in the previous section. These techniques are also utilized to forecast demand or consumption in mobile broadband (high-speed mobile internet) and mobile services. As expected, most of these studies, performed to generate forecasting for mobile broadband and services, are based on the 3G and 4G technologies in different markets and countries globally.

In accordance with this purpose, a model is proposed to achieve high accuracy in the case of internet services provided by a telecommunication company in Korea. The proposed model can be executed for the prediction of demand in new information and communication services, particularly when the influences of time-varying variables are unknown (Sohn et al., 2008). Again, in the Korean market, Nam, Kim, and Lee (2008) modified the Bass diffusion model by combining conjoint analysis and the Bass model that used the adjustment coefficient to reflect the relative relationships between specified mobile technologies; WiBro, 3G, and WiFi.

Furthermore, mobile broadband traffic is forecasted in the Korean market by focusing on the devices and usage patterns for mobile services. The research utilizes the Delphi technique to complete the experts' opinion in the mobile traffic forecasting over 10 years and scenario analysis to account for the uncertainty of dynamic situations in the future. The obtained results display that mobile internet traffic will ascend quickly and the usage pattern of mobile users will change to a higher level (Lee et al., 2016).

Additionally, the adoption of mobile broadband Internet is another substantial topic which requires forecasting studies based on surveys such as the method of Product Specific Adoption Potential (PSAP) so as to obtain a reliable forecast in terms of the size and nature of future

adopter segments (Evens et al., 2010).

In a recent study performed in India, the nationwide penetration of 3G and 4G mobile broadband services is analyzed with the help of Bass, Logistic, Gompertz, and Norton-Bass methods. According to the findings, the Norton-Bass model enclosing the whole mobile technology generations brings trustworthy predictions for diffusion parameters. On the other hand, Logistic and Gompertz models perform so appropriate for ‘optimistic’ long range forecasts and ‘conservative’ short term forecasts respectively. Figure 2.21 indicates forecast based on Logistic growth for mobile technology adoption in India (Jha and Saha, 2020).

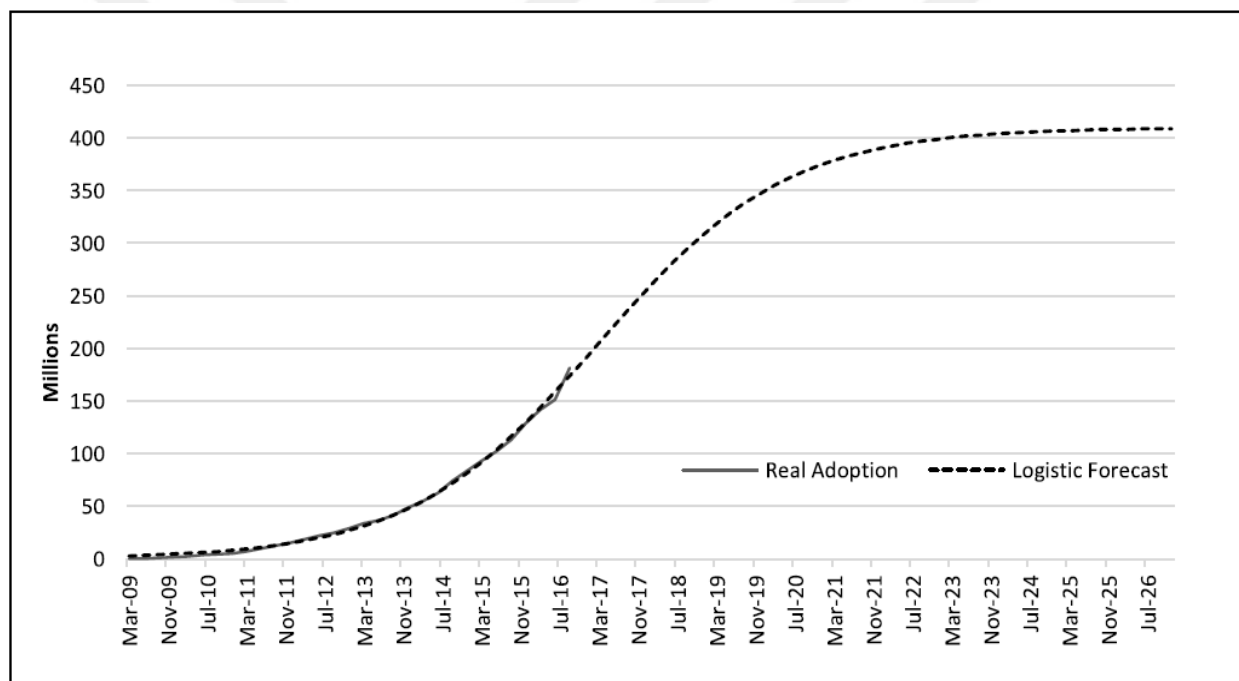


Figure 2.21. Logistic based forecast for mobile technologies (3G+4G) adoption in India (Jha and Saha, 2020)

2.2.3.3. Mobile telecommunication technologies

Technology Forecasting using Data Envelopment Analysis (TFDEA), an alternative quantitative approach previously used in various areas of technology forecasting, was applied to the telecommunication systems by Anderson (2008) and his colleagues. The TFDEA technique is exploited to introduce a framework for forecasting wireless communication technologies by including three steps: technology characterization, assessment, and forecasting (Anderson et al.,

2008). The same researchers also proposed a technical framework to forecast the commercialization timeline of mobile telecommunication technologies from 1G to LTE as well as insights into the path of mobile technologies, using a trend extrapolation method (Kim et al., 2010).

Moreover, fuzzy can be integrated into classical forecasting techniques in order to enhance the efficiency of results. In this direction, a new neuro fuzzy forecasting system is introduced as based on the Takagi–Sugeno–Kang fuzzy model by applying onto real-world data in a university campus with more than 6.000 employees and 70.000 students (Mastorocostas and Hilaras, 2012). Additionally, fuzzy integrated models are compared to diffusion models in terms of accuracy performances. For this purpose, a fuzzy piecewise logistic growth model based on the data forecast by both the Scenario and Delphi methods is proposed to predict the market share of multigenerational technologies such as OLED (Organic Light Emitting Diode) and 4G (Tseng and Yu, 2014). Similarly, a new forecasting model is also presented for the gradual development of telecommunications network infrastructure in Serbia depending on the fundamental Bass diffusion model (Velickovic et al., 2016).

As known most emerging technologies indicate obvious generational changes indeed. Diffusion models are also used to analyze the role of generational effects in the diffusion of mobile telecommunication technologies such as 1G, 2G, and 2.5G (Liikanen et al., 2004).

Moreover, there are many studies combining various quantitative or qualitative techniques with these diffusion models to make the methodology more robust. For example, to analyze Taiwan's telecommunications market, conjoint analysis, scenario analysis, and Bass diffusion models are combined to examine the penetration of 2G, 3G, WiMAX, and LTE technologies over the next 10 years. In the study, LTE is determined as the most promising next-generation telecommunications technology (Tseng et al., 2014). In the meantime, conjoint analysis is generally utilized to evaluate the new product development process in technological forecasting (Green et al., 2001). As a powerful tool for telecommunication policy and business decisions, the conjoint model was previously used in order to forecast the voice mail penetration and pricing levels from 1993 to 1997 in the US market (Batt and Katz, 1997).

2.3. Technology Life Cycle

Technologies naturally pursue a life cycle that is similar to a product life cycle (PLC). However, it is primarily distinctive since a product is an output of technology at a given time. The product life cycle is a more common definition in the literature when compared to the technology life cycle (TLC) indeed. When the technology gets mature in time and reaches to a limit in terms of its performance and so, it becomes defenseless for a disruption. In parallel, the new technology would try to either mature on its performance path or provide new value to be able to disrupt the previous technology in the cycle.

This section firstly defines the technology life cycle from different perspectives and then, investigates stages of TLC based on the literature. Thereafter, a review is given to find out the technology life cycle in mobile telecommunications.

2.3.1. Definition

Technology is defined as scientific know-how applied to suitable objectives. In fact, such a definition takes both product technology and process technology into consideration (Viardot, 2000). The mobile telecommunication industry is certainly one of the most visible of all high-tech industries. So, a mobile phone (or smartphone) is a typical example of a high-tech product in the case of product technology. On the other hand, the design and manufacturing of mobile phone chips is a notable example in the case of process technology. The fundamental feature of these high-tech products is that they are developed and replaced in a short while. The cycle of replacement is managed by the dramatic performance carried out by researchers in the development of technologies incrementally or radically.

The technology life cycle can be defined as applying the PLC concepts to technological innovation. It refers to a period that technology enters the market, rapidly grows, matures, and finally declines by following a life cycle by itself (Kim, 2003; Godoe, 2000; Bayus, 1998). In another definition found during the review, the technology life cycle is depicted as a sequence of technological discontinuity, an era of ferment, the emergence of a dominant design, and an era of incremental change (Markard, 2020).

The progress during the technology evolution especially in the high-tech industries, has gained speed in recent days and also brought an increasing uncertainty and complexity with it.

Consequently, this is mainly resulted in having shorter product life cycles, technology life cycles, and thereby shorter industry life cycles (ILC) in the production and service industry. Further, the growth in the competition with the help of globalization, where there are lots of competitors and large markets to be exploited, has actually played a major role at these shorter life cycles in the industries. While these notions are inter-related, unlike their counterpart PLC, both the terms ILC and TLC are not broadly utilized in the academic environment (Taylor and Taylor, 2012).

2.3.2. Stages of technology life cycle

It is denoted that technological innovation corresponds to the successful adoption of a technology-based invention for products and processes. The degree of this success in the diffusion is measured by the economic value and benefits generated in the marketplace (OECD Oslo Manual, 2005). The approach of the technology life cycle portrays the enhancement of technology in a path that is like the evolution of organisms as illustrated in Figure 4.1 (Viardot, 2004).

In the introduction phase, the increase in profit is not rapid and not so critical when the company makes investment massively. That is the period when radical technologies are presented. In the growth phase, the aggregation of know-how and competence brings an important income in general. The growth phase in performance is not reflected in direct proportion to the adoption rate in the market. Technology hits the top of perception that is called the “peak of inflated expectations” by the Gartner group. In the maturity period as the next stage, it seems more difficult to put further enhancements. Thus, it simply leads to incremental innovations as the industry becomes more stable and modest. As a matter of fact, this is the case for smartphones where radical changes have not been experienced for a long while. In the saturation stage, technology reaches its performance limits when the investments and R&D efforts decrease in parallel, such as in the fixed line in the telecommunication industry today.

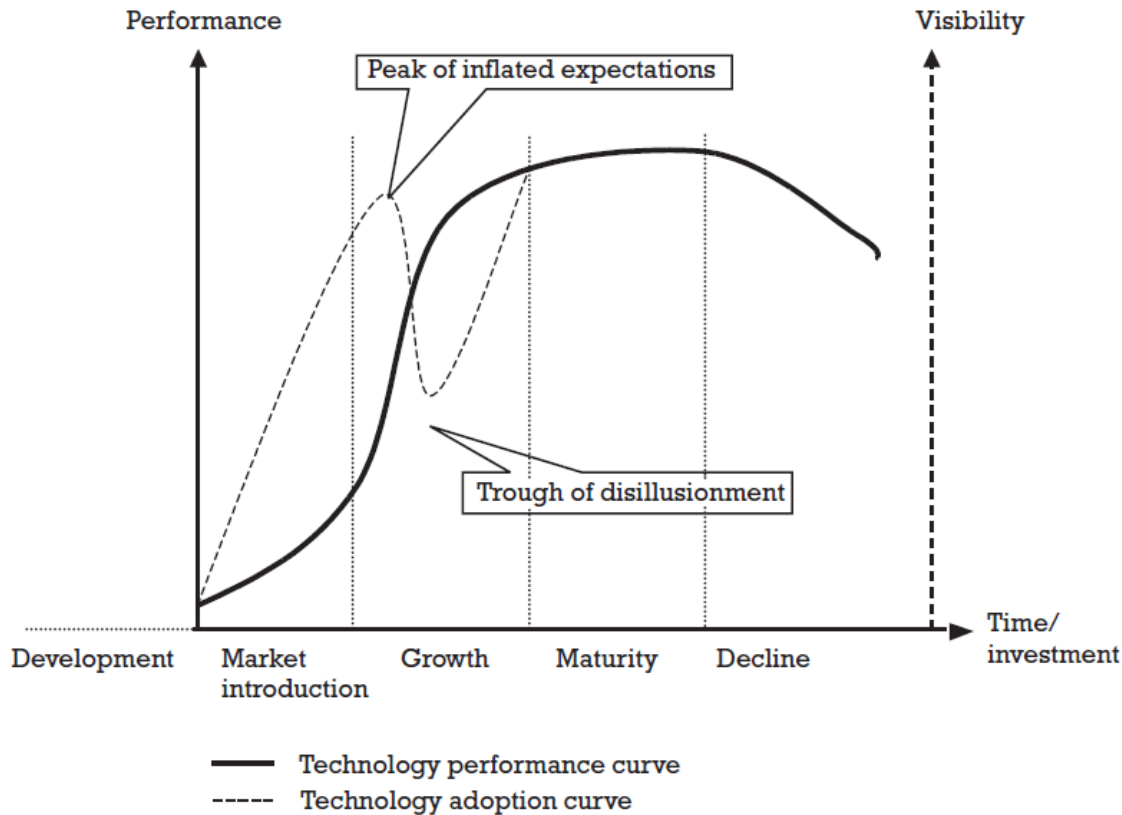


Figure 2.22. Technology performance and adoption curves (Viardot, 2004)

The advancement of technology “progresses slowly initially, then accelerates, and eventually inevitably declines” (Foster, 1986; Roussel, 1984). In light of these descriptions and technology performance curve shown in Figure 2.22, Figure 2.23 is presented with regards to the S-curve concept of TLC (Ernst, 1997; Sick et al., 2018). Distinctively, technologies are defined according to the following sequence; new, pacing, key, and base. For instance, the inclination of the curve corresponds to the pace of technology development, thereby it is called “pacing technology” (Ryu and Byeon, 2011).

In addition, this general form of an S-curve is also described with a number of stages such as embryonic, growth, maturity, and aging (Cetindamar et al., 2010). Each technology reaches maturity and saturation respectively, then it starts to decline in terms of the performance and satisfaction level of customers once an emerging technology whose own S-curve catches up with the incumbent’s performance level (Adner et al., 2004). Additionally, the technology life cycle consists of a pattern of changing characteristics regarding that technology, in which its

innovative and monetary performance alter over time (Huang et al., 2019).

