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CICLO XXVII

ROADMAPPING FOR CORPORATE STRATEGY: ACTION RESEARCH IN CONVERGENCE OF TECHNOLOGIES

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Esposizione Riassuntiva / Abstract

Italian Version

Questa tesi di dottorato verte sulle implicazioni strategiche della penetrazione delle tecnologie wireless e consumer in auto, un trend di crescente importanza. La convergenza di tali mercati, vale a dire del settore consumer e della connettività ed infotainment in automotive, genera opportunità e minacce, oltre che possibilità di ricerca. Un progetto di Action Research è stato effettuato presso uno dei principali Tier 1 del settore automobilistico e delle telecomunicazioni, al fine di implementare un processo personalizzato di Technology Roadmapping (TRM), in grado di riconoscere e operare in un contesto in rapida evoluzione e di gestire le implicazioni nell'organizzazione, a vari livelli e in modo dinamico. Un nuovo processo di TRM "on demand" e generale è stato ottenuto e aggiunto alle pratiche esistenti, consentendo un migliore supporto al processo decisionale strategico e alla pianificazione multi-progetto.

English Version

This PhD thesis deals with the strategic implications of the penetration of consumer wireless technologies in vehicles, which represents a trend of growing importance. The convergence of such markets, namely the consumer industry and the automotive connectivity and infotainment areas, generates opportunities and threats, and research possibilities. An Action Research project was carried out at a leading Tier 1 automotive firm, aiming to implement a customized Technology Roadmapping (TRM) process, able to recognize and deal with a fast changing context, and to manage implications within the organization, at various levels and very dynamically. A new "on demand" overarching TRM framework was obtained and added to the existing practices, enabling better support to strategic decision making and multi-project planning.

Keywords

Action Research, Architecture, Automotive, Connectivity, Consumer, Convergence, Innovation, Planning, Project Portfolio, Strategy, Technology Roadmapping, Wireless.

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List of Acronyms and Abbreviations

Table 1 – Acronyms and Abbreviations

1G	1st Generation of cellular telephony (GSM)
2G	2nd Generation of cellular telephony (DCS etc.)
3G	3rd Generation of cellular telephony (UMTS)
4G	4th Generation of cellular telephony (LTE)
AIL	Action Item List
AM	Amplitude Modulation
AR	Action Research
ATSC	Advanced Television Systems Committee
BU	Business Unit
CEO	Chief Executive Officer
CES	Consumer Electronic Show
CD	Compact Disc
Ce.R.Ca.	Calearo Research and Development Centre
CP	Circular Polarization
CSF	Critical Success Factors
C2C	Car-to-Car
C2I	Car-to-Infrastructure
DAB	Digital Audio Broadcasting
DCS	Digital Cellular System/Service
DSRC	Dedicated Short Range Communications
DRM	Digital Radio Mondiale
DVB-SH	Digital Video Broadcasting Satellite Handheld
DVB-T	Digital Video Broadcasting Terrestrial
DVB-T2	Digital Video Broadcasting Second Generation Terrestrial
DVD	Digital Versatile Disc
ECU	Electronic Control Unit
ESA	European Space Agency
E/EE	Electrical/Electronic (acronym typically used so in automotive)
FM	Frequency Modulation

GLONASS	Global Navigation Satellite System
GPS	Global positioning system
GSM	Global System for Mobile Communications
G/T	Gain over Temperature
HD-Radio	Hybrid Digital Radio
IF	Impact Factor
Infotainment	Information and entertainment (typ. automotive)
IRM	Industry Roadmap
KPI	Key Performance Indicator
LITREV	Literature Review
LTE	Long Term Evolution
OEM	Original Equipment Manufacturer
NF	Noise Figure
NDA	Non Disclosure Agreemen
NPD	New Product Development
PC	Personal Computer
PCB	Printed Circuit Board
PoC	Proof of Concept
PP	Product Portfolio
PPM	Project Portfolio Management
PRM	Product Roadmap
PTRM	Product-Technology Roadmap
RF	Radio Frequency
RfI	Requests for Information
RFID	Radio Frequency Identification
RfQ	Request for Quotation
RKE	Remote Keyless Entry
RQ	Research Question
RX	Reception
R&D	Research and Development
SBU	Strategic Business Unit
SDARS	Satellite Digital Audio Radio Service
SME	Small and Medium Enterprise
SOP	Start Of Production
STRM	Science-Technology Roadmap
TMPS	Tyre pressure Monitoring System
TRM	Technology Roadmapping
TX	Transmission
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VANET	Vehicular Ad hoc Network
WS	Workshop
W-LAN	Wireless Local Area Network

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I am indebted to Prof. C. Forza and Prof. R. Filippini, from Università degli Studi di Padova, for their precious insights and inspirational suggestions throughout the often solitary path of my PhD. I was fortunate to exchange impressions with Prof. S. Biazzo, from Università degli Studi di Padova, whom helped my with his passionate and accurate inputs and experience sharing on Roadmapping, and on doing research and applying it in corporations. I would also like to thank Prof. A. F. De Toni, from Università degli Studi di Udine, for his unconventional thinking and charismatic problem setting. I want to mention Dr. C. Battistella, from the Free University of Bozen, for her revisions of some of my work during the PhD years.

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Furthermore, my recognition goes to a few of my colleagues and team members at Calearo Group and Ce.R.Ca., who have provided continuous help and feedback while applying some management tools and innovative ideas emerging from my research and my workshops.

Lastly, but very importantly, this project could not have been done without my family, namely my wife and my young son, and without their constant patience and caring support every time I was so passionately involved in my PhD activities and challenges.

1 Introduction

This research project stems, on one side, from the direct interest of a leading Tier 1 supplier and its top management, of which incidentally I am a member, to capture, analyze and develop a better understanding of the strategic perspectives, and to set up adequate actions and tools. This applies in particular in relation to those trends and patterns in the automotive sector, in the context of current and future wireless applications and innovations, whereas consumer products and technologies for connectivity are more and more frequently being offered and becoming available in vehicles.

Furthermore, this practical involvement is juxtaposed to the research aim to study theoretical and methodological opportunities and issues present in case of fast changing context, as well as when architectural innovations and new technologies allow unexpected changes in an otherwise stable business arena. The coming together of those different objectives and singular circumstances has suggested to investigate on a tool in particular, apparently able to support strategic decision making with growing frequency in corporations, such as the Technology Roadmapping. To do so, Action Research was the core methodology used, as it shall be illustrated in detail throughout the present thesis.

This first chapter is structured as follows. The next Section 1.1 provides a brief background of the research. Section 1.2 illustrates the contextualization of the research. Section 1.3 specifies the overall research purpose. Furthermore, scope, goals, main definitions and methods are set and presented in Section 1.4. Finally, a description of the PhD thesis structure is outlined in the concluding Section 1.5 of the present chapter.

1.1 Background

For incumbent firms, especially in the recent turbulent years, adequately mapping the competitive landscape, timely recognising potential threats as well as opportunities, and, consequently, boldly acting or reacting within the necessary timeframes, are issues of critical importance. A large set of management practices is available, and some tools are established and have been known and used for a long time, while others are rather new or just emerging. In the specific firm under investigation, Calearo Group, where the research actually originated and eventually took place, some tools are in use, whilst others on the contrary might be at least desirable or particularly important, even if just known and never applied. The different practices could as well be more or less effective depending on the specific situation, scope, or business area under analysis. Furthermore, one or another management tool, or a set of tools, could be in use just for organizational inertia, or as a habit, or for ignorance of other more appropriate ones, and so on. A large literature is available on these intriguing areas of study (Oliveira and Rozenfeld, 2010); (Teller et al., 2012).

Furthermore, the situation can become even more critical and dangerous for the firm, in case of typical and persistent unbalanced customer-supplier relationships (Schiele, 2012). If the customers, namely top and global carmakers in this case, are practically steering the decisions of the Tier 1 supplier, driving and shaping for years its investments and development, both on products and competences, reducing the commercial force to a mere sales office merely responding to tenders and requests for quotation, then, directly or indirectly, these habits will drift the customers to other suppliers as soon technology changes or technical opportunities occur. The slowly or abruptly lack of adequate R&D, operational and sales competences, compared to other firms (newcomers, changing faster, or investing more consistently *despite* of the customers' unfair or drifting requests) shall put the firm under threat and possibly drive it out of business, without mercy (Schiele, 2010), (Ellis et al., 2012).

In such a scenario of managerial and technical threats, and in my professional role of General Manager for R&D, Innovation, Business Development and Strategy of the firm under analysis, I have been myself heavily interested and oriented to study the situation, to evaluate appropriate measures and means, and to put in place adequate tools and actions. Furthermore this situation appeared suitable to do research and to contribute, as far as possible, to the underlying management theories and tools.

1.2 Context

Founded in 1957, Calearo Group is an Italian Tier 1 supplier, present mostly in the automotive sector, in direct relationship with many global car makers, and known in particular for the design and production of antennas, cable harnesses and other products for vehicular wireless applications. Depending on the product range, it is one of the top-3 or top-5 international suppliers of its kind. As a Tier 1, it normally operates in response to strict specifications of the customers, following periodic Request for Quotations (RfQs) issued by customers for new car models or platforms, and aiming to meet demanding requirements in terms of prices, quality, supply chain, and technical characteristics. Entry barriers are present but limited for low-end products and mass market, while mid-range and premium carmakers often demand high investments, dedicated resources and production lines, custom services and localized operations, which are expensive to set up, to maintain, and, should circumstances need so, to dismantle.

As mentioned in the previous section, and typical in the often uneven customer-supplier relationship, struggling to either anticipate, recognise or react to demands for new functions, new products or new processes, or other innovations, is a normal situation for this company, as it shall be illustrated in Chapter 3. As an example, in the oligopoly of automotive suppliers, it is not unusual that one-to-one workshops and meetings are held between a carmaker and one supplier at a time. These events, often taking place on a yearly basis, mainly represent a good opportunity for the carmaker to know in better detail about the activities of suppliers, to track and assess their innovativeness and attractiveness. It is as well a way, virtually free of charge, to collect plenty of information and ideas, particularly on trends and patterns in new technologies, developments and processes, both from incumbent and new suppliers, and, indirectly, from competing car manufactures. Each supplier in fact will tend to provide the best references and advancements available. On the contrary, information and details provided from the carmaker, especially at system level, will be normally limited and very focussed on its specific goals (Takeishi, 2002).

These phenomena are dramatically magnified by at least two factors: on one side, the intensified and constantly growing speed of change, under many points of view, occurring nowadays; on the other side, the underlining relevance and increasing pressure of previously irrelevant firms, not necessarily start-ups only, coming from other market areas, and with different business models, unusual or brand new for the automotive sector, namely wireless and consumer technology experts, all eventually operating and *converging* into the so called "Internet of Things" eco-system.

Once the consciousness in this potential scenario is fully, or at least partially, reached by the supplying firm, or its key persons, the issue for that company, as for example for Calearo Group, becomes therefore to investigate independently on which areas it is worth investing time and resources. To do so it is necessary as well to select methodologies and managerial tools supporting those decisions aimed at remaining present and profitable in such changing and unprecedented environment, releasing a well probably costly and risky *roadmap* of initiatives and developments. The challenge here has been as well accepting and exploiting the need to extend the project and newly proposed practices at various levels, in line with the different priorities, and namely at Corporate level, at Strategic Business Unit level, and at a specific Technology/Product Portfolio level, as it will be reported in particular in Chapter 4.

1.3 Purposes

With an embryonic but clear managerial feeling that important changes are being planned, if not already occurring, in the just mentioned core technologies and business areas, at least to some extent, it was decided to invest time exploring how this firm, well established and incumbent in its market, should deal, internally and externally, with the described context and unresolved issues. This concern and urge for action requested to learn in detail about the status quo, studying and defining possible options, implementing solutions, and testing them, so to reach the most balanced managerial decisions for the future investments of the firm, and with the introduction and application of the most adequate managerial tool, possibly beyond the classic intra-business competitive analyses and the already available practices. This emerging and crucial motivation is illustrated in Chapter 3.

During the early phase of this PhD project, the words of Dr. Zetsche (Chief Executive Officer (CEO) of Daimler AG and Head of Mercedes-Benz Cars), pronounced during his keynote speech at the Consumer Electronic Show (CES) held in Las Vegas in early January 2012, appeared of particular pertinence and inspiration: "Connectivity cannot only safeguard existing benefits of mobility but can create additional ones", and so he indicated the need to "match the pace of automotive innovation with that of consumer electronics" (Daimler Communications Press Release, 10 January 2012).

These concepts were delineating the central problem that was to be dealt with, and possibly solved, both at theoretical level, as well as in practice. There was to understand and establish a better or more effective methodology to cope with the ongoing technology changes, the struggling sales, the possibly weakening product portfolio offering, and the need for a better corporate strategic planning tool. From there, it was also to find out how to put different departments in better connection and in adequate conditions to empower strategic decisions and leverage outcomes.

Since the speech of Dr. Zetsche back in 2012, the vehicle has become more and more a *device*, a connected object that operates in mobility, within a gigantic and fast-growing network of interconnected devices. The car is now often labelled as "smart", as it happens nowadays for many other concepts or products, such as cities, homes, phones, wearable objects, sensors, etc., often altogether named after the "Internet of Things" (or even "Internet of Everything") paradigm.

As it shall be reported in Chapter 3, it was decided to aim at the mentioned objectives with help of the Technology Roadmapping (TRM), a managerial tool by definition seeming very suitable for this purpose and of growing relevance in academia as well as in corporations. Once the systematic literature review in field of TRM was completed, as it shall be presented in Chapter 2, it highlighted various gaps and research areas, with four research questions (RQs) in total, whereas the two overall and central questions of the PhD project could be outlined as follows:

- How can the Technology Roadmapping process be customized to help meeting the objectives of a multi-project oriented company, operating in a competitive arena of converging technologies?
- How can the customized Technology Roadmapping process be integrated with the company's existing management practices, to help identify relevant trends and patterns, and sustain strategic decisions and projects?

The overarching objective to be achieved is therefore the research and design of the new strategic and operative action plan for the firm in urgent need of it, with the application of the TRM methodology in a real environment, while other practices are necessarily already in use.

1.4 Definitions, Scope and Methodology

Technology Roadmapping in the recent literature is considered a flexible management tool of growing relevance for academics and practitioners, particularly suitable to align future technologies and products with business strategy, which can become of primary importance and great help in turbulent times (Phaal et al., 2004b). In fact, timely understanding which market segments, features, technologies and products are going to be relevant or successful, and when, and how long for, can turn into a matter of life or death for companies, especially those not systematically supported by sufficient investments and resources devoted to strategic analyses and such. More on this will be provided in Chapter 2.

The definition of Technology Roadmapping is itself an issue often debated in the literature, nevertheless it is frequently defined as a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs, whereas its typical output is a Technology Roadmap, which identifies precise objectives and helps focus resources on the critical technologies that are needed to meet those objectives (Garcia and Bray, 1997). In the literature analysis several gaps and promising areas of investigation could be found, as this area of research seems very actual, and the application of the selected tool is still in an exploratory phase, and growing.

The main scope of this research project is to focus on how to guarantee and allow the increasingly limited R&D investments, and other types of strategic initiatives, being planned and deployed as effectively as possible, in the given turbulent and changing context. In parallel to the managerial perspective, from the technological point of view, the main scope of the research is to help maximize results where *convergence* occurs, being it defined as “the unification of functions, the coming together of previously distinct products” (Yoffie, 1997).

Among other recognised trends and ongoing convergence of technologies, the case and urgency to investigate with regard to the European telecommunication technologies in S-band well matched with both the ongoing research plan, and with the practical needs. In fact, studying about the S-Band standards, their potential impact on the automotive market, the possible dedicated product portfolio, also in relation to other consumer technologies and products in particular, was used to further experiment and practice the TRM tool. Actually Chapter 5 will be dedicated to this topic and the product family that generated from dedicated design projects.

Now, the overall plan for the present PhD project involved an active participation of the researcher in managing and resolving some of the problems present in the given context and in the described organization. A priority was to focus on how to resolve the described problems, and therefore on managing changes in the organization object of the study. Taking into particular account the research questions as previously formulated, exactly on how to improve existing practices, and customise new possible tools to do so, in a dynamic, cooperative and iterative way, and to address this issue in the most objective way, it was evaluated and decided to use the Action Research (AR) method.

Action Research resulted very suitable in the given context, to experiment actively, to do research, to assess and to learn in depth about the theory, the selected tool and the context, and driving possible changes while doing the research, even in the three different described levels (Corporate, Strategic Business Unit, Technology/Product Portfolio). Also in comparison to other possible research methodologies, as in particular the case study (also as longitudinal research), the chosen method was assessed as the most adequate to interact with the organization and to manage and build theory on the foreseen changes.

Finally, Action Research was also chosen as it is by definition an approach to research that aims both at taking action, i.e. solving one or more problems, and creating knowledge or theory about that action, i.e. contributing to science (Coughlan et al., 2002). And the possibility to do empirical research throughout the present PhD project while implementing for real and in real time the four steps of Constructing – Planning action – Taking action – Evaluating action (Coughlan et al., 2010) was recognized, also with the aim to maximize the potential results and the possible contribution to the theory.

1.5 Thesis Outline

This research project during the three years of the PhD program was conducted with passion and high devotion, balancing the eager to contribute to the theory and do academic research at managerial and technological levels, with the need and motivation to plan and obtain actions and results managing and working in a real, challenging industrial environment. Continuatively collaborating and exchanging experiences and workings with professors, researchers, and other academics, as well as with collaborators and colleagues, was actually important and enriching.

The hard work as exploited provided the opportunity to communicate various results in scientific outlets, and originated several publications over the last 3 years. The following list is a summary of the published papers for the present work:

P1) D. Zamberlan (2012), "Strategic Implications of an Innovative Architectural Change: Evidence from Automotive Antenna Systems", in M. Muffatto and P. Giacon (Ed.), *Entrepreneurial Strategies and Policies for Economic Growth*, Libreriauniversitaria.it, Padova, pp. 755-768.
P2) D. Zamberlan, M. Pannozzo, L. Salghetti Drioli (2013), "S-Band Transmit/Receive Antenna Systems for Automotive Satellite Applications", *International Journal of Satellite Communications and Networking*, first published online: 23rd October 2013, DOI: 10.1002/sat.1041.
P3) D. Zamberlan (2014), "A review of the technology roadmapping literature targeting strategic trends and patterns in the automotive and consumer wireless technologies", EDIM2014.
P4) D. Zamberlan, M. Pannozzo (2014), "Potential Implications and Roadmapping of Satellite Bidirectional S-Band Antennas in the Automotive Market", *IEEE Antenna and Propagation Magazine*, Vol. 56, No. 2, pp. 240-250.
P5) D. Zamberlan, C. Battistella, A. F. De Toni (2014), "A Framework for Strategic Action with Technology Roadmapping: an Action Research in Converging Automotive and Consumer Wireless Technologies", EurOMA2014.
P6) D. Zamberlan, M. Gallo, R Caso, P. Nepa (working paper), "A review in field of automotive antennas: publications and patents for roadmapping".

Based on these achievements and further workings, this PhD thesis follows this structure:

- The next Chapter 2 describes the systematic literature review carried out with regard to the strategic context, the Technology Roadmapping, and the S-Band technologies. It highlights gaps, possible research areas and the research questions. It is based on the cited paper P3).
- Chapter 3 provides details about the background and the context that originated from the early research period, setting the key problems, and inspiring the choice of TRM. It is based on the paper P1).

- Chapter 4 provides insights and details on the main methodology used, the research design and the core phases of the execution of the TRM processes with help of the Action Research. It is based on the paper P5).
- Chapter 5, intended as an extended analysis of one of the TRM processes presented in Chapter 4, illustrates the specific Technology/Product Portfolio Roadmapping for S-Band, and the resulting Roadmap, with related considerations originated during the research design and activities. It is based on the paper P2) and on the paper P4).
- Chapter 6 then provides a overarching discussion over the results of Chapters 3, 4, and 5, in relation to the literature, and including hints on the working paper P6), and other future activities.
- Chapter 7 is wrapping up the project and providing the Conclusions of the present PhD thesis.
- Chapter 8 finally report the references collected and analyzed throughout this work.

The following graph visually describes the logic flow of these chapters, from this introductory one until the bibliography provided in the last chapter.

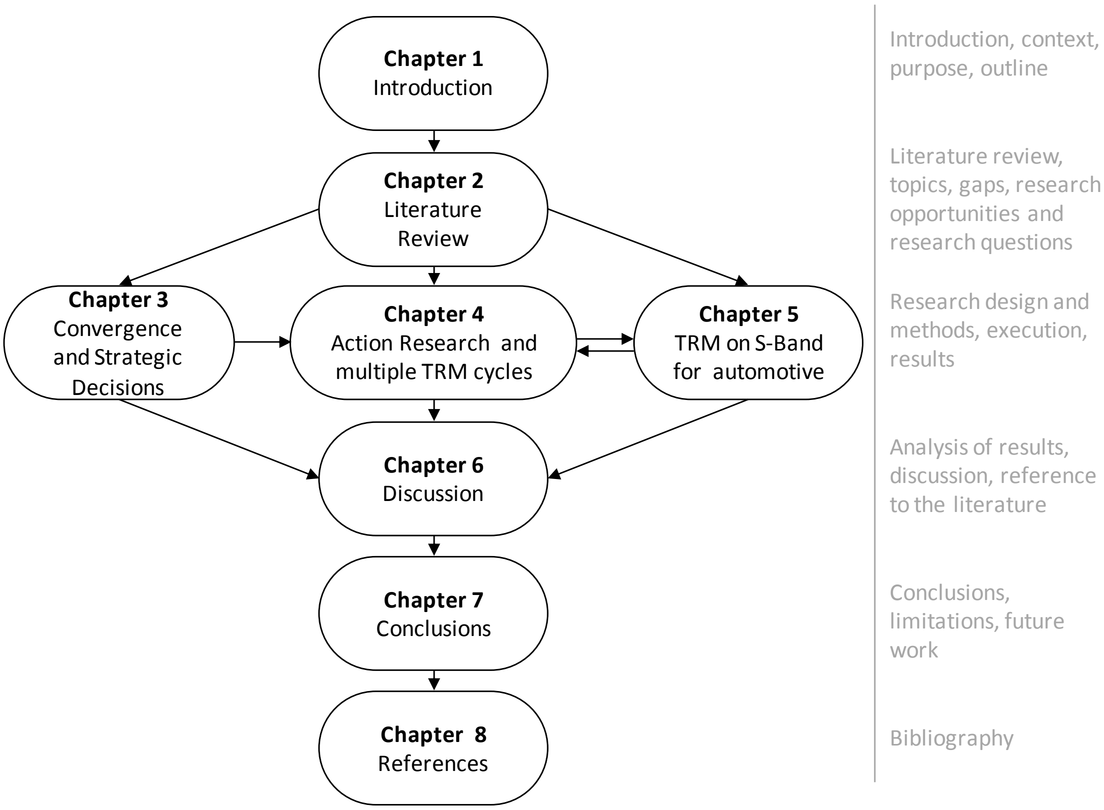


Figure 1 – Schematic logic flow of the thesis

2 Literature Review: Automotive Wireless, S-Band, TRM

This chapter reports the literature review carried out for the main topics under investigation. The identified implications, gaps and opportunities emerging from existing theory and publications are then discussed. The main focus and research topic here studied and critically evaluated is the Technology Roadmapping (TRM), as stated in Chapter 1. Furthermore, background and literature on two other main topics actually relevant for the project, and which shall be investigated in detail, is provided.

Initially, Section 2.1 is important to describe the first topic, namely the context of technologies for connectivity and antennas in vehicular applications. The indications found also in the specific literature analysed, especially focussing on evolutions and technologies in the automotive and wireless markets, are highlighted. Consequently, potential architectural innovations originating in relationship with these changes and convergence are documented. These aspects, mostly stemming from managerial intuitions and empirical evidence, are actually of particular relevance as they contribute to motivate the consequent choices and developments of the conceptual framework and managerial steps throughout this PhD thesis.

Section 2.2 covers the second topic, namely an extensive systematic literature review done in the field of Technology Roadmapping. This indeed constitutes the core topic of the present work. Based on the different sources found, analysed and selected, the TRM literature is studied quantitatively first, and then the outcomes are put in perspective and adequately clustered, so to recognise the different theoretical positions, and to synthesise the research areas and those of specific interest in the field.

Furthermore, in Section 2.3 a more technical literature review is reported, as it refers to the third and last topic, a specific Technology/Product Portfolio Roadmapping phase, carried out during the research project. In fact, one of the wireless systems emerging from the ongoing convergence and able to potentially add value and modify the connectivity services in automotive, could be the S-Band. The S-Band technologies, taking inspiration from other typical satellite and handheld features, can contribute to sustain the convergence of wireless and automotive functions. And the actual urgency present in the firm under investigation to decide and plan actions on the S-Band technologies well matched the practical need to understand how to deal and to effectively experiment the TRM tool, in its various phases and levels, as desired.

Finally, in Section 2.4, a synthesis is first provided, with the explicit statement of the hypotheses and research questions, and details on how they derive from existing theory and literature are given. The need for this study and the likelihood of its contribution and potential of obtaining relevant results are stated, through the rationale for the study. The present chapter ends then by focussing on the importance of the methodology thereof selected in the framework of the following chapters of the thesis, based also on the relationships among the considered topics.

