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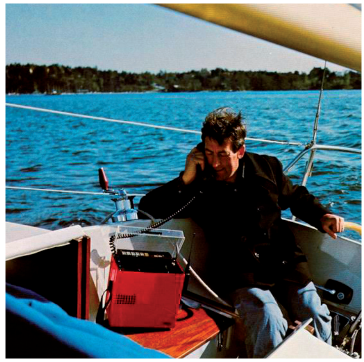

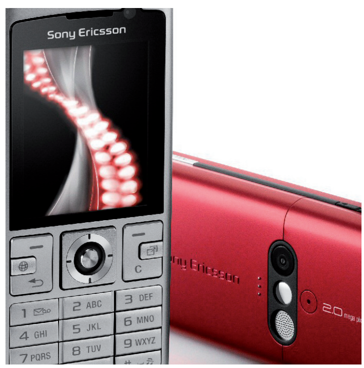

Effects of research on Swedish Mobile Telephone Developments: THE GSM STORY

ERIK ARNOLD, BARBARA GOOD, HENRIK SEGERPALM

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by funding *needs-driven research*
and developing *effective innovation systems*.

Through its activities in this field, VINNOVA aims to make a significant contribution to Sweden´s development into a leading centre of economic growth.

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Effects of Research on Swedish Mobile Telephone Developments:
The GSM Story

Erik Arnold, Barbara Good, Henrik Segerpalm
Technopolis Group

VINNOVA's foreword

Ericsson's development of mobile telephony is one of Sweden's outstanding industrial successes of recent years in terms of turnover, employment and exports. This impact study focuses on the role of Swedish government research funding in the development of technology for mobile telephony, especially GSM, and the subsequent Swedish success.

The study shows that a number of factors were important. These included the dialogue between the supplier Ericsson and the customer Swedish Telecom and their mutual support in the international standardisation process. Another factor was the technological capabilities and market strength already built up under the Nordic cooperation that created the NMT system. Under the research leadership of Sven-Olof Öhrvik and then Jan Uddenfeldt, the Ericsson subsidiary SRA (later Ericsson Radio) undertook key technical developments. At the time, this was a company with few resources, compared with today's Ericsson. Until its transformation into a state-owned limited company in 1992/93, Swedish Telecom had a 'sectoral responsibility' for research in the area, and its Radio Labo-ratory, managed by Östen Mäkitalo, played an vital role.

R&D financed by VINNOVA's predecessors STU and NUTEK in the period 1975 – 1998 was of major importance in two respects

- Building up research capacity at universities and institutes of technology that produced professors, PhDs and MSc engineers – individuals well prepared for a career within industry, whom Ericsson and Telia could employ during the huge expansion of business of the 1990s
- Financing research that made technical breakthroughs possible

The European R&D programmes RACE and ACTS were important to the developments that took place in the later part of the 1990s.

A team from the Technopolis Group, comprising Erik Arnold (project leader), Barbara Good and Henrik Segerpalm, conducted the study. They were supported by an eminent reference group including: prof em Lars Zetterberg, KTH; Östen Mäkitalo and Conny Björkvall, formerly Swedish Telecom/TeliaSonera; Jan Uddenfeldt and Jan-Erik Stjernvall, Ericsson; Lennart Alfredsson, formerly SRA and Ericsson, and Bengt-Göran Bengtner, formerly Swedish Telecom and Ericsson. The group also included Sven-Ingmar Ragnarsson, Eva Westberg and Anders Hedin from VINNOVA. Torbjörn Winqvist acted as VINNOVA's project leader.

The impact studies that VINNOVA performs, at the Swedish government's request, are particularly valuable in describing the longer-term effects of R&D funding. We wish to thank all those who have contributed to the study, both those already mentioned and the many others who have shared their experiences in interviews and in other ways.

VINNOVA in April 2008

Per Eriksson
Director General

Göran Marklund
Director
Head of Strategy Development Division

TABLE OF CONTENTS

Summary

The Swedish government requires that VINNOVA should produce 'impact studies' to illustrate the social and economic effects of its funding, or the funding of its predecessor agencies. This is one of a series of reports that is beginning to shed light on the long-term benefits of state-funded, use-oriented R&D. Unlike conventional evaluations, the VINNOVA effect studies focus on the longer-term relationships between research and socioeconomic development. They therefore have a scope that can in cases go back for 40 years, in order to explore the long-term effects of the heritage of innovation policy learning and practice represented by VINNOVA today.

This report looks at the connection between research funded by VINNOVA's predecessors STU and NUTEK and the extraordinary transformation of the Swedish telecommunications industry (notably Ericsson) over the past 30 years or so. We focus especially on the period when the GSM digital mobile telephone system was being discussed, standardised and designed.

Many relevant records have disappeared or are difficult to access, so the study involved a lot of oral history and archaeology. We interviewed some 70 of the people involved, sent a short questionnaire to people who took PhDs relevant to mobile telecommunications in Sweden during the last 30 years and built up a 'human capital' database to map what has happened to them since then as well as reading a great deal of secondary literature. Our intention was to find out the extent to which university research funded by STU/NUTEK influenced the development of GSM and the great Swedish industrial success in the area.

The links between public R&D support in Sweden, during and immediately after the period when the GSM digital mobile telephone standard were non-linear. Research did not develop new knowledge that industry then gratefully implemented. Rather, the interaction of industrial and research agendas focused university research and education on problems whose solution in theory and in industrial development enabled Ericsson's huge success and all the employment, trade and income benefits that has brought to Sweden. While the study examines one particular history, it suggests some general lessons about how to design public R&D policy and how and why companies and other producing organisations can fruitfully interact with the knowledge infrastructure.

Effects

Our conclusion in this study is that public research funding, especially that of STU/NUTEK, had a major effect in enabling Sweden's success in mobile telephony, bringing benefits to Ericsson, the university system, Swedish Telecom (Televerket and later Telia) and many other parts of Swedish society. There is always a problem of **attribution** in making such a claim, however, because while the research funding appears to have been necessary it was by no means alone sufficient to cause the success: many other factors were also important.

Ericsson

The Ericsson group is the most obvious winner from the research funding. Ericsson's economic success in the latter 1980s and the 1990s was massive, as a result of its transformation from a fixed-lines to a mobile telecommunications company. Employment peaked at over 100,000 before the crash of the early 2000s, from which Ericsson has now begun to recover. Ericsson has generated thousands of billions of kronor of economic activity, which benefits the Swedish economy and makes the major contribution to Sweden's large trade surplus in telecommunications.

The fact that Ericsson took the initial lead in the GSM market was crucial. Being second would not have delayed Ericsson's growth in mobile telephony – it would largely have prevented it. Technically, that success depended in part on Ericsson's radio access skills, in part on its components capabilities (including the ability to threaten to make its own unless suppliers were willing to offer acceptable prices and deliveries) and in part on the AXE switch developed in collaboration with Swedish Telecom and implemented using technology acquired through the National Microelectronics Programme. All three aspects benefited substantially from state research funding.

Ericsson faced the prospect of acute skill shortages in the 1980s – both in specific radio-related areas and in ICT more generally. Its ability to exploit its strong position in GSM depended upon the increasing output of PhD and MSc graduates resulting both from STU/NUTEK's Digital Communications programme and from the bigger national effort to expand IT research, training and education that STU had helped trigger in the early 1980s. Given the supply of manpower, Ericsson then had the capacity (just!) to build on its GSM capabilities and quickly to develop systems for the two other important standards that subsequently emerged in the USA and Japan. Its leading global position in 2G systems then provided the basis for strength in 3G.

Without STU/NUTEK's role as change agent in the research and innovation system, Sweden would not have been able to take advantage of the opportunities afforded by mobile telephony and in the best case Ericsson would have had to pursue its expansion to a greater extent outside Sweden.

Universities

The public research funding led to a body of knowledge and publications but its more important effect in the university sector was to launch a trajectory of growth in the capacity to do research and teaching in subjects relevant to digital mobile telephony.