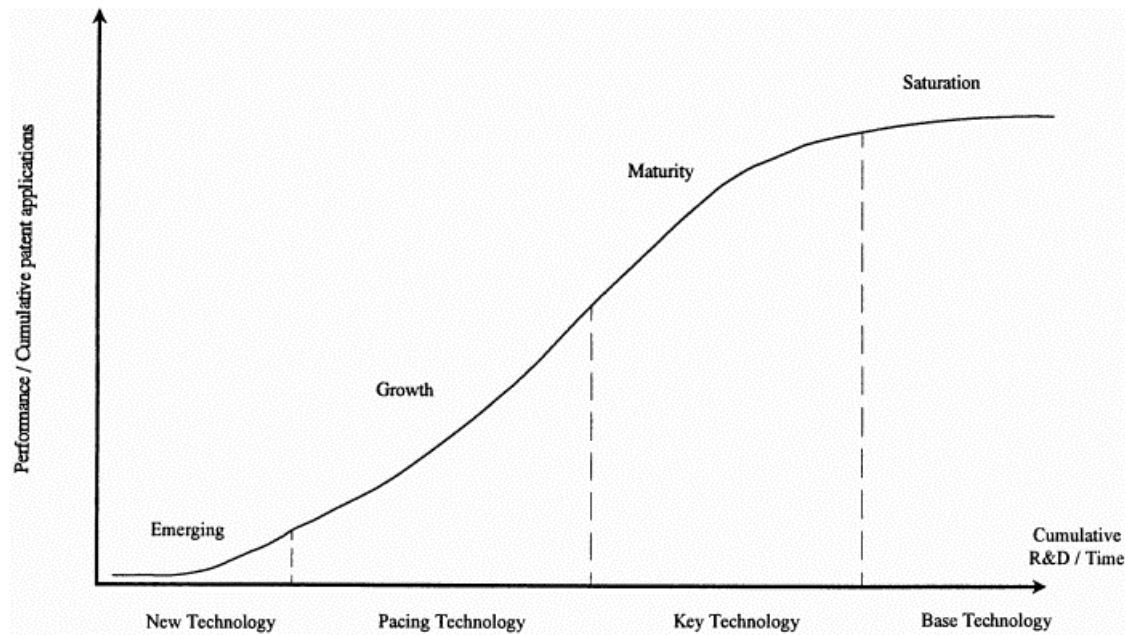


Figure 2.23. The S-Curve concept of technology life cycle (Ernst, 1997)

In another perspective, life cycle models obviously differ based on the industry. For example, a technological discontinuity cuts off the maturation of some technologies, and then the cycle begins repeatedly (Tushman and Anderson, 1986). It is discussed that the evolution of the product is labeled by repeating technological discontinuities, each pursued by the rise of a new dominant design (Anderson and Tushman, 1990).

Furthermore, some companies focus on process innovation in its competitive market (e.g. Dell) whereas another player can select to focus on design innovation (e.g. Apple) in the high-tech based industry (Giachetti and Marchi, 2010). Figure 2.24 figures out the ‘Dynamics of Innovation model’ defined by Utterback. In the early phase of technology development (fluid phase in the figure), innovation effort focuses on the development of products whereas the rate of process innovation is low at this stage (Utterback, 1994).

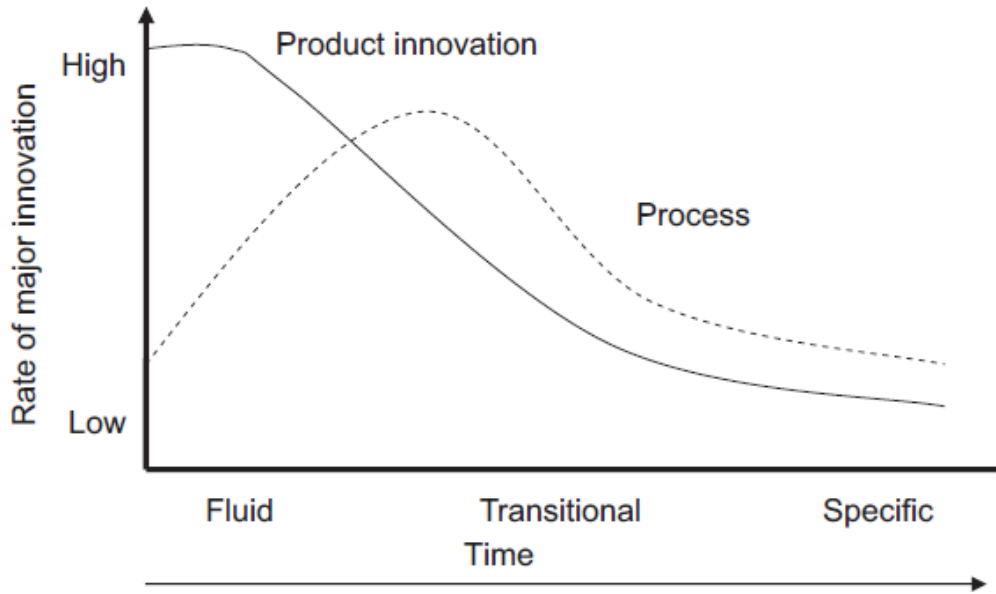


Figure 2.24. Dynamics of Innovation Model reflecting the TLC (Utterback, 1994)

The publication is the leading indicator that adheres to the technology life cycle nearly for all candidate technologies. In this direction, the dominant technique to analyze TLC is by building an S-curve to observe patent data collected in the research area (Altuntas et al., 2015; Ansari and Garud, 2009). Thus, bibliometrics is widely utilized to measure the degree of technological innovation in order to generate a technology life cycle based on the S-curve pattern of the product life cycle.

What is more, patents are so precious tools to preserve the inventions and innovations of companies, institutions, as well as individuals. Then, the correlation is extremely high between the number of scientific publications and patents in most of the technologies (Bengisu and Nekhili, 2006). Therefore, patents can be employed to be able to assess the technology life cycle (Chang and Fan, 2016). The technologies can be practically modeled through their technology life cycle by means of patents, scientific publication databases, and new product launches in this way (Suominen and Seppanen, 2014; Järvenpää et al., 2011). To illustrate, Table 2.9 exhibits the indicator listing that takes a look at publications of different types during the technology life cycle (Watts and Porter, 1997).

Table 2.9. The summary of the review

Factor	Indicator
R&D profile	
Fundamental research	No. of items in databases such as Science Citation Index
Applied research	No. of items in databases such as Engineering Index
Development	No. of items in databases such as U.S. Patents
Application	No. of items in databases such as Newspapers Abstracts Daily
Societal impacts	Issues raised in the Business and Popular Press abstracts
Growth rate	Trends over time in number of items
Technological issues	Technological needs noted
Maturation	Types of topics receiving attention
Offshoots	Spin-off technologies linked

In other words, to summarize, TLC can be regarded as a type of product life cycle when the technology is considered a product in its industry. It was first introduced to measure the changes in technology including four stages (Little, 1981). According to the definition, the emerging stage is characterized by new technology with a low competition effect. The growth stage is marked by pacing technologies with high competition. In the maturity stage, some pacing technologies transform into key technologies that keep their highly competitive effect. When a technology loses its competitive impact, it quickly turns into a base technology and enters the saturation stage, and is most probably replaced by new technology in the industry (Gao et al., 2013).

2.3.3. Technology life cycle in mobile telecommunications

Understanding the long-term patterns of innovation in mobile technologies is so significant for technological forecasting. The technology life cycle is an appropriate methodology of forecasting technology for mobile telecommunications. The companies need to know the current stage of the TLC to foresee the future development of technology and make strategic decisions on investing in the technology (Foden & Berends, 2010). Shorter time spans of each stage of the TLC make them more important for the company because the mobile telecommunication is a high-tech industry where the technological advances come out rapidly. As having swift and endless evolution, the mobile telecommunication industry brings an important dataset to analyze how companies react to dynamics in the market over time.

The generations of mobile telecommunication technologies, namely, GSM, 3G, LTE, and 5G, can be defined as sub-technologies in our case. These technologies can intersect and interact with each other during the entire TLC time span in mobile telecommunications. For instance, 3G was in the maturity stage when LTE was a new technology, also referred to as an “emerging technology” in industrial terms. Despite the fact that LTE is a key technology today, GSM is still existent in most markets.

Figure 2.25 illustrates the competitive evolution of mobile telecommunication technologies over time. Y-axis indicates an average mobile data rate per second for each technology life cycle while the x-axis refers to the resources invested in time. The red curve shows the industry life cycle between 1G and 4G technologies (Yeo et al., 2015). As of 2020, this should be extended by including 5G technology as well. The case study herein will be conducted with the help of the life cycle extension approach.

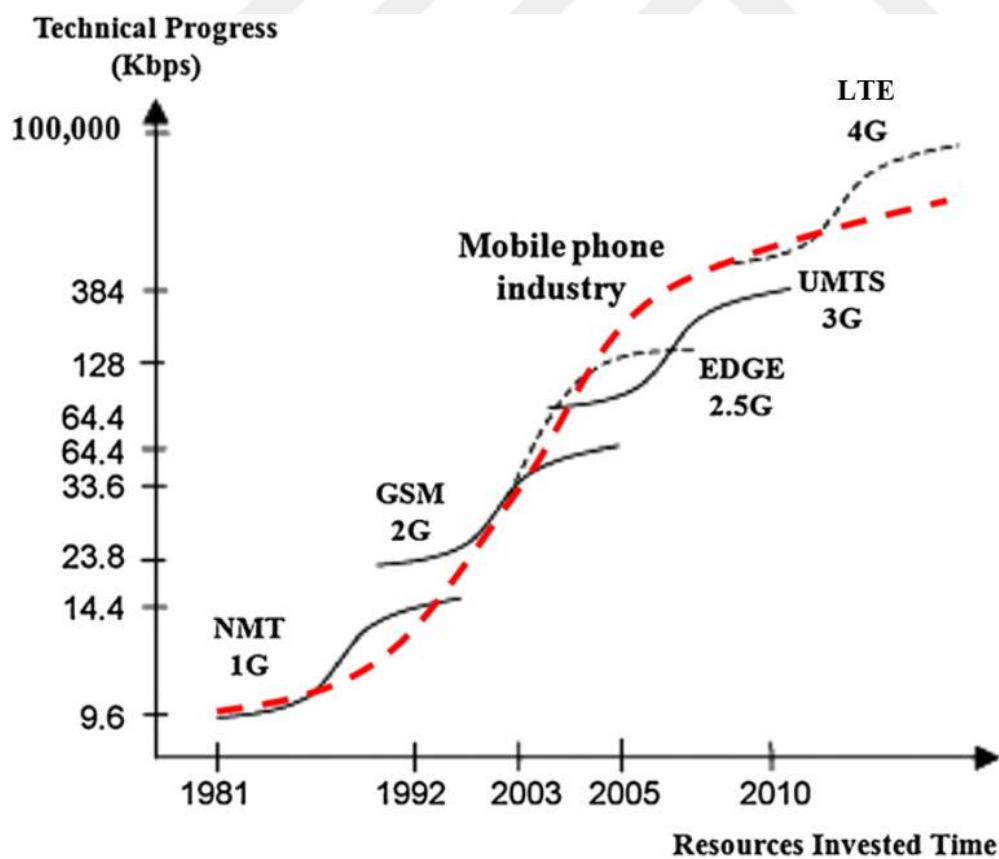


Figure 2.25. Evolution of mobile telecommunication technologies (Yeo et al., 2015)

As mentioned in section 2.1 in detail, the evolution of these technologies enables mobile users to reach faster data rates in the mobile internet as well as various enhanced technologies and features such as MMS, video calls, VoLTE, and VoWiFi besides legacy mobile services (e.g. voice call, SMS). Another important point to emphasize is that the generations in mobile telecommunications have evolved to a new one by keeping and supporting previous generations, with regards to technical capabilities of network infrastructure and end user products (e.g. smartphone, tablet) developed during this evolution process in the global market. It means that emerging technology does not kill the existing one entirely when replacing that in terms of adoption and usage among mobile customers. Therefore, 2G technologies have been still exploited even though some mobile service providers have already started to deploy 5G technologies in their networks.

The extension of GSM's life cycle looks noteworthy with the help of data enabled technology EDGE, also known as 2.5G in the industry (Scharnhorst et al., 2006). This improvement in GSM has obviously caused a delay in the introduction and growth phases of 3G technology since EDGE provides an entry-level mobile internet with very limited data rates below 300 kbit/s. Eventually, 3G has dramatically grown between 2005 and 2010 in the global market by enabling the users to have real internet experience via higher data transmission speeds in the level of Mbit/s. Nevertheless, the actual digital transformation, including smartphones, tablets, plenty of mobile applications, full motion 'streaming' video capability, enhanced voice services etc., has obviously occurred when LTE technology has been introduced in the market. Nowadays, 5G technology is well positioned and steadily progressed in the introduction stage of its technology life cycle.

On the other hand, TLC varies significantly depending on many local factors that are related to economy, policy, geography, development, or technological level of the country in question, as well as the diffusion rate, utilization degree, profitability of the existing technology, and adoption rate of the new technology. Consequently, each country, and even each telecommunication company, can define its own TLC to follow in the market. For instance, Figure 2.26 figures out the adoption of mobile broadband in India where technology life cycles of both 3G and 4G services have very identical patterns indeed. The difference merely exists in the initiation of these technologies because 4G has a delay of about 4 years (Jha and Saha, 2020).

It is clear that the diffusion rate of 3G technology starts to slow down when 4G enters the growth stage in its life cycle in parallel. Thereby, 3G approaches to saturation by the year 2020 that means a duration of 11 years after the 3G launch in India. Moreover, 4G technology experiences a decrease in its diffusion rate in the same year, and so it is apparently expected to become a base technology in its saturation stage by the year 2025. This inflection point in 4G technology, where the 4G arrives in the maturity, could be interpreted as the introduction of emerging technology, Fifth Generation of Mobile Telecommunications.