2.1 Topic 1: Convergence in Automotive Wireless Services

During the last decades, automotive original equipment manufacturers (OEMs) and suppliers have increased the pace of new product launches, and at the same time OEMs have been launching more innovative features, still with stringent requirements in terms of costs, quality and schedules (Beaume et al., 2009). This has been sometimes mandatory, due to new international regulations introduced by law over time. The car industry has become one of the leading innovators and a powerful incubator of advanced technologies (Gusikhin et al., 2007). It has been quite constantly a means of technological convergence, especially via two main drivers, namely innovation and competition, for different technologies, depending on the period of time, since its early years (Mueller-Rathgeber and Michel, 2008).

For infotainment (information and entertainment), safety, comfort (telematics) and environmental compatibility the offerings brought into series production by car manufactures, and the number and configurations of devices present, either as standard or optional equipment of cars, are dramatically changing, and not necessarily growing, depending on the vehicular networks implemented. At the beginning of the introduction and evolution of automotive electronics, the number of ECUs grew, as each new function was implemented in a stand-alone device (Navet et al., 2005). This soon started having negative implications, increasing the complexity and need of high speed vehicular networks, gateways and specific architectures. Today Dedicated Short Range Communications (DSRC) and Vehicular Ad hoc Network (VANET) technologies are providing opportunities to develop various types of communication-based automotive applications (Emmelmann et al., 2010).

From the specific point of view of automotive antenna needs and technologies, an antenna is a necessary component of any wireless communications device or system, being it designed to send and/or receive radio waves, or, in other words, enabling transmission and reception of signals in free-space (Goldsmith, 2005). However, design and placement of vehicular integrated antennas result growingly difficult with the increasing number of services (Pell et al., 2011). Furthermore, as some services require multiple antennas for diversity or Multiple In Multiple Out (MIMO) techniques, the number of antennas for each system may have to be multiplied by 2, or 4, or even by higher factors. And the number of wireless communication systems can vary, up to over 15 technologies. Finally, antennas for particular applications need to be designed and optimised with support of intensive field tests, together with the architectures they are dedicated to (Alexander et al., 2011).

Automakers often need to have a higher level of architectural knowledge,on how to coordinate various components for a vehicle, than of component-specific knowledge, which is supposed to be provided by the supplier (Takeishi, 2002). This applies correspondingly for suppliers, especially in case of new developments. Also the antenna systems increasingly need to be designed together with the other parts of the architecture. Component-specific knowledge has therefore a trade-off relationship with architectural knowledge, especially where, under a strong and opportunistic division of labor, a supplier is just involved in detailed engineering of individual components, based on imposed carmaker's requirements (Bozdogan et al., 1998). This means that just recognising that a new technology is architectural in character does not give an established organisation the architectural knowledge that it needs, since the core concepts of the design remain untouched (Henderson and Clark, 1990).

This short review of the literature for this first topic originated to gain and provide a brief overview and contextualization of wireless and antenna systems in vehicles, in particular due to the intuition of disruptive emerging architectural changes occurring within the vehicular on-board networks, especially for mid-range and premium cars. The evidence is that the perspective of a Tier 1 supplier, and in particular of a leading automotive antenna maker, is poorly addressed in the literature, especially with respect to some otherwise important and recognised technologies and their changes. This topic shall be addressed and studied in more detail in Chapter 3.

2.2 Topic 2: Technology Roadmapping[1]

A profound study during the PhD project was done to generate a systematic literature review oriented to understand the status and evolution of the available literature in field of TRM. This was done to investigate if and how such body of knowledge contributes and deals with the identification and analysis of possible market, product and technology trends and patterns relevant to support strategic decision making processes, with particular focus on intra-firm-level (from Corporate to Technology/Product) roadmaps.

As mentioned in the introduction, the definition of Technology Roadmapping is itself an issue debated in the literature, frequently defined as a needs-driven technology planning process to help identify, select, and develop technology alternatives to satisfy a set of product needs, whereas its typical output is a Technology Roadmap, which identifies precise objectives and helps focus resources on the critical technologies that are needed to meet those objectives (Garcia and Bray, 1997). From the literature analysis it emerged that this area of research is very actual and still in an exploratory phase.

In the reviewed literature on TRM, there is a quantity of variations on the roadmapping tool and implementation, on its scope, on the process details and phases, and so on (Lee et al., 2013). Consequently, the resulting roadmaps can be as well quite different, depending on a range of parameters (Phaal et al., 2004a). The tool itself is not rigorously defined in its characteristics, frame, or other aspects. Actually this could even be a positive fact, in hypothesis, as long as the effectiveness of the tool is guaranteed, and as far as the flexibility of TRM is concerned. In fact, various taxonomies have also been introduced over time (Carvalho et al., 2013). This will emerge in the next pages in detail, as well as in the next chapters of the document. The starting point and the general TRM process to which this PhD project is referred is taken from Farrukh et al. (2003), and it is presented in the following figure. As easily visible, a limited number of key areas (Market/Business; Product/Service; Technology) is reported in layers, over time.

[1] This section is based on the cited paper P3) – (Zamberlan, 2014).

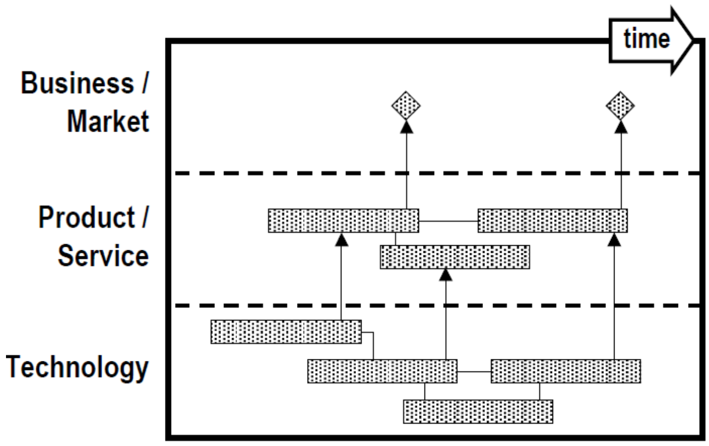


Figure 2 – Schematic Technology Roadmap for TRM (Farrukh et al., 2003)

The purpose of this review on TRM is twofold: on one hand, the results provide a comprehensive understanding of the phases, characteristics and evolution of such strategic technique. The 105 included publications illustrate a wide range of approaches and organizations where TRM was applied, and various general aspects and characteristics can be analysed. A specific clustering, carried out crossing possible types of technology roadmaps with evolution patterns, is therefore proposed and discussed. On the other hand, studying pitfalls and possible critical points with the regard to TRM and the involved aspects as well as possible gaps, research opportunities, and open questions are addressed.

2.2.1 Methodology of the Literature Review

The methodological approach here used consisted in a systematic review of the existing TRM literature, designed in particular to identify the theoretical state of the art, the main areas of use, and the practices related to such managerial tool. From there the work led a more dedicated and practical analysis, narrowed to studying the tool and its applications in the presented context.

Specifically, the directions given in Denyer and Neely (2004) and Tranfield et al. (2003) were used in the study and definition of the present systematic review, explicitly aiming to obtain replicable results. Some of the main databases as ISI Web of Knowledge, EBSCO, ScienceDirect Elsevier, and IEEE Xplore were used. It is to mention that in this particular research, the ISI Web of Knowledge database resulted the most effective, possibly due to its search engine in other databases and for its clarity and completeness of information on the identified publications. The criteria of inclusion brought to articles with availability of title, author(s), publication year and place, focussing on technology roadmap and TRM fields. Only publications written in English were considered. These were initially selected by screening titles and abstracts, then by retrieving full texts and assessing their eligibility. Only papers published between 1997 (the year of publication of the cited Garcia and Bray report) and the end of 2013 were considered. Editorials, book reviews, executive overview and proceedings were excluded. Publications related to medicine sciences were excluded as well. Exceptions, in case, are indicated.

The keywords, searched in particular in titles, abstracts, keywords, and topics, were: technology roadmap, technology roadmapping, roadmapping process, product roadmap, and industry roadmap.

After the initial planning of the review, which included the preparation of a protocol and the criteria as just described, the process went in the next central phase of the review, consisting in undertaking the research in the literature as reported in the following figure. The flow chart summarizes the work related to identifying, selecting, and assessing the eligibility of data and evidences found in the literature, before final synthesis, evaluation and dissemination steps.

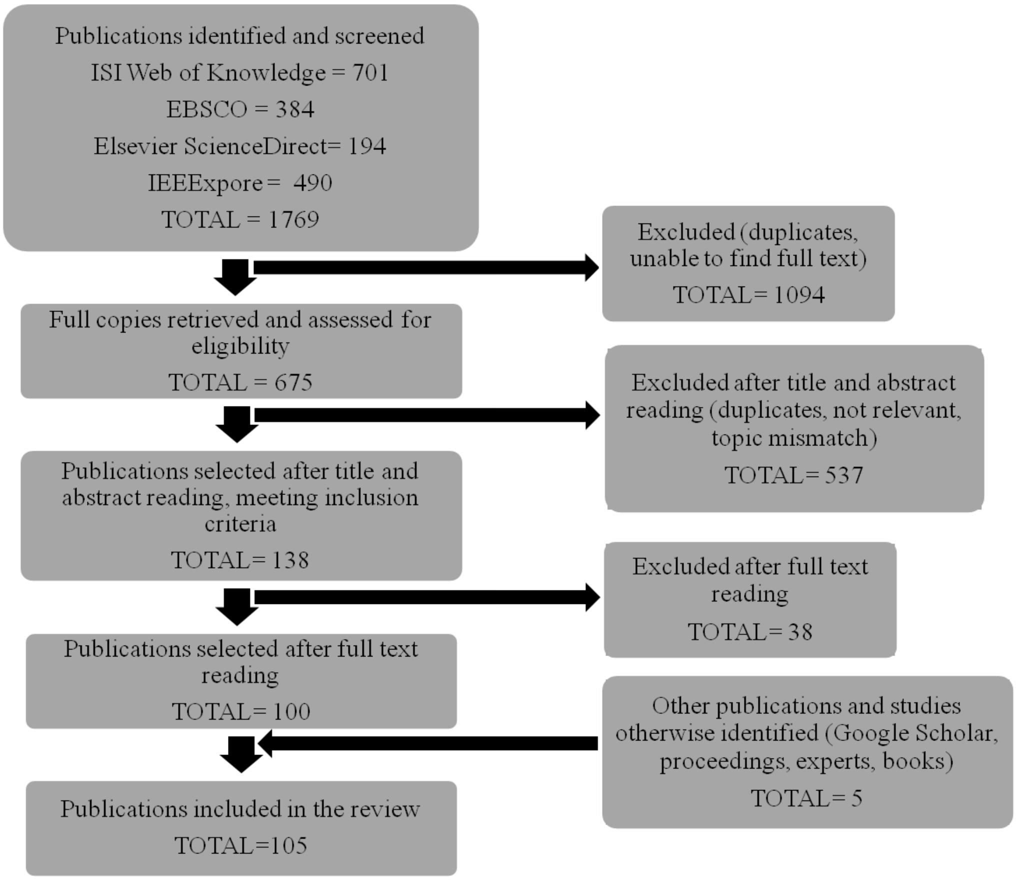


Figure 3 – Literature review flow chart, and main figures

"Roadmap" and "Roadmapping" are indeed words broadly used nowadays, also in many and diverse every-day contexts. This fact originated a very large initial selection of publications, while the first screening phase, up to reading titles or abstracts, quickly allowed the exclusion of many retrieved papers. Those in fact were often not about TRM or technology roadmaps in the scientific meaning under analysis and indicated here. Successively a more in-depth analysis of the remaining papers was actually possible and necessary, so to select and include those publications meeting the criteria as defined. After reading and including these publications, other sources or works, in fact cited in those already included, were evaluated and a few eventually included, even if not earlier or otherwise identified.

The publications selected and included in the review, 105 in total, were initially analysed according to various general criteria of occurrence, as year of publication, journal of publication, geographic area of publication and so on, which led to a first classification of the results. From there, a content review of the included publications was carried out in general terms, as it shall be described in the next sections. Furthermore, this analysis powerfully suggested attempting to innovatively utilise the emerging data and results for the specific scope and the case already stated and under analysis in the PhD project. Selected papers could be clustered critically and gaps and opportunities, as well as research questions, could be finally addressed.

2.2.2 Quantitative Results

The selected papers, retrieved as reported here above, proved that roadmapping is a research field of growing interest. The quantity of publications since 1997 is growing, going from a handful of papers in the early years altogether, to 10 or more relevant papers per annum in the last years (up to 15 included in 2004 and 2010). An overview of such growth is shown in the following figure.

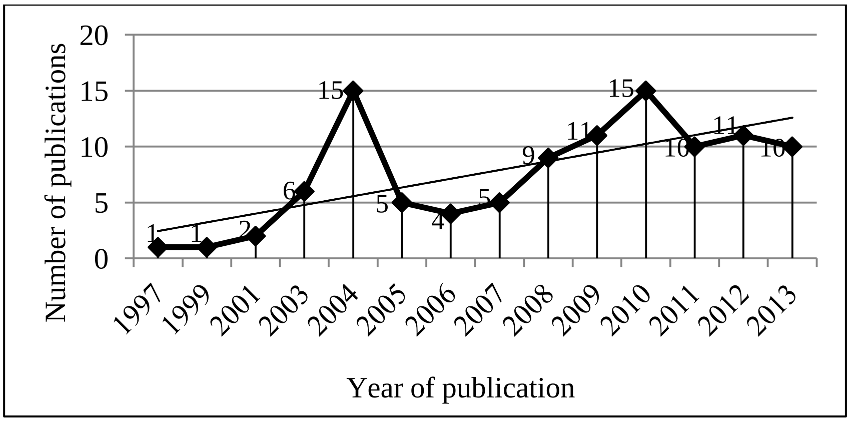


Figure 4 – Number of publications per year (bold line), and trend (linear, thin line)

The journals presenting the highest number of considered papers were "Technological Forecasting and Social Change" (Impact Factor (IF): 2.106), with over 30 publications in total over the considered years, and "Research-Technology Management" (IF: 0.77), with 12 papers, followed by many others, counting less than 10 publications each. Only few publications were included, even if not taken from journals: Albright and Nelson (2004), Arshed et al. (2012), Bruce and Fine (2004), and the already cited Garcia and Bray (1997). The next figure reports the occurrence of publications, for the different journals.

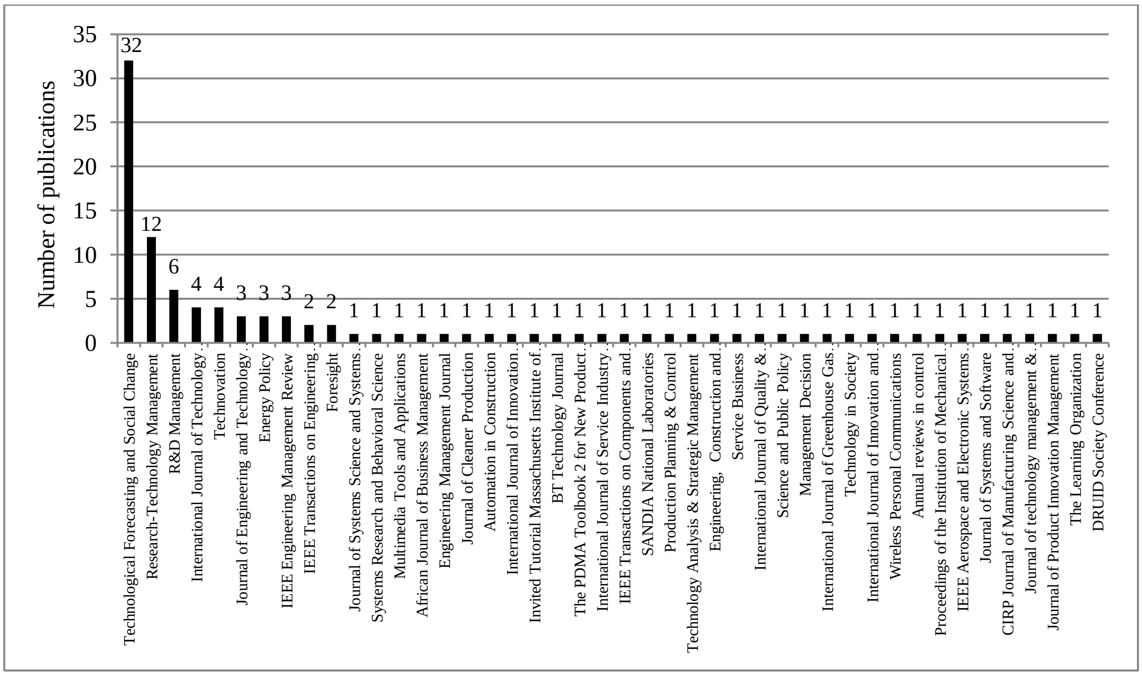


Figure 5 – Occurrence of included publications, by journal

Referring in particular to those two journals where the largest number of included publications appears, it is interesting to represent the rather different track record of published papers over the years. This is visible in the next figure.

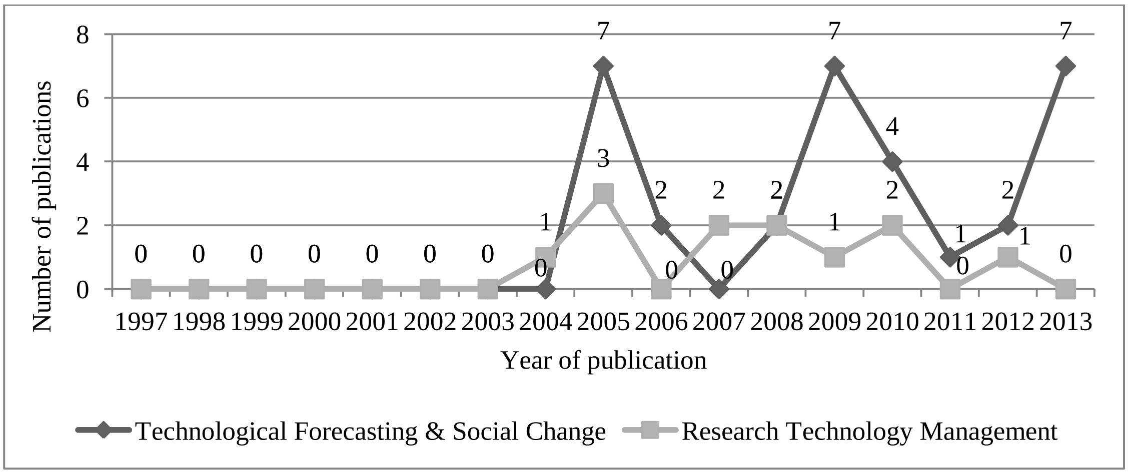


Figure 6 – Trend of included publications, for the 2 main journals

The quantity of those publications, divided per year of publication, is highlighting a particular scientific ferment in the UK, and in particular at the University of Cambridge), in the USA, in South Korea, in Japan, in Thailand, and in Germany, as reported in the following figure.

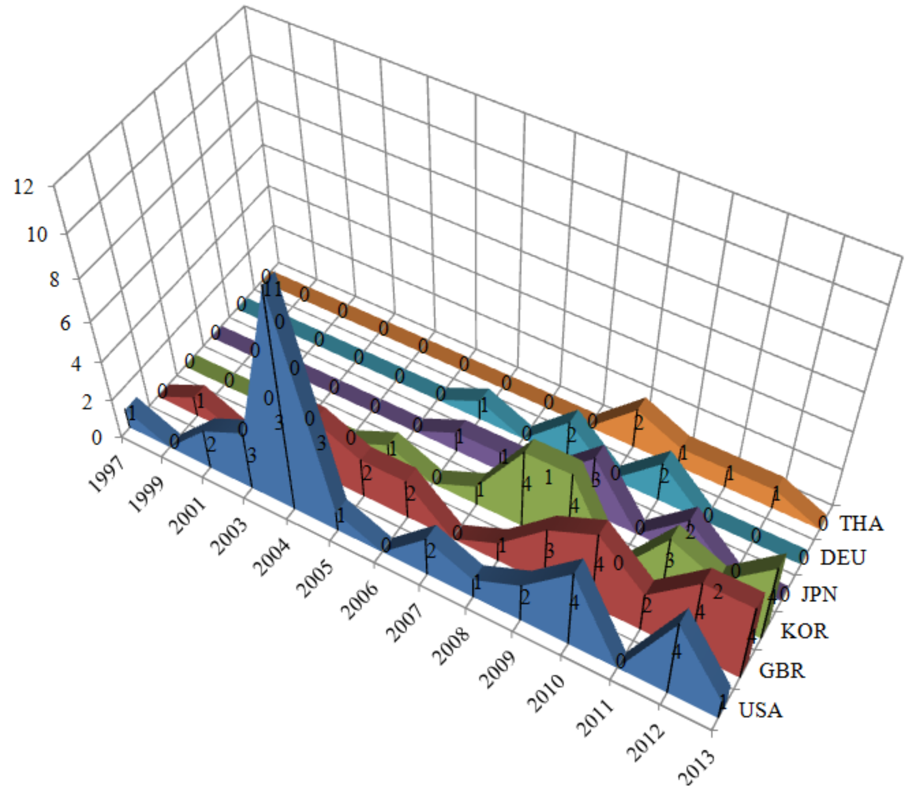


Figure 7 – Number of publications per year, for the most recurrent Nations

Finally, in terms of quantitative analysis on the included publications, a summary of the geographic distribution of the selected publications, expressed by affiliations of their authors, is reported in the following figure.

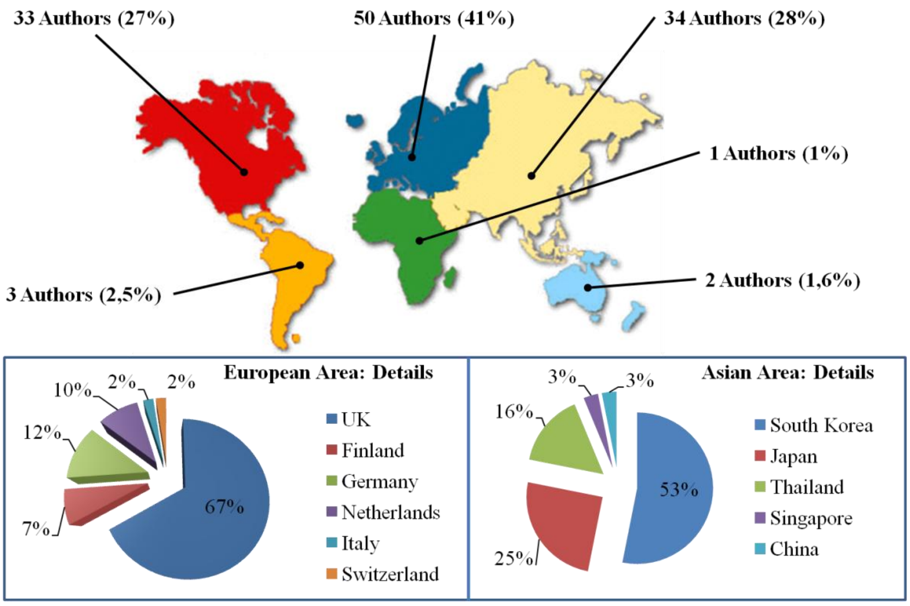


Figure 8 – Geographic distribution of the selected publications

2.2.3 Content Analysis

In terms of content analysis, it is initially worth mentioning that, within the included publications, a few reviews of the existing TRM literature have been published, as Carvalho et al. (2013), Arshed et al. (2012), Vatananan and Gerdsri (2012), Choomon and Leeprechanon (2011). In particular, Carvalho et al. (2013) provided an insightful overview of the evolution of the TRM tool, for example with an extended citation analysis, and highlighted that the large majority of the papers published in this field contributed in form of exploratory, qualitative research, mostly with case studies. Arshed et al. (2012) dealt in particular with TRM in Small and Medium Enterprises (SMEs) and the related peculiarities and criticalities. Choomon and Leeprechanon (2011) provided a rather short review and switched to a specific TRM application. Finally, Vatananan and Gerdsri (2012) described, among other aspects, the main tools in use to integrate and support TRM, together with a summary of identified research gaps and opportunities.

Most of the other papers included were written on TRM specific topics or research areas, but some offered also short reviews or insights of particular quality or interest. Lee et al. (2013) described TRM as a strategic decision supporting tool to be used for services, and not only for products. Then the paper stressed the importance of integrating TRM with other tools that are in place in organizations, like Quality Function Deployment in particular, as for example An et al. (2008). Finally, in a useful appendix, TRM processes, clustered by preliminary, development and follow-up phases, were listed. Also Fenwick et al. (2009) focussed on services, putting particular attention to the integration of TRM with marketing tools.

Suomalainen et al. (2011), more focussed on product roadmapping, discussed the role of TRM in its various fields of strategic application, taxonomies, phases, processes and stakeholders. Lee et al. (2011) focussed on R&D aspects, discussed the various definitions of TRM present in the literature, listed the potential benefits deriving from the application of TRM, and analysed the key factors influencing the TRM utilization. Amer and Daim (2010) put the TRM practices and possible scopes in perspective, with particular attention to this tool for its capacity of organizational integration. Yoon et al. (2008), providing a computer-based text analysis implementation, gave also a TRM taxonomy with six categories of roadmaps, ranging between normative or explorative, in terms of objectives, and from National/International to Industry/Cross-industry, and to Firm/Project, in terms of level of application. Walsh (2004) and Konstoff et al. (2004) focussed on models for disruptive technology roadmaps and roadmapping.