The universities were both enablers of Ericsson's success through their research and education activities and also beneficiaries of it – not only through research and teaching to meet the growing needs of the mobile telephony industry but also because there is positive feedback from Ericsson in particular in the form of funding, collaborative projects and a continuing flow of information about emerging problems. Odd as it may sound, a supply of problems is one of the most valuable things one can have in such disciplines, not only because they underpin day to day research and education but because they can define new research trajectories. And just as in industry, in academia timely knowledge of what the important problems are is often key to competitive success.

STU/NUTEK funding therefore triggered a very considerable expansion of doctoral education and a very large supply of highly qualified people into both industry and academia. This is a structural shift: the institutional structure is in place in the universities that should assure the continuation of this supply.

Swedish Telecom

While Swedish Telecom can reasonably be credited with creating one of the world's most advanced mobile telephone markets in the NMT era and was a crucial enabler of Ericsson's success through cooperation over AXE and in the GSM standardisation process, it has perhaps itself not benefited as much as other sectors from the expansion of ICT research and education – either at the general level or in the specific case of digital mobile communications. The choice of narrowband TDMA for radio access in the GSM specification meant that Swedish Telecom could use its existing NMT base station sites to deploy GSM rather than having to set up new ones to create the smaller cell sizes implied by other access methods, and this has produced a significant saving compared with alternatives. However, the change in Swedish Telecom's role with corporatisation and liberalisation means that it no longer makes so much use of highly qualified R&D manpower, so the effects of the research funding on human capital have been less important for Swedish Telecom than for others, though it has undoubtedly contributed to ensuring the company does not suffer from shortages in the technical manpower it needs to run the business.

Sweden

The Swedish taxpayer more broadly has benefited significantly from the Swedish success in mobile telephony to which public research funding has contributed.

One of the most important aspects from the national perspective is the creation of a large cadre of people in industry and in the knowledge infrastructure who understand and work with digital communications. Conventionally, we try to count the benefits of an intervention such as a research programme in the industrial world by looking at its effects on individual companies. In this study, we have focused heavily on the Ericsson group. But to a considerable extent, the community of people who work with a technology persists more strongly than individual companies. Thus, when Ericsson downsized in the early 2000s, many people set up their own businesses in related areas of telecommunications and electronics.

The research programmes studied here also triggered significant changes in the university system, making it much more adapted to the needs of the 21st Century than it had previously been. This is also an important effect for the taxpayer.

This study has focused heavily on Ericsson. We have not explored the effects on the company's suppliers but – while Ericsson products necessarily have a high import content in the form of semiconductors – the economic multiplier resulting from Ericsson's increased activity will also be considerable. However, even without considering this, it is clear that there are huge benefits for Ericsson in Sweden – and that these result in the employment of large numbers of Swedish workers and the payments of large amounts of Swedish taxes as well as a healthy contribution to Sweden's balance of trade.

Role and importance of STU/NUTEK

STU/NUTEK's strong internal technological capabilities and its ability to interact with the innovation system at project and programme level as well as at the level of large, coordinated national efforts were crucial to the Swedish GSM success.

The agency acted as an intelligent discussion-partner for industry and the universities from the earliest days of the radio club. It was a willing funder of often risky but small-scale projects proposed by the club and its funding served to legitimate the work within the universities and in industry. It thereby supported an arena (the club) that acted as a focusing device: connecting research and industrial opportunities, with mutual benefits to industry and the universities.

Over time, it became clear that digital communications was becoming important and that Swedish success in the new technology would depend upon massive increases in the availability of manpower with research and engineering capabilities specifically in digital radio communications. The radio club was too small to deal with this so STU/NUTEK was able to respond to signals from industry and the universities and launch the Digital Communications programme in 1987, which scaled up the effort.

This scaling up took place in the context of the bigger expansion of IT research and education that STU/NUTEK had planned and coordinated across ministries and agencies – an unusual act of cooperation in Swedish research and innovation policy. Without this larger strategy, the radio club and the Digital Communications programme would have been swimming against the tide and would have left Ericsson less able to take advantage of the rapid growth of digital mobile communications.

Policy Implications

This study illustrates the complexity of the relationship between innovation and research and the role of many conditions that are **necessary** for innovation, even though none is individually **sufficient**. In the absence of sufficient conditions, a crucial policy implication must be that interventions must have a systemic perspective, taking account of bottlenecks and opportunities as these arise. Simplistic interventions based solely in ideas like the linear model or the naïve human capital model are unhelpful, however attractive their simplicity may be. This understanding underlies the EU and OECD discussion today about 'policy mix'.

The mobile telephony history points to the need to think about policy mix on two levels. One is the mix between the research-council style of funding, dominated by concerns about quality and track record, on the one hand and on the other more explicitly use-oriented research funding, with its concern to establish links with innovation processes in order to generate social and economic benefits. Both styles are needed in a system that is intended both to do fundamental research and to support economic and social development (the 'third task' of the universities).

At the level of the innovation agency, the history suggests a need to balance response-mode project-by-project funding and programmed funds. The point of the response-mode funding is not only to react to isolated good ideas but also to act as a kind of 'search engine' to look for needs and opportunities. This requires substantial technological competence; bureaucracy and the mechanical application of standardised assessment criteria cannot accomplish it. It also requires a portfolio approach because no matter how good the intelligence applied, innovation projects are highly prone to failure. Neither a research council nor an administratively driven agency could have reacted to, fostered and eventually scaled up the radio club in the way STU/NUTEK's internal intelligence let it.

The success in mobile telephony naturally prompts the question: How can we do more of this?

- The point of departure of our story was SRA's internal technological capability and its 'absorptive capacity'. Instruments like 'industry doctorands' that encourage the injection of research skills into companies are also important, in order to raise the level of absorptive capacity and to form an 'advance guard' of research capability. Once such people are inside the firm, they start to suck in others
- 'Focusing mechanisms' are crucial, and drive not only research but also education. If a new area of knowledge becomes important then there will be a need for knowledge-bearers at both first degree and PhD levels. In a university system with research-based teaching, first-degree education will tend to follow directions established at PhD level
- Large-scale changes may nonetheless require national coordination across multiple agencies and ministries, as was the case in the national IT programmes
- STU/NUTEK, like VINNOVA, had the twin instruments of bottom-up and programmed funding at its disposal. This meant that it had the flexibility in the early years to respond to developments while in the later period to formalise the activity into a programme that was able to scale it up and meet national needs. This required planning and budgeting mechanisms that were tuned to the industrial wavelength – that could receive and amplify signals from groups of industrialists and researchers and use these to trigger programmes. An innovation agency needs to combine such responsiveness with its own centralised analytic intelligence. It needs a radio, it should be switched on and someone should be listening!
- Weinberger's description of STU as a 'network entrepreneur' is a good one and a good description of STU/NUTEK's activities more generally. The observation of STU's second director-general, Bertil Agdur, that STU should not be an administrative apparatus but a change agent goes to the heart of the role of an innovation agency
- Despite the policy focus on SMEs in recent years, the example of digital mobile telephony shows both that large companies can need support in establishing focusing devices and the massive rewards that can result from success when large firms are involved

1 Introduction

This study explores the interconnections between research funded by VINNOVA's predecessors STU and NUTEK and the extraordinary transformation of the Swedish telecommunications industry (notably Ericsson) over the past 30 years or so. We focus especially on the period when the GSM digital system was being discussed and standardised. The study shows that university research and the way it was funded were important contributors to the subsequent success but also that many other factors were involved, such as the active role of the state as a customer and development partner and strong Nordic demand for telecommunications. Some of these are historically specific, but there are nonetheless important lessons to be learnt from the mobile telecommunications story.

1.1 VINNOVA Effect Studies

The Swedish government requires that VINNOVA should produce two 'impact studies' per year to illustrate the social and economic effects of its funding, or the funding of its predecessors. This is one of a series of such studies that are beginning to shed light on the long-term benefits of state-funded, use-oriented R&D.