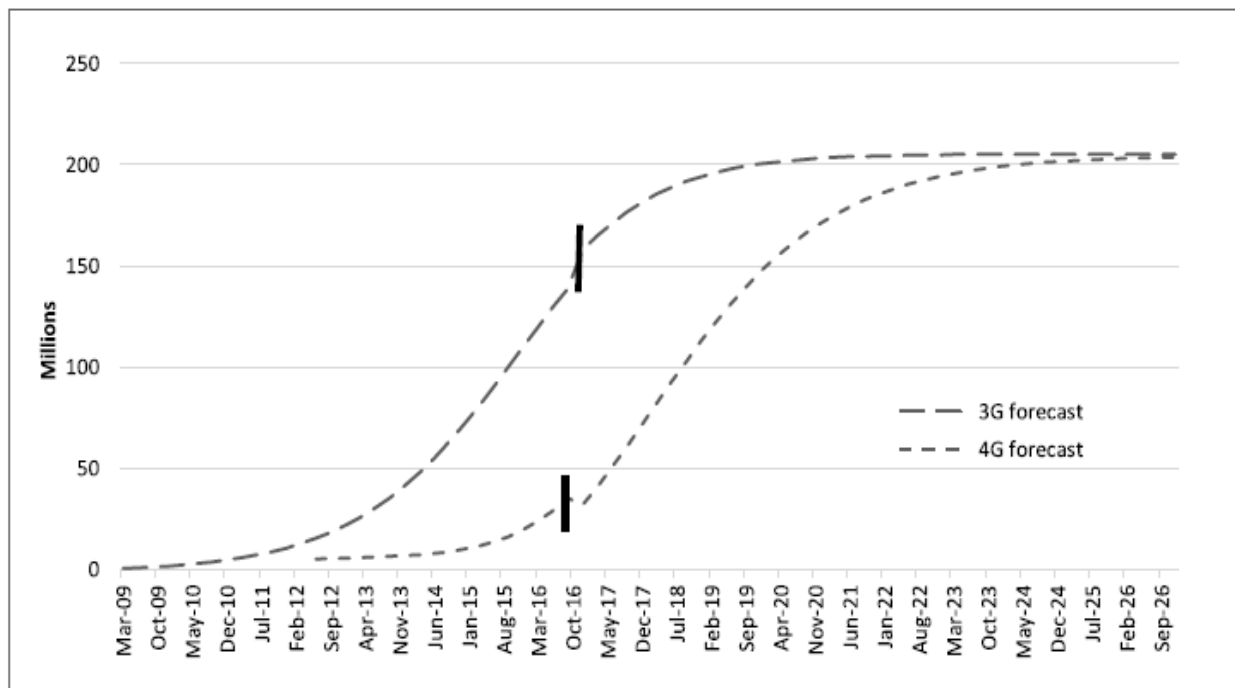


Figure 2.26. 3G and 4G adoption forecasts in India between 2016–2026 (Jha and Saha, 2020)

In another study, a theory is developed to explain global takeoff for mobile phones by collecting data from 41 developed and developing countries including Turkey. According to the results, the competitive environment in the country can be interpreted as a substantial factor in technology adoption, and so the technology life cycle of the mobile phone. To illustrate, take-off in the growth phase, the first dramatic and sustained increase in penetration are adequately faster in a competitive market when compared to others. Further, time-to-takeoff during the growth phase of the mobile phone seems a bit longer for developing countries in comparison to developed countries (Techatassanasoontorn and Kauffman, 2014; Stremersch et al., 2010;

Chandrasekaran and Tellis, 2008).

Furthermore, it is not hard to mention about other examples of TLC in the telecommunication industry. Telematics, which is a combination of mobile telecommunication, global positioning, and information management systems, takes place at the forefront as an emerging technology in the intelligent transport systems (ITS). Curve matching technique, based on classifying the patent data of this type of technology, is applied to determine the current technology life cycle stage of telematics (Chang and Fan, 2016).



3. CASE STUDY

The world witnessed numerous advancements in information and communication technologies after the first mobile dialogue took place over the GSM network, also known as 2G, in 1991. GSM was developed as a global technology with improved features compared with the so-called First Generation, or 1G, telecom systems, which were offered as local solutions in some countries, thus preventing their global reach. The globalized footprint of the GSM systems was complemented with enhanced mobility in the 3G technology, which provided information over the Internet anywhere and anytime, and the iPhone introduced by Steve Jobs in 2007 was one of the most influential triggers in this direction. Soon afterward, the 4G technology, also known as LTE, started to dominate the mobile telecommunication sector in the mid-2010s by providing faster connection speeds. For instance, based on the recent research performed by the Korean Ministry of Science, ICT and Future Planning, it is stated that LTE customers experience mobile data download and upload speeds 15 times faster than those using 3G technology (Jung & Kwon, 2015). This is achievable because LTE is not defined as just one technology or standard but as a compatible combination of technologies and protocols evolving over time. In particular, fiber optic technologies and advanced transmission capabilities have proven to be a significant contribution to the enhancement of mobile communications when going from 3G to LTE. The end result is that mobile broadband usage has grown significantly in recent years with the help of skyrocketing numbers of smartphones (Trestian et al., 2017; Kongaut & Bohlin, 2016; Chiyangwa & Alexander, 2016). Eventually, mobile communication occurs not only between humans but also between systems and machines.

Mobile telecommunication, which has a significant focus on customers and customer experience, has been one of the major industries leading the global economy. Because of the convergence of computing and communication technologies, smart devices have dramatically been a substantial part in our lives. Mobile network operators, infrastructure suppliers, original equipment manufacturers, regulatory authorities, and over-the-top platforms, including mobile application developers, content providers, and social media companies, stand out as the main players in this ecosystem. The mobile telecommunication industry is broader than it existed on the day of its inception. In fact, voice communication was the main function of GSM technology in 1990s and early 2000s, whereas data-centric communication is currently leading the

developments in 3G, LTE, and 5G, which are packet-based technologies. More, data-hungry video and social media applications such as YouTube, Instagram, Facebook, and Twitter are some of the primary actors pushing customers to embrace the latest technologies in the global environment.

Furthermore, applications and services that are “greedier” in terms of bandwidth are continuously being developed, and hence, future applications are expected to require much better performance than that can be achieved by the current LTE networks. The noteworthy growth of smart devices and demand for mobile data and the new drivers in the market have been accelerating mobile telecommunication technologies towards 5G faster than ever. This mobile transformation requires an evolution of connected devices because customer preferences and behaviors show remarkable changes when compared with previous years. For example, video content applications have become much more influential, especially in the late 2010s. These applications have actually affected many variables ranging from smartphone size to the Internet packages promoted by the telecommunication companies in the market. Taking the rise of mobile data traffic into consideration, schemes to make network enhancements should be explored.

Nowadays, industry players need a systematic approach in responding to customer expectations while considering the tough competition in the mobile telecommunications market. For example, an empirical combination of time series forecasting and expert opinion-based methodologies within the field of technology life cycle management of the mobile telecommunication industry is clearly non-existing in the current engineering management literature. This particular need is rising, whereby mobile network operators have to make their managerial decisions and draw strategies based on their foresights and predictions in their market.

The main purpose of the case study is to fill the mentioned gap in the ecosystem by forecasting the launch time for 5G technology with accompanying discussions on the technological advances in the mobile telecommunication sector. Herein the thesis also addresses an engineering management strategy design, based on the combination of time series forecasting with expert opinions in a leading telecommunication company, which has its headquarters located in Istanbul, Turkey. With this aim, a novel framework is built on the well-known

methodologies found in the literature and applied to determine the commercial launch time for the 5G technology.

The case study scrutinizes the technology forecasting techniques applied in the mobile telecommunication industry. The structure of the study is organized as follows. First, the research methodology is explained stepwise and in detail, and the results of the analyses performed in the study are highlighted and supported with relevant figures. Next, a strategy is designed using the obtained research findings. Finally, the practical implications for engineering managers are presented in light of the results.

3.1. Research Methodology

The company in our case study, which is a leading service provider in Turkey, requires a forecasting study for implementing 5G technology. It has been following the most advanced technologies in its network by being one of the several providers in the world that have the Gigabit LTE technology (GSA, 2018) by becoming aware of the importance of having its own mobile service ecosystem, such as the ones offered by Google, Apple, and Microsoft, to stay competitive against over-the-top providers (Wang, Lai, & Chang, 2016).

Further, the company is a converged telecommunication and technology services provider, founded and headquartered in Turkey, where mobile communication began in February 1994, later signing a 25-year GSM license contract with the Ministry of Transportation on April 27, 1998. Since then, the company has continuously increased the variety and quality of its services for mobile voice and data communication, and as a result, it is positioned as the leader of the Turkish telecommunications market. Thanks to its global footprint resulting from its subsidiaries and its diverse range of digital services that are also available abroad, it has subscribers from all over the world. The current vision of the company is to become a digital operator, attaining global leadership in digital services.

All those aspects require the company to see the horizon for the 5G ecosystem that is expected to create its own innovation environment, which is yet to be realized, bringing to the world such new models as the collaborative economy that boomed with LTE networks.

As the first step in this study, forecast parameters were identified and historical data were collected, followed by the definition of the technology life cycle. Before applying the Delphi

method, expert group members were determined and a questionnaire was prepared with the help of TLC and collected data. Subsequently, the Delphi method was applied and answers were gathered from the expert group, and the survey was finalized in the 2nd round. After analyzing the Delphi results, the first forecasts were obtained. In parallel, based on historical data, quantitative forecasting methods such as the Autoregressive Integrated Moving Average (ARIMA), Linear Regression, and Holt's Exponential Smoothing were utilized. By selecting accurate forecasting methods, the second forecasts were acquired. Finally, both forecasts coming from quantitative forecasting and Delphi methods were intersected, and the final results were used to design a strategy at the end of the study. To understand this flow of the methodology better, the research process is illustrated in Figure 3.1 below. Next, the stepwise details of the research process are discussed.

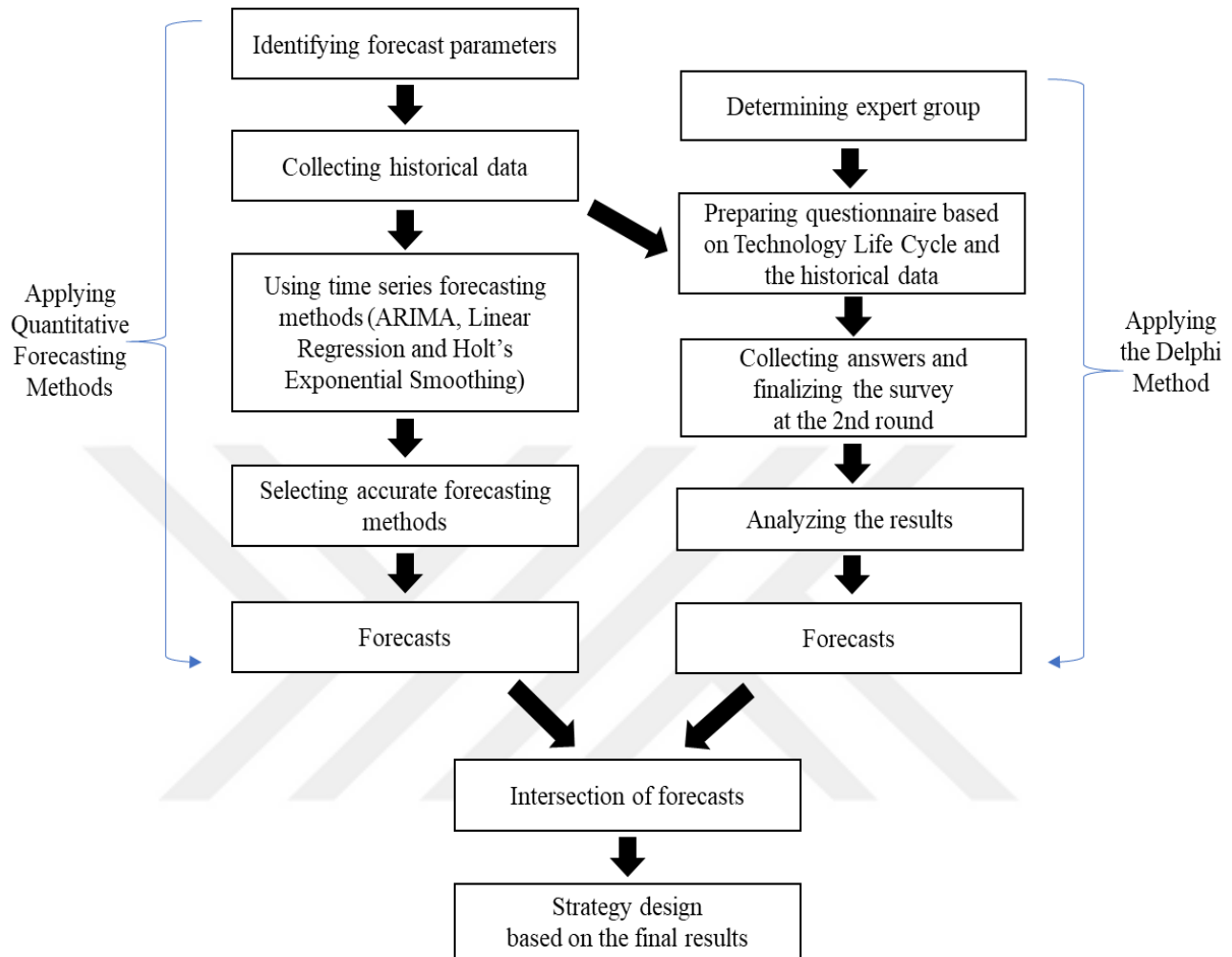


Figure 3.1. Diagram of the research process

3.1.1. Forecast parameters and collecting data

Forecast parameters identified for this research are the LTE mobile data ratio, the number of LTE users, LTE average download throughput, smartphone penetration, and the mobile video data ratio. Herein, the LTE mobile data ratio signifies the ratio of LTE mobile data over the entire mobile data volume consumed in the network. The number of LTE users corresponds to the count of mobile subscribers actively using LTE. The LTE average download throughput is the user-based average speed of mobile internet in the LTE network. Smartphone penetration is the ratio of the number of smartphone users overall mobile subscribers of the company. Finally, the mobile video data ratio refers to the ratio of the mobile data volume over the entire mobile data volume.

Historical data from April 2016—when LTE technology was commercially launched in Turkey—have been collected on a month-on-month basis from the network analytics department of the company. The origin point of the historical data has been selected as the launch date of LTE because previous technologies, such as 3G and GSM, were considered negligible when forecasting 5G technology.

3.1.2. Application of the Delphi method

The Delphi method, developed by the Rand Corporation in the 1950s, was built on the proverb “two heads are better than one,” and it has become the most popular method amongst expert opinion-based techniques in forecasting literature. It is applied to a group of experts in a specific area, and the group interaction is carried out through the responses and a series of questionnaires.

By means of this technique, the experts are given the opportunity to change their opinions and judgments. It is targeted to produce strategic information regarding the development of emerging technologies including their predicted launch date and features (Roper et al., 2011). Furthermore, the Delphi method is considered convenient for our study because of the current lack of data regarding 5G technologies. There are only a few mobile network operators announcing commercial 5G operations in the USA, Europe, China, and South Korea as of the end of 2019 (Ericsson, 2019).