Other papers did not address a specific area of TRM application, but rather explored and described the methodology itself in its variants, main phases and implications. Under this category, various publications can be mentioned, with Kerr et al. (2013), Kerr et al. (2012), Lee et al. (2012), Kusala et al. (2012), Phaal and Palmer (2010), being the most recent ones.

Possibly one of the most cited papers in the TRM literature, as Phaal et al. (2004a), described, also graphically, 14 typologies of technology roadmaps present in the literature, clustered and depending in particular on the TRM purpose and format. For clarity on the TRM possibilities and applications, those typologies, divided in the two groups just mentioned, i.e. purpose and format, are reported in the next two figures, from the cited paper. The specific source of each roadmap representation is cited, if available, in the same paper. Out of this comprehensive list, it is to note that the TRM specifically used for this project, at least as starting point, shall be indicated later on in this chapter.

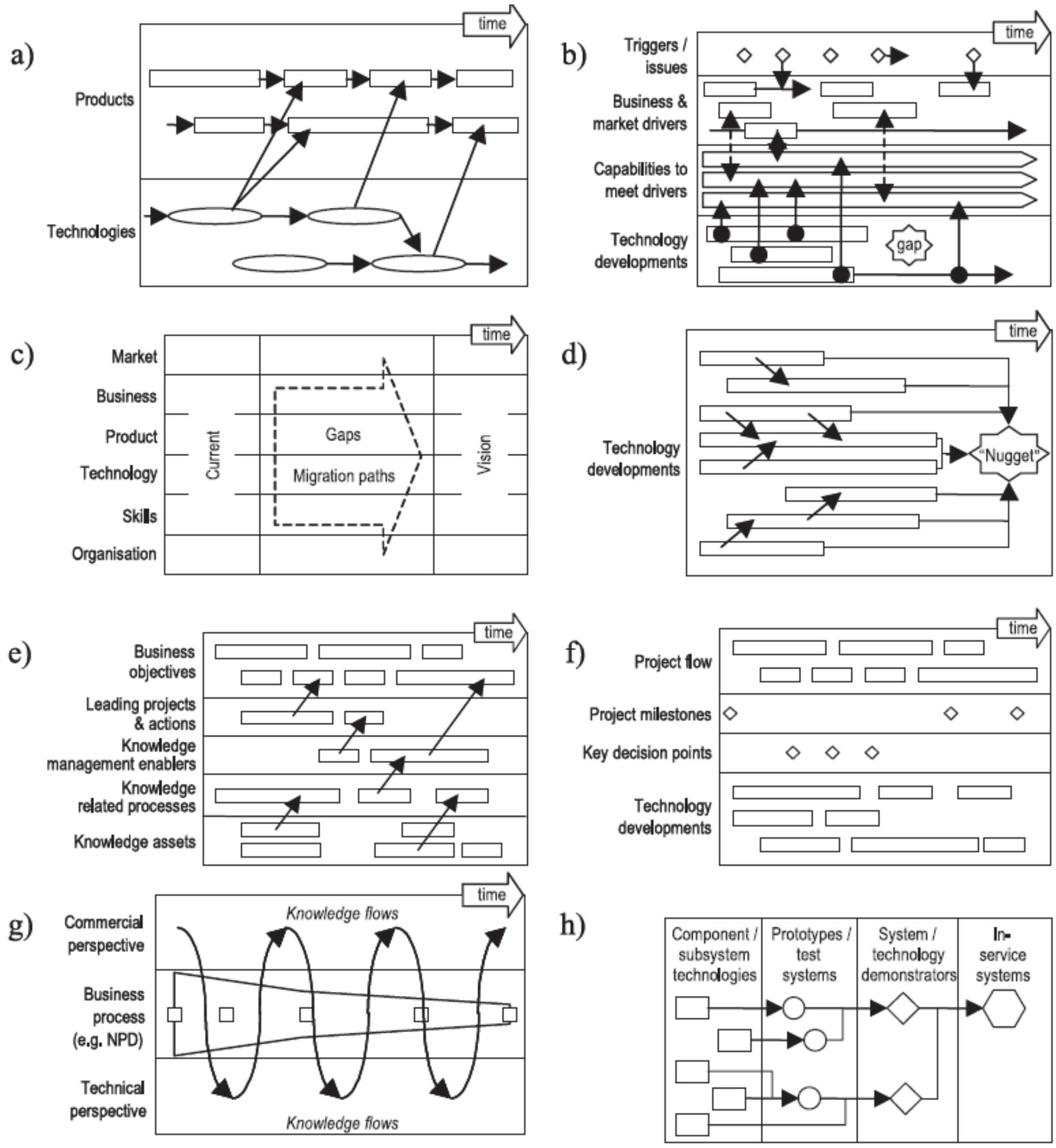


Figure 9 – Types of roadmaps and TRM, by purpose (Phaal et al., 2004a) – See text

In the figure above, the various technology roadmap types are categorized by purpose, as follows: a) product planning; b) service/capability planning; c) strategic planning; d) long-range planning; e) knowledge asset planning; f) program planning; g) process planning; h) integration planning.

The next figure provides instead an overview of the remaining 6 types of roadmaps, out of the mentioned total of 14 typologies. In this case the focus is not on the purpose, but rather on the format of the roadmap, as follows: a) multiple layers; b) bars; c) tabular; d) graphical; e) pictorial; f) flow chart.

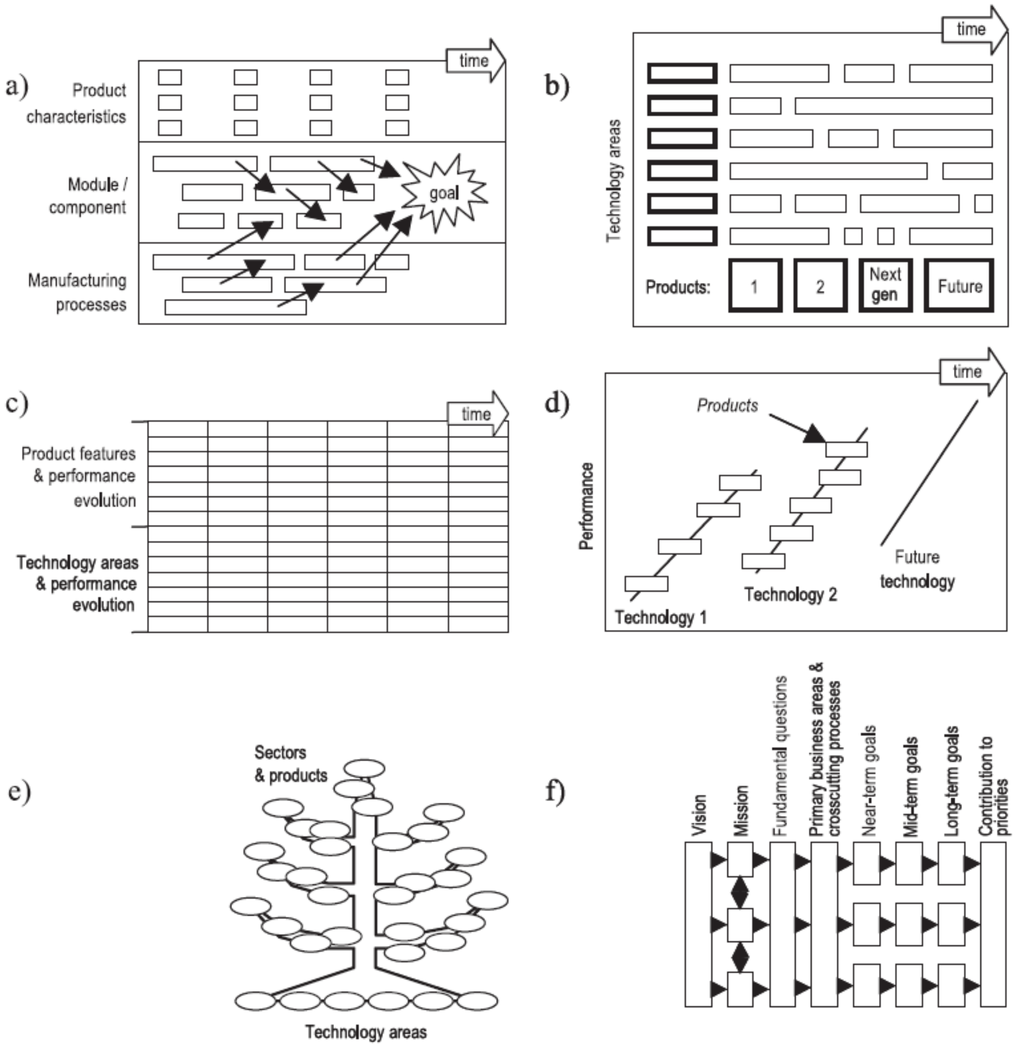


Figure 10 – Types of roadmaps and TRM, by format (Phaal et al., 2004a) – See text

The possible or specific uses of TRM have been addressed in various papers. Petrick and Echols (2004) provided an insightful perspective of TRM for decisions on New Product Development (NPD). Oliveira and Rozenfeld (2010) tried to align NPD, TRM and Product Portfolio Management (PPM), where for the latter TRM indeed seems to show a particularly critical stage. Also Albright and Kappel (2003) addressed the use of TRM for project and portfolio management. In the peculiar case of disruptive technologies, Vojak and Chambers (2003) proposed the usage of TRM to forecast and track future technologies, with the description of a new methodology, which actually included also the evaluation of architectures and architectural changes, and tested it in three interesting cases (one also being, as rarely seen, in field of automotive). The use of TRM as planning and management tool for coordination of developments and products was reported in Phaal et al. (2004a), Groenveld (1997) and several other publications.

Summarizing, most of the included papers were based on qualitative description and research on TRM, through case studies, while surveys, as for example Lee et al. (2005), seem quite rare, so far. Notably, only one single paper was based on an Action Research (AR) project, namely Caetano and Amaral (2011). Finally, as already described above at the beginning of this section, some papers were about TRM methods and models, and a minority were reviews of the literature.

2.2.4 Gaps and Research Opportunities for TRM

In line with the stated scope of the PhD project, in the present section the outcomes are put in perspective, so to assess, and eventually confirm and support, the potential applicability of TRM and the existing body of knowledge also in cases of converging technologies, and even more specifically in apparent convergence of automotive and wireless technologies, as in the indicated context and firm. Reviewing a large quantity of publications with the described methodology and criteria, led to the recognition of a still limited number of clusters and patterns throughout the papers, anyway useful to evaluate and classify the selected works. Various patterns and practices, similar among them, were found in different articles, also for different business areas and technologies, leading to comparable issues, similar measures, and possibly general solutions.

The taxonomy introduced in Kappel (2001) appeared particularly suitable and helpful to cluster papers on TRM. Interestingly, the exploration with help of the roadmapping process of existing, or new, or disruptive architectures, in this paper is explicitly mentioned: “In maturing product areas, firms also cease to invest in learning about alternative architectures. New component knowledge is more valuable to such firms because components refinement is the basis of their competitive position” (Kappel, 2001). Of course, various authors proposed other taxonomies for TRM, as the cited Garcia and Bray (1997), Albright and Schaller (1998), Yon et al. (2008). The following figure is taken from the mentioned paper of Kappel (2001).

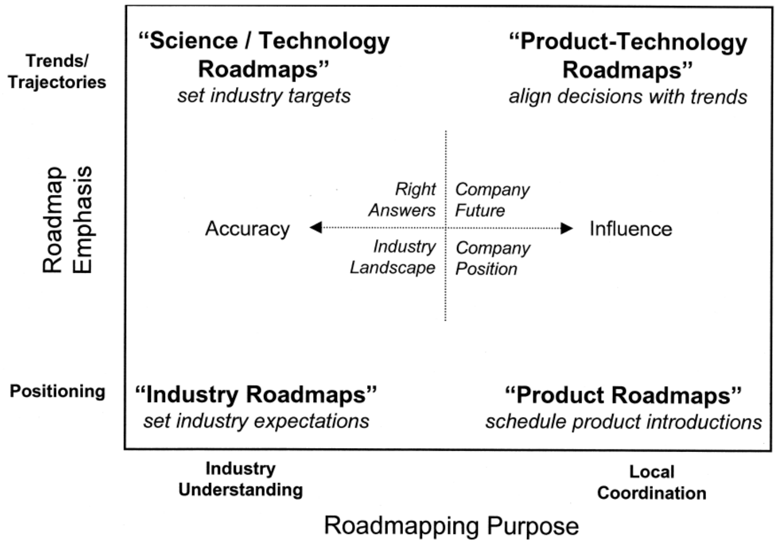


Figure 11 – Roadmapping taxonomy according to Kappel (2001)

Incidentally, the work of Kappel tackled the Product-Technology roadmaps (i.e. the Technology/Product roadmaps) with particular attention, and its emphasis on the "company future", i.e. in terms of strategy, trends and positioning, is basically just the core purpose of the overall PhD project, as emerged. Anyway, according to such clustering, among the papers selected in the systematic review, at least 7 were related to "Science-Technology roadmaps (STRM)", 38 to "Industry roadmaps (IRM)", 39 to "Product-Technology roadmaps (PTRM)", and 7 to "Product roadmaps (PRM)". The following figure shows the trend over the years for the different mentioned types.

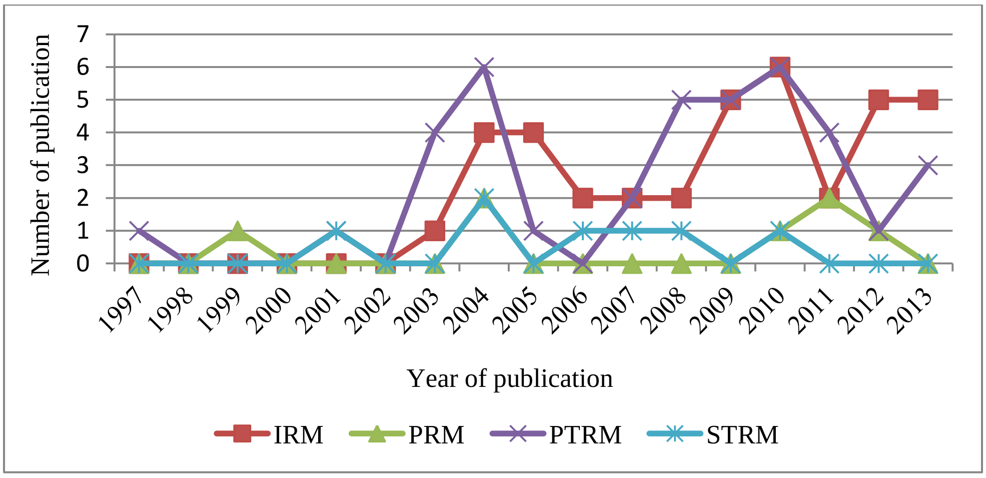
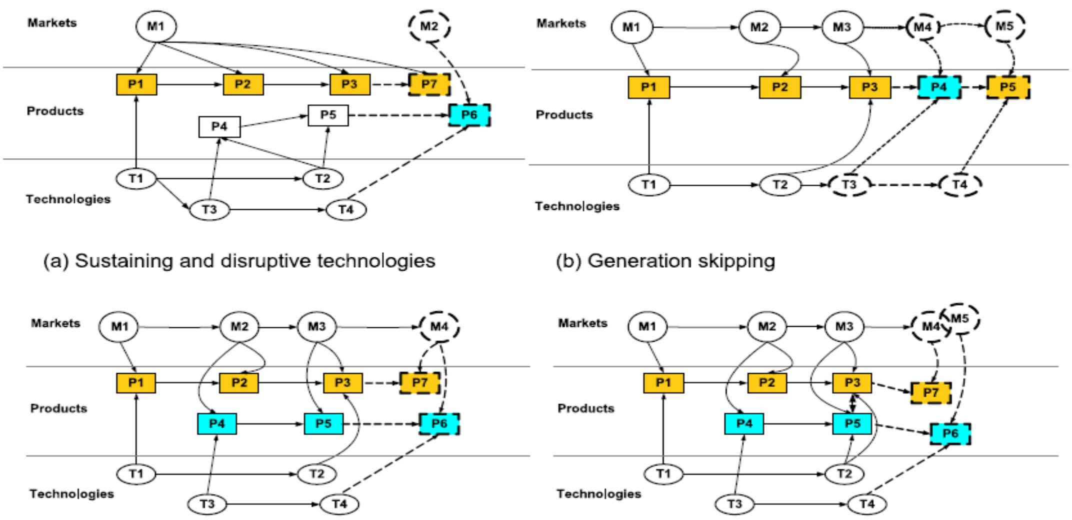


Figure 12 – Number of publications over the years for the various TRM types

Furthermore, the insightful paper of Rinne (2004) was taken as second cornerstone in this analysis to refine the taxonomy and research. In fact, nowadays it appears crucial to find and exploit management tools capable to help recognise possible patterns in markets, products and technologies, so to optimise resources utilization and efforts in companies, for example, but not only, in cases of both sustaining and disruptive innovations, and for fast evolving technologies. Therefore the included papers were then clustered so that the 4 various possible patterns listed in Rinne (2004) could be recognised. The following figure is taken from that paper and provides a visual representation of possible clusters, as then it shall be further described in the text.



(a) Sustaining and disruptive technologies (b) Generation skipping

(c) Path dependence (winner takes all) (d) Standardization

Figure 13 – Patterns of technological changes and TRM, according to Rinne (2004)

At least 65 papers dealt with “Sustained and disruptive technologies” (i.e. when new technologies or products lead to reconsider preferences), 6 with “Generation skipping” (i.e. when too many product generations appear in rapid succession), 26 with “Path dependence” (i.e. in case a winner emerges and dominates the market), and 26 with “Standardization” (i.e. where customers are freed to choose the best performing product). In some cases no pattern could be recognised, and in others a double categorization was actually possible. These results, expressed over time, are reported in the following figure.

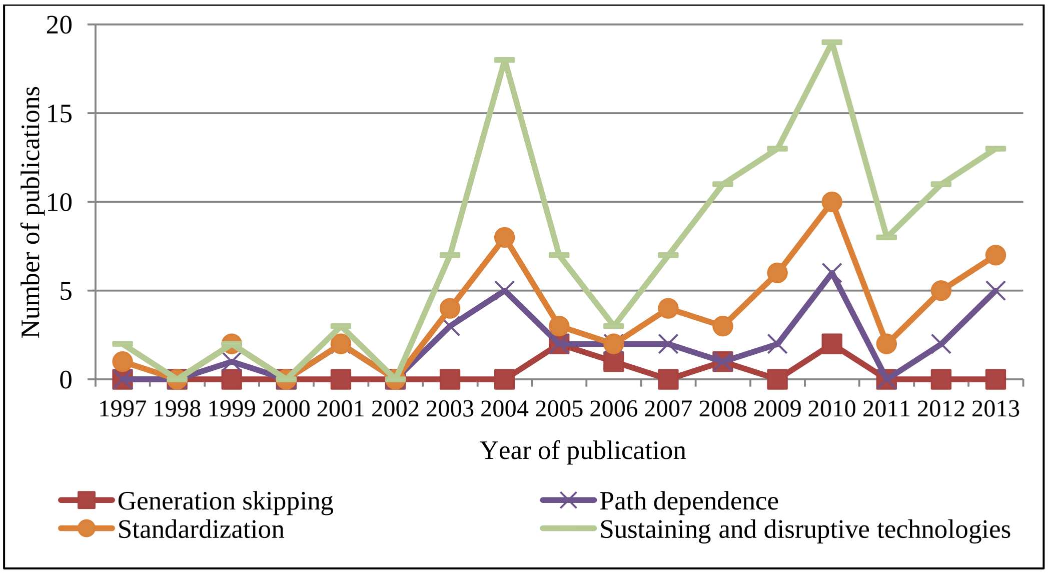


Figure 14 – Number of publications over the years for the various patterns

The complete outcomes of the overall classification and crossing of the two clustering processes just described are reported in the following table.

Table 2 – Authors, year of publication, cluster and patterns of the included papers

Authors	Year	Cluster	Main patterns
Abe et al.	2009	PTRM	Sustaining and disruptive technologies
Albright & Kappel	2003	PTRM	Sustaining and disruptive technologies; Path dependence
Albright & Nelson	2004	PTRM	Standardization; Sustaining and disruptive technologies
Amadi-Echendu et al.	2011	IRM	Standardization
Amer & Daim	2010	IRM	Sustaining and disruptive technologies
An et al.	2008	IRM	Standardization; Sustaining and disruptive technologies
Arshed et al.	2012	LITREV	Not Applicable
Blismas et al.	2010	IRM	Standardization
Bruce & Fine	2004	IRM	Path dependence
Caetano & Amaral	2011	PTRM	Sustaining and disruptive technologies
Carvalho et al.	2013	LITREV	Not Applicable
Castro et al.	2012	IRM	Sustaining and disruptive technologies
Choomon & Leeprechanon	2011	LITREV	Not Applicable
Cooper & Edgett	2010	PRM	Sustaining and disruptive technologies; Path dependence
Cosner et al.	2007	PTRM	Sustaining and disruptive technologies; Path dependence
Daim et al.	2012	IRM	Standardization; Sustaining and disruptive technologies
Daim & Oliver	2008	PTRM	Standardization; Sustaining and disruptive technologies
De Reuver et al.	2013	PTRM	Path dependence
Dissel et al.	2009	PTRM	Sustaining and disruptive technologies
Elliott	2005	IRM	Generation skipping; Sustaining and disruptive technologies
Farrukh et al.	2003	PTRM	Path dependence; Sustaining and disruptive technologies
Fenwick et al.	2009	PTRM	Sustaining and disruptive technologies
Foden & Berends	2010	PTRM	Standardization
Garcia & Bray	1997	PTRM	Sustaining and disruptive technologies; Standardization
Gerdsri et al.	2010	PTRM	Sustaining and disruptive technologies
Gerdsri et al.	2009	PTRM	Sustaining and disruptive technologies
Geum et al.	2011	PTRM	Sustaining and disruptive technologies
Geum et al.	2011	PTRM	Sustaining and disruptive technologies
Geum et al.	2013	PTRM	Sustaining and disruptive technologies

Authors	Year	Cluster	Main patterns
Geum & Park	2013	PTRM	Path dependence; Sustaining and disruptive technologies
Gough et al.	2010	STRM	Path dependence; Sustaining and disruptive technologies
Groenveld	2007	PTRM	Standardization
Grossman	2004	PTRM	Standardization
Harmon et al.	2012	IRM	Path dependence; Sustaining and disruptive technologies
Heide & Henning	2006	IRM	Path dependence
Hicks et al.	2004	IRM	Sustaining and disruptive technologies
Holmes & Ferrill	2005	PTRM	Sustaining and disruptive technologies
Hooshangi et al.	2013	IRM	Sustaining and disruptive technologies; Path dependence
Jeffrey et al.	2013	IRM	Path dependence; Sustaining and disruptive technologies
Juehling et al.	2010	PTRM	Standardization; Sustaining and disruptive technologies
Jun et al.	2013	IRM	Sustaining and disruptive technologies
Kajikawa et al.	2008	STRM	Sustaining and disruptive technologies
Kappel	2001	PTRM	Sustaining and disruptive technologies; Path dependence
Kerr et al.	2013	METHOD	Not Applicable
Kerr et al.	2012	METHOD	Not Applicable
Kim et al.	2009	IRM	Standardization; Sustaining and disruptive technologies
Kostoff et al.	2004	STRM	Sustaining and disruptive technologies
Kostoff & Schaller	2001	STRM	Not Applicable
Kusala et al.	2011	METHOD	Not Applicable
Lee et al.	2012	IRM	Standardization; Sustaining and disruptive technologies
Lee et al.	2009	IRM	Sustaining and disruptive technologies
Lee et al.	2012	METHOD	Not Applicable
Lee et al.	2011	PTRM	Sustaining and disruptive technologies
Lee et al.	2013	IRM	Standardization; Sustaining and disruptive technologies
Lee et al.	2008	PTRM	Sustaining and disruptive technologies
Lee et al.	2007	IRM	Standardization; Sustaining and disruptive technologies
Lee et al.	2008	PTRM	Sustaining and disruptive technologies
Lee & Park	2005	IRM	Sustaining and disruptive technologies
Lee et al.	2009	PTRM	Path dependence
Lee et al.	2009	IRM	Standardization
Lichtenthaler	2008	PTRM	Sustaining and disruptive technologies
Lichtenthaler	2008	PTRM	Generation skipping; Sustaining and disruptive technologies
Lichtenthaler	2010	PTRM	Generation skipping; Sustaining and disruptive technologies
Liu & Gallagher	2010	IRM	Path dependence
Ma et al.	2006	STRM	Sustaining and disruptive technologies
Ma et al.	2007	STRM	Sustaining and disruptive technologies
Martin & Daim	2012	PTRM	Sustaining and disruptive technologies
McCarthy	2003	IRM	Sustaining and disruptive technologies
McDowall	2012	IRM	Standardization; Path dependence
McDowall & Eames	2006	IRM	Generation skipping
McMillan	2003	PTRM	Path dependence
Mihovska et al.	2007	IRM	Path dependence
Oliveira & Rozenfeld	2010	PTRM	Sustaining and disruptive technologies
Pagani	2009	IRM	Standardization; Sustaining and disruptive technologies
Petrick & Echols	2004	PTRM	Sustaining and disruptive technologies; Path dependence
Petrick & Martinelli	2012	PRM	Sustaining and disruptive technologies
Phaal et al.	2003	PTRM	Standardization
Phaal et al.	2004	PTRM	Sustaining and disruptive technologies; Path dependence
Phaal et al.	2006	METHOD	Not Applicable
Phaal et al.	2004	METHOD	Not Applicable
Phaal et al.	2011	IRM	Sustaining and disruptive technologies
Phaal & Muller	2009	METHOD	Not Applicable
Phaal & Palmer	2010	METHOD	Not Applicable
Porter	2004	STRM	Path dependence; Sustaining and disruptive technologies
Probert & Shehabuddeen	1999	PRM	Standardization; Path dependence
Probert et al.	2003	METHOD	Not Applicable
Richardson et al.	2005	IRM	Sustaining and disruptive technologies; Generation skipping
Rinne	2004	PTRM	Not Applicable

Authors	Year	Cluster	Main patterns
Routley et al.	2013	IRM	Standardization; Path dependence
Saritas & Aylen	2010	IRM	Generation skipping
Schiele	2010	PTRM	Sustaining and disruptive technologies; Path dependence
Schwery & Raurich	2004	PRM	Sustaining and disruptive technologies
Shibata et al.	2011	PRM	Sustaining and disruptive technologies
Suomalainen et al.	2011	PRM	Standardization
Talonen & Hakkarainen	2008	METHOD	Not Applicable
Tuominen & Ahlqvist	2010	IRM	Standardization; Sustaining and disruptive technologies
Vasconcelos Loureiro et al.	2010	IRM	Not Applicable
Vatananan & Gerdsri	2012	LITREV	Not Applicable
Vojak & Chambers	2004	IRM	Sustaining and disruptive technologies
Vojak & Suarez-Nunez	2004	PRM	Standardization; Sustaining and disruptive technologies
Wall et al.	2005	IRM	Standardization
Walsh	2004	IRM	Sustaining and disruptive technologies
Wells et al.	2004	PTRM	Path dependence
Yasunaga et al.	2009	IRM	Path dependence; Standardization
Yoon et al.	2008	IRM	Sustaining and disruptive technologies

Legend. IRM: Industry Roadmaps; LITREV: Literature Review; METHOD: Methodology; PRM: Product Roadmaps; PTRM: Product-Technology Roadmaps; STRM: Science-Technology Roadmaps

From here, a merge of the two distinct outcomes just described was done, crossing the results given by the first clustering with those given by the second one. This permitted to design the overall matrix reported in the following table.