VINNOVA was established in 2001 and is the third generation innovation agency in Sweden. Its largest predecessor was the technology division of NUTEK[1], which in turn was formed in 1991 through a merger of SIND, STEV and STU[2]. VINNOVA's other direct antecedents were the Swedish National Board for Transport and Communications (KFB) and the Swedish Fund for Working Environment (RALF).

1 Then officially translated as the Swedish National Board for Industrial and Technological Development

2 The Swedish industrial development agency (Statens Industriverk), the Swedish energy agency (Statens Energiverk) and the Swedish National Board for Technological Development

Exhibit 1 VINNOVA Effect Studies

VINNOVA Effect Studies

2001

1. Impact of R&D – the impact of VINNOVA's predecessors support for needs during the period 1975-2000. Four pilot studies, report in Swedish only: Effekter av VINNOVAs föregångares stöd till behovsmotiverad forskning - Fyra effektanalyser av insatser under perioden 1975 – 2000, VINNOVA Innovation i Fokus VF 2002:1.

2004

2. Impacts of the Swedish Competence Centres Programme 1995-2003, Erik Arnold, John Clark, Sophie Bussillet, Technopolis Ltd, VINNOVA and Swedish Energy Agency, VINNOVA Analysis VA 2004:03
3. Impacts of Neck Injury Research at Chalmers University of Technology – Summary report VA 2004:05. Full report in Norwegian: Effektanalys av nackskadeforskningen vid Chalmers 1985-2003, Knut Sandberg Eriksen, Arild Hervik, Arild Steen, Rune Elvik och Rolf Hagman, VINNOVA Analys VA 2004:07

2005

4. Swedish Traffic Safety Research in a Lead Position – a Pre-study. Report in Swedish: Svensk trafiksäkerhetsforskning i tätposition – Framträdande forskare och forskningsmiljöer i statligt finansierad trafiksäkerhetsforskning 1949 – 2005, Anders Englund (förstudie), VINNOVA Analys VA 2005:08

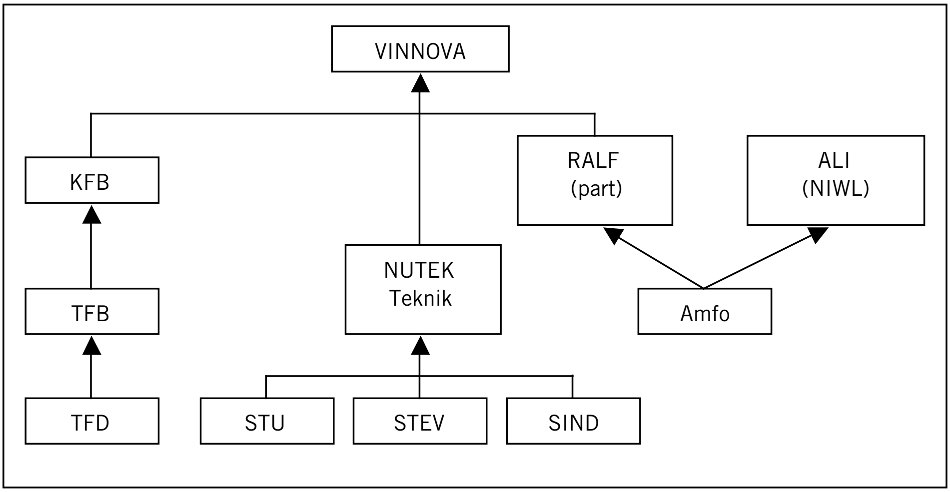
2006

5. Summary - User-driven development of IT in working life VA 2007:13. Full report in Swedish:Användningsdriven utveckling av IT i arbetslivet – Effektvärdering av forskning och utveckling kring informationsteknologins användning i arbetslivet, Per Tengblad och Åke Walldius, VINNOVA Analys VA 2007:02
6. Effects of Swedish Traffic Safety Research 1971-2004, Marika Kolbenstvedt, Rune Elvik, Beate Elvebakk, Arild Hervik och Lasse Braein, VINNOVA Analysis VA 2007:10

2007

7. Effects of Research on Swedish Mobile Telephone Development: The GSM Story, Erik Arnold, Barbara Good and Henrik Segerpalm, VINNOVA Analysis VA 2008:04
8. Impacts of Swedish Public Seed Financing. Full report in Swedish: Effektanalys av offentlig "Såddfinansiering', Andreas Johnson, Enrico Deiaco, Karla Anaya Carlsson, Fredik Scheffer, VINNOVA Analys VA 2008:05

Exhibit 2 VINNOVA and its Predecessors



Unlike conventional evaluations, the VINNOVA effect studies focus on the longer-term relationships between research and socioeconomic development. They therefore have a scope that can in cases go back for the 40 years since STU was formed, in order to explore these long term effects of the heritage of innovation policy learning and practice represented by VINNOVA today. At first sight the effect studies appear to be evaluations, but they have perhaps more in common with the TRACES and HINDSIGHT[3] projects of the 1960s, which tracked the movement of knowledge elements respectively from applied and basic research into industrial practice across very long periods of time and which were done at about the time STU was born. Since that time, there have been very few such long-term studies, so VINNOVA's effect studies provide an important research contribution to our long-term understanding of research and innovation policy and the functioning of innovation systems. While in its early days (between 1968 and 1979) STU only financed individual projects, since that time STU and then NUTEK Teknik developed a tradition of programming about half their resources that VINNOVA has continued, though with the addition of occasional focused calls for proposals in order to encourage bottom-up applications in areas of national need. Because of the continuities in practice between VINNOVA and its predecessors, the effect studies are a contribution both to knowledge and to policy practice.

In order to focus this study enough to make it manageable, we primarily tackle aspects

3 Illinois Institute of Technology, 1969, *Technology in Retrospect and Critical Events in Science (TRACES: A report to the National Science Foundation)* , NSF Contract C535; Office of the Director of Defense Research and Engineering, *Project Hindsight - Final Report,* National Technical Information Service, 1967

of research and innovation policy in the late 1970s and through to the early 1990s. However, there is a continuity of policy for telecommunications and mobile telephony in Sweden that goes right up to today. As we were drafting this report, VINNOVA announced a SEK120m programme of R&D in mobile and communications and broadband, funded in cooperation with the government and industry. This is the latest in a series of interventions in the intervening period, starting with NUTEK's Telecommunications programme in 1993, when Swedish Telecom was privatised and the state through NUTEK took over the 'sectoral responsibility' that most Swedish state agencies have for research in areas of relevance to their own operations. Other initiatives have included a number of centres of excellence within the Competence Centres and subsequent VINN Excellence programmes, a test bed project at the ACREO IT institute, the Broadband Mobility programme, Mobile Communication Broadband and Mobile Services programmes.

1.2 Background to the Study

So far, following some very early, small and rather primitive systems, there have been three generations of mobile telephone. The first was analogue and was represented in the Nordic countries by the Nordic Mobile Telephone (NMT) system. The second was digital, represented in the Nordic area by the GSM (Groupe Spéciale Mobile) system. The third generation is an improvement of the second, offering much higher bandwidth and eventually opening the door to mobile video telephony and other high-bandwidth services.

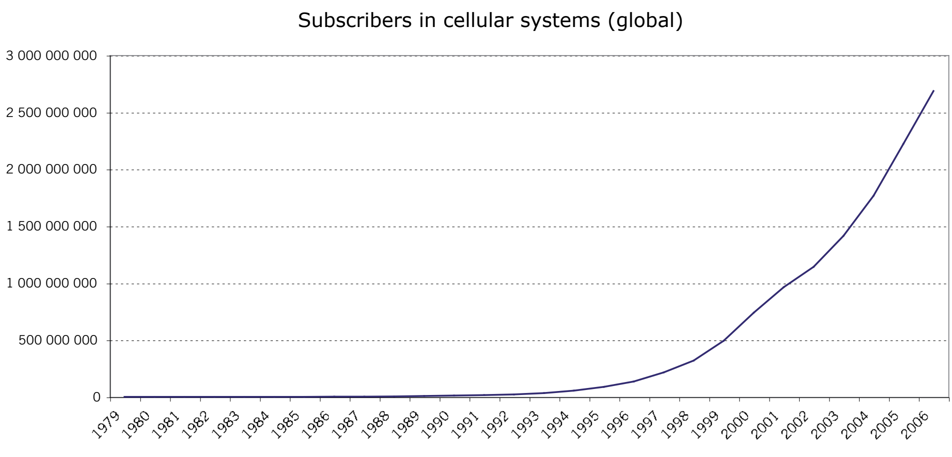
It was the move from analogue to digital systems that allowed mobile telephones to become mass-market products that almost everyone has. Without digitalisation, there simply is not enough room on the airwaves to make mass use of mobile phones possible. The second-generation systems like GSM, however, can transmit very little information. Third generation (3G) systems can transmit more information more quickly – though this potential is generally under-exploited today: most of us neither know nor care whether we are using second or third generation services because we use our phones only for speech and text. Full exploitation of 3G awaits the widespread use of more bandwidth-intensive mobile services.