The Delphi method has been applied to extract expert judgment and quota sampling has been used as the sampling technique in the study. Quota sampling is an appropriate method when conducting a purposive sampling strategy with a series of categories and a minimum level of requirements for the case (Robinson, 2014). When determining group members, the following criteria—based on which experts have been invited to the survey—have been taken into consideration:

- Having a minimum of 8 years of experience in the mobile telecommunication industry,
- Working in relevant planning departments of the company (strategy, architecture, and investment),
- Having the title of senior engineer, at the least.

The answers have been collected from a total of 21 participants. The average experience in the

telecommunication industry of the participants is roughly 18 years, including 16 electronics/telecommunication engineers (3 senior, 5 expert, 6 senior experts, and 2 principal engineers) and 5 managers. The need for diverse expertise and experience over the LTE and 5G technology has limited the size of the survey group in our study. With regards to their educational level, 11 participants have M.Sc. and 3 have Ph.D. degrees, whereas the others have B.Sc. degrees from related departments.

The questionnaire, which can be found in Appendix A, consisted of 11 questions based on historical data about the mobile telecommunication technologies in the company. The questionnaire primarily consisted of multiple choice questions based on the company's LTE network data; LTE being the latest technology used before transitioning to the 5G era. The questions have been designed taking into account forecast parameters, which are key drivers of mobile network technologies in the future. Next, the hard copies of the questionnaire were distributed. Participants were required to fill them individually reflecting on their views of the situation of the mobile technologies used in the company at that point of time. When the 2nd round was applied, the number of changes in the answers of the expert group was lower than 10%. Upon gaining a consensus, the Delphi method was completed at the end of the 2nd iteration by considering the answers stable enough to finalize the study.

3.1.3. Application of quantitative forecasting method

As a quantitative forecasting method, time series forecasting is used to extend existing time series data into the future. Time series is undoubtedly one of the most popular research techniques used in trend analyses of emerging technology topics, as it successfully provides data-based forecasts over short and middle range periods (Khatibi, Keramati, & Montazer, 2017; Meade & Islam, 2015).

The mobile telecommunication industry has also witnessed many time series forecasts quantifying the future of mobile technologies. Time series forecasting constantly requires a substantial amount of data to be effective. The literature review revealed that the ARIMA technique is more accurate according to most measures, especially when monthly data are considered (Taylor, 2008). Because of this, it was decided to utilize the Box-Jenkins method by ARIMA in this study.

As demonstrated in Figure 3.1, the quantitative forecasting process was conducted depending on ARIMA, Linear Regression, and Holt's Exponential Smoothing methods after collecting historical data of the forecast parameters determined at the beginning. However, we have forecast future data by selecting the Linear Regression and ARIMA methods since the forecasts from Holt's Exponential Smoothing method were less accurate. These forecasts have been obtained using the R software, R-Studio, and Microsoft Excel tools.

Table 3.1 indicates the forecast equations based on the time series forecasting technique and calculation for each forecast parameter exploited in the study. The forecasts indicated in Figure 3.2, 3.3, 3.4, 3.5, and 3.6 have been plotted with the help of these equations and calculations.

Further, autocorrelation function and partial autocorrelation function plots of time series data have been given in Appendix C to exhibit testing process employed during the application of quantitative forecasting method in the thesis. In addition, summaries of these time series forecasting models have been explicitly provided in Appendix D as including training set error measures.

Table 3.1. Time series forecasting of forecast parameters

Fig.	Forecast Parameter	Forecast Calculation	Forecast Equation for Time Period t
3.2	LTE Mobile Data Ratio (%)	The forecasts from ARIMA (0,2,1) for LTE Mobile Data Volume (GB)/The forecasts from ARIMA (1,1,1) for Total Mobile Data Volume (GB)	$\frac{Y_t = 2Y_{t-1} - Y_{t-2} - 0.8473e_{t-1} + e_t}{Y_t = (1 + 0.9997)Y_{t-1} - 0.9997Y_{t-2} - 0.9855e_{t-1} + e_t}$
3.3	Number of LTE Users	The forecasts from ARIMA (1,1,1) for the Number of LTE Users	$Y_t = (1 + 0.9956)Y_{t-1} - 0.9956Y_{t-2} - 0.8499e_{t-1} + e_t$
3.4	LTE Average Download Throughput (Mbit/s)	Linear Regression	$Y_t = 50.133 + 0.2835t$
3.5	Smartphone Penetration (%)	The forecasts from linear regression for Number of Smartphones/The forecasts from linear regression for Number of Mobile Subscribers	$\frac{Y_t = 21068842 + 109220t}{Y_t = 31773894 - 15837t}$
3.6	Mobile Video Data Ratio (%)	Linear regression for Mobile Video Data Volume (GB)/Total Mobile Data Volume (GB)	$Y_t = 0.4086 + 0.005t$

3.2. Results of the Analyses

3.2.1. Delphi results

According to the findings obtained using the Delphi method, the majority of the expert group members consider LTE to be in the maturity stage of its TLC, as the key technology of the company and expect it to be a base technology in 2021. The strongest drivers of the 5G technology are high speed, low latency, high capacity, and FWA. Besides these, industrial IoT and augmented reality (AR)/virtual reality (VR) applications are propelling the emergence of 5G technology. Based on the current data, LTE is carrying approximately 60% of all data traffic in the mobile network of the company. The expert group members think that this ratio should be 80% at the time of the commercial 5G launch.

Moreover, the number of LTE users is now around 12.5 million, whereas the number of LTE devices is 18.5 million. It is forecast the number of subscribers using LTE is going to be 17 million at the time of launching 5G technology. The smartphone penetration ratio is also an important factor in increasing mobile data traffic in the network. It presently stands at around 70% of all mobile subscribers, whereas the percentage value expected at the time of 5G technology launch is 80%. The current share of mobile video in the total mobile data traffic of the network is rising up to 50% and it is expected to be 60%. In addition, the average LTE download speed for the period of the last six months is about 60 Mbps based on the “Speedtest” application of Ookla, which is globally the most renowned app used for speed testing. With the help of advanced features in the network roadmap, this value is estimated as 65 Mbps before the 5G launch. This is also positively affected by enhanced smart devices and their advanced capabilities in the network.

The Delphi results are demonstrated in Appendix B with the details including answers of experts in the group. A summary of the results gathered from the Delphi method is simply presented in Table 3.2 as well. These values are obtained by analyzing the answers to the questionnaire applied in this step. The highest rated options in the answers produce the Delphi results for the forecast parameters.

Table 3.2. Summary results from the Delphi method

	Forecast Parameters	Results
1	LTE Mobile Data Ratio	80%
2	Number of LTE Users	17 Million
3	LTE Average Download Throughput	65 Mbit/s
4	Smartphone Penetration	80%
5	Mobile Video Data Ratio	60%

3.2.2. Combination with the time series forecasting results

The forecasts obtained in this section present the projection for the next three years based on historical data. Forecast results mentioned above, acquired using the Delphi method, are shown with the help of dashes and dots in the figures. The expert opinion-based results coming from the Delphi method are intersected with the time series forecasts in order to determine the launch time of the 5G technology in the case study. The final results are extracted after intersecting these results. Therefore, the results of our study are built on both quantitative forecasting and Delphi methodologies to be able to help engineering managers design their strategies.

Herein, it is expected that the final results forecast the launch time of the 5G technology in the company. As mentioned earlier, LTE is considered by most mobile technology experts to be in the maturity stage in terms of its TLC. According to Yeo and colleagues, mature technologies are always followed by emerging technologies in the TLC of mobile telecommunications, as experienced before (Yeo et al., 2015). Hence, it is predicted that 5G will be launched when the conditions are satisfied as to the existing mobile technology, LTE, becomes mature. Next, a time for the commercial launch of 5G technology is targeted based on the final results of the forecasting study.

3.2.3. Demonstration of the forecasting results

First, Figure 3.2 illustrates that the forecast of the LTE mobile data ratio by the expert group is 80%. It is found that the intersected point corresponds to May 2020 in the timeline of the figure. According to the TLC approach, LTE technology is expected to reach its maturity in the near future with the diffusion of 5G in the market. Therefore, the rise of the ratio of the LTE Mobile

Data in Figure 3.2 shows a decline over time when moving towards 2022 because of the 5G technology factor.

According to Figure 3.3, 17 million is the forecast number of LTE users based on the Delphi method, projected for June 2020 depending on the time series forecast on the graph. This means that the forecast value for the number of LTE users will be met at this time. The characteristics of the historical data indicate a linear increase, and hence, the forecast trend also follows this linear behavior over time.

In the next graph, Figure 3.4 points out the forecast of the LTE average download throughput as 65 Mbit/s which means the mobile connection speed obtained from the Delphi results. This value intersects with the time series forecast on the date of August 2020. In other words, that means the curve of time series forecast catches the value of expected average mobile connection speed in August 2020.

Figure 3.5 illustrates the forecast of smartphone penetration in the network. Smartphone penetration is expected to rise up to 80% by January 2020 based on both the Delphi method and time series forecast results. The growth of LTE usage has played a major role in this increase and it is anticipated to keep rising with the help of emerging 5G technology.

Finally, the mobile video data ratio, as one of the most significant parameters driving mobile data volume consumed in the network, is expected to reach 60% based on the results of the Delphi method. Figure 3.6 reveals that this ratio is exceeded by the end of December 2019 over the plotted time series forecast. In addition, the mobile video data ratio is expected to accelerate with the help of 5G technology coming up with the enriched video applications in this new mobile technology era, such as AR/VR, 4K/8K video contents, online games, and 360-degree videos.

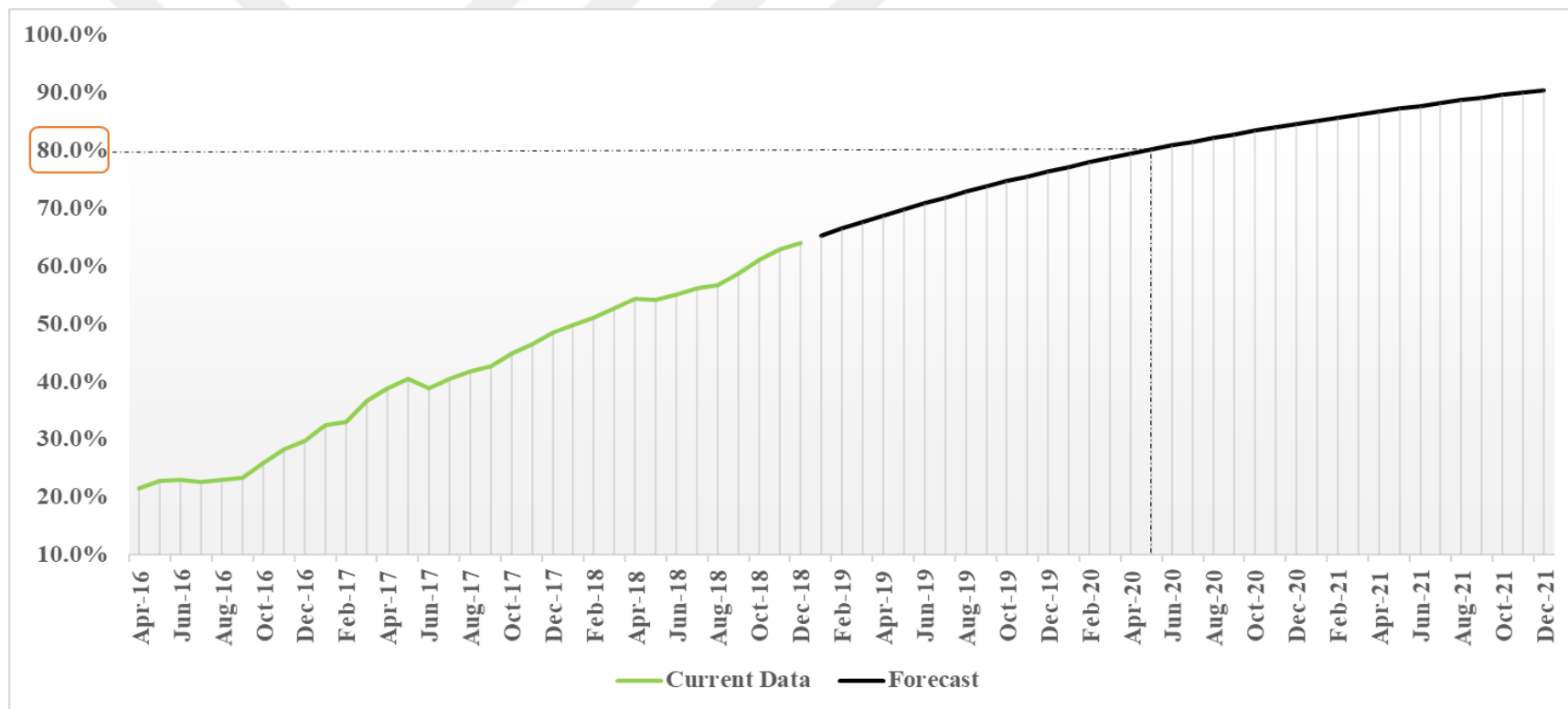


Figure 3.2. LTE Mobile Data Ratio (%)