Table 3 – Matrix crossing patterns and clusters for roadmaps in the included papers

Roadmap type	Generation skipping	Path dependence	Standardization	Sustaining and disruptive technologies
IRM	4	10	15	24
PRM	0	2	3	5
PTRM	2	12	8	30
STRM	0	2	0	6
Total (patterns)	6	26	26	65

Note: for each of the 105 included paper, none, one or two types of patterns have been recognised.

The final analysis of those publications, studying in particular the patterns in the 39 papers on Product-Technology roadmaps, which is the type of highest relevance for the firm in exam, highlighted 23 publications primarily on “Sustaining and disruptive technologies”, 2 on “Generation skipping”, 6 on “Path dependence”, and 7 on “Standardization”. Unfortunately, the type of innovation or scope of the articles was sometimes not explicitly stated, and in some cases it could just be either estimated or not assigned at all. The next figure shows the described results, over time.

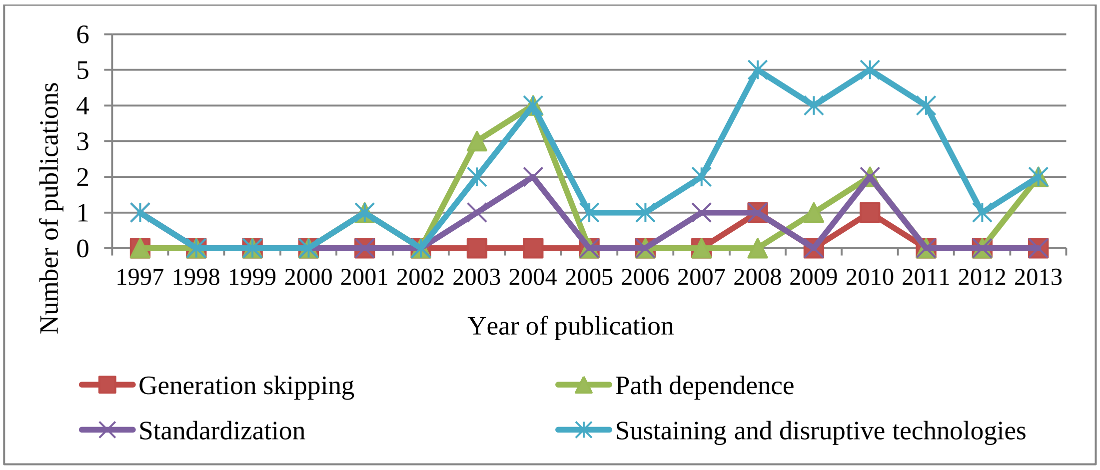


Figure 15 – Number of publications for each pattern over the years, for PTRM

Now, in this cluster, which seems the most frequently addressed, namely PTRM for "Sustaining and disruptive technologies", but not exclusively, this review highlighted opportunities of recovering management solutions, indeed applicable in the mentioned firm and context. In parallel to that, further research gaps could be spotted. As seen above, in Oliveira and Rozenfeld (2010) the critical passage from TRM to PPM was described in a possible exploitation, in a high-tech firm, recognising this point as crucial. Furthermore, in terms of models and methods, the interface between TRM and other corporate initiatives relevant to innovation seems poorly addressed in the literature, and the alignment of this tool with incumbent core business processes was investigated, as in Phaal and Muller (2009), but those could be further studied. In case of SMEs, as highlighted in Arshed et al. (2012), but in other cases as well, the company size or the TRM timeframe are unfortunately not even mentioned. Indeed a potential bias on TRM and its success rate could be present, as Konstoff and Shaller (2001), Probert et al. (2003), and others more recently, stated that this tool is very popular and widespread, but there is limited evidence of surveys in the literature. TRM is applied in many sectors, as reported in Amer and Daim (2010), but not necessarily at academic level. Carvalho et al. (2013), Vatananan and Gerdsri (2012), as well as Cooper and Edgett (2009) described the lack of studies identifying Critical Success Factors or measuring quantitatively organizational and other benefits deriving from the application of TRM, or the relationship between TRM and corporate performances.

In the present review just few papers addressing automotive or wireless areas were found, as Routley et al. (2013) and Tuominen et al. (2010), for the first area, or Pagani (2009) and An et al. (2008), for the latter. Still, rarely or never, these articles dealt with corporate or component/architecture levels in these business areas. So, and finally, architectural changes are rarely addressed together with TRM, as in the cited paper of Kappel, (2001), on in Vojak and Chambers (2003), or in Rinne (2004).

Nevertheless this issue appears of high relevance in our case as seen in Section 2.1 of this chapter, and the selected articles seemed particularly helpful and promising on this specific perspective. Rinne (2004) addressed the crucial point tackled in the analysis provided in this review, namely dealing with innovations and evolutions "languishing" in other or "side" roadmaps compared to the scope strictly under analysis. This threat of idleness is particularly present in case of architectural innovations, as mentioned, as introduced by Henderson and Clark (1990), and the convergence of wireless technologies in automotive can lead to such scenario, suggesting the chance to accurately use the TRM tool.

Based on the papers included in this literature review, and crossing the papers clustered according to the taxonomy provided by Kappel (2001) and in particular, but not exclusively, dealing with Product-Technology roadmaps, with the "Sustaining and disruptive technologies" pattern, as intended by Rinne (2004), the high potential of the TRM tool could be largely hypothesised, in parallel with the need to further investigate on it, in various directions.

2.3 Topic 3: Trends of Wireless Technologies and S-Band in Cars

The increased amount and types of electronic products and services implemented in vehicles, as highlighted above, confirms the old pattern given by empirical evidence that continuous technological innovations and new services are increasingly shortening lifecycles of products (Olshavsky, 1980). An interesting case regards the satellite communication systems developed and produced for vehicles, in the US and Canadian automotive markets. Specifically, the Sirius/XM satellite radio system can be seen as an established and relevant context (Akuturan, 2008). On the contrary, problems of penetration and the lack of success of the Worldspace Satellite Direct Audio Broadcasting technology, tentatively developed for the European market some years ago, could be seen as another useful technology and market situation to be considered (Courseille et al., 1997).

Nowadays, for the European market a new satellite system for bidirectional communications is potentially available, as the S-band technologies are being enabled by launched or programmed satellites (European Commission, Press Release, 14 May 2009), (Inmarsat plc, Press Release, 2 July 2014). The related new services, originally designed for handheld consumer devices, are potentially very relevant for the automotive market, as they appear capable of overcoming typical constraints known in the automotive environment, as adequate audio and video quality even at high speeds, satellite return channel availability for bidirectional services (in normal use cases, or in disaster recovery and professional scenarios), seamless integration with terrestrial and local gap fillers, and highly efficient band utilization (Reimers, 2009). Such services are part of the infotainment, comfort, environmental, and safety-related functions that wireless communications can enable in modern vehicles, as mentioned in the previous Section 2.1.

In the field of connectivity – and specifically in the context of antennas for wireless and satellite functions – the case of the European satellite technology based on S-band includes the DVB-SH standard (Digital Video Broadcasting-Satellite Handheld (Kelley and Rigal, 2007)), typically planned for the forward link (satellite to Earth), and the ETSI S-MIM standard (S-Band Mobile Interactive Multimedia (ETSI Standard TS 102 721, Parts 3 and 6)), typically planned for the return link (Earth to satellite), is therefore very important. These standards can provide satellite services for mobile terminals, such as broadcasting of radio, TV, and data by using DVB-SH, and interactive services on the return link by using the ETSI S-MIM. With respect to digital satellite multimedia broadcasting services and their diffusion, market configurations and business analyses are particularly critical for the assessment of the perceived innovativeness and potential success over time of such new features (Sawng and Han, 2007). Furthermore, the feasibility and integration of this kind of new vehicular antenna system is to be proven.

Now, the choice on whether or not to study and adopt a new feature in a future vehicle platform is more and more demanding, for carmakers as well as for suppliers, considering in particular the wide differences between typical automotive processes, projects and validation cycles, and those of consumer products. The related issue of the lifespan gap between consumer electronics and the automotive industry is particularly relevant for the decision on the integration of a new feature or technology in cars (Gil-Castineira et al., 2009).

Furthermore, surveys and other literature confirm that from the customer's point of view, the "old" FM radio remains quite a "must" in any new car, while virtually any other entertainment and wireless feature is often considered just as complementary, if not unnecessary (Strategyanalytics website, 2014). In fact, the availability of some features on personal devices, such as smartphones, could be assessed as sufficient and satisfactory by the majority of users, even if this scenario can be unsatisfactory, as for the European regulations, i.e. in terms of emergency call use cases (Esafetysupport.org website, 2014). This situation applies in particular to those cases where the services require a registration or a subscription, as satellite radio systems do. This is eventually even more evident in Europe with respect to other markets, where end-users are generally not willing or ready to pay for virtually unnecessary or unknown functions and services.

This brief review just provided on this third topic, actually documented background and motivations to evaluate possible investments in the potential market sustained by the S-Band technologies, converging from consumer into automotive applications. Nevertheless, engineering and knowledge gaps for automotive antennas and terminals enabling this new satellite communication were identified, and generated the need to study and prove the technical feasibility of such products. On the other hand, at managerial level, a relevant argument was here identified and seen as a critical part and action phases in the firm and for the PhD project, generating the Technology/Product TRM thereof planned and experimented at Product Portfolio (PP) level during the second specific cycle of the Action Research program, as it shall be addressed in detail in Chapter 5.

2.4 Summary, Gaps and Research Questions, Hints on Methods

A vast literature on concepts and techniques ranging from dedicated architectures and modularity to multimedia and telematic platforms in automotive is available and may help characterising such competitive landscape (Weber, 2009). Specifically, investments and novelties in the so called "electrical/electronic" (E/EE) vehicular areas seem making the pace in this sector, as stated in a recent McKinsey&Company report, if "approximately 90% of automotive innovations in 2012 featured electronics and software, especially in active safety and infotainment options" (Mohr et al., 2013).

Wireless systems are particularly impacted, and so are the companies competing in that field, to efficiently realize seamless coexistence of incumbent and emerging services (Beaume et al., 2009). Furthermore, the lifecycles of vehicles and consumer wireless products and services are clearly unsynchronised and generating new challenges in analysing market trends, understanding and eventually adopting or discharging emerging technologies and offerings, and consequently planning strategic projects for future products and processes (Gil-Castineira et al., 2009).

As documented, today Technology Roadmapping is a tool of growing importance, for practitioners and in academic field (Carvalho et al., 2013) and therefore it appears to be a suitable and powerful management tool, needed to link technology to business planning practices, to provide integrated project planning, and to engineer new systems and products, supporting communication between company functions (Farrukh et al., 2003), (Phaal et al., 2004a). The next figure well represents this key points. (Note to the figure, reported in both cited papers: I stands for Identification; S stands for Selection; A stands for Acquisition; E stands for Exploitations; P for Protection.)

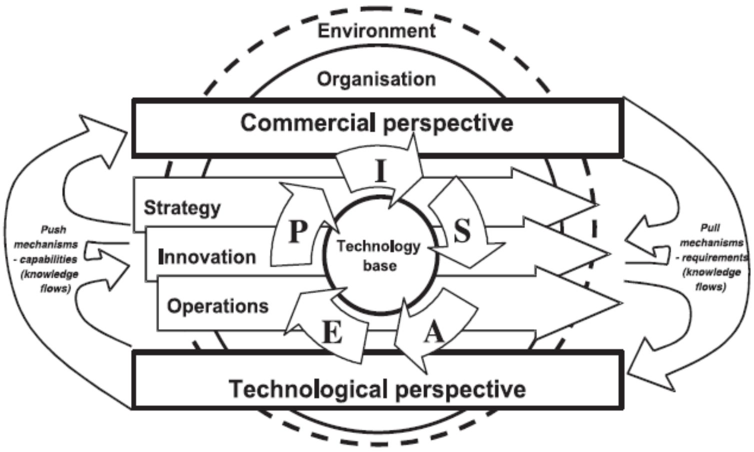


Figure 16 – Technology Management Perspective (Farrukh et al., 2003)

In our specific area of interest, within the identified and analysed body of knowledge and classification, the TRM process, allowing to cross market, product and technology trends and patterns, in hypothesis should actually help focus and address resources and efforts, also in presence of critical architectural changes. After the review, among the various TRM types identified, in case of the present context and scope as defined in Chapter 1, the most appropriate types of roadmaps in exam should be in hypothesis those of “process planning” and of “strategic planning” type, as defined in Phaal et al. (2004a). Those two types of roadmaps are visible in the next figure.

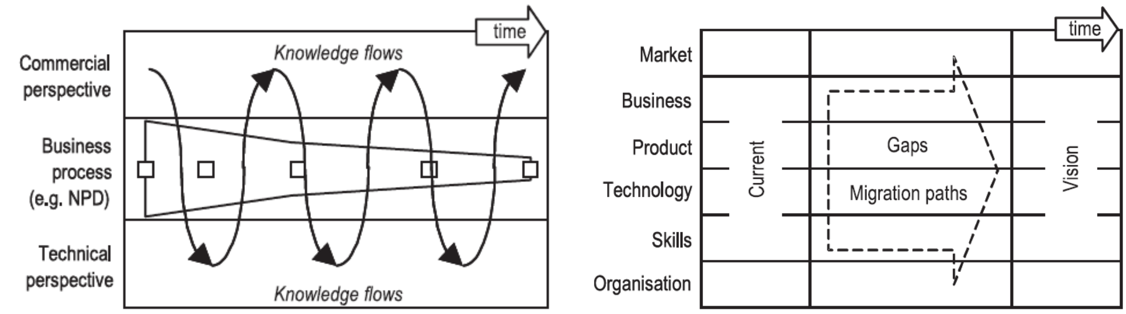


Figure 17 – Addressed types of Roadmaps (Phaal et al., 2004a)

Furthermore, another important initial hypothesis, after evaluating the reviewed literature on TRM, is that the overarching framework that could be introduced and used in the given circumstances, and in the company under analysis, could be the one reported in Phaal and Muller (2009). Such framework, represented in the following figure, is described as a fractal and scalable approach, where different levels can be carried out and can then become available for the relalization of a complete roadmap (according to the arrows indicated at the top of the figure, and in the middle of it).

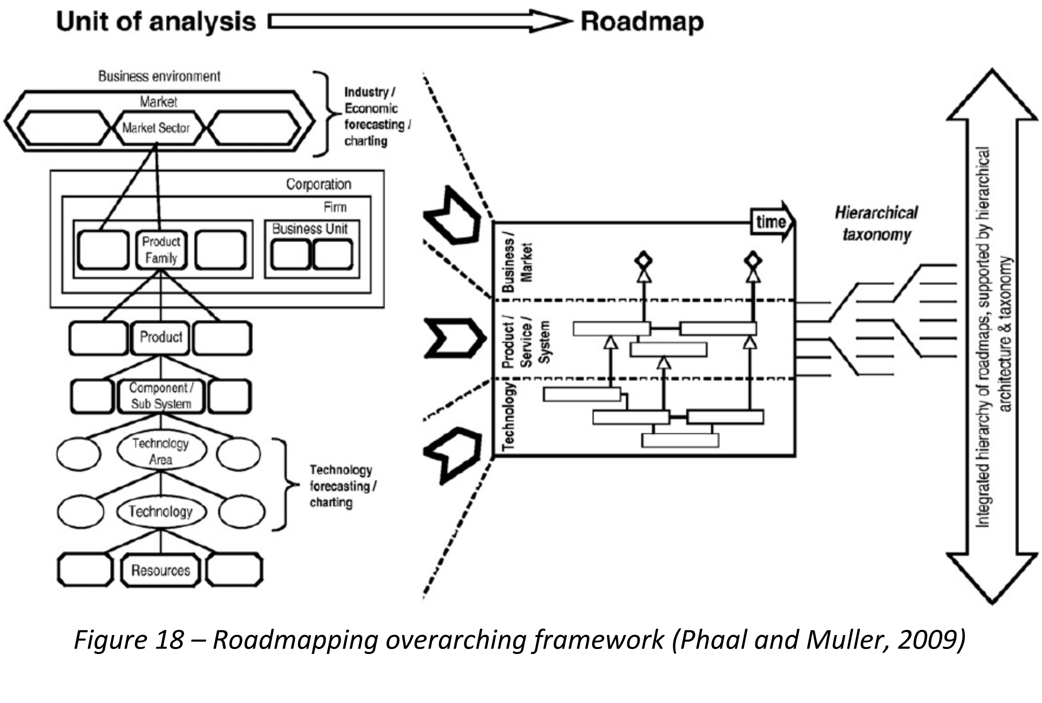


Figure 18 – Roadmapping overarching framework (Phaal and Muller, 2009)

One of the main problems when important but unusual – if not unexpected – market and technology information, collected in whatever way, converge and become available for a firm, and powerfully suggest urgency for action and adaptation of business objectives, lays in the introduction and coordination of changes and measures timely needed by the management and within the organization. As presented above in this chapter with regard to Topic 1 (Section 2.1), this is particularly true and challenging in case of architectural innovations (Henderson and Clark, 1990): gaps between habitual management practices and new needs have to be fulfilled with adequate solutions. As mentioned in the previous section, there have been abundant studies on the subject of project evaluation and selection, while there is little evidence of the integration of TRM and Project Portfolio Management (PPM) (Oliveira and Rozenfeld, 2010). Another among the main gaps lays in ensuring momentum and follow-up activities to the TRM process, where PPM comes into play, and when other tools are already in use. In the TRM literature there seems to be a gap with regard to a realistic and effective introduction of such managerial tool in parallel, and not as theoretical substitute, to practices already in place.

On the other hand, TRM in the present case shall be studied in particular in a mature market, the automotive sector, whereas and whilst architectural innovations, pushed by other market areas, as the consumer wireless market, emerge. In fact, as cited in Section 2.2.4, in maturing product areas, firms cease to invest in learning about alternative architectures (Kappel, 2001), and a lack of studies with regard to the application of TRM in case of mature product areas and/or architectural innovation seems apparent.

The following table recapitulates some of the gaps emerged in the literature review, especially in the ones related to TRM, and indicates possible interesting areas of research.

Table 4 – Some of the emerged gaps and research opportunities

Topic	Knowledge Gaps	Research Opportunities
TRM for Project Portfolio Management (PPM)	There is little evidence of the integration of TRM (PPM)	Ensuring momentum and follow-up activities to the TRM process, when PPM comes into play, and other tools are in already use
TRM in mature markets and architectural innovations	Lack of studies with regard to TRM application in case of mature product areas and/or architectural innovation	Developing procedures that are able to help recognize architectural innovations and new linkages of existing concepts, and patterns in mature product areas
TRM and other innovation and corporate processes	The interface between roadmapping and other initiatives is poorly addressed	At operational level, investigate monitoring tools and metrics useful to screen TRM influence and impact
Lack of surveys on TRM	Nevertheless there is little/no evidence in the literature of surveys	Plan and execute surveys in organizations implementing TRM
TRM, measures, and critical success factors	Lack of studies measuring TRM impact quantitatively and identify Critical Success Factors (CSF)	Developing studies for TRM with CSF and measuring systems to assess TRM benefits
TRM and impact on innovation and organization	Lack of evidence of the relationship between the application of TRM and various corporate outcomes	Investigation on TRM influence and effects at innovation and organizational levels
Convergence in automotive and consumer wireless technologies	Lack of literature and adequate cases where and how consumer products have been integrated in cars without issues, or vice versa for car makers adopting consumer technologies at fast pace	Defining measures and tools to help in the management of converging technologies
Missing S-Band automotive antennas and unclear market perspectives	S-band antennas for cars and in vehicular form factor and characteristics to be studied and possibly realized, if the market is interested	Design, measure and tune the antennas; define tools and methods to map and monitor the market needs, given the technologies

Considering the conducted review of the literature, and especially the one related to the TRM body of knowledge, many research gaps have therefore emerged. A range of research questions originated, and were motivating further research activities, as it shall be presented in the next chapters. In particular, a preliminary RQ derives from Topic 1 (Section 2.1), as follows.

- (RQ1): Once analysed some wireless technologies and applications available or currently foreseen, and evaluated the ongoing architectural innovations, what strategic implications, what reactions and solutions a leading antenna manufacturer should consider and plan, in particular from technical and managerial perspectives.

From the overarching Topic 2 (Section2.2), the core assumptions lead to define the need to develop custom TRM procedures, able to help recognize and deal with spotted issues, innovations and changing linkages of existing concepts, as well as with new patterns and trends. Therefore, as anticipated in the introduction, the core underlying research questions of the PhD project can be outlined as follows:

- RQ2: How can the Technology Roadmapping process be customized to help meeting the objectives of a multi-project oriented company, operating in a competitive arena of converging technologies?
- RQ3: How can the customized Technology Roadmapping process be integrated with the company's existing management practices, to help identify relevant trends and patterns, and sustain strategic decisions and projects?

As already explained in the introduction of this chapter, Topic 3 (Section 2.3) is exploited as a sub-case of the previous Topic 2. It resulted suitable for a specific application of the TRM tool in the firm, because there was the opportunistic need to take decisions on investments and projects for the S-Band wireless technologies in vehicular applications, i.e. in presence of convergence from the consumer wireless market. It was also useful to allow a refined verification and customization of the TRM tool under study. So, for Topic 3 the underlying research question is:

- RQ4: Based on the potential diffusion of the European S-band satellite services as highly interesting for future strategic investments and efforts for an automotive supplier, how the first vehicular product can be realized and how the TRM process can help discuss the maturity of such technology compared to its commercial impact and potential results.

In the given context, the power of TRM to spot, as early as possible, trends and other critical factors, and to sustain strategic decisions, was likely to allow investigations and a broad research program, i.e. with multiple TRM processes. An academic and operational relevance is then expected, whereas beside the inner potential of the tool itself, applied in this case, the need for further research and practice have emerged, and should lead to reach new meaningful, relevant and significant results.

From setting the research propositions and questions as provided above, the outlined rationale and hypotheses led to conceive an ambitious Action Research project within the involved Tier 1 company, enabling the design and investigation of a multiple TRM scheme. Indeed the new framework so defined, namely a TRM studied with the AR methodology, is very rare in the literature, as only one previous work was found, as mentioned in Section 2.2.3. And this is part of the contribution expected for the next phases of the present PhD research project. As anticipated in the introduction, in section 1.4, Action Research seems very suitable in the given context, to experiment and do research, assessing and learning about the theory, but also using in practice the TRM selected tool, governing possible changes in a real organization while doing the research, and adopting the research to the workings, virtually in real time.

Methods and results for the 3 listed topics shall be described in detail at the beginning of each of the next 3 chapters.

3 Strategic Implications of an Innovative Architectural Change: Early evidence from Automotive Antenna Systems[2]

The present chapter originated from Topic 1, as introduced in the previous Chapter 2, Section 2.1. This chapter is relevant in contextualizing the whole project motivation and in generating the necessary awareness of the emerging problems, as anticipated in the previous Section 2.4. As it will be reported in the next pages, it definitively contributed to decide to use the TRM tool for the rest of the research project.