Our study focuses on the shift from the first to the second generations in Sweden. This involved resolving significant technological challenges and finding ways to implement the new techniques in equipment that was both small in size and low in power consumption, changing mobile telephones from being 'car phones' to 'pocket phones'. These challenges were addressed as part of an international standardisation process dominated by European monopoly Posts and Telecommunications authorities

(PTTs), amongst which the Nordic PTTs (especially the Swedish Televerket – which we refer to in this study for consistency as Swedish Telecom[4]) were very influential, in part thanks to Swedish and Norwegian technical developments. The way they were overcome underpinned the Swedish lead in digital mobile telephony, giving Ericsson in particular 'first mover' advantages in both handsets and infrastructure, the operators in Sweden with a rapid return on their investment in GSM infrastructure and providing both business and consumers with the benefit of a more effective telecommunications system.

Mobile telecommunications have moved from being a trivial niche market for business and the rich in the 1980s to probably being the largest worldwide use of advanced Information Technology. Today, almost half the people in the world have a mobile phone (Exhibit 3). Global revenues from mobile phone services in 2003 were $346 **trillion[5]** according to the OECD. The dramatic cheapening of these services is illustrated by the fact that in the USA the mean revenue per subscriber fell from $919 in 1993 to $454 in 2005 (measured in current dollars)[6]

Exhibit 3 Global Subscribers in Cellular Systems



Source: OECD

4 Strictly, Swedish Telecom was never a PTT. It never was responsible for the postal service and it never had a legal monopoly of telecommunications. However, it was formed through the state buying up a number of competing phone companies, in the past held a de facto monopoly every bit as powerful as the PTTs and behaved like them in forming a 'development pair' with its major equipment supplier, LM Ericsson

5 $336,481,296,799

6 OECD, *Communications Outlook*, Paris: OECD 1999 and 2005

1.3 Structure of the report

In the next Chapter, we discuss 'models' of the interaction between university reach and industrial development. This discussion is intended to provide a theoretical framework for considering the effects of research funding and to connect this study to policymaking. Theory matters in the context of policymaking; policymaking based on bad theory produces bad policy.

In Chapter 3 we describe key technical challenges that had to be overcome in order to move from the first to the second generation of mobile telephony. There are quite a number of studies of economic and innovation aspects of the mobile telephone industry, but they tend to skate over the technical 'details' – which are complex. (The GSM standard itself is about 8,000 pages long. The standard 'simplified' introduction to GSM[7] is 700 pages.) We make no apology for going into a little of the technology, especially in the context of innovation agencies whose competence is built partly on its understanding of technology. Had we not done so, it would have been impossible with any confidence to identify the key researchers and research groups involved or to understand the ways in which their work connected to industrial and economic development. The authors of this study are from the social sciences and humanities, so we have had to learn about and explain these things to ourselves and our discussion of the technical issues is intended to be one that other non-engineers can follow. (There is a list of acronyms at Appendix D.) This chapter shows some of the dynamics of technological change and its governance and also gives us the vocabulary to tell the rest of the story.

We go on to tell the story of standardisation in mobile telephony. The importance of standardisation is generally under-estimated in accounts of technological development and its links with society. Very many advances in technology can only be taken up at large scale once there is agreement about the standards that it should follow – whether is a de facto standard (such as the order in which manufacturers place the clutch, brake and accelerator in cars) or a formal standard, such as the distance between the rails for European railway lines. As this chapter shows, standardisation is not a neutral process but a battleground in which different stakeholders try to influence the emerging standard in ways that benefit themselves.

The role of the research funding agencies, especially STU, in these developments is not immediately obvious. Chapter 4 explains that role. It discusses the supportive role of Swedish Telecom and shows that STU and NUTEK allocated resources in ways that enabled not only mobile telephony but also Swedish capabilities in ICT more generally to grow. It did this in ways that reflect good understanding of industrial needs and

7 Michel Mouly and Marie-Bernadette Pautet, *The GSM System for Mobile Communications*, Paris: Cell & Sys, 1992

opportunities and in a proactive manner that scaled up research and education capacity rapidly enough to take advantage of new opportunities such as mobile telecommunications. This could not have been done in a national innovation system where all research funding was 'researcher-directed' (*forskarstyrd*).

In Chapter 5, our attention turns to the research community and to the way it was co-opted by Ericsson and Swedish Telecom, providing first some of (but by no means all) the intellectual underpinnings of the needed new technologies and how it was instrumental in supplying the human capital needed for the growth of mobile telephony. In Swedish culture, it is a *faux pas* to try to take credit for doing important things and it is easier to attribute change to social forces and consensus. The history shows that some individuals did play crucial roles – but that actions by organisations and institutions were also important.

The effects of the research funding were considerable. We discuss them in Chapter 6. Of course, it led to a body of knowledge and publications but its more important effect in the university sector was to launch a trajectory of growth in the capacity to do research and teaching in subjects relevant to digital mobile telephony. Given the huge recruitment needs of the industry at both MSc and PhD level, this was an important achievement. What began as a series of decisions to fund individual projects from an informal network of researchers interested in questions to do with digital mobile telephony developed into a formal Digital Communications programme and has now built to at least a ten-fold increase in the ability to the university system to do research and teaching in the area.

The effects of the funding at Ericsson were to support the beginning of a radical change in the composition and size of the company. It moved from being a slow moving, traditional supplier of fixed telecommunications equipment somewhat dependent upon its main customer in Sweden for technological development to become a high-growth, technology intensive firm that took and held abut one third of the global market for digital mobile telephone systems for the next 20 years. As a result, it generated significant wealth, employment and a positive telecommunications trade balance for Sweden. Naturally, research was not the only reason for this development but the significant capabilities it gave Ericsson produced a leading position with which others could not catch up.

Chapter 7 sets out our conclusions about the effects of the research funding and draws a number lessons in the form of policy implications.

1.4 Method and acknowledgements

This study has been as much an act of archaeology and oral history as of social research. It is based on extensive review of the secondary literature, some 70 interviews with people involved, a short questionnaire to people who took PhDs relevant to the subject in the past 30 years and a great deal of research on the World Wide Web, tracking down people who participated in the research and finding out where they are now. Our intention was to find out the extent to which university research funded by STU/NUTEK influenced the development of GSM and the great Swedish industrial success in the area. One question was whether there were 'critical events': points at which it is possible to see a particular research result passing into practice.

There are few written records of crucial events in the 1970s and 1980s that have survived – and, to be fair, these were pioneering times when there was less of a fussy tradition of documentation among research funders than there is today. STU was merged with SIND and STEV to form NUTEK in 1991, and its papers moved to the national archive (*riksarkivet*), where they occupy half a shelf-kilometre, mostly filed by diary number.[8] In the absence of a proper index, most of this material was inaccessible to us. The use of diary numbers as the basis for administering and now archiving STU means that one of the key innovations STU made – the move from project to programme funding – remains largely invisible in the historical record. Only in the last days of our project was VINNOVA's IT department able to breathe life again into STU and NUTEK's administrative system 'Peanuts' and to help us search for information on researchers.