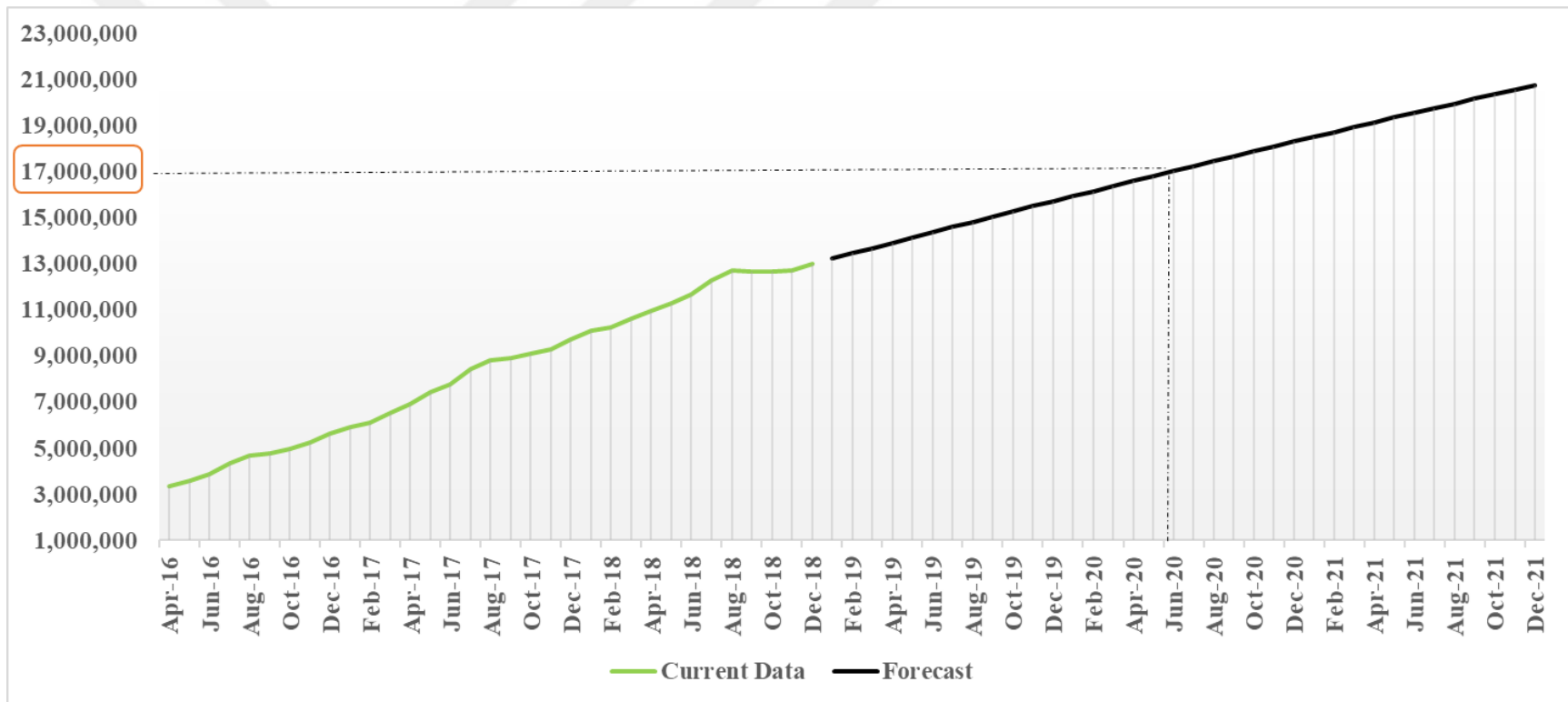


Figure 3.3. Number of LTE Users

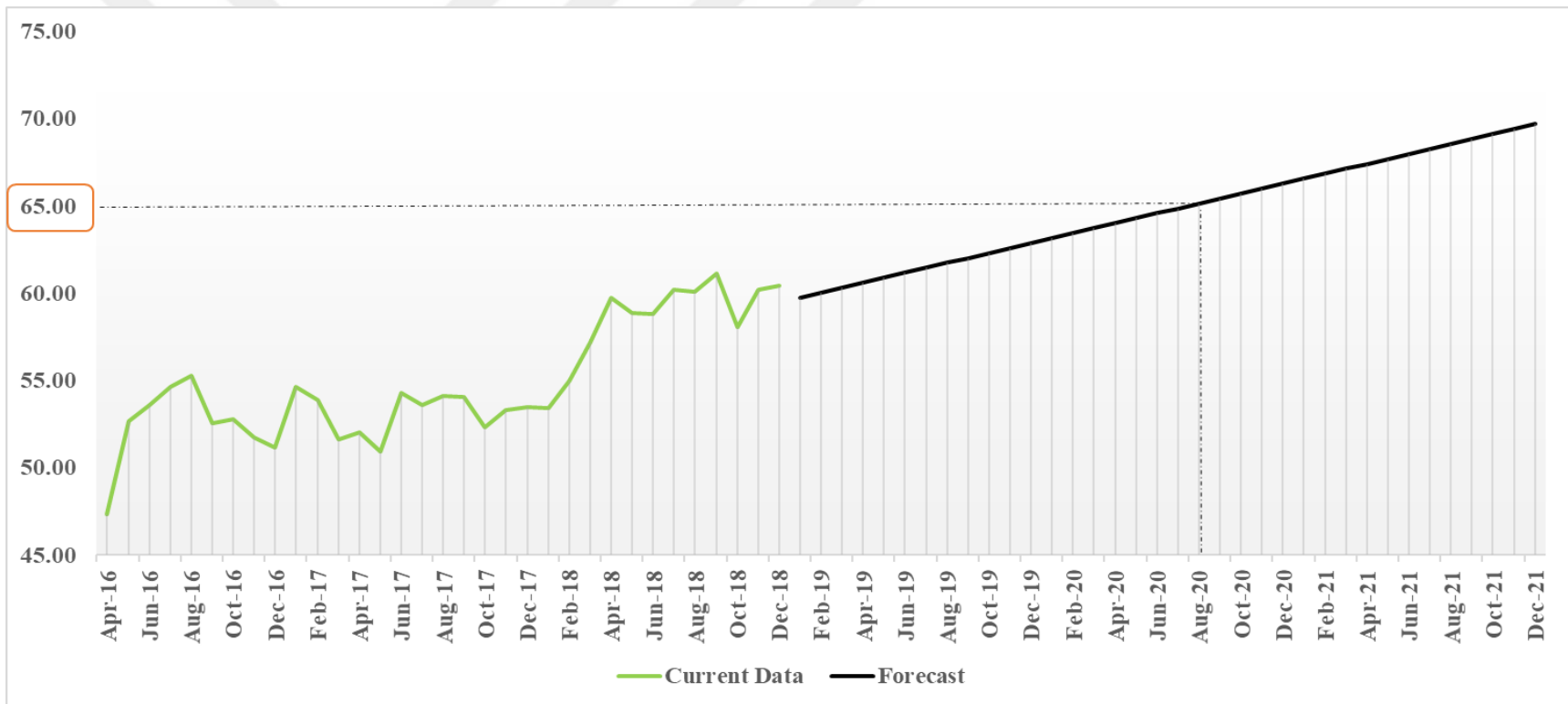


Figure 3.4. LTE Average Download Throughput (Mbit/s)

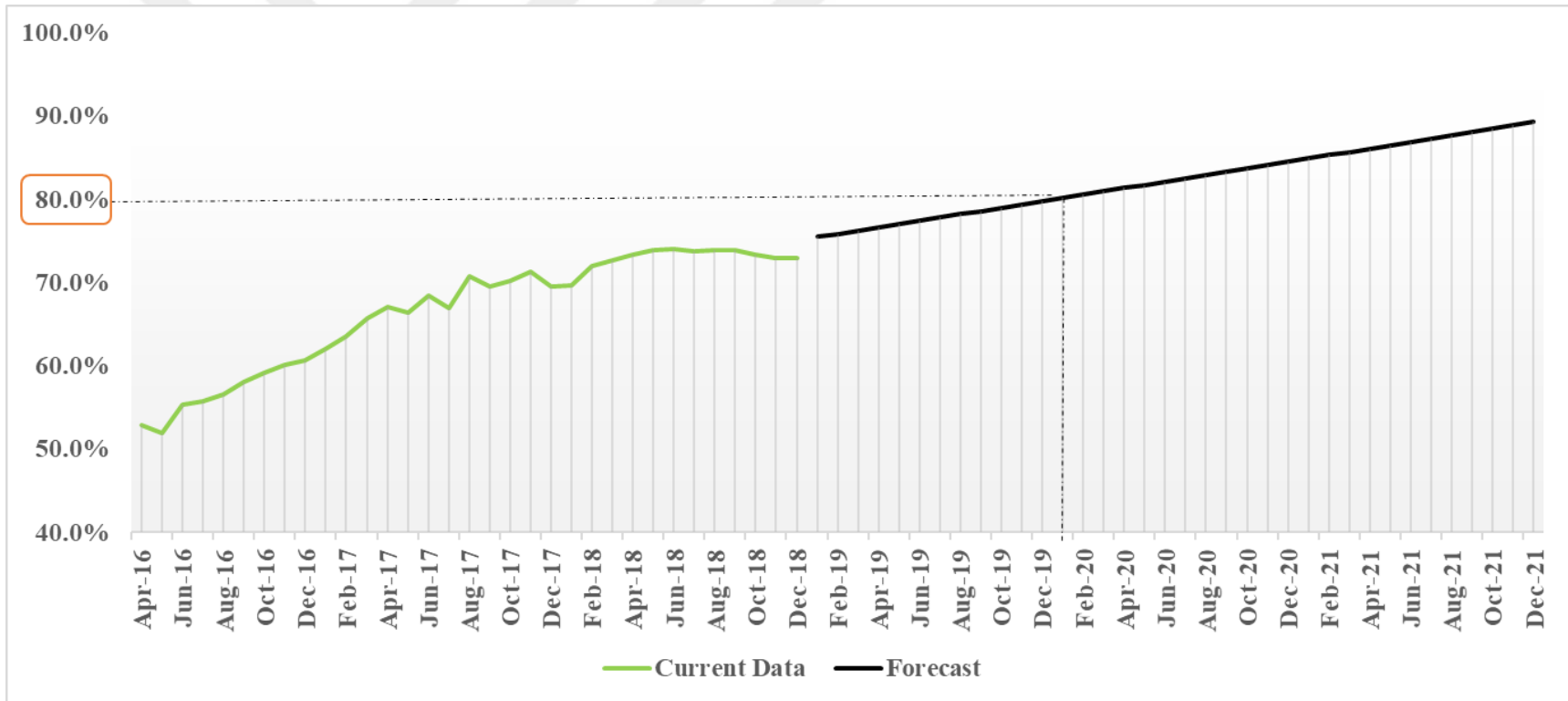


Figure 3.5. Smartphone Penetration (%)

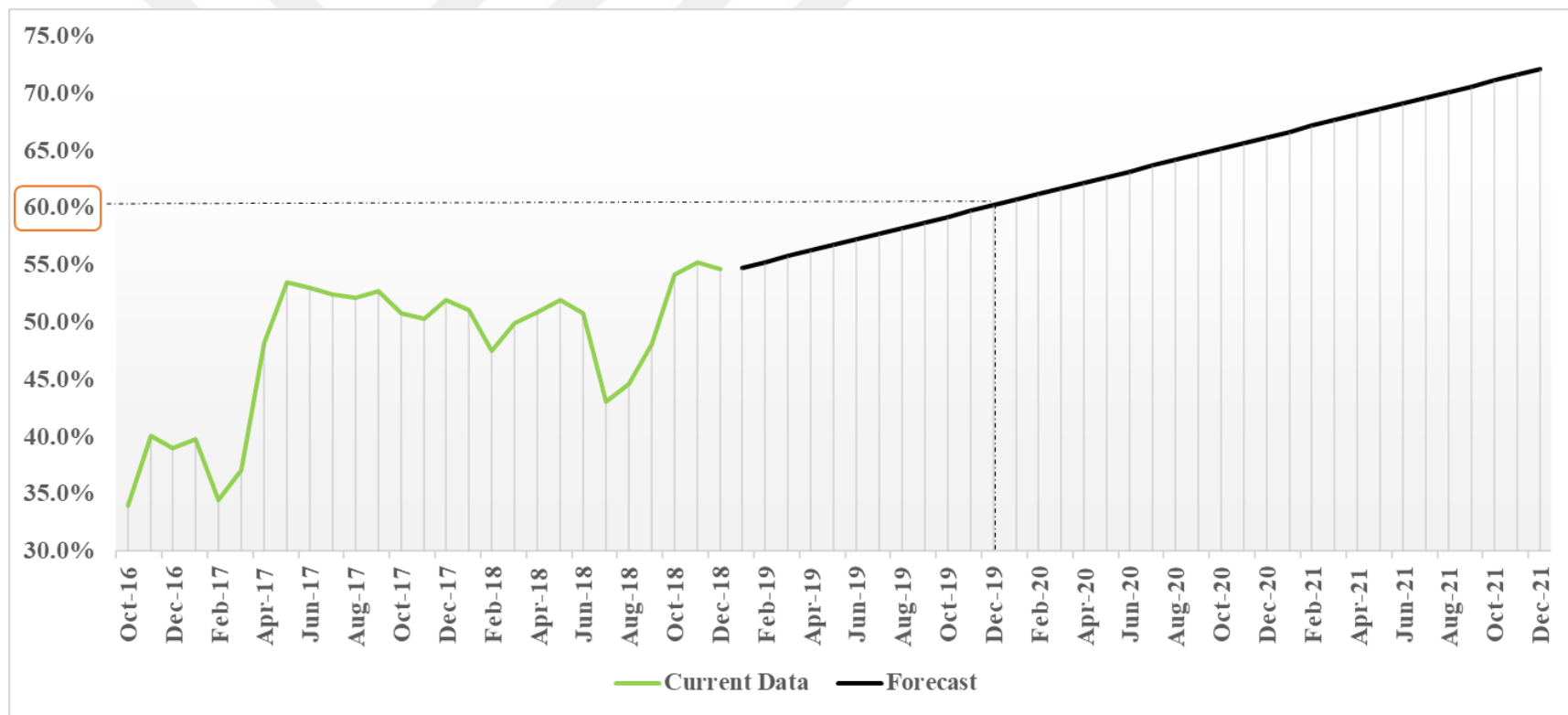


Figure 3.6. Mobile Video Data Ratio (%)

3.2.4. Final results

The forecast results explained in this section are apparently summarized in Table 3.3 below. The smartphone penetration and mobile video data ratio are satisfied a bit earlier than others by reaching their estimated value before 2020. However, the remaining forecast parameters are met for a 5G launch time in the 2nd and 3rd quarter of 2020 based on the intersection points of both time series forecasts and Delphi method results. In light of these results, August 2020 is the earliest launch time of 5G when all forecast parameters are satisfied in the timeline of the company, moving towards the 5G technology era.

Table 3.3. Summary results

	Forecast Parameters	Time Forecasts Intersected in Figures
1	LTE Mobile Data Ratio	May 2020
2	Number of LTE Users	June 2020
3	LTE Avg. Download Throughput	August 2020
4	Smartphone Penetration	January 2020
5	Mobile Video Data Ratio	December 2019

According to the Delphi results indicated in Appendix B, 2021 and 2020 are the best- and second-best rated years respectively to launch 5G technology in the market, and LTE is also forecast to become a base technology in 2021, as explained earlier. It means that final results are also compatible with the Delphi results because August 2020, which is the launch time of 5G technology, falls within this range indeed.