In fact, the analysis of the antenna systems for automotive, as well as of new wireless technologies growing in the consumer market, and becoming available for vehicular applications, as it will be delineated, brought consciousness with regard to the necessity to introduce new tools for managerial decisions, as for technical and strategic planning. This early but fundamental phase of the study gave initial stimulus to the selection and momentum of the TRM tool that soon followed.

The chapter is structured as follows. The next Section 3.1 provides insights on the research design, and on the methodology used in this phase of the PhD project. The successive Section 3.2 recalls the literature review on this topic presented in Section 2.1 and gives further insights on the emerging scenario of convergence, counterpointed by an analysis of the potential challenges. Section 3.3 concludes the chapter providing the first results, and indicating the motivation for the following steps of the research, both in terms of methods and contents.

[2] This Chapter is based on the cited paper P1) – (Zamberlan, 2012)

3.1 Research Design and Method

This initial part of the research was conducted trying to respond to the preliminary and broad research question defined Section 2.4 (RQ1), and namely for Topic 1. Once recognised the issues from collected data (from customers, competitors, media, conferences, as well as from scientific literature), the need for a fast analysis was apparent, and a first research phase was deliberated.

The available information and data were provided to 10 persons in Calearo, the company under analysis, and some related questions were provided to them, so to collect qualitative and quantitative data on the indicated trends. PhDs, very experienced persons, and other highly qualified professionals, active in the automotive and/or wireless business areas for decades, were interviewed. The following table reports the persons selected (names are omitted).

Table 5 – Areas/functions involved in the initial internal survey

Interviewee (names omitted)	Area, Function in the firm
1	Sales Department, Director
2	Sales Department, Key Account Manager
3	Supply Chain Department, Sales Support
4	R&D, Strategy, Innovation Department, Director (researcher)
5	Electronic Design Team, Electronic Design Manager
6	Mechanical Design Team, Mechanical Design Manager
7	Project Management Office, Senior Project Manager
8	Purchasing Department, Director
9	Financial/Accounting Department, Cost Engineering Manager
10	Operations Department, Director

Admittedly, a clear limitation of the research in this phase is given by the fact that only internal persons were involved. This choice was mostly dictated by time constraints, and also by the necessity to generate a sense of urgency in the firm, a status that could originate momentum when involving key persons directly in such analysis.

This approach allowed to retrieve various details, otherwise tacitly known just to a few different employees, thanks to direct questions aiming at mapping the technical and sales requests from customers and their trends, and the internal studies on the new products to develop. Questions were also oriented to understand the current or new customers' requests originated from meetings, and other information exchanges, as well as insights regarding the various technologies. A simple questionnaire was prepared and sent out, being then collected after some days, as soon as completed by each involved person. In the following table, some of the questions as supplied to the involved persons are reported, whereas other questions were omitted to protect confidential information directly related to the firm, its products, businesses and operations.

Table 6 – Some of the questions provided on antenna markets and technologies

Question number	Question
1	List what functions were always requested in the last 20 RfQs
2	List what new functions were discussed with customers, or suppliers, or partners, in the last year
3	List what solutions you see studied, proposed, introduced, or patented from competitors or other entities in the last year
4	Have you heard about smart antennas or highly integrated products at customers? For what types of wireless functions?
5	What installation positions are requested for the GPS function?

It is particularly relevant to mention that, especially in automotive OEM projects, Requests for Information (RfIs), Requests for Quotation (RfQs), etc., are normally issued by carmakers two to three years before the actual Start of Production (SOP) dates. On one hand, these requests provide precious information on what the customers are prefiguring to introduce in cars, some years in advance: a relevant fact, also compared to other markets. On the other hand, this means that key suppliers, as Calearo, need to collect data, and manage competences on forthcoming requests and technologies, rather largely in advance, and this can often be a very critical issue.

The collected data were then processed and qualitatively analysed, as far as possible at this stage. Eventually, and importantly, the responses to the questionnaire and the highlighted issues described in the further notes provided by each respondent, generated more awareness and urgency in evaluating new tools and initiatives, needed to deal with the current and future automotive markets and with carmakers, as it will then be described also from Chapter 4.

3.2 Context analysis

Since the 1920s, when radios were first introduced in automobiles for commercial and professional purposes, wireless communications have played an important role for the car industry. The variety of wireless consumer products, infotainment and comfort features, and safety-related services available on the market and dedicated also to the automotive sector, is particularly high, thanks to telecommunication technologies nowadays developed, deployed and continuously improved (Beaume et al., 2009). The exposed issue of networking vehicular components and communication elements and architectures, allowing the different functions to be integrated and seamlessly addressed to the drivers and passengers, has been present and tackled with various solutions over the years (Mueller-Rathgeber and Michel, 2009).

One of the key elements in the chain of the automotive telecommunication systems is represented by the antennas installed on cars, and as modern passenger cars can be equipped with over 70 highly interconnected electronic control units (ECUs), up to 500 sensors and actuators, about 1.9 miles of wires, and over 15 internal antennas (Weber, 2009), the custom design and integration of highly dedicated and multiple antennas for OEMs is strictly necessary.

In the field of automotive connectivity and multimedia, the following market and product trends seem empirically manifest, and other literature is confirming such data (Breitschwerdt et al., 2013):

- New features are continuously added, also with diversified regional variants and volumes can range from very low to very high, i.e. depending on configurations;
- The increase in antenna products, system technologies, and complexity levels is often necessary, while being less and less valued and recognized by carmakers and end -customers;
- The time-to-market is shortening, as in the consumer market but not up to such fast-paced rhythms, while lifecycles of new features are sometimes unclear;
- Sales channels are fragmented and diversified.

As briefly mentioned in Section 2.3, there is a lifespan gap between consumer electronics products and the automotive ones. This fact is particularly true for example for smartphones, as any of such devices normally has a lifespan of around 18 months, while an automobile has an estimated lifecycle of up to 8 or even 10 years (Gil-

Castineira et al., 2009). In fact, a car model it typically on sale in shops for around three years, and for another three or four years after some minor changes (known as "face-lift"). A particular model of a smartphone, on the other hand, will hardly be on sale for longer than two years, regardless of its qualities and features.

In cars, technological changes for mechanical parts are relatively slow, while electronic changes are relatively quick, but still very slow compared to consumer electronics, or even slower if compared to features completely based on software (known as Applications, or as Apps). The following figure provides a graphical representation of this phenomena (in the figure, SOP stands for Start Of Production, which indicates the product launch on the market, as explained earlier).

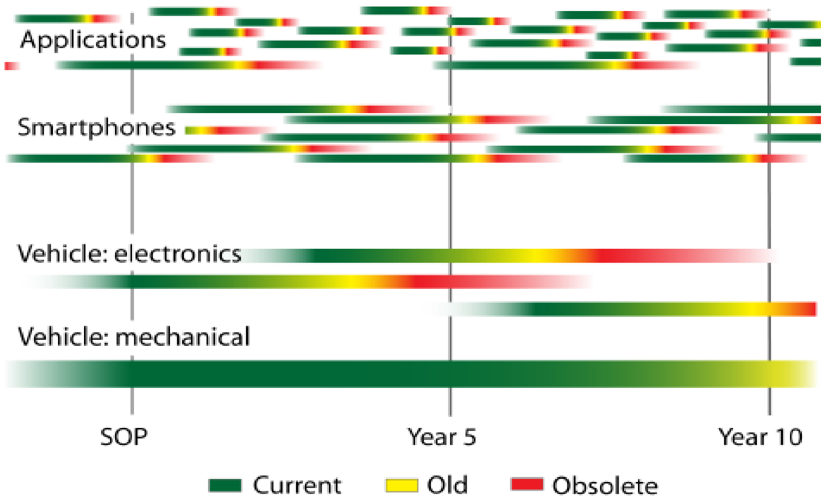


Figure 19 – Lifespan comparison for smartphones and vehicles (Gryc, 2011)

If a successful or relevant new wireless (or portable) product or service becomes available on the market, or mandatory, i.e. due to regulations introduced by law, car manufacturers and involved suppliers have to evaluate how to react and make its integration available in the vehicle's infotainment, telematics or safety systems. As anticipated in the introductory chapter of this thesis, it is a case of convergence, intended as a unification of functions, where previously distinct products eventually come together (Yoffie, 1997). The following figure represents this powerful trend.

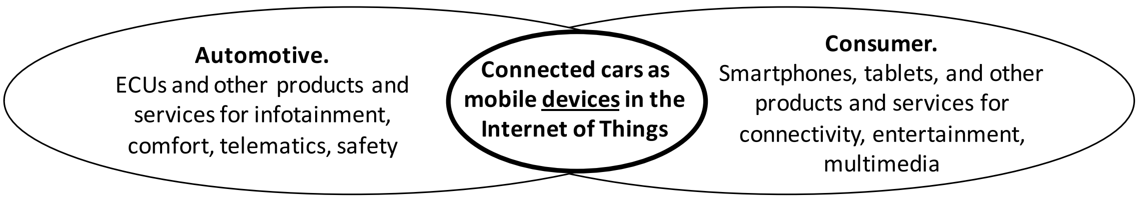


Figure 20 – Convergence of Automotive and Consumer wireless areas

On one side, in the automotive business there is a growing set of products and services for connectivity, entertainment, safety, comfort and improved driver's and passengers' experiences with cars. On the other side, the speed of evolution of consumer products, such as smartphones, tablets, and so on, together with the applications and services they can offer and enable, is turning such objects into life companions at virtually any level, for any user. Crossing these experiences, services and products generates a new business area, the one of connected vehicles, where cars are intended as *devices*, part of the giant local or wide networks of sensors and moving objects today increasingly known as "Internet of Things", or "Internet of Everything". A new virtually holistic eco-system where everything is connected and the amount of data virtually available is paramount (this trend is also related to the "Big Data" paradigm).

In cars, differently than for the case of innovative devices or consumer solutions, the introduction of some new features implies a series of demanding efforts, and sometimes this integration could be hardly possible within the lifecycle of a vehicle. Recent examples, emerged in particular in field of infotainment, are:

- personal or portable navigation systems, based on satellite positioning systems (i.e. GPS);
- mobile and portable TV systems, both based on satellite or terrestrial technologies;
- Digital Radio Broadcasting (DAB) and its evolutions, or internet radios, as alternative or service improvements for FM radio;
- W-LAN to Cellular phone routers for in-vehicle high speed internet navigation and connectivity;
- (non wireless) mp3 players, and other mass storage devices, with USB/iPod integrations;
- (non wireless) CD and, more often, DVD and Blu-ray players;
- (non wireless) rear seat entertainment systems.

Those are eventually available to customers from aftermarket vendors first, and instead they remain unavailable for a long time as OEM products, typically until they are planned, designed, and fully tested and integrated in existing or new vehicular systems.

A specific and very peculiar issue with regard to automotive antennas is that in most cases a new feature is added to all those previously available, without necessarily replacing any of the existing ones. This fact directly impacts on the number of antennas and on the complexity of multiband antenna systems installed. As already described earlier in Section 2.4, this issue is becoming more and more critical, also with respect to vehicular networks. In particular new solutions being designed and proposed by co-operations of other leading and highly competitive suppliers appear to among the possible turning points in this business area. In fact, moving digital tuners, telematic and safety control units closer to antennas, connecting them with digital buses, reducing coaxial cables and limiting weight and grounding issues, could actually represent a major advantage for next-future cars.

3.3 Early Research Work and Empirical Results

At this stage, empirical evidence of the ongoing phenomena and technical evolutions in field of vehicular antennas and related front-ends here described comes from the internal analysis of R&D projects and product designs of Calearo, and its Ce.R.Ca., the R&D Centre of the Calaero Group. It was also confirmed monitoring over 5 past years of Requests for Information, Requests for Quotation, competitors' benchmarking and market analysis, in particular for European and American car manufacturers, for new car models, new platforms and pre-development projects.

The following table reports an overview and summary of wireless systems in line with the latest scenarios and architectures. Statistic details and business figures, as take rates, variants, interfaces and others, could not be reported being often covered by Non Disclosure Agreements (NDAs), either with OEMs or other suppliers. This table is the result of the elaboration of the data collected from various sources as listed here above, and from the internal survey carried out at Calearo, as described earlier in this chapter in Section 3.1. Also recent literature confirms, at least for some technologies, the resulting work here presented in the next table (Pell et al., 2011), (Fujimoto, 2008), (ARTIC project website, 2010).

Table 7 – Antennas and wireless systems, for current and near-future vehicles

Wireless system (EU and US, up to 6GHz)	Typical positions	Number of antennas	Applications	Trend of demand	Possible convergence?
AM	Glass, roof, plastic parts	1 (typical)	I, E, Rx, radio	Decrease	No
FM	Glass, roof, plastic parts	1, 2 or more	I, E, Rx, radio	Stable (slow decrease?)	Yes, ongoing
DAB/DRM/HD-Radio	Glass, roof, plastic parts	1 or 2	I, E, Rx, radio	Fast increase	Yes, ongoing
DVB-T/T2, ATSC	Glass, roof, plastic parts	2 or more	I, E, Rx, broadcast, television	Increase	Yes, ongoing
SDARS (Sirius/XM) (US)	Roof, plastic parts	1	I, E, Rx, satellite radio	Stable (increase)	Yes, ongoing
S-Band (DVB-SH ,EU)	Roof, plastic parts	1	I, E, S, Tx/Rx, satellite TV and radio, messages	New; unclear	Yes, ongoing
GPS, GLONASS, GALILEO	Roof, plastic parts	1 or 2	I, Rx, navigation and positioning	Increase	Yes, ongoing
1G/2G/3G/4G (GSM/./LTE)	Roof, plastic parts	1 to 4	C, E, S, Tx/Rx, cellular telephony	Fast increase	Yes, ongoing
RKE (RFId)	Roof, glass	1	C, Rx, remote vehicle access	Stable	Yes, ongoing
Telestart/Stand-Heating	Roof, glass	1	C, Rx, remote heating	Stable	No, but possible
TMPS	Plastic parts	4	C, S, Tx/Rx, tyre pressure	Stable	No, but possible
Bluetooth	Plastic parts	1	C, E, Tx/Rx, short range communications	Stable (increase)	Yes, ongoing
802.11.a/./n (W-LAN)	Roof, plastic parts	1 to 4	C, E, I, Tx/Rx, short range communications	Increase	Yes, ongoing
802.11.p (C2C, C2I)	Roof, plastic parts, glass	1 to 4	I,S, Tx/Rx, safety and data	Slow increase	Yes, ongoing
Legend:	C = Communication; E = Entertainment; EU = Europe; I = Information; Rx = Reception; S = Safety; Tx = Transmission; US = North America.				

In presence of so many antenna systems, ECUs and features, efforts to reduce cable harness weight, space and costs started already decades ago, with automotive bus systems evolving since then, as many projects with the scope of improved approaches and design rules for automotive E/EE architectures are already implemented and visible in modern cars.

In the specific context, it looks like a consistent answer to the problem of the increasing complexity and number of antennas (and higher frequencies, which are directly proportional to attenuations introduced by cables) is to be seen in particular in the architectural innovation announced and being introduced by the mentioned co-operation of leading suppliers. Furthermore, the proponents of this innovation have filed a series of international patents (Chakam et al., 2011), (Gee et al., 2010).

The new technical solutions are moving ECUs for wireless telematics and infotainment services form their typical positions in vehicles, i.e. in the boot or under the rear seats, and so on, much closer to the antennas, just below the surface of the roof and juxtaposed to the antenna, or even inside the roof antenna, at least for some features. Such solutions, today becoming possible thanks to the miniaturization of critical components and their extended working ranges, appear to meet the requirements of the key players involved, namely premium car manufacturers and several suppliers, especially thanks to the consequent architectural redefinition of the linkages between the specific devices of a typical VANET.

Even if these technical solutions being introduced by co-operations of suppliers as exposed appear to be able to bring on the market an important answer to the extensive need of flexibility against the convergence of consumer wireless applications and automotive standards, such changes might also present limits, to be seen as opportunities for competitors. In fact from a technical analysis on the so far available materials, this range of innovations seems necessarily carried out, at least to some extent, with the introduction of proprietary and self-contained systems (highly integrated ECUs and antennas, with dedicated networks, patented fixing systems, unique physical interfaces, etc.).

This is an approach that in the past often turned out to be unappealing for those car manufacturers not willing to sustain a new potential monopoly of one or another supplier, or just deciding not to risk to adopt the technology proposed by a few coordinated players. Furthermore, even if some top carmakers may find such proposals successful, and adopt them for future cars, some other OEMs may find them too far away from current implementations. Some car manufacturers could be not ready to deal with the consequent organisational changes of some E/EE internal departments. In fact, teams dedicated to telematic units, antennas, and other ECUs could be simply reduced to a single department or functional group. Finally, this new systems would shift architectural competences and deep system understanding from each OEM exclusivity, to a few suppliers, typically forced to single-device knowledge and controlled by OEMs, as described in Section 2.1.

The work carried out in this first, and mostly empirical, phase was not sufficient to solve the first problem stated in Section 2.4, and to fully respond to the preliminary research question (RQ1). Nonetheless, it was fundamental in providing evidence about the spotted issues, i.e. in the problem setting. Eventually, it strongly supported the intuition that new tools helping decision making and strategic planning were urgently necessary, in a context like the one described in this chapter, in particular in Section 3.2. In fact, important strategic and technical implications are now evident for antenna manufacturers, and in particular for the company involved in the project, as they possibly were for various carmakers already.

However, while an E/EE vendor providing solutions for infotainment or telematics might introduce new features even with mere software adaptations, and therefore very quickly as convergence requires, an antenna maker is expected to implement new functions mostly via hardware changes (including electronics, interfaces, etc.). These changes need time and resources to be designed and implemented. And therefore an antenna supplier should try to collect information on market, product and technology trends as soon as possible, and continuatively, with the appropriate tool. This process would help anticipate decisions on such requests, making possible to respond more timely and profitably to new demands.

The results of this first analysis, together with some early readings and investigations, suggested to investigate on a tool in particular, which seems able to support strategic decision making with growing frequency in corporations, such as the Technology Roadmapping. There was also to find out how to put different departments in better connection and in adequate conditions to confront and circulate information from all possible sources. And again, TRM seemed suitable for this purpose as well. Furthermore, TRM was described as a managerial tool able to empower strategic decisions and generate improved outcomes, which is in the scope of the research project, and the purpose of the firm, acting in the recognized context.

All these assumptions were soon supported by the systematic literature review, carried out as reported in detail in Section 2.2. And so, as it shall be described in the next Chapter 4, it was decided to evaluate this tool, aiming to change approach to future requests and anticipating possible needs coming from the market, as well as from existing and new customers, leveraging adequate and timely knowledge about the most promising technology trends and opportunities.

4 Research Design and Resulting Framework: Multiple TRM with Action Research for Converging Technologies[3]

After the previous chapter set and described the problem, this central chapter is about the iterative application of the Technology Roadmapping (TRM) tool programmed in Calearo, the firm under analysis, so it refers in particular to Topic 2 introduced in Section 2.2. As the research questions RQ2 and RQ3 delineated in Section 2.4, the main objective of this phase lays in understanding how the TRM tool can help, and, in case, what customisations are needed. As the level of investigation is multiple and extended over a long period of time, a particular attention is given to theoretical and methodological aspects too.

As anticipated at the end of Chapter 2 and in Chapter 3, a core hypothesis is that TRM, already in use in many fields, carefully applied and tailored for the described environment and issues, can help the particular firm that has recognised critical situations, and is struggling to deliberate the right strategic decisions and projects, so to let it remain in a leading position in its challenging and changing business field.

In particular, it was decided to use apply the TRM tool with use of the Action Research (AR) methodology, and with special attention to the unit of analysis and planning of the iterations. In fact it will also emerge that Topic 3, introduced in Section 2.3, is actually a case within this overall process described in this chapter (namely, the second AR cycle and TRM application, on S-Band). The next Chapter 5, consequently, will then and indeed focus on that part of the research project, providing more technical details and results about such phase.

[3] This chapter is based on P5) – (Zamberlan et al., 2014)

The chapter is structured as follows. The next Section 4.1 provides background and details on the research design and methodology applied in this core part of the project. The following Section 4.2 is particular relevant within the entire PhD project, as it delineates the way the three successive TRM processes were done with help of the AR method, with incremental results and refinements of the desired framework. Section 4.3 finally provides the results of such research, illustrating the obtained TRM framework and the overall framework, and other emerged outcomes, in particular with respect to the TRM tool and the research method, as here chosen and investigated.

4.1 Research Design and Method

In the perspective of the described background and research questions (labelled as RQ2 and RQ3 in Section 2.4), it was decided to proceed operating actively within the organisation, as just anticipated at the end of Chapter 3. There was to understand and establish a better or more effective methodology to deal with the ongoing technology changes and to boost struggling sales, product portfolio and corporate strategic initiatives. From there, It was decided to aim at those objectives with help of the Technology Roadmapping, a managerial tool by definition seeming very suitable for this purpose and of growing relevance in academia as well as in corporations.

Technology Roadmapping in the recent literature is in fact considered, as already reported, a flexible management tool of growing relevance for academics and practitioners, particularly suitable to align future technologies and products with business strategy, which can become of primary importance and great help in turbulent times (Phaal et al., 2004b). Actually from the literature review, in case of automotive technologies, markets or products, TRM seemed often applied at a different level compared to the one relevant in this project, i.e. in particular to delineate broad industry trends. So its applicability in the presented context, and the design of the research capable to obtain the needed results, were challenging targets and not trivial points at all.

In fact when starting to apply the TRM tool, it emerged rather immediately that the ideal dynamics of TRM, with technology push and market pull working together (Phaal et al., 2004a), remained quite far from their real applicability, especially when, as in our case, the supplier-customer relationship is not balanced, as mentioned above in Section 1.1 and in Section 3.3. So, the practical and urgent managerial needs, in parallel with the opportunity and the academic will to investigate and track rigorously and continuously such tool use, context and endeavour, suggested to carry out this core phase of the project urgently, and in form of Action Research (Karlsson, 2009), as introduced in Section 2.4.

To address the research objectives in the most focussed way, after careful evaluation, it was therefore decided to use the Action Research methodology. It resulted very suitable in the given context, which is to do research, assess and learn in depth about the new tool and driving the changing context, as far as possible. In parallel, with this method, there was the possibility to contribute to knowledge and theory, having decided to deal with some of the highlighted gaps, as seen in Section 2.2.4. Action Research is by definition an approach to research that aims both at taking action, i.e. solving one or more problems, and at creating knowledge or theory about that action, i.e. contributing to science (Coughlan et al., 2002). Furthermore there were the conditions to do research work while implementing in real time and iteratively the four steps of Constructing – Planning action – Taking action – Evaluating action (Coughlan et al., 2010).

With respect, for example, to other possible methods as the case study or the survey, the choice of Action Research appeared more suitable for the declared core research questions, as described in Section 1.4. In this case, the will to have a practical and iterative approach during the project, and to contribute to the theory, having to work in multiple cycles, and with the challenge to focus dynamically on different units of analysis (i.e. Corporate, SBU, Product Portfolio), and on organisational aspects, seemed possible at best with the AR method.

With the issues, the scope and the objectives described, the role of action researcher was directly undertaken by the scholar, being in the particular and favourable condition of top manager as well as doctoral student. Under these circumstances, the action researcher could both manage the AR project, and study and follow all its phases and outcomes with direct participation and with adequate primary and secondary access (Coghlan et al., 2010).

In fact, this research methodology, with the chance to do research while at work in the organization, was applied implementing the four steps of constructing, planning, taking and evaluating action, in a 2-year corporate project, and aiming at three full AR cycles of TRM processes. While the whole AR project itself was carried out and monitored in parallel to the AR operative cycles, the overall project context and purpose was consistently related to the background and hypotheses previously described in Chapter 3 in particular, from the perspective of Calearo Group.

Even if Coghlan and Brannick state that "in any AR project there are multiple action research cycles operating concurrently", considering to have different time spans (Coghlan and Brannick, 2010, p. 10), in this case three AR cycles were substantially performed in sequence, one after another. This deviation from the standard AR "clock metaphor" in this implementation helped keep the purpose and focus on the context in perspective. In fact:

- The first AR cycle was operated by doing the TRM process at Technology/Product level, for the Strategic Business Unit (SBU) of the firm;
- The second AR cycle was successively carried out in the same SBU, at Technology/Product level, on a more specific field of interest (and on this cycle, outcomes and technical details will be provided in the dedicated Chapter 5 as well);
- Finally, the third AR cycle was done by exploiting a Technology-Product TRM at corporate level.

4.2 Action Research Activities Performed to Tailor the TRM Framework

This section is aimed at covering in detail the three AR cycles that were carried out in the firm under analysis, with the TRM tool being introduced, used and possibly customised during the various phases and cycles of the research. In the following pages, the first Section 4.2.1 provides details and results from the first application of the TRM tool, which took place within the first AR cycle, at Strategic Business Unit level. Then the second AR cycle is reported in Section 4.2.2. This section shall cover the application of TRM at Technology/Product level, with the regard to the S-Band technologies and product portfolio, and more technical details and results of this cycle, originated from Topic 3 as introduced in Section 2.3, will be provided in Chapter 5. Finally, Section 4.2.3 will close the AR project with its third cycle, and with TRM operated at corporate level.

4.2.1 Action Research and TRM, Cycle 1 (SBU)

The first AR cycle was possibly the most critical, as for example no practical experience on the methodology and tools was available in the company and no budget for external support, i.e. consulting, was allocated. An initial idea to achieve a corporate level TRM process at the first attempt was immediately aborted, as it resulted in many ways not credible. At this stage, the TRM process described in the literature, defining 3 phases, preliminary, development and follow-up (Garcia and Bray, 1997) was considered and taken into account, among others.