NUTEK was created in the middle of STU's key R&D funding programme, the Digital Communications programme and NUTEK has not been able to recover the programme documentation it inherited. Fortunately, the national archivists went beyond the call of duty and stored information about the first part of the programme, even though they could have avoided this work because the files were active and were being passed on to NUTEK. The de-merger of NUTEK that created VINNOVA (or, perhaps, reincarnated STU) involved moving to a new office in the centre of Stockholm, where space was at a premium. A lot of the informal archives belonging to individual programme officers disappeared at that time – much into the recycling bin; some into various cellars and lofts.

Like many companies, Ericsson does not archive things for long and while there is a substantial history of Ericsson[9] it ends just as our story begins. There is a small exter-

8 That is, the number allocated to an item of business when it is first registered by an administration. Normally it consists of a year plus a sequence number

9 Artur Attman, Jan Kuuse and Ulf Olofsson, *LM Ericsson 100 År* (3 Volumes), Stockholm: Ericsson, 1976

nally written literature on Ericsson since that time, of which we have been able to make use. Swedish Telecom's history is better documented, but its archive is almost as impenetrable as that of STU. While we suspect there is a lot of relevant material in the three shelf-kilometres it occupies at the national archive, mining this will have to be a task for technology historians with more time on their hands than we had at our disposal. There are undoubtedly some interesting PhD theses in there waiting to be written.

All this meant that we had to be base our work strongly on interviews and people's memories. We are therefore probably approaching the last possible time when this study could be done. Almost all the central characters involved have retired or are about to do so.

We tried to identify 'critical events' in technological development and to understand the extent to which they formed 'bridges' between the academic and the industrial efforts to move from the 1G to 2G mobile telephony. It turned out that the links between the two sides were rather 'soft': capabilities and understanding rather than very specific research results made up the important traffic. We have tracked many of the people involved in university research and their subsequent careers and used the resulting patterns in our analysis. And, of course, wherever possible we have made use of existing histories that touch on our subject.

We owe a huge debt of gratitude to the many people who have helped and supported us

- Torbjörn Winqvist at VINNOVA, who conceived the idea for this study and who has been working hard for many years not only to ensure high evaluation standards at NUTEK and VINNOVA but also to try to preserve the lessons from evaluation and other forms of history in the research funding system
- Other colleagues at or recently retired from VINNOVA, notably Sven-Ingmar Ragnarsson (who ran the first STU programme in electronic components in 1979 and who has ever since functioned as STU, NUTEK and VINNOVA's IT strategist and unofficial IT archivist); Lars Näslund and Tony von Knorring who tickled STU's obsolete administrative computer system 'Peanuts' back into some sort of life and extracted a few of its secrets for us; Anders Hedin; Eva Westerberg; Lennart Stenberg; and Staffan Håkansson
- Our reference group (listed at the Appendix) , which has guided and argued with us while sometimes meandering off into discussions about the pioneering days of mobile telephony where we felt as irrelevant as children at a grown-ups' party, but listened attentively nonetheless
- We own a particular debt to Sven-Olof Öhrvik, who quietly and behind the scenes took us to radio school, explaining technical matters with great patience

(sometimes several times) and helping us to look in the right direction for people and information to fit into our huge jigsaw-puzzle

- Not least, we are grateful to all the people who helped us through interviews and by filling in our questionnaires

We also have some 'negative acknowledgements' to all those who indiscriminately throw away records, who share Henry Ford's famous view that 'history is bunk' and who are therefore condemned to reliving the lessons of the past instead of learning from them.

Finally, while we want to acknowledge the support we have received from so many people, we must stress that the responsibility – for good or ill – for this report lies entirely with its authors.

2 Swedish Policy and Theory about the Effects of Research

The subject of this study matters not only because it sheds light on the value society derives from at least one style of funding use-oriented research but because it illuminates the relationship between research and society more generally. We need theory about this in order to make good policy. In this sense, as Kurt Lewin famously said, there is 'nothing as practical as a good theory'.

In a Swedish context, Sörlin[10] argues that there are fundamentally two types of theory about the social value of university research: variants of the 'linear model'; and 'human capital' model. The traditional 'linear' (science or technology push) model and its variants is based on the idea that if the universities do enough high-quality research then some of the knowledge produced will find social and economic uses. Its central assumption is that research is essentially **knowledge production,** in the sense of producing information. A key policy problem in this linear world is to create 'focusing devices'[11] that increase the probability of the new knowledge being useful. The human capital model sees research and education together as the **'production' of experts** with generic capabilities who can play key roles in innovation processes. Since the experts themselves constitute the value of research, the policy problem is how best to maintain a well-functioning, autonomous system of research-based (higher) education.

Swedish research policy since the 1940s has struggled with this dichotomy – largely coming down on the side of the human capital model (though with institutional exceptions, such as to some degree the funding agencies we study here). Seeing no need for focusing devices, the human capital perspective does not conflict with the old Mertonian view of a self-governing Republic of Science and the high degree to which academic governance of the research funders and the universities persists in Sweden reflects this position.

The dominance of the human capital view goes back at least to 1942, when Gösta

10 Sverker Sörlin, *En Ny Institutssektor: En analys av industriforskningsinstitutens villkor och framtid ur ett närings- och innovationspolitiskt perspektiv, report to the Swedish Ministry of Industry, Stockholm: KTH, 2006*

11 Erik Arnold, Ben Thuriaux and Anne Lavery, *Putting Users in Charge of R&D: International Experience of State Actions*, report to the Research Council of Norway, Brighton: Technopolis, 1996; the tem is borrowed from Nathan Rosenberg, *Perspectives on Technology*, Cambridge University Press, 1986. Rosenberg uses the term to refer to triggers for industrial innovation, whereas Arnold et al refer specifically to activities that induce academic research to focus on problems of social and economic relevance

Malm was appointed by the government to chair two committees, respectively dealing with the future of technological research and higher education in Sweden. Malm found[12] that a key problem for industry was a lack of researchers in technology and concluded that the universities' capacity to produce such people should be increased. Rejecting the idea of establishing a central institute of technology, Malm proposed that funding should be aimed at the universities and provided by a technology research council – *Statens tekniska forskningsråd* (TFR) – which the government set up in 1942 at the same time as providing special grants to Sweden's two technical universities: the Royal Institute of Technology (KTH) and Chalmers (CTH). A key effect of setting up a research council was to make the research community responsible for the allocation of resources – a tradition that was continued as the state successively set up research councils in other areas of science and, eventually, also in humanities. Malm's conclusion that the focus of technological research policy should be on university research was reinforced by a parliamentary decision in 1979[13] that "the universities shall undertake a significant proportion of sector-related research, viz research that aims to support or develop state agencies' activities".[14] The universities were to function as "research institutes for the whole of society". The expansion of the knowledge infrastructure refocused on the universities and the production of qualified manpower. PhDs were then seen primarily as inputs to the higher education system, and not as something needed in industry. By the 1990s, however, there was growing concern that the level of qualifications in Swedish industry was too low. The conservative government of the early 1990s set up a number of Wage Earner Foundations[15] in 1994, many providing research funding. This reinforced the new Foundations' inclination to build centres of excellence and focus on the university sector and the production of PhDs and it was one of the factors that prompted NUTEK to launch its Competence Centres programme in 1995.

However, the dichotomy between the linear and human capital models is essentially a false one because the linear model has long since been overtaken by a more sophisticated understanding of the role of knowledge and skilled people in innovation and production. In this newer perspective, human capital is one of several links between university research and society more widely.