4. CONCLUSION

Emerging technologies replace existing mature products and systems in the market in line with the TLC in an industry. 5G technology is likely expected to take the place of the previous technologies as the emerging technology in the mobile telecommunication industry. Then, nowadays the dramatic adoption of smart devices and increasing consumption of mobile Internet have been accelerating mobile technology development activities towards a 5G ecosystem. Therefore, it is significant to make decisions on network investments and services in terms of engineering management of mobile telecommunications. To provide a contribution to this issue, the launch time of the 5G technology is forecast based on both quantitative forecasting and Delphi methodologies applied in a leading telecommunication company, headquartered in Turkey, researched in the thesis.

What is more, the thesis scrutinizes the evolution of mobile telecommunication technologies, the background of technological forecasting techniques, and the technology life cycle in the mobile telecommunication industry. Hence, the literature review in the relevant topics supports the thesis to understand the study framework technically and historically. Besides, this provides a contribution to comprehending the research results and findings obtained throughout the thesis as well.

The research methodology is fundamentally built on a combination of expert opinion based Delphi method and time series forecasting results. Further, with the help of this approach, the TLC stages of the company are taken into consideration since the questionnaire applied in the Delphi method was prepared based on this point of view. Both knowledge-based technical foresight produced by the expert group members and the quantitative analysis through the time series forecasts enables the company to find out the launch time of 5G technology in Turkey. Eventually, the research findings reveal that August 2020 stands out as the earliest launch time for the 5G technology based on the research process applied in the thesis. This is the time when most of the forecast parameters used for making decisions on network investments are predicted to reach maturity.

4.1. Managerial Implications of the Research

The mobile telecommunication industry can be regarded as both a market-driven and a technology-driven industry. Therefore, technological progress and market development are strongly coupled with a high change rate. The companies need to make the correct investments to be able to struggle with the fierce competition and hence, stay robust throughout the technological advances and changes in the local and global environment. Technological forecasting tools and techniques can be employed for this purpose.

The consolidated knowledge based on the combination of time series forecasting and Delphi methods provides a significant contribution to the practicing engineering managers working in the mobile telecommunication industry. This novel and complementary framework, built on the well-known and accepted methods found in the literature, can be conveniently applied by practicing engineering managers in order to determine the commercial launch time for the 5G technology, or any other emerging technology in the industry. Therefore, the ultimate findings gathered at the end of the research are so valuable for practicing engineering managers in terms of making decisions and designing strategy when the mobile technologies have been evolving towards 5G.

Furthermore, the forecast parameters utilized in this study definitely have similar trends in developing countries, therefore making the results of this study more applicable to different markets. Thus, practicing engineering managers can utilize the findings of this study to make better-informed decisions when drawing risk mitigation strategies for their 5G launch projects in the industry. In particular, the approach proposed in the thesis can also generate accurate results for other mobile network operators and service providers in the telecommunication industry except for those that have already commercially launched their 5G networks.

4.2. Limitations of the Research

The findings of the research set the light on identifying the appropriate launch time of 5G technology in Turkey called one of the developing countries in the world. Nevertheless, the company can prefer to launch the 5G technology sooner or later depending on its strategic position by considering the competitive environment and local market, as the competition and marketing parameters are not included in the thesis. In addition, regulatory issues and

government policies along with the technical and commercial subjects play a major role in the telecommunication industry. For instance, the spectrum auction for the required frequencies and regulative approval for these new technologies are completely administrated by the related authorities of the government.

More, the government policy in the localization of products and solutions, pursued especially in the information, telecommunication, and defense technologies, will be probably affecting the launch time of 5G technology in Turkey. Without a doubt the topic is also very sensitive to the unexpected external incidents such as the occurrence of Covid-19 and its cross-sector influences in the whole world since the first days of 2020, that can be led to some delays in the introduction of 5G service in some countries and the technological roadmap of 5G. In accordance with the market dynamics and changes in the massive environment of the industry, all these factors create limitations in order to achieve the desired aim of this study.

4.3. Future Work

To further expand the research, much more forecast parameters, instead of some specific parameters, can be utilized during forecasting in both quantitative and expert opinion based methodologies such as investment KPIs used in the annual plans of the mobile network of the company. Then, well-accepted modeling techniques such as Bass, Gompertz, and Logistic can be merged into the methodology by comparing them in terms of forecasting performance over time series through the LTE data. These actions can surely provide additional viewpoints to determine appropriate launch time when moving toward the 5G era.

As a future work of this study, learning algorithms should be used to make the research methodology robust and to keep up with the advances in artificial intelligence and neural networks in the world. The Nonlinear Auto-Regressive network with eXogenous inputs (NARX) can be a good alternative amongst these solution algorithms.



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APPENDICES

APPENDIX A

Questionnaire

TECHNOLOGICAL FORECASTING IN THE DIRECTION OF 5G IN MOBILE TELECOMMUNICATION

Dear participant,

This survey was prepared to be used in a Ph.D. Thesis study which is concerned with the topic of technological forecasting in the Engineering Management Doctorate Programme of Marmara University.

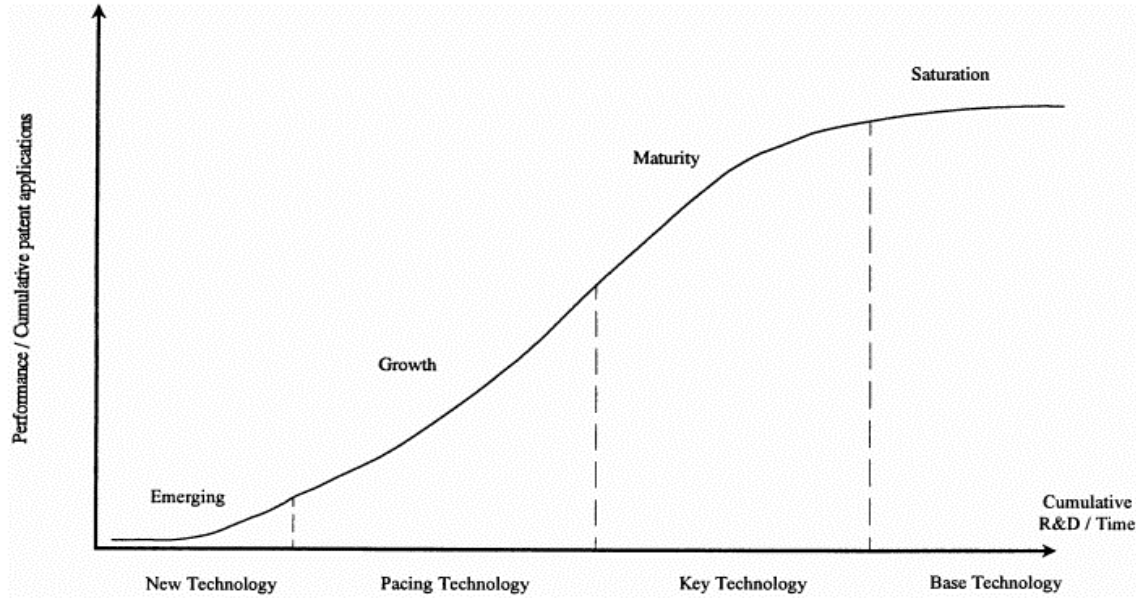
This part consists of 10 questions in the first stage. Your answers will be used for only scientific evaluation.

Thanks so much for your contribution.

A. Please reflect on your views when answering the questions below about the company.

1) In which stage is LTE in terms of its technology life cycle (as seen in the figure below)?

- a) Emerging (New Technology)
- b) Growth (Pacing Technology)
- c) Maturity (Key Technology)
- d) Saturation (Base Technology)



2) When will LTE become a base technology for the company? (Please consider your answer in the 1st question)

- a) 2019
- b) 2020
- c) 2021
- d) 2022
- e) 2023

3) Please rate the degree of power of the following drivers triggering 5G technology. Please consider the current situation at the company.

	Very Strong	Strong	Neutral	Weak	Very Weak
High Speed					
Low Latency					
High Capacity					
FWA					
Industrial IoT					

4) Currently LTE is carrying ~60% of the whole data traffic in our mobile network. What do you think this ratio should be when 5G is launched commercially?

- a) 65%
- b) 70%
- c) 75%
- d) 80%
- e) 85%

5) Currently the number of LTE users is around 12.5M whereas the number of LTE devices is 18.5M in the mobile network. What should be the number of users of LTE at the time of 5G launch? (Note: The number of LTE devices has stabilized around 18.5M over the last 3 months)

- a) 13M
- b) 14M
- c) 15M
- d) 16M
- e) 17M

6) Average LTE download throughput (for the period of the last 6 months) is ~60Mbps (based on Ookla Speedtest) in the last 6 months. What should be the LTE DL throughput at the time of the 5G launch?

- a) 50 Mbps
- b) 55 Mbps
- c) 60 Mbps
- d) 65 Mbps
- e) 70 Mbps

7) Average LTE latency (for the period of the last 6 months) is ~26ms (based on Ookla Speedtest) in the last 6 months. What should be the LTE latency at the time of the 5G launch?

- a) 24 ms
- b) 25 ms
- c) 26 ms
- d) 27 ms
- e) 28 ms

8) The smartphone penetration ratio is an important factor that increases the data traffic in the mobile network. Now it's around 70% of the whole mobile subscribers. What percentage do you think it will be when 5G is launched at the company?

- a) 70%
- b) 75%
- c) 80%
- d) 85%
- e) 90%

9) Currently the ratio of mobile video is about 50% of the total data traffic in the network. What percentage do you think it will be when 5G is launched at the company? Please consider the whole apps including video content such as YouTube, Netflix, TV+, social media apps, AR/VR and 360-degree videos.

- a) 50%
- b) 60%
- c) 70%
- d) 80%
- e) 90%

10) When do you think the company should launch 5G commercially?

- a) 2019
- b) 2020
- c) 2021
- d) 2022
- e) 2023

11) Please write the main reason underlying your answer in the above question (how to determine when to launch the 5G service at the company).

B. Personal Information

- Name
- Gender
 - a) Male
 - b) Female
- Age
 - a) 30-34
 - b) 35-39
 - c) 40-44
 - d) 45-49
 - e) 50+
- Total experience in the telecommunication industry
 - a) 8-12 years
 - b) 13-17 years
 - c) 18-22 years
 - d) 23-27 years
 - e) 28+ years
- Title in the company
 - a) Senior Engineer
 - b) Expert Engineer
 - c) Senior Expert Engineer
 - d) Principal Engineer
 - e) Manager
- Education level
 - a) BSc.
 - b) MSc.
 - c) Ph.D.

APPENDIX B

Results of the Questionnaire

1) In which stage is LTE in terms of its technology life cycle?

a) Emerging (New Technology)	0
b) Growth (Pacing Technology)	6
c) Maturity (Key Technology)	12
d) Saturation (Base Technology)	3

2) When will LTE become a base technology for the company?

a) 2019	3
b) 2020	6
c) 2021	8
d) 2022	3
e) 2023	1

3) Please rate the degree of power of the following drivers triggering 5G technology.

	<i>Very Strong</i>	<i>Strong</i>	<i>Neutral</i>	<i>Weak</i>
High Speed	11	7	3	0
Low Latency	9	7	4	1
High Capacity	11	7	3	0
FWA	11	9	1	0
Industrial IoT	3	6	10	2
AR/VR	0	0	2	0

4) Currently LTE is carrying ~60% of the whole data traffic in our mobile network.

What do you think this ratio should be when 5G is launched commercially?

- | | |
|--------|---|
| a) 65% | 3 |
| b) 70% | 3 |
| c) 75% | 3 |
| d) 80% | 7 |
| e) 85% | 5 |

5) Currently the number of active LTE users is around 12.5M whereas the number of LTE devices is 18.5M in the mobile network. What should be the number of active users of LTE at the time of 5G launch?

- | | |
|--------|----|
| a) 13M | 2 |
| b) 14M | 2 |
| c) 15M | 4 |
| d) 16M | 3 |
| e) 17M | 10 |

6) Average LTE download throughput (for the period of last 6 months) is 60 Mbps (based on the application “Ookla Speedtest”) in the last 6 months. What should be the LTE DL throughput at the time of 5G launch?

- | | |
|------------|---|
| a) 50 Mbps | 5 |
| b) 55 Mbps | 2 |
| c) 60 Mbps | 1 |
| d) 65 Mbps | 8 |
| e) 70 Mbps | 5 |

7) Average LTE latency (for the period of last 6 months) is ~26ms (based on the application “Ookla Speedtest”) in the last 6 months. What should be the LTE latency at the time of 5G launch?

- | | |
|----------|---|
| a) 24 ms | 9 |
| b) 25 ms | 2 |
| c) 26 ms | 5 |
| d) 27 ms | 2 |
| e) 28 ms | 3 |

8) Smartphone penetration ratio is an important factor which increases the data traffic in the mobile network. Now it’s around 70% of the whole mobile subscribers. What percentage do you think it will be when 5G is launched at the company?

- | | |
|--------|---|
| a) 70% | 1 |
| b) 75% | 5 |
| c) 80% | 7 |
| d) 85% | 5 |
| e) 90% | 3 |

9) Currently the ratio of mobile video is about 50% of the total data traffic in the network. What percentage do you think it will be when 5G is launched at the company?

- | | |
|--------|----|
| a) 50% | 2 |
| b) 60% | 10 |
| c) 70% | 7 |
| d) 80% | 2 |
| e) 90% | 0 |

10) When do you think the company should launch 5G commercially?

- | | | |
|----|------|---|
| a) | 2019 | 3 |
| b) | 2020 | 7 |
| c) | 2021 | 6 |
| d) | 2022 | 4 |
| e) | 2023 | 1 |

11) Please write the main reason underlying your answer in the above question (how to determine when to launch the 5G service at the company).

Comment 1: Target date is the end of 2020 for the domestic 5G network.

Comment 2: We are expecting the spectrum tender to be made by BTK. Then, we can start commercial deployment. I think this will be in 2020.

Comment 3: Regulatory and economical (LTE investment return rate) issues are the main reasons.

Comment 4: LTE should be saturated before 5G deployment because the emergence of mMTC and URLLC use cases likely to be delayed due to the standardization efforts in 3GPP. The main driver for 5G is still eMBB which can be partially offered by LTE Advanced that are still evolving.

Comment 5: 5G signal launch is expected in 2019. The whole 5G service will be launched later.

Comment 6: Spectrum availability, readiness in Turkey, late launch of LTE (2016), specs are yet to be complete for full 5G services, 5G devices need to be more mature.

Comment 7: Opportunity increases in vertical industries in 2021. Leadership should be continued in 5G as well. It does not seem feasible before 2021.

Comment 8: 5G devices should be ready for 5G launch. So, it will be in 2020.