In the "constructing" phase for the first AR round, where the first TRM workshop needed to be defined and organized specifically for the context and the SBU defined, the action researcher had first to explain the idea and the objectives to obtain the "go" from the owner of the company, and then to involve and motivate the potential team members. The team itself, then composed of 5 persons selected primarily from sales, R&D, engineering and accounting, found challenging to stimulate and obtain awareness and sense of urgency within the firm, especially while other ordinary activities, or emergencies, and business processes were occurring as usual. The following table lists the persons present in the core team, eventually confirmed in all the 3 AR cycles.

Table 8 – Areas/functions of the core team members

Core team member (names omitted)	Area, Function in the firm
1	Sales Department, Director
2	Sales Department, Key Account Manager
3	R&D and Strategic Marketing Department, Director (researcher)
4	Electronic Design Team, Electronic Design Manager
5	Financial/Accounting Department, Bidding Accountant

It immediately appeared clear to the involved team, as well as to other members of the company occasionally involved, that the ideal situation of full availability and stability of purpose was just theoretical, at least in such a medium-size company. It was fundamental to get and keep the company owner involved and convinced, at least informally, about possible specific improvements deriving from the new initiative, also on a short term and at many levels, including technical aspects (i.e. reactivity to changes in mobile technologies), organizational aspects (i.e. growing gap of competences with respect to digital communications), market aspects (i.e. speed of competitors), etc., while mitigating the tendency to rush to "quick and dirty" shortcuts and changes.

Exercising leadership and inspiring commitment while illustrating the methodology was also necessary: for this reason, papers on TRM and TRM examples from the literature were distributed and presented to key colleagues and to the owner. Gathering concerns and taking them into account, as well as setting clear responsibilities and illustrating potential benefits for internal teams and involved stakeholders was important: sales people (possibly narrow-minded, jealous of their information, unaware or indifferent of time-to-market issues, pulled from needs and habits of customers); R&D people (eventually too innovative and remote from real needs, open to new and risky technologies); finance people (unaware of future trends, not willing to invest); operations people (mainly lamenting lack of time for such initiatives) were informed and eventually involved.

In the "planning" phase of the first AR cycle, the first TRM process was planned, defining what and how to focus on: who to involve in the organization, depending on the scope, and from what level(s) people should be; what support and resources were needed, depending on the specific tasks; how commitment could be sustained and how resistance and potential skepticism could be mitigated, and so on. Indeed some persons were involved as temporary team members, in particular if specifically dedicated to the most reactive and interesting car makers with respect to the trends described, and therefore having possibly key information on the context. With these preconditions in place, the TRM workshops (in sequence on markets, products, and technologies) were organized and arranged in detail.

In the "doing" phase for the first AR round of the first TRM process, three 1-day TRM workshops were carried out, going across past-short-mid-long term and vision time horizons, placed and organized on a grand visual board. Afterwards linkages among the outcomes of the different workshops were discussed and drawn. This last part was done by a subset of the team members, recognizing the implicit difficulty of this final step, which led to the definition of relevant projects and priorities. These "candidate" projects were assessed with help of the existing financial analysis, risk analysis and strategy alignment tools in use in the firm, presented to the board of directors, and eventually prioritized and tentatively inserted in the existing multi-project management system, as any other initiative.

The first resulting roadmap is visible in the following figure. With such picture, details on the projects are deliberately not visible and not disclosed, as confidential information of the firm under investigation, and in any case not necessary for the specific scope of this work.

Figure 21 – First resulting roadmap (SBU level)

In the “evaluation” and final phase for the first AR cycle and first TRM process, it was assessed that the gaps (internal methods, awareness, urgency, new technologies not properly studied, etc.) were actually very present and threatening, at least at SBU level. The resistances of various colleagues and the short term expectations were occurring quite often and mitigated continuously. The risky feeling that an external consultancy would have been better than the job done by internal people remained a problem to consider with attention. The “post-it” cards placed on the board during the workshops required standardization. More coherent information on each topic was needed, up to generating an early and compact business case and a scorecard for each idea, before assessing each project or product feasibility, possibly with dedicated people (whereas this critical follow-up task resulted often in contrast with the existing resource allocation process and practice, and with the pace required in such process). Importantly, the technology workshop was evaluated necessary and pivotal before the product workshop, and not vice versa, as normally in the literature.

The lead time of the first AR cycle was about 6 months, for its complete execution, whereas the assigned and dedicated time for each resource has been up to 15% of her/his total available time, corresponding to an average of 2 to 3 hours per week.

4.2.2 Action Research and TRM, Cycle 2 (S-Band)

Having consolidated some internal expertise and confidence in the TRM process, the following second AR cycle was a “zoom in” from SBU level into a specific business field that had been under study in that SBU for some time, namely the S-Band technologies, as they represented a promising new service for the automotive and mobile sectors, and where eventually the firm had earlier decided to consider investing. While this section concentrates on the AR and TRM execution and theoretical aspects, more technical details of this phase will be provided in the next Chapter 5.

In the “constructing” phase for the second AR round, which took around 4 months, a new TRM process was considered so to evaluate and decide the most appropriate actions in perspective of S-Band future strategy and developments. The scope of this TRM process was therefore narrower and more vertical, on a specific technology and product strategy. The idea and need in the background was, on one hand, to obtain a roadmap with indications on possible new investments and projects in this eco-system, and on the other hand to refine the TRM process customization, in particular addressing precisely the issues emerged in the first AR cycle and TRM process, and the coexistence with other procedures already in place in the company.

With such practical and research objectives in scope, the new “planning” phase was rather delicate and took another 3 months. The team focussed on the criticalities emerged, at execution level, in the previous AR cycle and TRM process, in particular in the “doing” and “evaluation” phases. The critical phases and customization of the process, the necessary or key functions and persons, the delicate roles, the main tools used, and other emerging issues were among the themes clustered and analyzed at this stage.

The “doing” phase was then conducted in 4 successive workshops (differently from the previous AR cycle, on markets, technologies, products, and linkages), of an average duration of 5 hours each, based on the same grand visual board used in the first TRM process, with the same core team, but aided by 3 new persons. This was introduced in response to some of the aspects emerged in the first AR cycle: the person in charge of feasibility studies, the person in charge of the Project Management Office, and a colleague from the finance department were now involved. The following table lists the complete team at this stage of the research.

Table 9 – Areas/functions of the extended team members

Core team member (names omitted)	Area, Function in the firm
1	Sales Department, Director
2	Sales Department, Key Account Manager
3	R&D and Strategic Marketing Department, Director (researcher)
4	Electronic Design Team, Electronic Design Manager
5	Financial/Accounting Department, Bidding Accountant
6	Financial/Accounting Department, Cost Engineering Manager
7	Financial/Accounting Department, Finance Director
8	Project Management Office, Senior Project Manager

This novelty boosted and simplified the successive dissemination and support in the activities of follow-up and project sponsoring, creating direct commitment of key personnel. Furthermore, the "quick business planning" and standardization for each project and product proposal was assessed and validated directly during the workshops, improving the general quality and insightfulness of each potential project and product proposal.

The final "evaluation" phase of the second AR cycle, parallel to the exposition of the results to the board, was this time more dedicated to the analysis of the outcomes and the possible ways and schedules to implement the proposals emerged, rather than to criticizing practical aspects and the methodology itself. On the other hand, some issues and refinements for successive TRM processes were apparent: based on the patterns recognized during the workshops, and on the market and technology trends in particular, the projects aiming at future products were hard to define and therefore to release, due to the high risks related to the inner instabilities highlighted.

It happened that crucial information were available only to key persons and players of the specific ecosystem, and therefore hard to collect and to trust. Furthermore, it was clear that R&D decisions were pushed beyond some market needs, stressing the threatening mismatch between technical and sales priorities, and engaging discussions between different departments, which did not help the exploitation of the TRM central phases. Finally it emerged that, whenever possible and acceptable, riskier projects and product developments should have been or be financed with use of external fund rising, rather than by internal resources, typically already allocated otherwise.

In any case, the projects and initiatives originate during the TRM process and approved were inserted again in the multi-project tool in use in the firm, but this time with higher visibility (i.e. with different colours), allocating the needed resources, if available, from the same pool normally dedicated to R&D and normal design.

The second AR cycle took about 11 months for its complete execution, with an availability of each internal assigned resource of up to 10% of her/his total working time, corresponding to an average of 3 to 4 hours per week. The resulting roadmap is provided directly in the next Chapter 5, Figure 29, together with other results originating from the analysis of this phase.

4.2.3 Action Research and TRM, Cycle 3 (Corporate)

After two complete AR cycles a third and, as far as the team and project was concerned, conclusive AR cycle was carried out, according to the AR project plan. The TRM process for the first time could be applied and executed at corporate level. The consolidated expertise, the general confidence in the tool, the released and ongoing projects stemming from the previous TRM processes, played in fact the role of best internal sponsor for the leverage of a company-wide, autonomous TRM initiative.

After the initial AR cycle and TRM process at SBU level, and the second AR “zoom-in” cycle and TRM done at a more specific level, the third AR cycle could finally take place “zooming-out” with a TRM process at corporate level, as initially desired. Actually, the fact that the first and second AR cycles and TRM processes were developed by and at the Strategic Business Unit, as described, appeared fundamental for this final research and practical step. The involved team this time was again the same, with an additional member coming from the family owning the firm, previously informed on the activities anyway. The following table lists the entire team involved in this phase of the research.

Table 10 – Areas/functions of the extended team members

Core team member (names omitted)	Area, Function in the firm
1	Sales Department, Director
2	Sales Department, Key Account Manager
3	R&D and Strategic Marketing Department, Director (researcher)
4	Electronic Design Team, Electronic Design Manager
5	Financial/Accounting Department, Bidding Accountant
6	Financial/Accounting Department, Cost Engineering Manager
7	Financial/Accounting Department, Finance Director
8	Project Management Office, Senior Project Manager
9	Member of the owning Family, Strategy and Synergies Manager

The entire AR cycle went on in a smoother way, surely as a consequence of the experience and momentum gained in the previous cycles, even if the scope was actually wider. In this case the “constructing” phase took less than two months, in which the standard tools were prepared and the current state of the ongoing projects was collected. The following “planning” phase was also rather short, with the confirmation of the 4 workshops and the preparation of a short and homogenic analysis for each already ongoing or planned project within the firm.

The “doing” phase, exploited in half-day workshops, showed that data on market and business evolutions and trends were rather consistently available in the firm, while an accurate analysis of the relevant or potential technologies could not be done simply by means of such internal workshop. This led to the necessity to investigate at some key customers, and to involve major current or potential suppliers, as actually suggested in the literature (Petrick and Echols, 2004), as well as with distributors, or, in some cases, to meet with competitors and possible co-operating companies, so to adequately map, understand and select the technologies (and target markets) currently available or foreseen in the near or far future. An important university was also involved to support in particular the literature review on technologies used for new wireless solutions and antennas and patents in automotive (this contribution will be exposed with some more details in the discussion, Chapter 6). In practice, along the supply chain, especially suppliers and potentially co-operating firms were called in for dedicated meetings and half-day workshops to assess and crosscheck technology trends, patterns and further information, useful to complete the technology workshop of the ongoing TRM process. This unexpected investigation delayed the “doing” phase, but donated more consistent and robust data also to the consequent workshops dedicated to products and linkages between the various emerging outcomes. In any case, as expected, the final integration phase of the TRM process required the highest levels of effort (Gerdsri et al., 2010).

The “evaluation” phase of this third AR cycle took around 3 months for its preliminary results and for follow-up deliberated projects to be inserted in the multi-project tool and to kick-off, well integrated together with other initiatives, milestones and deadlines. So, in total, this third AR cycle took a bit longer that 12 months from start to end, with an availability of each internal assigned resource of up to 10% of her/his total working time, corresponding to an average of about 3 hours per week.

In the following picture, an overview of the corporate roadmap obtained in this TRM is presented (again, details on contents are deliberately omitted for confidentiality reasons; white board for temporary notes as well as computer, projector and white canvas screen are not visible in the figure). Some details:

- The roadmap itself is visible in the central portion of the picture, with markets, business, products, technologies, resources on the rows from top to bottom, and past, present (budget), near future, far future (vision), on the columns, from left to right;
- Part of the supporting data stemming from market analysis, reports, etc., are present on the upper left hand side of the roadmap;
- Details on product sales figures and business activities for the main customers are present on the right hand side of the roadmap;
- Technology insights, patents’ analyses, competitors’ data, macro-trends, and other references, are visible on the far left side of the roadmap.

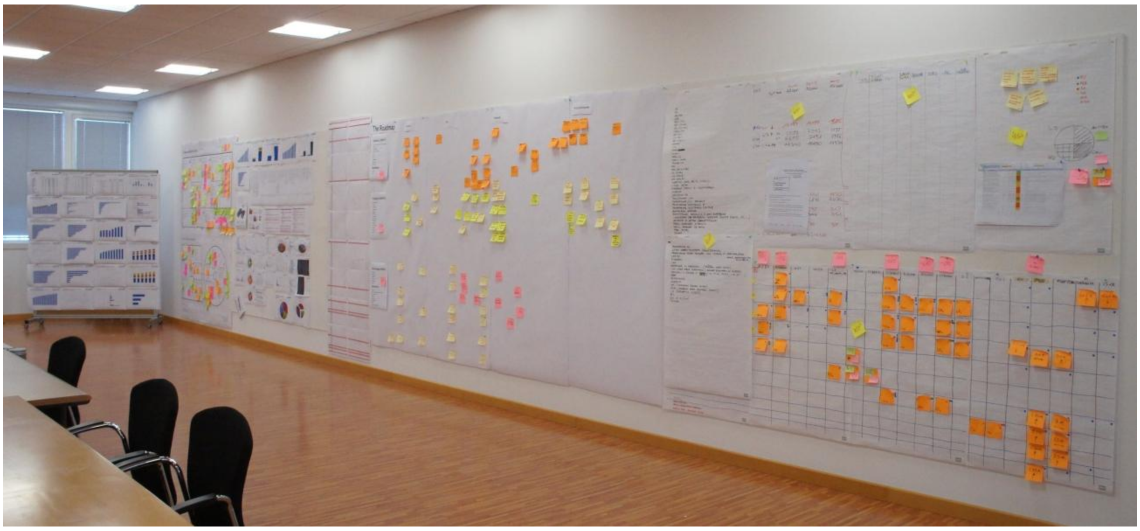


Figure 22 – Third resulting roadmap and supporting data (corporate roadmap)

More details related to all the previous phases here described with regard to the third AR cycle shall be provided in the next Section 4.3, and in the discussion in Chapter 6, as this cycle allowed to recognise communal elements and points of integration among all the three AR cycles carried out throughout the PhD project.

The following figure synthesises the timeline as described and recorded for the entire project and AR phases.

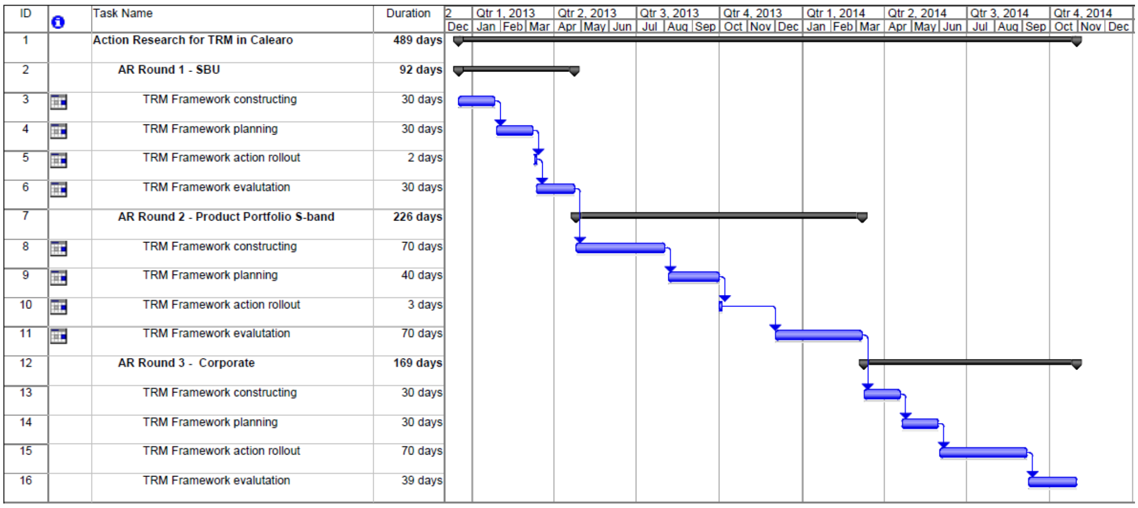


Figure 23 – Overall Action Research execution GANTT chart

4.3 Summary of Findings

The previous Section 4.2 and its sub-sections already reported both methodology insights and the main results of the AR cycles, iteratively and incrementally emerging during the activities adapted while learning about the TRM tool as well. This section now briefly presents the TRM and roadmap form as customised and obtained, and the final and overarching framework resulting from the long AR work done. More considerations, in particular with respect to the literature review presented earlier in Chapter 2, and in particular in Section 2.2, will be provided in the discussion, in Chapter 6.

For what concerns the single TRM process and the resulting roadmap, according to the classification present in the literature, throughout the workings done, the project was confirmed focussed on "process planning" and "strategic planning" roadmap types (Phaal et al., 2004a), as hypothesised in Chapter 2. In fact, taking into consideration the third roadmap originated at the verge of the third AR cycle, i.e. with the corporate TRM, the TRM process structure emerged as in the following figure.

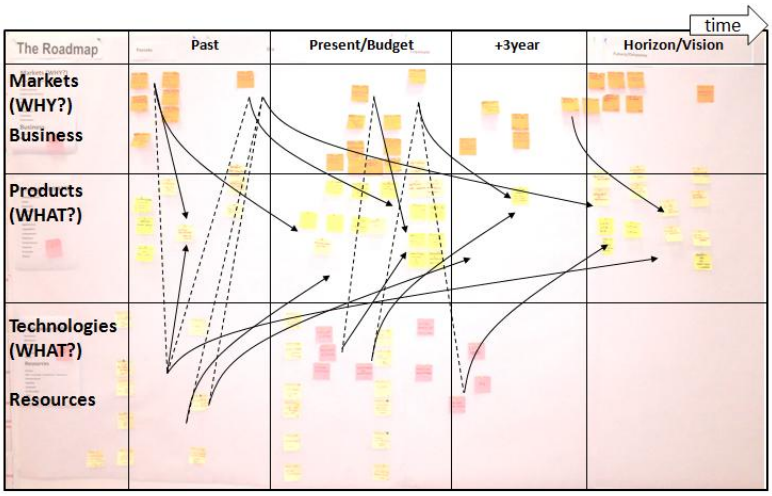


Figure 24 – Custom roadmap format proposed and used for the TRM process

The figure above describes the general logic of the single TRM process carried out as customised in the firm where the Action Research took place. As explained, it is a blend of the two roadmap types "strategic planning" and "process planning" initially targeted, namely those presented in the cited paper of Prof. Phaal. The figure is obtained just overlapping the central portion of the picture of the corporate roadmap shown in the previous Section 4.2.3, with the schematic description of the time frame (left to right) and the areas of focus (top to bottom).

The execution of the workshops must be performed just when an accurate preparatory work has been done by the team with respect to all the areas to be documented in the roadmap itself, and this could take a considerable amount of time, as external sources of information as seen (suppliers, customers, distributors, exhibitions, papers, patents, reports, etc.) should be included. In this manner, the TRM working logic behind the scheme flows as follows:

- The first (or second, if after the Technology Workshop) workshop, as described in this Chapter, aims at mapping and drawing the market trends first, and the business trends afterwards, over a large period of time, from the recent past, to the far future. The recurrent question to the team to complete this phase is "Why…?";
- The second (or first, if before the Market/Business Workshop) workshop is oriented to list the relevant technologies over time, whether known and in use by competent colleagues, or to be studied and investigated with adequate resources, if new or unknown. The recurrent question in the team, to complete this phase, is "How…?";
- The third and fourth workshops, which could even be condensed together (i.e. morning products; afternoon linkages) when the team members are well aware of the practices needed, as described in this chapter already, are oriented to generate product ideas, product portfolio integration or brand new ones, and hypothesize future products, platforms and services. Each output shall emerge from an overarching cluster of market or business indications (from the upper part of the roadmap), and of technologies and resources needed (from the lower part of the roadmap). Those clusters are originated and correlated by the dotted lines in the previous figure. The recurrent question at this point is the "What…?". In this phase it is crucial to have well present (ideally on large boards, or projected on a wall near-by the roadmap, as for example already described to some extent in Oliveira and Rozenfeld (2010)), the multi-project tool in use in the firm, to have a continuous and immediate recognition of the compatibility or criticalities of the emerging plan with the ongoing project and present initiatives.

The TRM tool, as shown and described in the presented scheme, was applicable at least for corporate, business unit and product portfolio roadmaps, as proven by the effective use of a so modified framework during the various cycles of the Action Research, and as documented earlier in this chapter. Other cited roadmap formats are surely adequate for the purpose, as documented in the literature. In any case, the one here tailored as shown help in particular generate clusters of new projects and initiatives, or changes and integrations of the ongoing ones. The outcomes have of course to be timely inserted in the existing multi-project tool, as otherwise the follow-up phase becomes possibly critical and the new initiatives could even risk not to kick-off or to suffer in the first project phases.

The following screenshot shows a small section of the multi-project tool in use at Calearo, with the integration of the TRM outcomes, i.e. new projects in this case, in fact inserted as new projects. The top rows on the right indicate the weeks and months (about 5 months are shown in this example). The rows on the left indicate the programs and the single projects (4 programs and 15 projects are shown in this example). On the right of the projects' description area, the dark red lines mark the work packages related to projects emerged from the roadmapping activities, while the work packages of other projects are marked in pink. At the bottom of the figure, the workload for each team and resource is marked in green (resource correctly allocated), or orange (resource overloaded). Each cell is labelled with numbers, indicating the detailed quantity of time per task, per work package, or per resource, and other key performance indicators (KPIs), in form of a broad dashboard. The figure was blurred on purpose, not to allow recognizing other confidential details of the multi-project tool, or names of persons, of customers, or of projects.

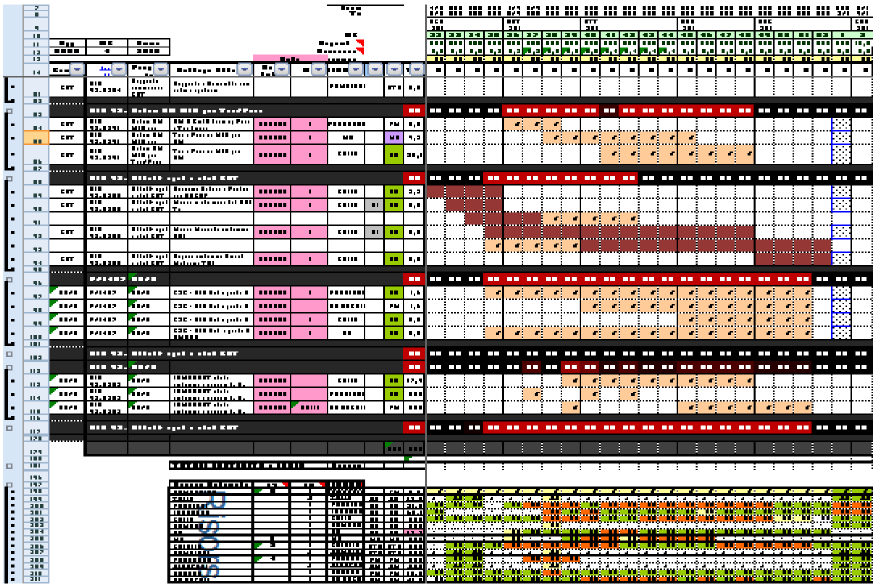


Figure 25 – Multi-project tool, with additional projects from the TRM process

The bottom-up and top-down flows, as in particular in the "process planning" type described by Phaal in the cited paper, remain useful and are preserved, so to converge to effective NPD and project planning within the multi-project tool. This approach supports as well the necessary and wished flow of information between technical, sales and other departments, and sponsor the continuous contamination and collection of information from external sources, not only from customers. On the other hand, the typical market and business evaluations present in the "strategic planning" type of roadmap described in Phaal et al. (2004a) are also supported and complementary to the evaluation of options, patterns and trends, and to the generation of new initiatives or optimizations to report and monitor in the multi-project tool.

Furthermore, the workings and outcomes took to the resulting overall framework reported in the next page. This new overall framework aims at, and in fact it seems able to, support and change the corporate decision process, and allows its evolution into a more effective and holistic practice, at least in the firm under study. From a typically mere market and, even riskier, customers' pull approach (as in the following Figure, on the right), the defined framework (as in the following Figure, on the left) allows a credible and continuous balance of market pull and technology push between an incremental approach and a possibly disruptive one, still without removing the more classic internal ways of doing. Depending on the needs and situations, a TRM can be done at corporate, business unit (BU), or Product Portfolio (PP) level, still considering and "protecting" the ongoing activities typically originated from customers' requests. Vice versa, standard projects and resources are continuously and visibly aware of the emergence of new projects, pushed in the structure as a result of the TRM process.