12 SOU 1942:6, *Utredning rörande den tekniskt-vetenskapliga forskningens ordnande 1: Allmänna uppgifter angående den tekniskt-vetenskapliga forskningsverksamhetens nuvarande läge*

13 SOU 1980:46

14 Our translation

15 These have their origins in the so-called 'wage earner funds' set up by the social democrat government of the late 1980s, which used a levy on payrolls to buy shares in major Swedish companies and which were intended over time to share the benefits of ownership with the workers. The conservative government of the early 1990s argued that this was nationalisation by the back door, and used the money so far accumulated to set up Foundations that provided investment funds and sponsored research

The linear model was essentially constructed following the Second World War as an attempt to separate science from society and served to justify the huge investment in research and education infrastructure in the decades that followed. The idea of research as the production of knowledge or information also chimes perfectly with the way knowledge ('technology') is treated in neoclassical economics, so two strong social factions have had an interest in promoting this model. But the scientific community that researches on research and innovation has comprehensively rejected the linear model in its original form. Key elements of this rejection come from

- The fact that trying to make realistic models of the relation between knowledge production, innovation and society quickly leads to much more complex models[16] with many linkages among actors. Innovation processes do not always 'start' at a particular place ('basic' science, or the market) but can be prompted by changes anywhere
- The observation that the innovation system contains many sources of knowledge and many people who produce knowledge – this is not a monopoly of the universities[17]. The Community Innovation Survey and other similar surveys consistently confirm that a very small proportion of innovations have their antecedents in university research – but also that successful innovators tend to build relationships with the knowledge infrastructure
- The realisation that innovation is essentially done by firms. Much innovation therefore does not involve formal R&D. Indeed, R&D is often not a source of innovation but an effect of innovation decisions[18]. Firms very often seek to innovate by exploiting their existing knowledge assets. Unforeseen problems often emerge, however, and these may require R&D for their solution. From this perspective R&D should be seen not only as a process of discovery but also as a problem-solving activity within already-existing innovation processes
- A key to successful innovation is that firms possess 'absorptive capacity': namely, "the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends." [19]. The corollary is that R&D has 'two

16 David Mowery and Nathan Rosenberg, 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', *Research Policy*, April 1978; SJ Klein and Nathan Rosenberg, "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.), *The Positive Sum Strategy: Harnessing Technology for Economic Growth*, National Academy Press, Washington, DC, 1986

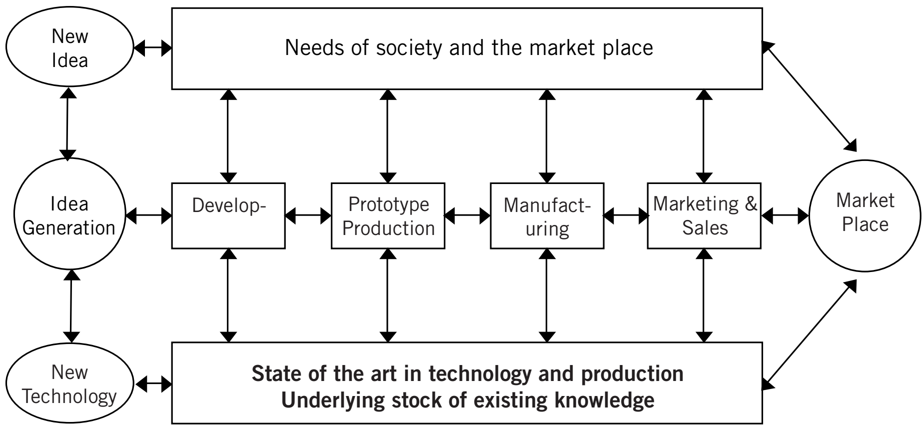
17 Michael Gibbons, Camilla Limoges, Helga Nowotny, Schwartzman, S., Scott P. and Trow, M., *The New Production of Knowledge*, London: Sage, 1994

18 Smith, K. and West, J (2005), *Australia's Innovation Challenges: The Key Policy Issues*, submission to the House of representatives Standing Committee on Science and Innovation, Inquiry into Pathways to Technological Innovation, Hobart: University of Tasmania, April 28, 2005

19 Wesley M Cohen and Daniel A Levinthal, 'Absorptive capacity: a new perspective on learning and innovation,' *Administrative Science Quarterly*, Vol 35 (1), March 1990, pp128-152

faces' – one looking outwards for learning and one looking inwards to work with what it learns or knows already[20]

Exhibit 4 Modern 'Coupling' Model of Innovation



Source: Mowery, D.C. and Rosenberg, N., 'The Influence of Market Demand upon Innovation: A Critical Review of Some Recent Empirical Studies', *Research Policy*, April 1978

Mowery and Rosenberg's innovation model (see Exhibit 4) nicely captures some of the newer thinking. It shows a complex process that essentially rests on the **stock** of existing knowledge or the 'state of the art in technology and production' and in which new knowledge adds an increment rather than (as the old linear model would imply) being the whole innovation story.

In an important sense, the difference between the linear and the complex perspective is a Gestalt or a result of what you look at. If you focus on the universities and their research, you naturally see the innovation process as being a result of the knowledge they produce. If you focus on the innovators, you see university research as a useful but often minor part of a much bigger process. Given the evidence that university research can be useful to industrial innovators, the policy response is to look for focusing devices. How can the links between industry and research be made more productive?

Ben Martin has periodically been reviewing the literature on the links between public research and socio-economic benefits for over ten years. In the latest version of this review, he and Puay Tang list 7 'communication channels' between research and society

20 W Cohen and D Levinthal, 'Innovation and learning; the two faces of R&D,' *Economic Journal*, Vol 99, 1989, pp 569 - 596

- Channel 1: increase in the stock of useful knowledge
- Channel 2: supply of skilled graduates and researchers
- Channel 3: creation of new scientific instrumentation and methodologies
- Channel 4: development of networks and stimulation of social interaction
- Channel 5: enhancement of problem-solving capacity
- Channel 6: creation of new firms
- Channel 7: provision of social knowledge[21]

They observe that "Case studies and surveys suggest only some of the benefits flow through 'Channel 1' – ie in the form of new useful knowledge that is directly incorporated into a new product or process … although this varies with the scientific field, technology and industrial sector. Hence, attempts to assess the socio-economic benefits of basic research that focus solely on 'Channel 1' will inevitably underestimate the benefits." They go on to point out that in surveys industry tends to focus on Channels 2, 3, 4 and 5 as the most important ones – tending to confirm out point that what you see depends upon where you look. They conclude that

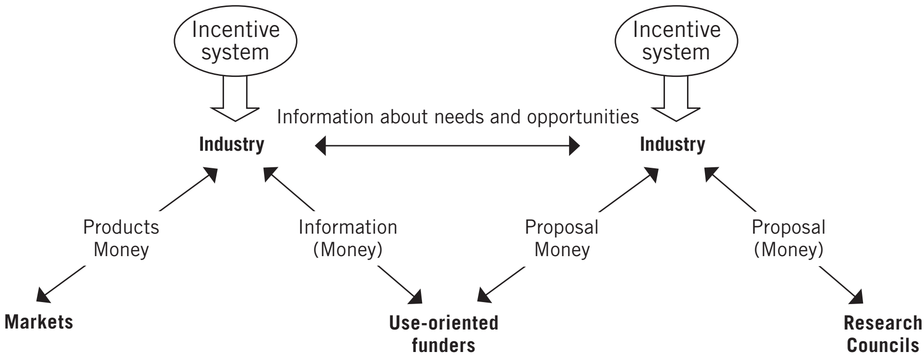
> … in recent years, much science policy has focused on the 'science push' aspect of innovation rather than 'demand pull'. Yet many of the economic benefits from basic research depends as much, if not more, on the approach that companies take to innovation as n the strength of the science base. In other words, these benefits depends on whether firms adopt a positive and far-sighted approach to drawing on the results of research through all the channels we have identified. Government policy needs to reflect this fundamental point and find effective ways of influencing the thinking of companies accordingly.

In effect, Martin's findings – in line with a wide consensus among those who share an 'innovation systems' perspective – suggest that there is not a dichotomy between the human capital model and modern innovation models, which have effectively **internalised** human capital as one of the (most important) links between university research and society. There is only a dichotomy if we persist in the linear idea that innovation is solely about information or knowledge. However, once the human capital model is inside the 'innovation system' model, it implies that we need extra-scientific criteria to construct focusing devices and that we need some kind of agency to balance the opposite tendencies of the research and industrial systems by identifying the need for, designing and constructing focusing devices. In particular, this implies a need for a change agent working not under industrial or academic rules but with the innovation system itself.