Comment 9: 5G is not only new technology, it's also transformation of information by shaping the requirements. The operators, which do not understand the logic of 5G, probably loss the game. So, the company should immediately start to transform itself in this way.

Comment 10: 5G standards must be completed. Devices must be ready.

Comment 11: To have a successful launch, both network equipment and device sides should be mature enough. And it requires new services to increase usage.

Comment 12: When 5G services are mature enough, so they cannot be supported over LTE. When 5G devices are 10% of the network. When f/o penetration is at least 75% of target sites.

Comment 13: Commercial products are required.

Comment 14: To be one of the first operators with 5G network, it is needed to launch 5G in 2020. In reality, our company will not need 5G until 2022 since the number of 5G subscribers will be few in the first 3 years. 5G devices will be too expensive and mid-range devices will not be in the market before 2022.

Comment 15: Competition and marketing strategies require 5G launch in 2019.

Comment 16: Maturity threshold is at least 5 years for LTE. Necessary use cases for 5G is not mature yet. FWA could come before, only if spectrum usage possible at optimum price.

Comment 17: Mobile data traffic will be increasing a lot and so, LTE capacity will be insufficient due to technological constraints and limited bandwidth. 5G should be launched in 2021 latest.

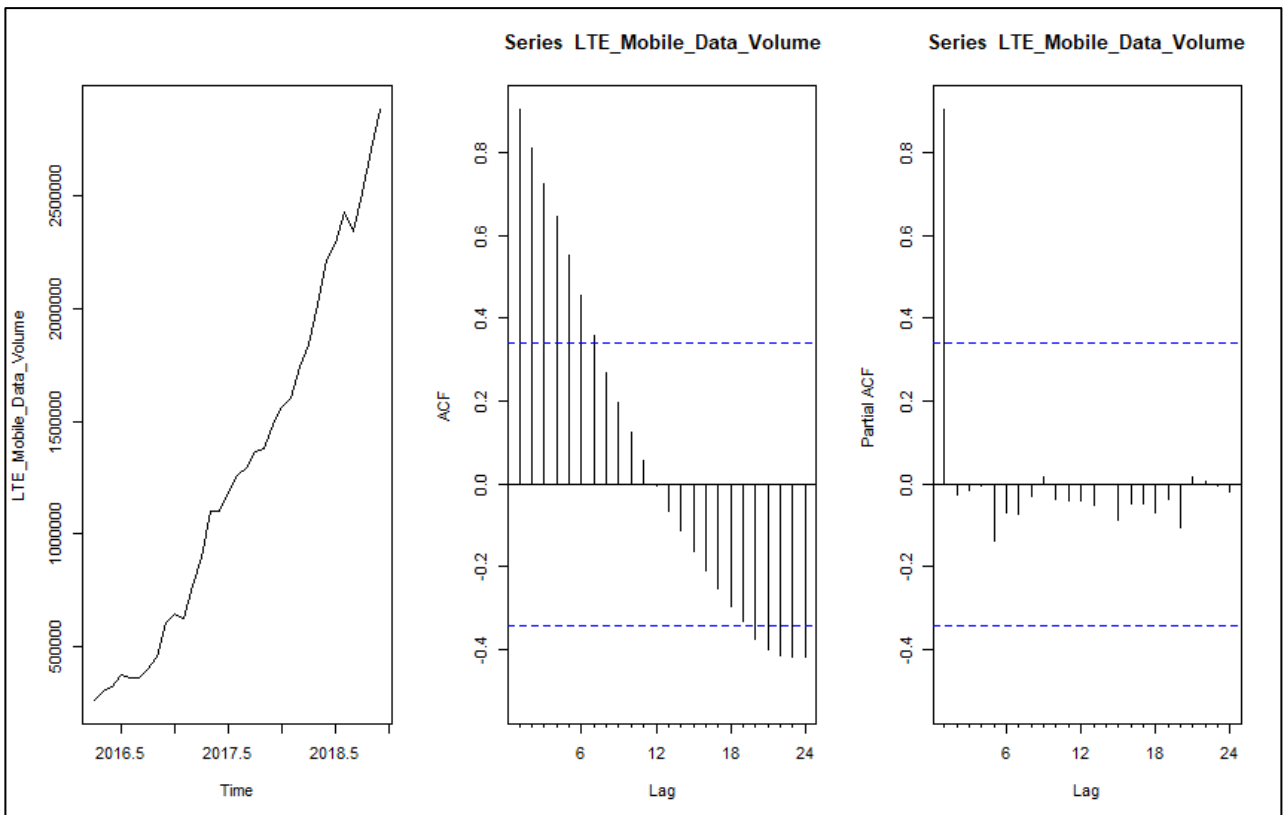
Comment 18: Existing network and spectrum capacity will be insufficient. Market needs 5G readiness. Maturity of verticals and new business cases.

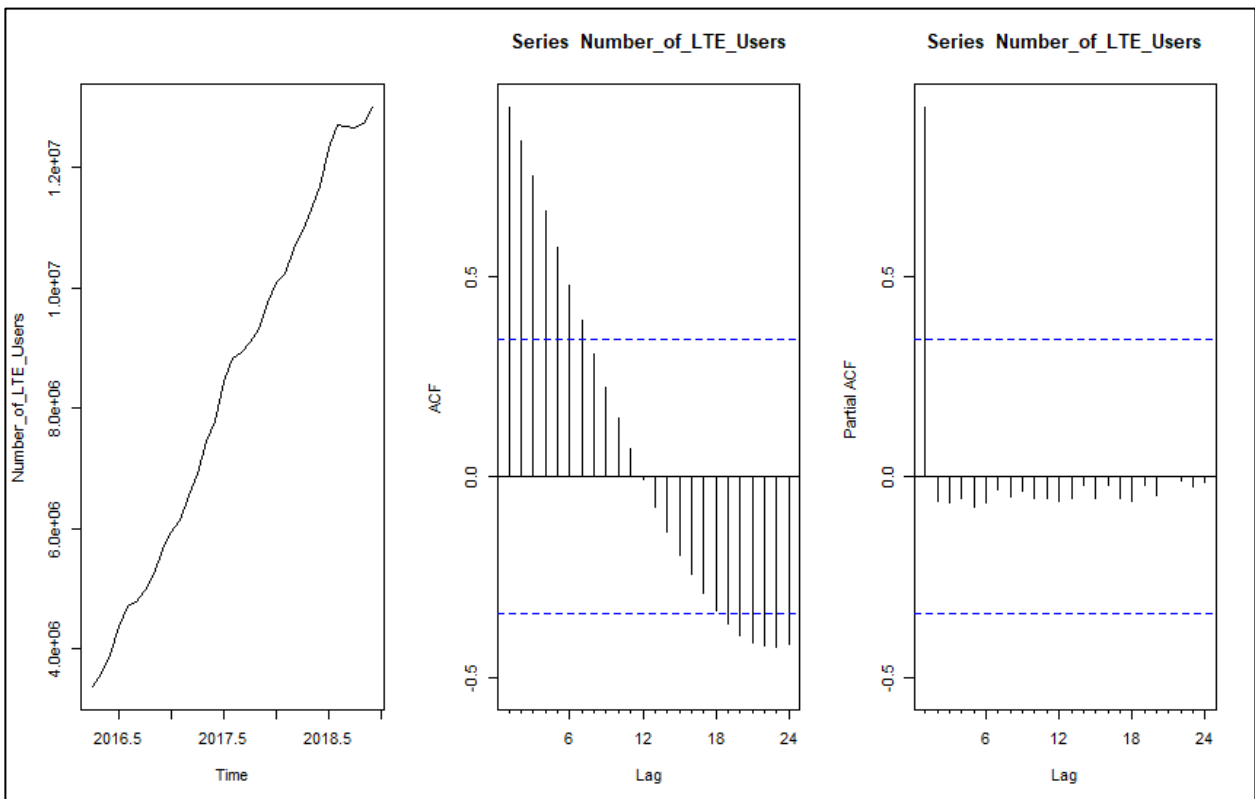
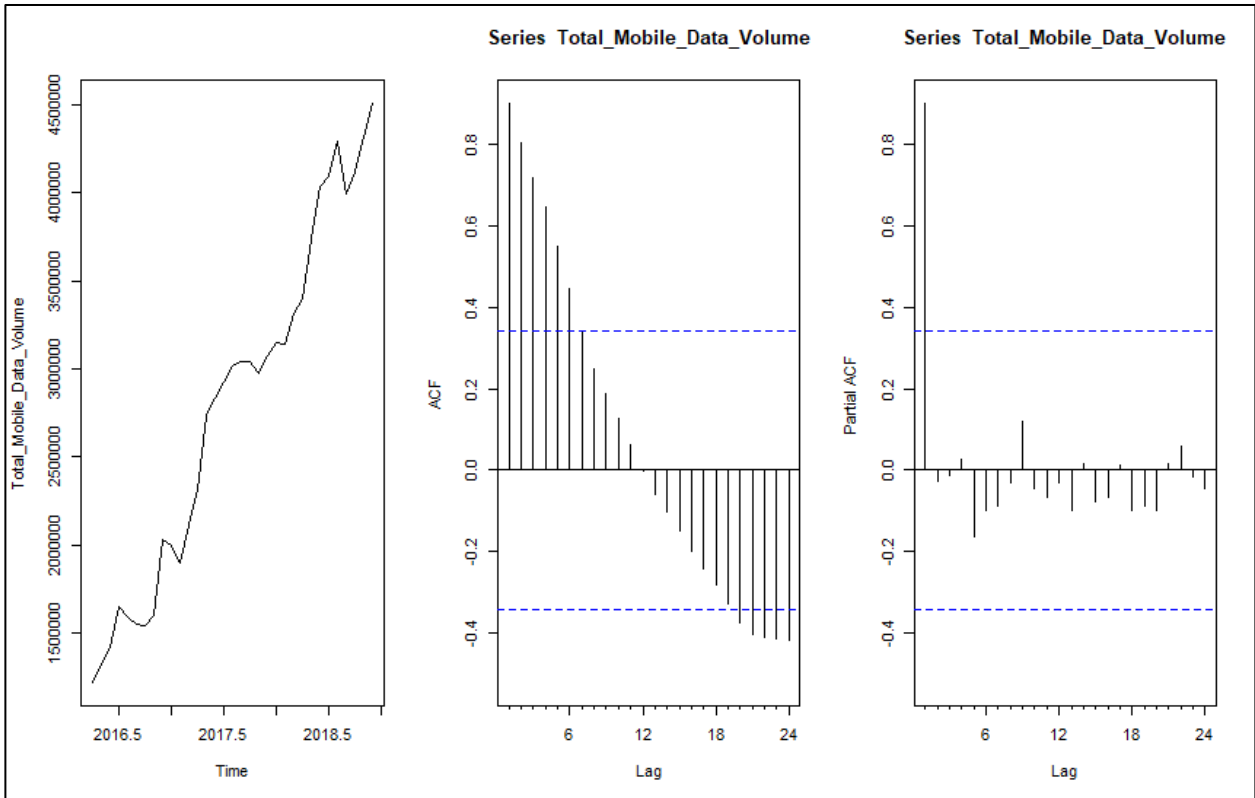
Comment 19: 5G use cases should be evaluated separately. FWA is a solution for FTTX where f/o is not available. It's developed faster when compared to others. Commercial launch of 5G depends on many factors like spectrum assignments, readiness of devices and business cases etc. In addition, we also have another requirement; development of local 5G products as the leader in the mobile technologies.