As described earlier in this section, the parallelism between the emerging activities and new projects, mostly oriented to future products, and the projects already ongoing or planned otherwise, is allowed and monitored by the multi-project tool in use. This requires a compentent Project Management Office, and qualified Project Managers, as well as adequate project-oriented culture.

The structure of the proposed overall TRM framework reflects the coexistence of new projects and other projects, which aims at sustaining changes in the organization through new initiatives, products and competences, for existing and new markets, without spoiling the ongoing activities, often still fundamental to finance the entire structure and operations of the firm.

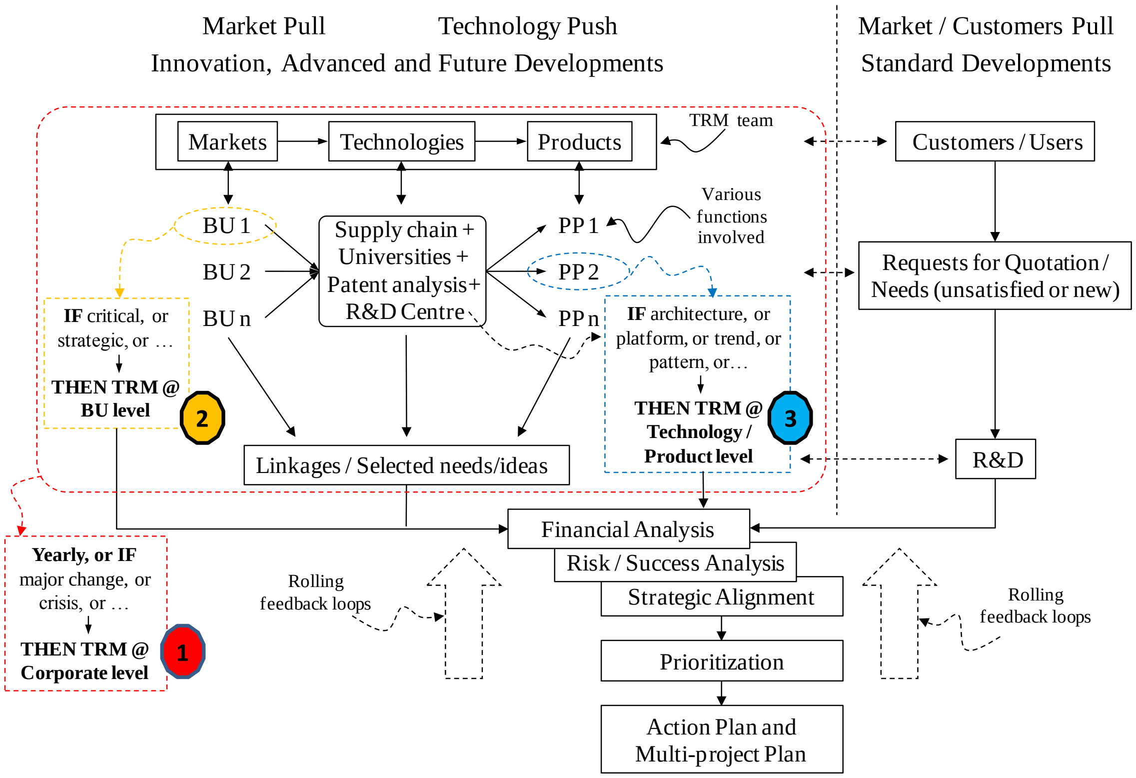


Figure 26 – New TRM multilevel overall framework proposed

As emerged during the various AR phases, the long time spent on the AR three cycles and on three levels of TRM was challenging, but well invested. The TRM tool could be designed and exploited at different levels, with the AR method used in sequence, for various units of analysis. This unusual approach allowed refining the TRM tool by steps, facing diverse issues, and, also very importantly, guaranteed the possibility to keep the tool alive in the firm, making it used and available with a particular and flexible frequency. The experimented and achieved coexistence of TRM at different levels, guaranteed having a general tool ready to be used "on demand". This is actually rather different from what the literature typically presents, where different levels seem necessarily used in fixed sequences, a rigidity possibly difficult to apply in real and high-paced environments. More insights on what has been carried out and achieved until this central phase of the PhD project, and with respect to the existing literature, shall be provided in the discussion in Chapter 6.

Before concluding the chapter, the following Table summarizes some of the outcomes emerged from the data as collected, described and analysed during the AR project, at its various stages. On the columns the three main AR phases are reported. Each corresponding level (BU, Technology/Product, Corporate) is highlighted, just as applied and described in the framework presented in this section, in the previous figure. On the other hand, the rows of the table collect critical factors that appeared transversal drivers to the various AR cycles: critical phases, customizations and criticalities, critical roles, tools and open issues are provided for each cycle and TRM process carried out. These key points will be useful for the discussion and the evaluation of the elements of methodological integration and commonalities achieved between the different AR cycles, as it shall be argued in Chapter 6. This is particularly relevant because, even when the units of analysis were admittedly different, nonetheless the AR method as applied allowed to reach useful theoretical contributions and managerial results.

Table 11 – Summary of emerging key points and findings

	AR Cycle 1 (Business Unit)	**AR Cycle 2 (Technology/Product)**	**AR Cycle 3 (Corporate)**
Process most critical phases	Constructing action; team assembly; planning action	Taking action; evaluating action	Evaluating action
TRM process customizations and criticalities	Preliminary activities (motivation; sense of urgency...); teamwork; methodology; follow-up; lack of resources	Careful preparation of materials; involvement of customers; finding patterns/architectures; follow-up; linkages; more accurate "post-its"	Role of shareholders; Roles of key suppliers and customers; TRM in parallel to present tools; TRM as multilevel process; deep financial assessment for priorities
Most critical roles	Methodology expert; team leader	Technical and sales personnel	Shareholders; persons of key suppliers
Main tools	Internal data; available papers; workshops	Workshops; data on internal projects	Internal and external workshops
Open issues	TRM activity due to limited knowledge of the methodology	Dynamics in the involved team and various phases	High expectations; Outcomes of previous rounds and follow-ups

5 Implications and Roadmapping of Satellite S-Band Antennas for Automotive[4]

As already mentioned in Section 2.4 and in Section 4.2.2, specifically in relation to the Product/Technology TRM experimented at Product Portfolio level, the second cycle of the Action Research project reported in Chapter 4 was dedicated to the technical aspects, the emerging target markets, and the possible products for the S-Band technologies. In fact, among other recognized trends and cases of convergence, the urgency to investigate on the S-Band technologies well matched the ongoing research plan and practical needs, and it was used to further study and experiment the customized TRM tool in further depth, i.e. at Technology/Product Portfolio level.

It is to mention that most of the technical studies and prototypes produced in this chapter were conducted at Calearo within the Ce.R.Ca., the central R&D, innovation and strategic centre, over an extended period of time, whereas the main projects related to the S-Band technologies as described were also in part supported by ESA, the European Space Agency. On the other hand, the managerial aspects specifically related to the application of the TRM tool, and the thereof obtained roadmaps, were studied and produced during the present PhD project.

This chapter reports the research activities, both at technical and at managerial levels, carried out around this technologies in the firm. Section 5.1 shall report the design of the research and the methodological aspects. Then Section 5.2 and Section 5.3 briefly describe the technical results and features of the studied and implemented prototypes. Finally Section 5.4 illustrates the results of the TRM carried out in the way described in Section 4.2.2 in the previous chapter, also highlighting patterns

[4] This Chapter is based on P2), P4) – (Zamberlan et al., 2013), (Zamberlan and Pannozzo, 2014).

recognised and resulted with the approach introduced in the TRM literature review (Section 2.2.4).

5.1 Research Design and Method

In this chapter a new kind of automotive antenna for satellite communications, and in particular for reception and transmission in S-Band, is briefly illustrated. The antenna was actually designed after studying the body of literature on satellite vehicular antennas for other bands (i.e. SiriusXM), and the various types of antenna elements capable of reaching the specifications drafted in the initial statement of work. After a long period of simulations with appropriate tools in use, the early prototypes for the proof of concept were mounted in the laboratory. After a tuning phase, other simulations, and further refinements, the prototypes compliant with the expected performances could be realized as presented in the next two sections.

As the antenna was produced in a small batch and tested, and in parallel the satellite for such services was launched and operational with partial coverage over Europe, the targeted market, namely the carmakers and the end-customers, did not react with the expected interest. The research question (RQ4), as stated in Section 2.4, was then how this could happen, and if further investments in this technologies were actually going to turn profitable. In other words, to align the technology now proposed in form of real products, the expected market need with respect to better multimedia services in mobility, and the relevant trends in the targeted automotive business area, a dedicated Product/Technology Roadmapping process was designed and implemented.

5.2 Product Portfolio: Switchable Dual Polarized S-Band Tx/Rx Automotive Antennas

For satellite communications, in handheld devices (García-Aguilar et al., 2010) as well as in the automotive market (Pannozzo et al., 2010), planar and low weight antennas are required to be low profile and low cost. Several solutions are proposed in the literature such as slots (Takada et al., 1995), microstrips (Pannozzo et al., 2012), staked microstrip antennas (Shih-Hsun et al., 2009) and helix antennas (Hyun-Sung et al., 2010).

Circularly polarized (CP) patch antennas have been widely used for satellite communications because of their broad beam width and good polarization performances. However, as the size of the ground plane is reduced, the CP patch antennas exhibit high backward radiation. This means that the antennas have less forward radiation and receive more noise from the bottom. Indeed, satellite systems are very susceptible to the background noise. This was a critical issue taken into account for the design of an automotive antenna, because the Gain over Temperature (G/T) of the antenna and the Noise Figure (NF) of the receiver affect the overall performance (Toniolo et al., 2011).

The following figure illustrates the resulting design of the antenna, in its dedicated automotive shark-fin compact form factor.

Figure 27 – The new multiband satellite S-Band antenna

One of the novelties of the mentioned antenna here described is in the possibility to combine the forward link based on DVB-SH standard with the return link based on ETSI S-MIM standard, enabling interactive services and contents in cars. In order to make the product more attractive for the automotive market, the additional integration of telephone and/or navigation features to the mentioned S-band services was implemented. This allowed to obtain a multiband and modular product family, in a typical shark-fin shaped roof radome.

5.3 Technical Details of the Antenna

From the technical point of view, both RX and TX S-Band sections might be seen as composed of an electromagnetic section and an electronic section each. The design of the main antenna radome was achieved in form of a standard automotive cover, in this case moulded in Polyamide 6 – PA6. It offers a dissipation factor (tanδ) of 0.02 and a relative permittivity of 3.1, on a wide range of frequencies (100 MHz – 7 GHz).

The design of the radiating sections is a trade-off of RF performances, mechanical profile/form factor and realisation costs. For such a reason, a compromise between a dual feed rectangular patch and a dual feed circular patch is given by the electromagnetic elements used for the present antenna. This antenna includes two octagonal, double ported patches, suitable for the RX (rear element) and TX (front element) sections. Physical details of the mentioned structure are visible in the following figure.

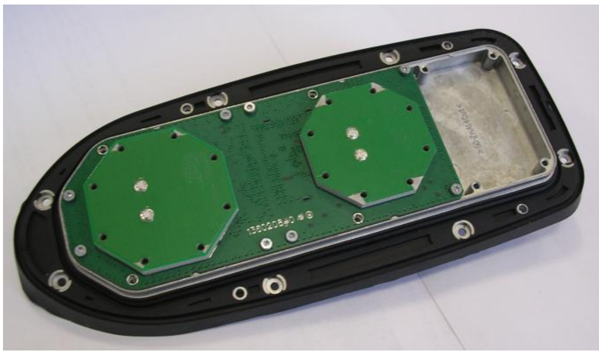


Figure 28 – Radiating elements of the S-Band antenna, S-Band elements only

The illustrated product is today available for mass production, either in the here presented form factor or in more customized ones. This antenna and its variants have been successfully used in all field trials carried out in recent times by car manufactures, service providers and other interested players, to assess and validate the S-band standards and technologies.

As described, the S-Band antennas here presented are a relevant part of a complete set of satellite communication dedicated products today ready for the market. In the next section the current mismatch with the market situation will be finally outlined.

5.4 Evaluations and Product/Technology Roadmapping

To date, it emerges that the European S-Band technologies (DVB-SH and ETSI S-MIM) did not penetrate the automotive market as a new feature. It seems new actions at top level of this overall eco-system (satellite service providers, European institutions, Space Agencies), and through more accurate analyses and plans, would be greatly needed to make sure whether the introduction of these technologies can turn into a market success.

So far no private vehicle runs on any European street offering OEM-fitted S-Band features to its driver and passengers. Even if such standard is available, products for mass production are potentially there, and all have been tested and integrated with good performances, the future for this eco-system is unclear. Actually, the launch of new satellites dedicated to S-band has been announced very recently by another satellite service provider, whereas this might target different customers, more oriented to professional uses and applications.

The described situation was here newly investigated in strategic terms in the firm, with use of a Technology/Product roadmapping, and in particular in the second cycle of the overall AR project described in Chapter 4, with the aim to recognise possible patterns applicable in this case. The specific roadmapping process wanted to trigger the trends and lifecycle curve of the S-Band technologies and their applications, so to highlight potential room for further action, investments and integrations, eventually useful to support managerial decisions on whether and how value and visibility could be still given to what was achieved so far. This process could as well help investigating ongoing dynamics within the automotive industry and typical consequences when those are out of alignment (Abernathy , 1978).

This TRM process was carried out as described in the second AR cycle of the overall project, as mentioned. This phase was described in Chapter 4, Section 4.2.2., and the roadmap obtained as outcome of such process is reported in the following figure (its validity is intended for the European region).

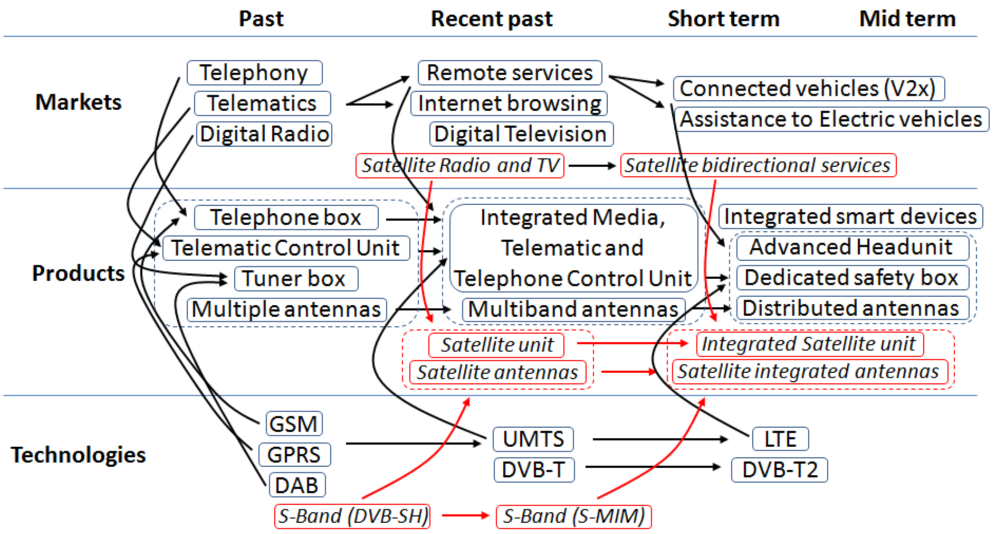


Figure 29 – Communications and broadcasting technologies roadmap, S-Band focus

The obtained roadmap reports the recent, present and future evolution of markets, products and technologies for wireless communications in vehicles, with focus on the S-Band track record (in red). With regard to the markets, it is visible that consumer business areas, as telephony and digital television, are present in parallel to more typical automotive areas, such as telematics. Here satellite communications are rarely present in Europe, while in US, for example the digital satellite radio is rather common. For the technologies, over time the incoming S-Band is paralleled by high-speed, high-quality terrestrial communications, such as LTE and DVB-T2, threatening its success. Finally products dedicated to hybrid communications and broadcasting in vehicles, with satellite digital tuners and related antennas, are the potential answer to the foreseen market and technology evolution.

In particular, the cited contribution of Rinne (2004) was then applied to recognise in more depth the situation under analysis. Based on this approach, in the short history of this particular technology, various patterns were recognised. It emerges that a case of "generation skipping" pattern is manifest, as "failed product generations are due to a misreading of the market either because the market is changing or because the market is not ready to absorb another product generation" (Rinne, 2004). Moreover, in case too many product generations appear in rapid succession, it may be the time where a generation is simply skipped. This fact is described in the following figure.

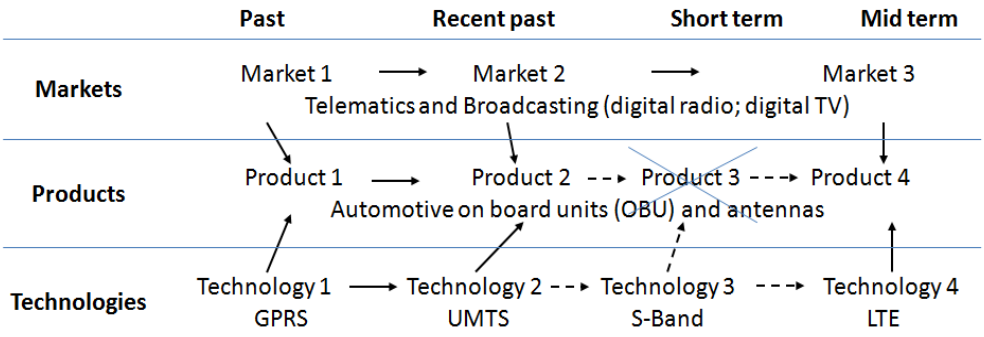


Figure 30 – Pattern of "Generation skipping", adapted from Rinne (2004)

Furthermore, it appears possible to recognise a pattern of "path dependence", generally applicable to evolving technologies becoming more and more available for mass market. This situation is represented in the following figure.

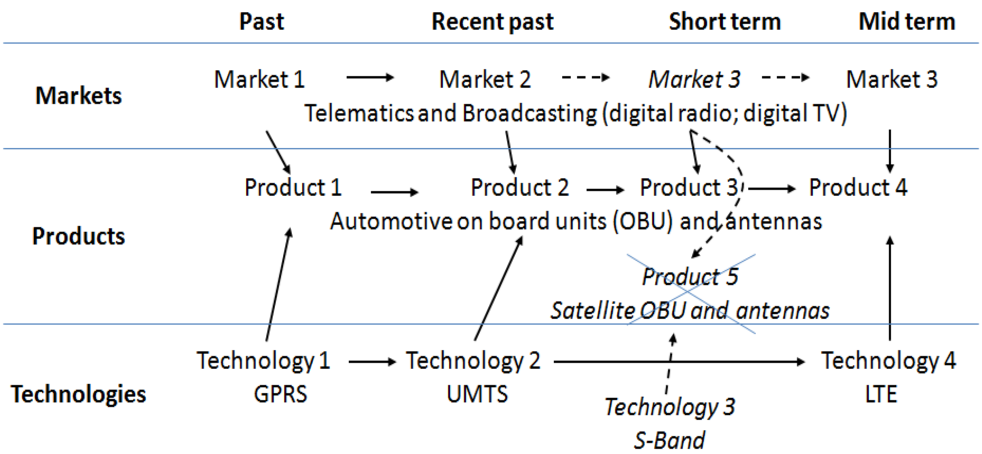


Figure 31 – Pattern of "Path dependence", adapted from Rinne (2004)

A dominating technology, in parallel with dedicated products, brings market leaders to emerge and sustain their business dominance by leveraging their "first-mover" advantage over time, in successive generations and standards. This is for example the case of 3G (UMTS), and even more of 4G (LTE). Those mobile technologies, even if they are not satellite communications, are able to provide the services needed in the specific field of automotive connectivity, while the new S-band technologies increasingly struggle to get sufficient visibility, at least in the mass automotive market. And the possibility to obtain good sales results are lowered, at least within this frame. For this reason, a new market positioning, or new business opportunities have to be found, as for example trying to move from a mass market to a professional market, and therefore getting away from typical consumer standards as fast time-too-market and low-price driven, high-volume products, as it seems to be happening, with very similar products.

6 Discussion on Convergence in Automotive and Consumer Wireless Technologies, TRM, and Action Research

In the previous Chapters 3, 4 and 5 the methods, the activities and the main achieved results were presented, together with early evaluations. These three chapters were crucial in generating and providing evidence that the research activities, as designed and carried out throughout the different intense phases of the overall PhD project, were helping in achieving the objectives as set, in verifying the hypotheses, and in answering consistently the research questions formulated in Section 2.4.

Now the present chapter is in fact oriented to in-depth discuss and link the findings, so to verify whether the research questions initially issued, for the topics introduced in Chapter 2, were already or can be answered, with adequate quality and completeness, through the obtained results. The purpose of this chapter is also to discuss in a overarching manner throughout the obtained results and on the theoretical framework, for each objective, in relation and comparison with the theory and the literature reviewed in Chapter 2, aiming to contribute at academic and managerial levels, and indicating possible future directions.

This chapter is structured as follows. The next Section 6.1 discusses the first topic introduced in Section 2.1, with regard to the changing context in automotive antennas and wireless systems, influenced by the consumer electronic markets, and converging. Section 6.2 discusses the Action Research and the whole TRM workings and obtained results, previously presented in Chapter 4. Then Section 6.3 discusses the results presented in the previous chapter on the S-Band antennas and the related Product/Technology roadmapping phase. Finally, Section 6.4 concludes the chapter wrapping up in brief the outcomes, verifying whether and how the research questions have been answered, and looking into limitations and future directions.

6.1 Implications of Converging Automotive Wireless Systems

Working at the research problem and emerging context presented in Section 2.1 led to newly map the main automotive wireless technologies and applications in their availability, and potential or expected success and convergence. The outcomes of this early process were presented in Chapter 3, and in particular in Section 3.3. Among other aspects, it was confirmed that this growth of features is suggesting to implement architectural innovations. Empirical evaluations and interpretations of such scenario led to various considerations and, ultimately, to plan and execute the remainder of the PhD project at the automotive antenna manufacturing firm, then searching the right reaction with help of adequate tools and methods. In any case, at this early stage various aspects emerged and could be discussed, as follows.

Firstly, car manufacturers in any new platform shall expect from antenna suppliers a growing level of flexibility, compared to the past or to older projects. OEMs are putting Tier 1 suppliers under pressure in search of quick and innovative, but cost-effective solutions, both for mature markets (i.e. Europe) and for fast growing areas (as the Far East, and China in particular), where end-users have diverse expectations (often generated by patterns of consumer electronics) and limited patience for automotive lifecycles and adoption capabilities to follow.

Secondly, antenna suppliers must develop a broader knowledge base, an extended competence range and a deeper system and architecture understanding, also via alliances, partnerships, et cetera. From hardware, radiofrequency and analog electronics design the step into firmware, software and system networking features is largely necessary. Even if this is not applicable in general, but rather to the premium segment, the scenario of various car multimedia systems has evolved from multiple ECUs, into multifunctional, possibly stand-alone, headunits (HUs), and then further into a limited set of distributed units, also due to higher frequencies and necessary multiple antenna systems. Antenna manufacturers need then to focus on technical management of new standards, interfaces and compatibility with the whole set of network components, as well as with external devices. Another observation with respect to this point is that the current overall market trend in this area is positive, and potential new business are apparent, especially when cultivating broader competences.

Thirdly, changes and adaptation to customer requests (i.e. with new consumer electronics and features being introduced at higher pace, compared to previous automotive development cycles) are necessary also for antenna manufacturers. This applies in particular in field of antenna design, as new wireless technologies are normally added to existing services, and not substituting any previously required ones, or may require extended bandwidths, or higher filtering, etc., for some services, depending on the convergence and coexistence of systems.

A fourth consideration is that in the last 15 years some features, especially in area of infotainment, have actually disappeared or decreased their presence (i.e. compact cassette players, CD-changers, in-vehicle fixed telephone systems, etc.). Some features have been replaced inside the car by other ones (i.e. compact cassette by compact disc; then compact disc by mass storage devices; and mass storage devices by data streaming), but others may be replaced by features outside the car, i.e. tablets in place of headunit dashboard displays, mass storage devices (mp3 players) in place of CDs and DVDs, or smartphones in place of Bluetooth-integrated phones, and so on.

The latter example is relevant for antenna manufacturers, as it could have a negative correlation with the automotive antenna business: automobiles and end-users could opt for consumer devices and highly portable applications, rather than automotive (OEM and aftermarket) hardware. This is applicable in particular in vehicles of middle range and low cost segments, where drawbacks from non perfectly automotive-grade and integrated devices are of little or limited relevance to customers.

Another consideration is driven by external factors, as take rates, meaning the percentage of antennas installed for a certain function or group of functions, could in some cases (due to geographic restrictions, dedicated bands, etc.) be very poor. Nevertheless, antenna manufacturers must guarantee full, on-specification functionalities with each required configuration, and some rare products could require paramount design efforts to be realized and meet specifications, without any return on investment, for years if not for the entire car lifecycle (i.e. multiple antennas for TV reception may be in this group of low penetration designs). In this cases, better market understanding and openness of approach (i.e. some options being not valued by customers or not profitable) between Tier 1 suppliers and car manufacturers could lead to overall advantages.