21 Ben R Martin and Puay Tang, The Benefits from Publicly Funded Research, SPRU Electronic Working Paper Series No 161, Sussex University: SPRU, June 2007

This study provides us with an opportunity to test whether it matters what researchers research: or, in other words, whether we need focusing devices in a well-functioning innovation system. If it indeed matters, we expect to find well functioning relationships that have the shape described in Exhibit 5.

Exhibit 5 Hypothesis: Balanced Research Funding



Capable industrial firms with a good degree of absorptive capacity live in an incentive system that rewards them for understanding the technologies they need and using them to satisfy market needs. They are therefore constantly interested both in learning from the outside world (including, but by no means only, the universities) and in influencing the universities to produce both knowledge and people that help them innovate. They internalise learning. If their relationships with universities continue, it is because there are new things to learn. Successful innovating firms and universities develop positive feedback loops, becoming attuned to each other's evolving needs. Incentives for the universities to participate include the fact that the companies provide interesting problems (or identify which out of many possible problems are likely to lead to a line of research), justify expansion not only of the research effort but also of education, and influence a use-oriented R&D funder to provide money.

Capable university research groups respond to these incentives but also tend to live in a world where there are other sources of funding and requirements for success than only doing industry-relevant research. They build portfolios of funders and research that let them follow their own 'real projects' and may well for example get money from both use-oriented funders and researcher-governed research councils. The combination allows them to perform well in the scientific incentive system. Both the research money and the need to train and educate people relevant to industry's needs help them build their empires within the university. Elsewhere[22], we have found that the most successful professors in TEKES electronics programmes were what we called 'super-nodes': attracting money from both TEKES and the Academy of Finland and bridging between more applied and more fundamental research, so that they succeeded within both the innovation agency's and the research council's reward systems.

We suspect there are important tensions within Exhibit 5's crude model and that these help sustain the structure. The companies are pulled by the market towards short term actions and minimum use of technology, but the opposite pull towards new knowledge and people to help develop the business tends to makes the company more sustainable and successful. The university research groups have incentives to follow some of the signals from industry because in that way they can grow by expanding research and education, but both the institutional incentives of the universities and the personal interest of the academics in more fundamental research pull them to work on problems that are more fundamental and long-term than those that concern the companies.

To the extent that this study shows the importance of focusing devices, we will have to conclude that there is a need for a balanced **mix** between researcher-directed and use-oriented research.

22 Erik Arnold, Terttu Luukkonen, Leonhard Joerg, Juha Oksanen, Ben Thriaux, Shaun Whitehouse, Gabriel Crean, Dieter Hogrefe, Yung Chi Liang and Raymond Steel, *Evaluation of Finnish R&D Programmes in the Field of Electronics and Telecommunications (ETX, TLX and Telectronics*, Helsinki: TEKES, 2002

3 Going Digital: Technological Change and Standardisation

This Chapter explains a little about the technology of mobile telephony by discussing the history of successive generations of mobile phones, focusing on the transition between the first and second generations that is the focus of this study. It then goes on to describe the standardisation process, how that has changed in successive generation and the role of key Swedish actors in that process in the first and second generations.

3.1 Developing Second Generation Mobile Telephony

Mobile telephony is conventionally divided into successive technological generations (Exhibit 6). Our attention in this study focuses on the second generation '2G' systems, and especially GSM, which is the globally dominant standard in 2G and in the development of which Sweden was one of the leading countries.

Exhibit 6 Mobile Telephony Generations

Generation	1G	2G	3G-	3G (2)	3G+ (4G)
System Examples	NMT AMPS TACS	GSM, PDC, D-AMPS, cdma One, DECT, PHS	GPRS EDGE	WCDMA TDCDMA MCCDMA	HIPERLAN/2 WLAN WATM
Maximum user data rate		9.6 kbps	384 kbps	2 Mbps	20 Mbpd
Dominant service	Analogue speech	Digital speech	Internet Data Speech	Multimedia Internet IP-telehony	High speed data using IP
Introduced	1982	1992	2000	2002	3G: 2002 (4G: 2012?)

Source: Sven-Olof Öhrvik

This Chapter gives a – highly simplified – account of the technological challenges that had to be overcome in moving from 1G to 2G.

3.1.1 Cellular mobile telephony – a long time to implement a simple idea

While two-way radio communications has been a familiar principle since the 1890s, its use has always been limited by the fact that the electromagnetic spectrum is finite

– there is a limit to the number of different frequencies on which parallel communications can take place. Were governments not to regulate the use of the spectrum, there would be a 'tragedy of the commons'[23] where a growing number of individual radio users eventually clog the airwaves, making the spectrum useless. Much of the technological effort in radio over the past 30 years has focused on increasing the amount of communication that can be squeezed through the fixed amount of spectrum.

Spectrum scarcity also means that in the past most permitted uses of the spectrum have social purposes: radio systems for the emergency services, for certain kinds of providers of services to the public (such as taxis), for defence and for broadcasting. Except in CB (Citizens' Band) radio, the individual has not really been allowed access to radio communications.

Some very early mobile phone systems enabled a handful of users to access the normal (fixed) telephone system via a radio link. In Sweden, the first was the MTA (Mobile Telephone A) system[24] that Swedish Telecom[25] started to design in the 1940s and launched in 1956. This operated until the late 1960s, when 125 users in Stockholm shared 4 radio channels[26] and were able to make a connection with the telephone network via a single radio mast at Lidingö in the Stockholm suburbs. An improved version of the system (MTB) allowed automatic dialling and was allocated new frequencies, so that by the 1960s small numbers of subscribers in Stockholm and Gothenburg could enjoy a car phone service (the terminals were far too big to carry). But subscriber numbers were limited by lack of spectrum, as well as the high cost of equipment.

The US phone company AT&T had, in principle if not in practice, solved the spectrum problem already in 1947. Since radio involves transmitting energy in the form of waves, in the ideal case[27] the strength of the signal received declines according to an inverse square law in relation to the distance from the transmitter. AT&T's Bell Labs proposed to use low-power mobile terminals and many low-power 'base stations' arranged so that adjacent base stations would use different frequencies. Because low-power signals do not travel far, frequencies could be re-used by other base stations some distance

23 From the idea that on common grazing land it is always in the individual animal owner's interest to graze more animals – but the resulting increases in grazing eventually destroy the common resource so that everyone loses

24 Originally called Mobile Telephone Lauhrén (MTL) after its inventor and built by the Swedish Radio Company SRA

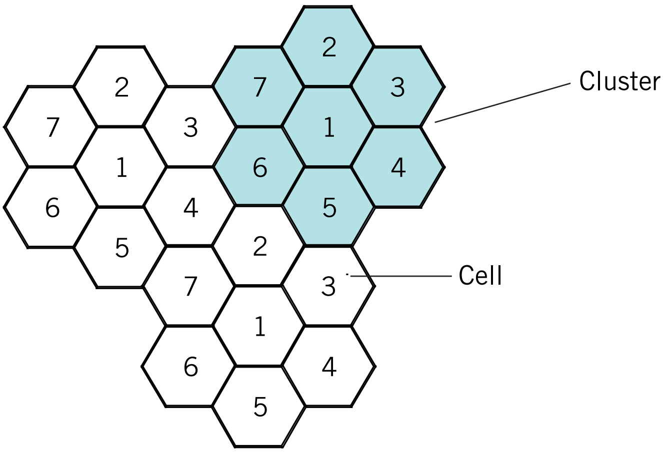
25 Swedish Telecom was the Swedish telecommunications authority. Unlike equivalents in other countries, it never had a legal monopoly, but it enjoyed a de facto monopoly following a period when the state encouraged it to buy all its competitors

26 A radio channel is a radio interface or path that enables communication. Originally, this was a certain fixed part of the spectrum, hence we talk of 'tv channels'. These days, a range of techniques make it possible for multiple channels to share the same piece of spectrum

27 In practice, terrain effects cause additional attenuation

away. This 'cellular' concept (illustrated in Exhibit 7) is the basis of mobile telephony (and is the reason why Americans refer to their mobile phones as 'cell phones').