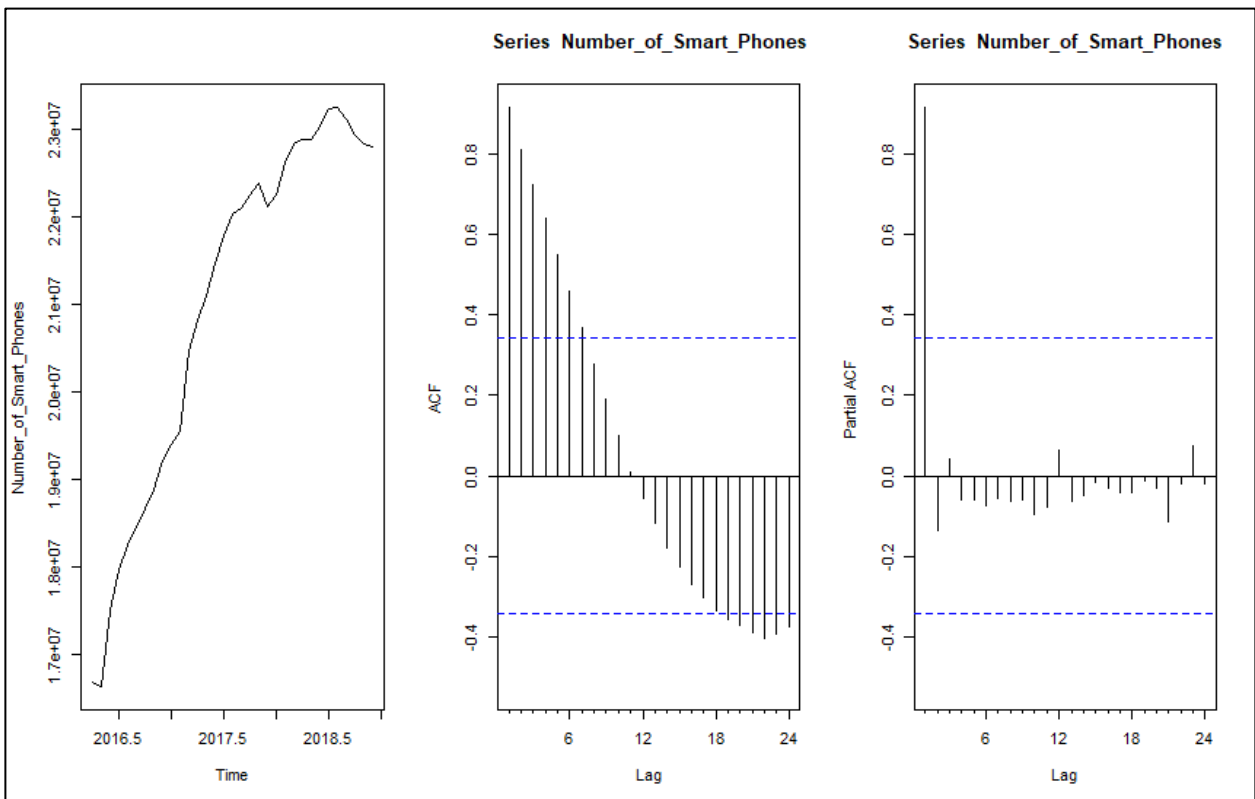
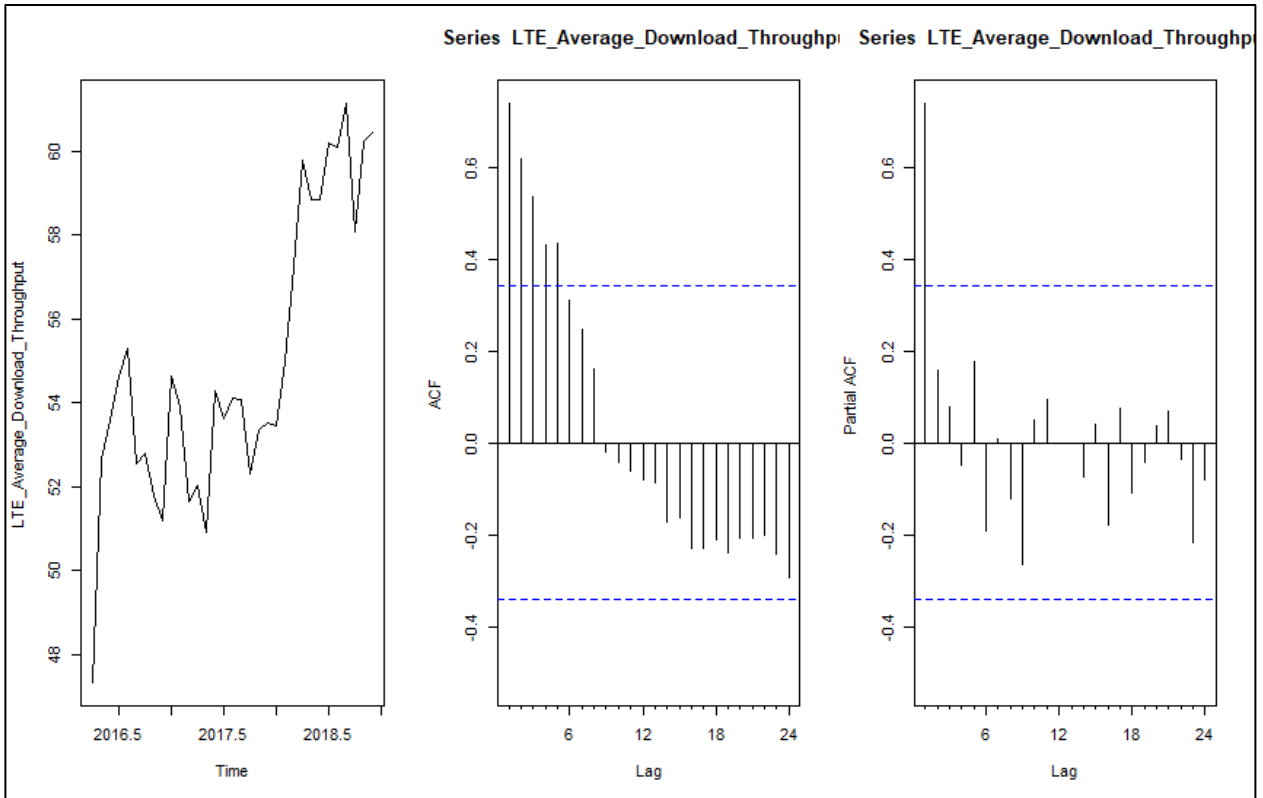
Comment 20: 5G must be launched commercially in 2019 as a market leader even if it's partially or locally possible to enable in the network. However, 5G will be technically ready in 2020 from end to end including devices and infrastructures.

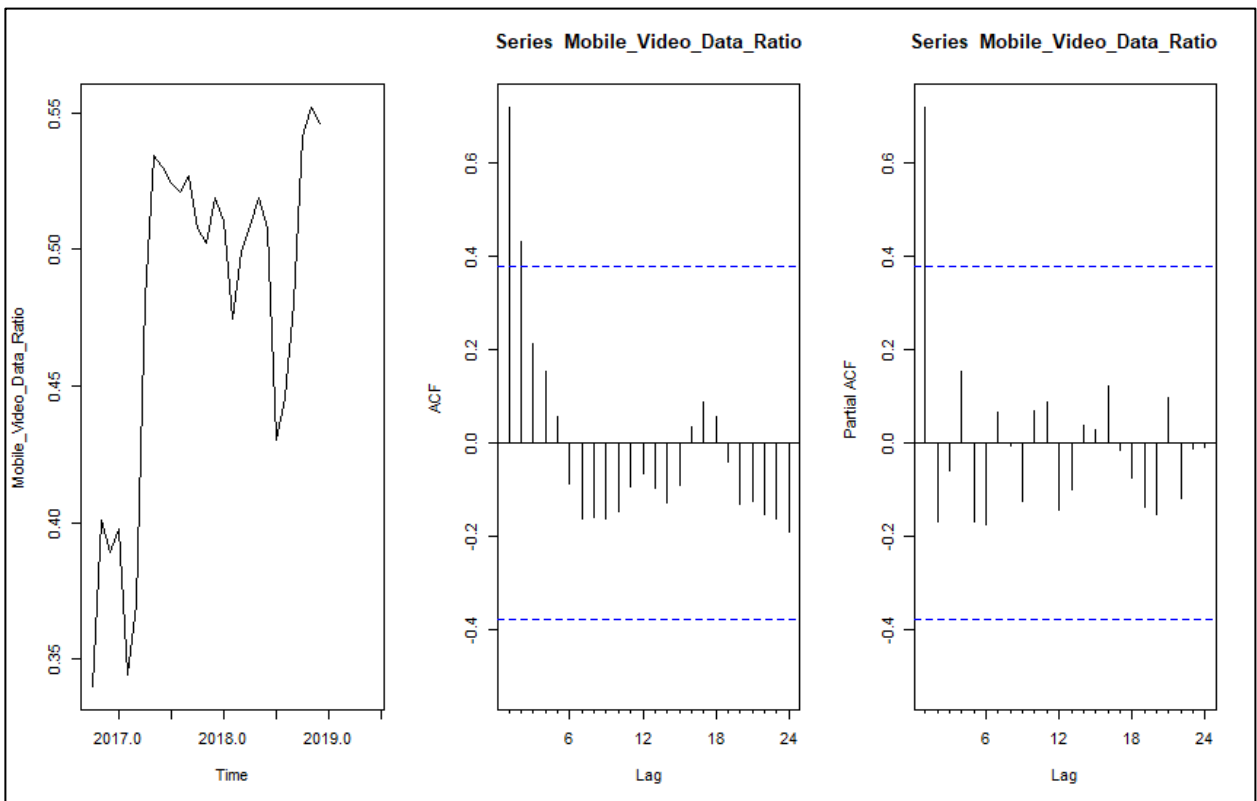
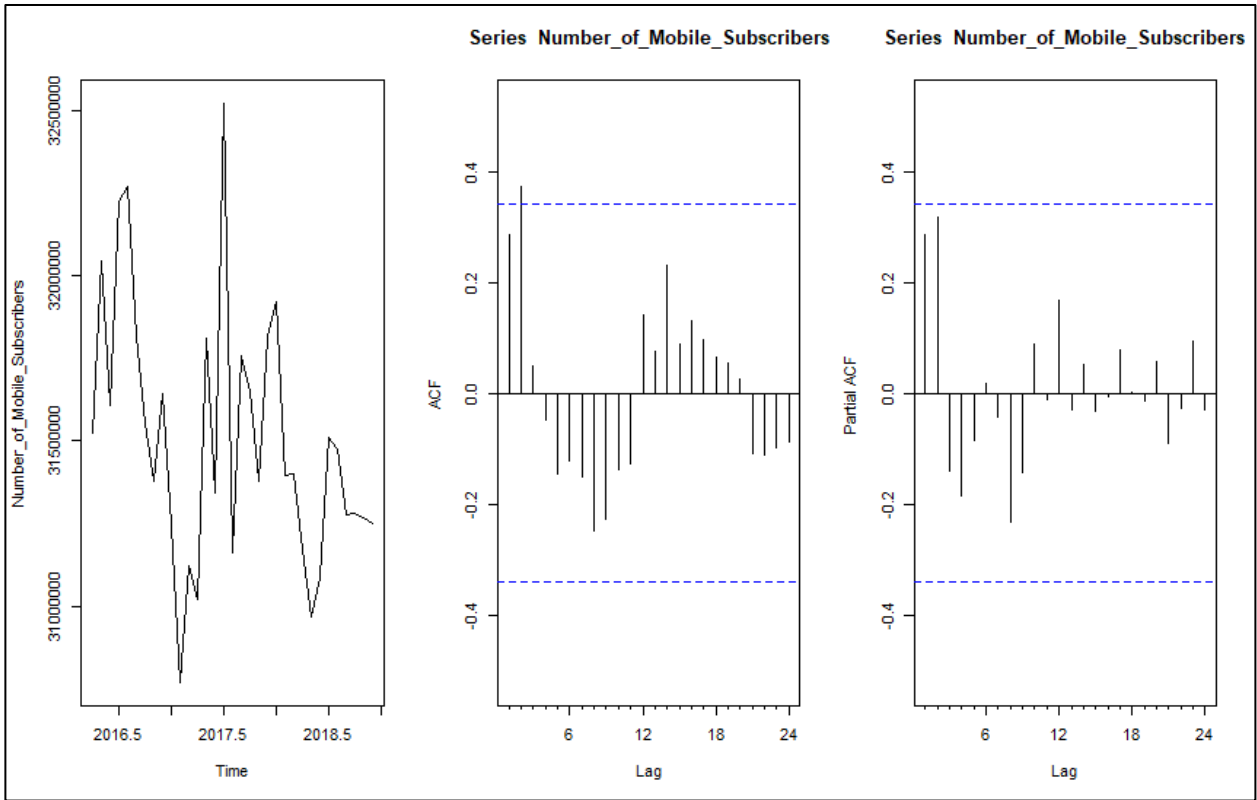
APPENDIX C

Time Series, Autocorrelation Function, and Partial Autocorrelation Function Plots of Time Series Data Used for Quantitative Forecasting









APPENDIX D

Summary of the Time Series Forecasting Models Used for Quantitative Forecasting

Series: LTE_Mobile_Data_Volume
ARIMA(0,2,1)

Coefficients:

ma1
-0.8473
s.e. 0.1009

sigma^2 estimated as 5.63e+09: log likelihood=-392.11
AIC=788.22 AICc=788.64 BIC=791.08

Training set error measures:

	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
Training set	16684.57	71541.07	54069.41	1.150787	5.04876	0.05494453	-0.08461738

Series: Total_Mobile_Data_Volume
ARIMA(1,1,1)

Coefficients:

ar1 ma1
0.9997 -0.9855
s.e. 0.0018 0.0503

sigma^2 estimated as 2.503e+10: log likelihood=-428.58
AIC=863.17 AICc=864.03 BIC=867.57

Training set error measures:

	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
Training set	25279.84	150845.2	110442.4	0.9921926	4.402132	0.08861152	0.02600931

Series: Number_of_LTE_Users
ARIMA(1,1,1)

Coefficients:

ar1 ma1
0.9956 -0.8499
s.e. 0.0299 0.4550

sigma^2 estimated as 3.103e+10: log likelihood=-432.04
AIC=870.09 AICc=870.95 BIC=874.49

Training set error measures:

	ME	RMSE	MAE	MPE	MAPE	MASE	ACF1
Training set	9780.15	167962.5	130205.3	0.3517901	1.677991	0.03342374	0.3314193

Series: LTE_Average_Download_Throughput
Linear Regression

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	50.13319	0.73676	68.046	< 2e-16 ***
trend	0.28353	0.03781	7.499	1.89e-08 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.068 on 31 degrees of freedom
Multiple R-squared: 0.6446, Adjusted R-squared: 0.6331
F-statistic: 56.23 on 1 and 31 DF, p-value: 1.892e-08

	ME	RMSE	MAE	MPE	MAPE	MASE
Training set	0	2.004595	1.753116	-0.1337676	3.224129	0.6331711

Series: Number_of_Smartphones
Linear Regression

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	21068842	157007	134.191	< 2e-16 ***
trend	109220	11954	9.136	1.41e-08 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 355700 on 20 degrees of freedom
Multiple R-squared: 0.8067, Adjusted R-squared: 0.7971
F-statistic: 83.47 on 1 and 20 DF, p-value: 1.413e-08

	ME	RMSE	MAE	MPE	MAPE	MASE
Training set	-6.773152e-10	339173.5	286142.1	-0.02468244	1.291153	0.4570516

Series: Number_of_Mobile_Subscribers
Linear Regression

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	31773894	131721	241.222	<2e-16 ***
trend	-15837	6760	-2.343	0.0257 *

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 369800 on 31 degrees of freedom
Multiple R-squared: 0.1504, Adjusted R-squared: 0.123
F-statistic: 5.488 on 1 and 31 DF, p-value: 0.02574

	ME	RMSE	MAE	MPE	MAPE	MASE
Training set	1.128846e-10	358390.7	270040.9	-0.01285099	0.8549549	0.8750032

Series: Mobile_Video_Data_Ratio
Linear Regression

Coefficients:

	Estimate	Std. Error	t value	Pr(> t)	
(Intercept)	0.408588	0.020425	20.005	< 2e-16	***
trend	0.004955	0.001275	3.887	0.000663	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.0516 on 25 degrees of freedom

Multiple R-squared: 0.3766, Adjusted R-squared: 0.3517

F-statistic: 15.11 on 1 and 25 DF, p-value: 0.0006626

	ME	RMSE	MAE	MPE	MAPE	MASE
Training set	2.05502e-18	0.04964951	0.04057123	-1.254124	9.04061	0.7728257

CURRICULUM VITAE



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01.07.2010 – 01.10.2010 : Young Talent (PAF) Program • Turkcell

01.06.2009 - 01.09.2009 : Young Talent Program • Vodafone Turkey

Education:

01.09.2014 – current : Engineering Management Ph.D. Program, Marmara University

01.09.2010 - 01.11.2013 : Engineering Management M.Sc. Program, Istanbul Technical University

01.03.2010 – 01.04.2010 : Athens Exchange Program, Delft Technology University, Netherlands

01.09.2005 - 01.06.2010 : Telecommunication Engineering BSc. Program, Istanbul Technical Uni.

Expertise:

5G & LTE Radio Network, Mobile Device & Chipset Technologies, Smartphone Performance Analysis, SmartLab Engineering, Data Mining, Technological Forecasting in Mobile Telecommunication Ecosystem, 5G and beyond Technologies, Internet of Things.

Language:

Turkish (native), English (advanced), German (intermediate).