Lastly, (late) design changes for antenna products under developed could be more and more critical when getting closer to the Start of Production (SOP) milestone. This applies in particular for roof antennas with potential mechanical issues eventually arising only when the first cars are available before a product launch (i.e. painted shark fin antenna colour matching, or mechanical roof coupling), as those antennas are externally mounted and highly visible. The crucial capacity to quickly react and settle for last minute changes shall have to be addressed also to Tier 2 suppliers (i.e. for printed board circuits, moulding tools, painting, etc.), obtaining solid and reliable modifications at affordable prices, along the supply chain.

In summary, the analysed literature on automotive wireless services and the implications, practices and ongoing changes there documented were indeed largely confirmed. The convergence of car technologies for connectivity and consumer technologies, supported by the growth of electronics and features in cars, was confirmed as well. The findings of this part of the work, mapping the antenna and wireless functions in cars, and their trends, contributed to evaluate the power of this technological changes and the urgency to recognise architectural innovations and other changes, as soon as possible. From these considerations, as well as from the presented results with regard to this topic, as done in Chapter 3, originated the urgency to introduce adequate tools and bold managerial changes.

6.2 Action Research, Customized TRM Framework

Regardless of the unit of analysis and the timeframe in scope (corporate, BU and Technology/Product level, as per the AR project carried out and reported in Chapter 4) the so enabled integration in the firm, and the deriving linkages, decisions and projects, confirmed to be able to allow a crucial flow of information as well as bottom-up and top-down continuous exchanges. In case new patterns, or trends, or architectural changes are recognized while carrying out the TRM process, a specific process, depending on the level of analysis, can now be enabled swiftly, on demand, and conducted consistently in the dedicated field of interest.

Furthermore, if a business unit is suffering from critical situations or foreseeing a new strategic need, a TRM process at BU level might be organized and exploited, directly and locally. The resulting practice, especially in a typical situation of chronically scarce or limited resources, and especially if the TRM process can be kept alive and activated quickly and when actually needed, and not only at designated intervals, represent a major achievement for the project and for the firm under analysis. This result seems to add value to the proposed theoretical and managerial framework compared to the TRM literature review as conducted. It was shown in figure 26 in Chapter 4.

The introduction of a systematic scouting and collaboration along the supply chain, with key customers, and in particular with selected suppliers (the latter practice having being a reason for a certain delay in the “doing” phase of the third AR cycle), as described in Section 4.2.3, together with the analysis of patents, of competitors, and with universities, contributed adding confidence and concreteness to the outcomes. It also allows better availability of data and consequent lean convergence of processes and information for the support of decision makers and business strategy alignment. Again this aspect is scarcely documented in the TRM literature and represent a contribution to the theoretical body of knowledge.

The “zoom-in” (to Technology/Product level) and “zoom-out” (to Corporate level) performed during the AR project has actually enabled extended trust in the tool, at various levels, and seems to have contributed to improve the methodology itself. The different levels of TRM over time is an aspect already present in the literature, as seen in the review in Chapter 2. But the novelty is in the different approach introduced in this research. TRM in the literature is normally planned to occur at a level, say BU level, and after all BUs are ready, it can take place at higher level.

In the present project, instead, on one side it resulted that waiting for all BUs to be through their TRM will lead to great delays, with motivational issues, and so on. Furthermore, to perform a TRM process at one level, the TRM processes done at other levels beforehand are relatively important, if not unnecessary, especially if considerable time occurred between one process and the next. For these reasons, it appears consistent to allow the execution of TRM processes not is some sort of sequence or logics, normally related to the organizational chart, but on demand, i.e. depending on multi-project requirements, or deadlines, or milestones, and so on, as in one of the emerged hypotheses presented earlier in this thesis.

The structure and logic for the single TRM process and resulting roadmap was adopted from the identified TRM types present in the literature, considering the customized Market-Technology-Product sequence, as described, highlighting the importance of the construction of the linkages between those, and of a careful preparation of the contents and inputs for the workshops, also with help of external parties. This TRM structure, as illustrated in figure 24 of Chapter 4, resulted applicable for all the different levels analysed and where it was applied (Product Portfolio, Business Unit, Corporate).

The so defined TRM, in tight integration with the overall framework defined and presented, thanks also to the iterative approach proposed, introduced and tested with the help of Action Research, allowed to obtain a robust coexistence with other managerial practices, and namely with the main multi-project tool in use in the firm. The strategic initiatives defined in the TRM processes are actually introduced in the multi-project tool, with work packages, resources and workloads monitored and followed-up together with the standard and ongoing projects, and not relegated to a separated, and possibly isolated and risky, planning and management flow. The principle of this relevant outcome is visualized in figure 25 of Chapter 4.

Stressing the different approach implemented with regard to the various TRM processes carried out, the consecutive rather than concurrent AR cycles helped reaching a potential change of perspective with regard to the TRM tool. Even if this topic might be object of further and future study, it could be considered that TRM can and *has to* be done at different levels, as long as scope and depth of the AR and TRM intervention remain clear. In a certain way, and possibly typically for the AR method, the obtained “action and reflection” could actually add strength to the research, also by exploring critical elements of integration and coherence throughout the various cycles. The following figure aims to represent the transversal elements of integration throughout the various phases.

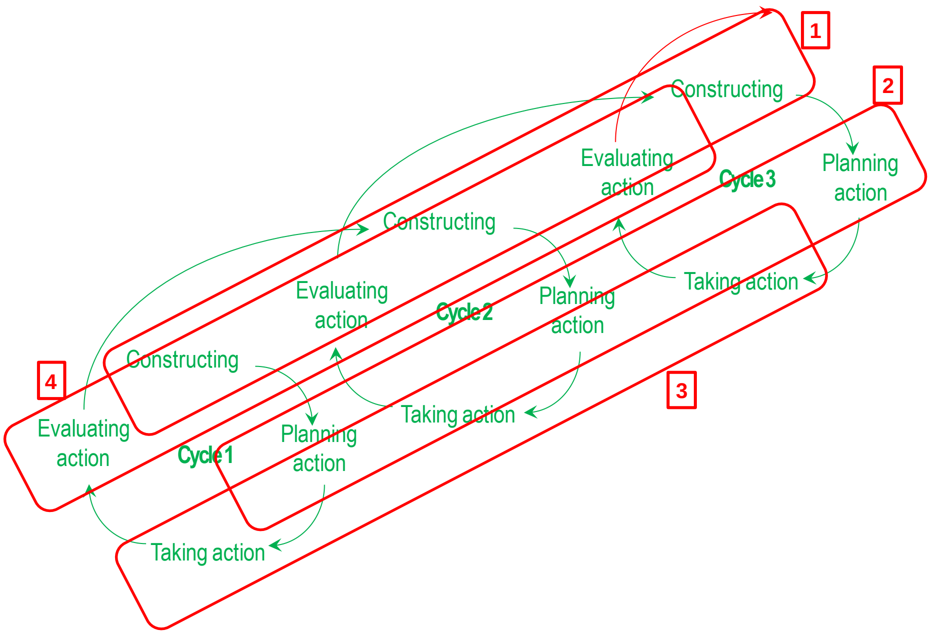


Figure 32 – Integration elements for different AR cycles

Furthermore, already in the AR Cycle 1 the TRM methodology needed to be in place and in action. The initial idea to perform a corporate TRM, rather present in the literature, was aborted immediately. The hypothesis here is that, with no budget for consulting intervention available, and scarce room for a “try & error” deal in the real fast-paced environment of a private company, the tool was to be understood and introduced in the company before risking to practice it at corporate level. This requested to assure high commitment with leadership, with internal dissemination, and so on. Incidentally, but not negligibly, the internal presentation of the autonomous TRM literature review, carried out and published, helped on this point.

Another key success factor and enabler of the rationale supporting the AR cycles and TRM as implemented was the fact that the involved team members were consistently the same, primarily employed in the same SBU, and that specific SBU is substantially in charge of the R&D program and innovation projects for the firm. This has allowed and facilitated one of the possibly most critical aspects in TRM, namely the capability, within the firm, to use such tool and exploit the various phases effectively, or even virtually on demand, especially if related to an external consultancy, as often seen in the literature, which possibly is one of the main reasons why the follow-up phase results so critical. Successive TRM utilization should be done, as far as possible, with (at least part of) the same team, so to concentrate on contents rather than on tools and methods. This aspect represents a contribution at managerial level, and also a possible indication for future investigations at theoretical level.

Compared in particular to another framework available in the literature (Cooper et al., 2010), here the defined and tested framework was separated from the strategic phase at the beginning of that model, as the introduced TRM processes aimed to intervene aside and in parallel to the existing strategy and set of tools, practices and projects already in place. Furthermore, the gained speed in executing the TRM process appears fundamental in its real application and to sustain its potential in a changing business environment.

Furthermore, the AR process guaranteed quick and focussed growth of internal resources and their competences in field of TRM, going from initial difficulties in understanding the tool itself, to confidence in applying it and thinking boldly and in team about the company’s future challenges and opportunities. In the literature this aspect, which is crucial, seems scarcely studied and could be an area of future research and developments.

The following figure instead, collects the transversal elements communal to the various TRM processes carried out, potentially independently of the TRM targeted level, and gives strength to the chosen sequential use of the AR cycles as carried out and described in Chapter 4.

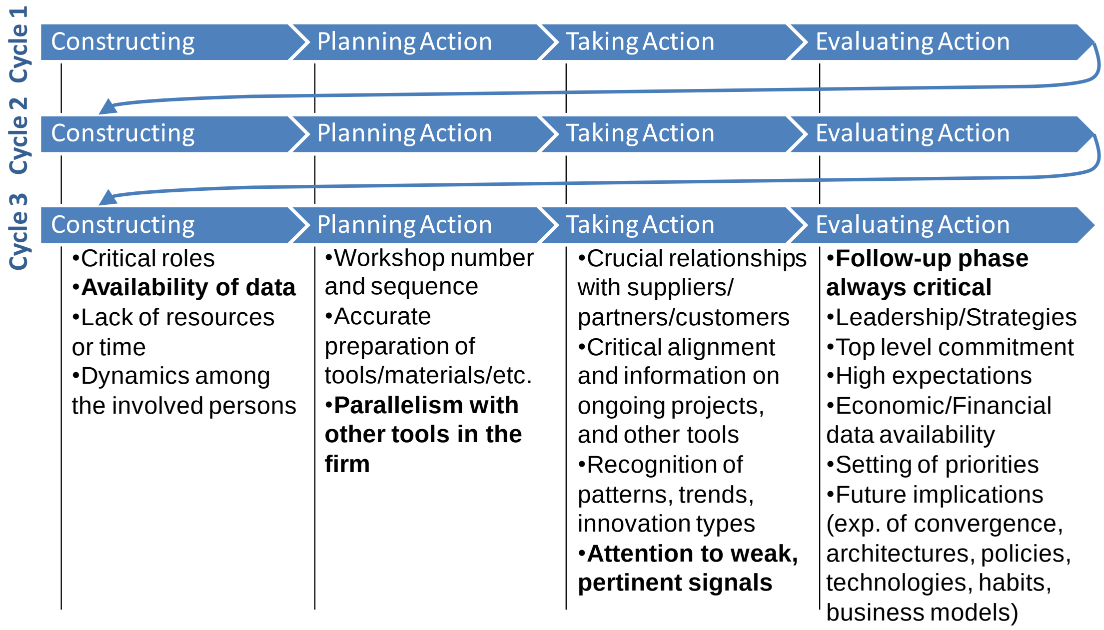


Figure 33 –Evidence of communal elements throughout the AR cycles

Another interesting point of discussion from the results reported in Chapter 4 lays in the different workshop sequence that was put in place. Markets-Technologies-Products was the one that was applied after the first AR Cycle, mostly because new products, or portfolio trends and such, seem to benefit from details on technology trends and technical "enablers". This is another point of differentiation, when compared to "main stream" theory and literature of TRM. At the end of this work, it seems that further study could be dedicated to investigating whether even a Technology-Markets-Products sequence could bring further advantages. Generalising, it could be argued that the sequence of the workshops is not to be considered fixed.

From the literature it emerges that the biggest efforts with TRM are possibly in the final phase of integration (Gerdsri et al., 2010). This was confirmed in this work, and in fact it is one of the points reported in the summarizing table presented in Section 4.3. It seems that this phase could remain critical, and a potential limitation to be mitigated, exactly because the TRM tool has to be integrated and used in rather obvious presence of other managerial tools, practices and projects. And therefore this issue might be not specific of the TRM practice itself, but related to the introduction of any new tool in an existing environment, with a normally limited number of resources.

Before providing a summary of the discussion on the overall project, following the sequence of topics as presented in Chapter 2, in the next section insights on the S-Band technologies and the specific TRM application, are reported.

6.3 TRM for Future of S-Band Technologies

As described in Section 4.2.2 and in the whole Chapter 5, the second TRM process was carried out within the defined research program to refine the management framework under definition and to experiment the capability of TRM to respond to the question whether the first vehicular products for S-Band technologies can be realized and assess the maturity of such technologies, considering the market situation as described and the potential results.

These technologies were object of specific attention because they allowed crossing technical and practical needs of execution, as well as evaluations at Portfolio Management level in the firm, and also they helped for a more refined definition of TRM aspects and customisations for the firm under analysis.

To synthesise the obtained results, technically the antenna systems required on vehicles to enable the S-Band features are feasible, and could be provided at attractive prices. From the marketing and managerial standpoints, in the conducted research it was identified that there are several reasons which could lead to a critical situation, as the one that today seems to be ongoing:

- Some decision makers, particularly relevant for the specific value chain, were and are missing in the eco-system (i.e. carmakers or top automotive suppliers);
- The European S-Band may simply be too different from past, current and next vehicular needs or applicable use cases;
- Other technologies and service enablers look increasingly more attractive for broadband or broadcast services (i.e. terrestrial wireless standards, as LTE);
- Such cost effective or alternative technologies in the meantime are becoming successful and turning the S-band quickly obsolete, at least for mass market;
- Standardization and validation, either through integration into existing platforms or via the support of open standards, could be assessed as unprofitable, as happening in case of the fragmented TV standards proposition;

- The attractiveness of these technologies, for investors and developers needed in the value chain, was not sufficiently sustained by key stakeholders.

Finally, another reason which may have caused the present situation of missing sales for the S-Band products could be the apparently not-robust-enough assumption of satellite service providers, that all new and extended features that were virtually to be introduced and planned for the European S-Band platform were actually what customers wanted, or what they were aiming at, for their vehicles.

It may also be the case, in the particular oligopolistic business of satellite service providers, in which alliances and joint ventures, even if started with the most promising expectations, failed to succeed and became problematic as soon as results did not seem as easy to achieve as expected by non-automotive experts. In other words, entry barriers limited the access of satellite service providers into the automotive eco-system and market.

Surely it was confirmed that this technology, as documented in the literature review on this topic, and provided in Section 2.3, is struggling also for the aggressive convergence of other consumer wireless technologies and services into the automotive market. Nevertheless, based also on the literature on this matter, Calearo decided to proceed investing in the S-Band technologies, and maintaining its leading position, moderately working on this area until concrete opportunities do become available.

Actually very recently another European telecom operator in a previously cited announcement (Inmarsat plc, Press Release, 2 July 2014), supported by International Institutions, seems interested in the real exploitation of this satellite wireless system, especially targeting its high potential in professional uses, disaster recovery uses, and such, markets this satellite provider dominates and knows particularly well.

6.4 Discussion Summary

As contextualized in the introductory chapter and in Chapter 2, the different topics and phases of the long research project ranged from setting the problem and recognizing the macro-trends impacting on the firm under analysis, to assessing a new management tool to allow a better internal and external integration of the resources, until tailoring it to the needs of specific firm under study. The central part of the research project was indeed carried out with help of the Action Research methodology, which allowed to dynamically manage and document the ongoing and changing activities within the organization, contributing in parallel to the theory.

In summary, wrapping up the entire project, and in particular in response to the research questions as set in Chapter 2, key achievements of the PhD work were:

- (RQ1): From the awareness on the convergence of automotive and consumer wireless technologies and consequent architectural innovations, to the consciousness to need the introduction of a new management tool, such as the TRM. This result responded to the first preliminary research question set, i.e. to react strategically to the ongoing changes and to enable the management to start generating solutions. The amount of technologies and potential antenna systems for automotive wireless systems in convergence with consumer products and services was shown in table 7.
- RQ2: A newly defined TRM framework, with outcomes inserted in a multi-project tool, especially to allow monitoring and following up the definition and development of any new project or product defined. This point aimed at answering to the second research question, with the integration and follow-up of the TRM processes in an overall multi-project framework. These results were illustrated in figure 24 and figure 25.
- RQ3: A customized, overall and "on demand" TRM process, identified and tailored for the specific case here investigated, tested and applied throughout the firm, at different levels (innovatively oriented to push for new projects and products), and in parallel to the existing main management tool (strongly oriented to serve the customer, in typical market pull, as the firm is used to act). This overarching framework responded to the third research question, introducing, tailoring and testing the TRM tool for a better strategic planning, while working and operating in presence of existing tools, at different levels. This result was illustrated in figure 26.
- RQ4: As a sub-case and an execution of the previous point at product portfolio level, an analysis of the S-band technologies, the design and realization of new, high-performing S-band and multiband antennas, and a dedicated TRM process that highlighted the complicated future, possible pitfalls and potential evolutions of these technologies born for handheld consumer devices, in the automotive sector. The results were also shown in figure 27 throughout figure 31.

Rarely, or never, in the included literature on TRM, were described companies which, starting from a given situation, could implement roadmapping systematically and across the entire corporation. And seldom TRM is described as a tool used in parallel to other decision support systems. This is possibly due to the consulting approach it seems often to be proposed and described. On the contrary, in the present project, the parallelism was instead studied, observed as a critical point, and introduced accordingly in the overall framework. TRM was therefore introduced in a living and operative company, becoming a parallel practice, integrated with the multi-project management tool, used to manage programs and projects in the firm.

At the end of the project, some organizational changes were introduced in the firm. As the TRM team members seemed the most committed and stable working group, the core TRM team was eventually moved into a Steering/Strategic Committee, which could either execute TRM to push decisions, or monitor clients' pull actions, and use other tools if required.

However, as described in the literature, strategic planning remains a critical activity for the firm in today's fast and turbulent times. Theories, methods, practices and so on can surely help when applied with competence and experience, but opportunities can turn into threats at any time, as the competitive landscape is very tough, at least in the analysed market arena. The rationale of the TRM tool choice was supported and prized with technical outcomes, i.e. with regard to the S-Band technologies, with organizational changes and improvements, with high-quality teamwork and sustained motivation. Theoretical contributions to the used methods could be also achieved.

In any case, limitations of the work are also present. In the literature, as described, the TRM tool is normally struggling in sustaining and keeping the interest in its application alive in the organization. This implies a long term effort and top level commitment, also with respect to other (present/future) tools, and only more time will confirm or confute the work done so far. Another limitation is to be seen in the risk to have limited awareness of the tool in areas of the firm of which personnel is scarcely involved. Means for internal promotion of the TRM tool and its application, an aspect rarely found in the analyzed literature, could be studied and improved in future.

For what concerns the methodology used, and Action Research in particular, even if all efforts were done to always reach and keep objectivity of work and results, still just a limited number of persons contributed to the activities, and so the researcher might have failed somewhere to recognise and mitigate possible biases.

Actually in the literature the vast majority of works analysed has show positive results on TRM and on Action Research, and this might be per se source of suspect.

Finally, the necessity to have a clear and continuative overview of forthcoming antenna technologies of potential future impact and interest in field of automotive, connected cars, mobility and, in brief, in the “Internet of Things”, with specific attention to academic and competitive activities in the field, is suggesting to keep working with a new roadmapping activity, based on the state of the art of the literature in field of automotive antenna technologies and a deep statistical analysis of patents in this field. This ongoing work is today at in an initial status, a working paper, but it highlights the momentum and the importance of strategic tools and planning, as TRM seems to be able to empower.

Furthermore, as highlighted in the literature review in Chapter 2, and in particular in the synoptic table there reported, for the analysed topics there are various research opportunities well worth future efforts, for the various illustrated clusters, ranging from assessing TRM with other innovation processes and initiatives, to doing more quantitative research and measurement on the impact of implementing TRM; or from doing surveys in organizations implementing TRM, to testing TRM used in other converging areas, or to measuring the impact of TRM on organizations.

7 Conclusions

This final chapter of this thesis provides conclusions, possible limitations, and recommendations for practitioners and for additional research work.

This PhD project originated from a practical interest to support a leading firm involved in particular in automotive and wireless converging fields. In this critical situation, the company under study recognised the threats and opportunities generated by this emerging convergence, on one hand, and the consequent architectural innovations and other novelties at antenna and wireless system levels, on the other. The firm understood the needs to evolve and improve its decision support system, and chose to use and assess the TRM tool.

In the analysed sectors, there is a continuous technological evolution and growth of innovative offerings from key players, to meet the increase of features and services a connected vehicle, ultimately a *device* and part of the "Internet of Things", demands. The excessive production capacity, a spasmodic quest for cost reductions and economies of scale, the needs of new features and innovations for marketing actions, typical of the automotive industry in particular, push the key players in this arena to elaborate and propose architectural changes, inspired also by practices well tested and available in the consumer wireless business areas, where instead very fast time-to-market and high volumes are crucial.

Methodologically, this empirical evidence on the changing environment, and the consequent urgency resulting from internal investigations as well as from technical and market analyses, led to study the TRM tool in its various phases with help of the Action Research. To exploit in an appropriate manner the use of this tool in the organization, it was applied various times, and customized and refined according to the context, the purpose and the scope. This was done both on the single TRM process and therefore on the resulting roadmap, as well as at overall framework level. The TRM tool actually resulted an adequate management tool to help detect present and future opportunities and potential threats, to circulate critical information in the organization and along the supply chain, and to support portfolio and project planning and prioritization.

From the academic point of view, this work contributed to prove the applicability of TRM as an internal tool, where a company can obtain to introduce it in parallel to existing practices. To do so, the Action Research method helped consistently, with the TRM tool implemented in subsequent stages at three different organizational levels, namely Product Portfolio, Strategic Business Unit and Corporate levels. The Action Research, as seen, has been scarcely used in conjunction with TRM, but its use should be recommended in future. In using this method, it was also achieved to slightly adapt it to the specific needs of the project, i. e. executing the different stages consecutively rather then concurrently. AR was carefully applied for different units of analysis, guaranteeing the integration in the each of the four AR phases, transversally to the three cycles carried out over the two years.

The multilevel TRM framework as defined actually appears to allow better linking of technology trends to corporate business planning, aligning critical R&D investments to PPM, sustaining more frequent communication and exchanges in the organization. The proposed and experimented framework promotes the extension of TRM to resources along the supply chain, from key suppliers to relevant customers, and other partners as well. Furthermore, the overall TRM framework was studied and applied from start to end of the project in parallel to other tools and practices, and not a stand-alone process. This latter fact, rarely explicit in the TRM literature, seems very important and is probably due the internal management participation obtained also with the AR method.

The maturity of the presented framework and its future application require further validation, in particular with follow-ups, roadmaps maintenance, and measurements of TRM contribution to business performances, with key performance indicators to be carefully defined. Nevertheless the new proposed framework was here applied with success, in case of automotive and consumer wireless convergence, because it provided a simple way to visualize and track trends and patterns, and so to support decisions. Defining, preparing and doing workshops within the core team and the involved departments, and obtaining the roadmaps, allowed working in heterogeneous groups, extracting critical information and data otherwise often forgotten or hidden in personal computers, or logbooks, and so on.

It can be assumed that the TRM as customised, both for the single "on demand" TRM and resulting roadmap, as for the overall iterative and multilevel framework, and with the AR method as used, could be applicable at least in other firms and sectors, if not in general, where recognised trends and patterns require ambitious management measures and projects, up to business model and organizational changes. Working from a Corporate level down to a Business Unit level and further down to a Product Portfolio level, donated consistence and confidence in the practical aspects and in theoretical hypotheses and emerging findings, still allowing integration and uniformity of study and results.

In other words, as presented in the literature, the TRM process, already used and in use in many fields, if carefully applied and tailored for the described environment and related issues, can become a distinctive, fast and practical process over an extended period of time and scope, and not only a "one off", or consulting instrument, able to leverage informed decisions and strategic planning, at various levels, and on demand.

Interestingly, during the topical phases of the Action Research, having produced and published, among others, a specific systematic literature review on TRM, turned out to be a key element for motivating and involving key personnel on the proposed tool. In any case, the research requested strong leadership and commitment to generate outcomes both for the theory and the firm.

Among others, a limitation of the present work might be recognised in the possible biases of the researcher (manager, practitioner and researcher, a rather ideal state to do Action Research), and in the limited scope of the project (one business/firm, which, again, is accepted as far as the Action Research method is concerned). So, aside the application of the proposed framework in other firms, future work opportunities could involve the attempt to better study and standardize this contribution to the theory, as in the emerged need for a supply chain (of knowledge and information) of the TRM.

Another (predictable) limitation of this work, is that certainly it cannot supply the final solution to react to phenomena occurring in the relevant eco-system, such as the convergence of technologies and sectors described and intensively studied here, or answer the systemic question on where the highly connected world as we know it and the "Internet of Things" will go, even in a few years from now. Nevertheless, also for future research activities and for firms operating in presence of convergence, an area and set of questions worth investigations could be on how new or redefined business models should be structured to attract a larger but possibly qualitatively better customer base, where modular and co-operative approaches to design and to markets should sustain innovation and growth.

In the end, managers, practitioners and academics should keep proposing and testing new or refined means and effective ways to contribute to mitigate the following hard truth: “The true threat a company faces is not from price competition, but from technology competition” (Petrick and Echols, 2004)

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