Exhibit 7 Re-using Frequencies via the Cellular Principle



To make a cellular system work with mobile terminals, there has to be a way to hand over responsibility among base stations for communicating with the terminal, otherwise calls will simply be disconnected as the terminal moves out of range of the base station via which it established a call. Unfortunately, achieving this handover was a task that defeated Bell Labs, given the technology available at the time, so the cellular principle lay unused on the shelf for some decades.

3.1.2 First Generation (1G) Systems

It was only in the 1970s, with the arrival of large-scale integrated circuits and the development of the first microprocessors that it became possible to implement handover, giving rise to the first generation of cellular mobile telephony systems. The first to the market was the US AMPS system. The Nordic Mobile Telephone (NMT) system followed in 1981 and the UK launched the TACS system in 1985. These first generation (1G) systems all transmitted speech in analogue form via frequency modulation (FM) but used digital signalling to coordinate handover between base stations. Using analogue speech meant that many analogue components were needed, and this was an obstacle to miniaturisation because the main technological trajectory in electronic components was the rapid miniaturisation of digital components in CMOS technology. Initially, terminals were so big that they had to be mounted in cars. By the mid-1980s, 'portable' terminals weighing a few kilograms appeared, and the first hand-held terminals went on sale in 1988. By 1990, the smallest hand-held mobile phones weighed about 400 grams – they might fit a coat pocket, but would do serious damage to a suit.

Exhibit 8 1G Mobile Phone Systems in Europe, 1991

Country	Systems	Freq. band (MHz)	Date of launch	Subscribers (thousands)
United Kingdom	TACS	900	1985	1200
Scandinavia (Sweden, Norway, Finland, Denmark)	NMT	450	1981	1300
		900	1986	
France	Radiocom 2000	450, 900	1985	300
	NMT	450	1989	90
Italy	RTMS	450	1985	60
	TACS	900	1990	560
Germany	C-450	450	1985	600
Switzerland	NMT	900	1987	180
The Netherlands	NMT	450	1985	130
		900	1989	
Austria	NMT	450	1984	60
	TACS	900	1990	60
Spain	NMT	450	1982	60
	TACS	900	1990	60

Source: Michel Mouly and Marie-Bernadette Pautet, *The GSM System for Mobile Communications*, Paris: Cell & Sys, 1992

While the cellular principle permitted a dramatic increase in the efficiency with which spectrum could be used, analogue systems were nonetheless very capacity constrained. The biggest networks had some hundreds of thousands of customers and there was no prospect of finding enough spectrum to turn 1G mobile telephones into a universal product – not that many people initially conceived of mobile phones as other than exotic toys for business people and the rich.

3.1.3 Moving to 2G

The most significant changes in moving from 1G to 2G involved taking advantage of advances in components to move from analogue to digital communication between mobile phones and base stations. This had the double benefit of dramatically increasing the number of mobiles a network could support within a fixed amount of spectrum and giving access to digital components technologies where cost reductions and performance improvements were faster than in analogue circuitry.

Widely usable general-purpose microprocessors like the Intel 8080 (1974) and the

Zilog Z80 (1976) were appearing in the mid-1970s. In 1978, Intel released the first specialised signal processor that could convert analogue to digital signals and vice versa. In 1979, Bell Labs launched the first single-chip digital signal processor (DSP). These early DSPs were originally developed to handle calculation-intensive tasks in telecommunications and were much more efficient in these tasks than the general-purpose microprocessors. In 1983, Texas Instruments launched the TMS32010, which became the first large-scale success among DSPs and (together with other chips like the Motorola 56000) opened the way to a wide range of signal processing applications, including digital mobile telephony.

1G systems relied on quite a lot of analogue radio components such as filters and amplifiers, which had to be rather precisely manufactured, could not be reconfigured and used a lot of space and power. By performing equivalent operations digitally, some of these components could be eliminated. Since their digital replacements were actually software running on digital signal processors, design and incremental improvement became much more flexible. Just as with computers, many improvements therefore came in the form of new releases of software.

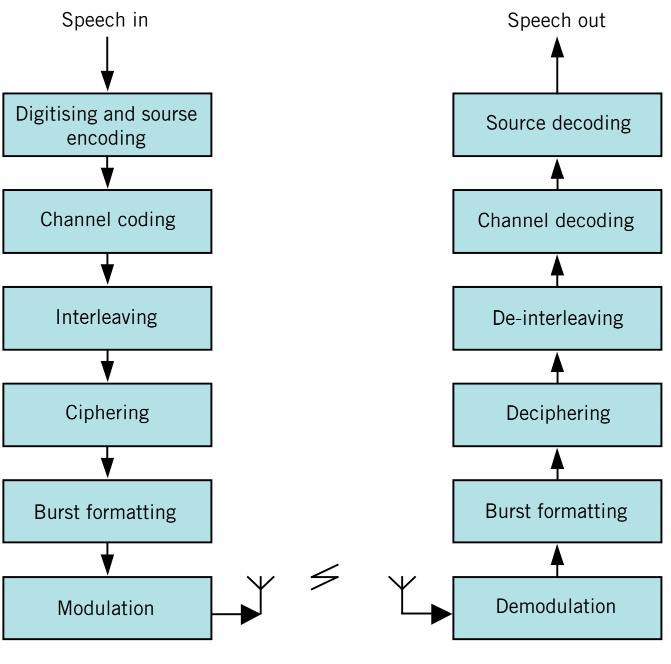
While the new DSPs increasingly gave the engineers the raw calculation power needed to build 2G mobile phones, designing the digital radio access posed a number of more fundamental challenges.

1. How to convert and code speech into digital form, using as little bandwidth as possible while maintaining a level of speech quality that the consumer would accept
2. How to code multiple conversations (and other forms of communication such as fax) into a single channel while getting very fast communication between the mobile phone and the base station
3. How to protect the coded signal from fading and noise in the radio channel
4. How to modulate the resulting digital signal over radio waves while maintaining high bit rates
5. A particular problem was how to cope with 'inter-symbol interference' caused by Rayleigh fading (we'll come back to this one)
6. How to implement the solutions to these problems in electronic components

All these problems had to be solved within important constraints. The solutions had to be economical with bandwidth; they had to be small so that it was possible to make hand-held mobile phones; their implementation had to be affordable, in order to allow the market to develop; and they had to use very little power, so that available battery technology could be used while giving handsets a long enough battery life to be practical.

The intellectual foundations of the solutions to these problems were often well established. Digital speech coding had been researched since the middle of the 1960s but was hampered by the high cost and low power of computers – a bottleneck that was broken only in the 1980s by the new DSPs, which were fast enough to code and decode speech as fast as speech itself. A lot of exploratory mathematics was needed, coupled with evaluation and testing. There were surprises, such as discovering that coding schemes that produced good results for European languages could make Mandarin incomprehensible, so the solutions eventually found were based on a combination of theoretical and engineering design efforts.

Exhibit 9 Sequence of Operations from Speech to Radio Waves and Back



The solutions for coding multiple conversations and protecting the codes from disturbances during radio transmission tend to overlap. (Exhibit 9) gives an overview of the steps involved in going from speech to a coded radio signal and back again. Channel coding takes the digital signal from the speech coder and other information sources and adds additional coding bits. This helps the receiver recognize and correct errors that have been introduced during radio transmission, for example through noise interfering with the radio signal. In the GSM implementation of 2G, this is done by sending 'words' or blocks of code that are 456 bits long and putting standard 'training codes' into the middle of each word. These let the receiver confirm that it understands where the words start and finish and – because the receiver knows what 'training codes' it should be receiving – lets it also know whether the signal has been corrupted during transmission. The principles of channel coding go back to the work of Claude Shannon at Bell Labs in 1948, but the actual implementation and the design of codes are non-trivial tasks, which themselves involve a lot of research.

Because noise and fading (loss of signal or interference) tend to occur in bursts, it is useful to spread digital radio signals out in time. GSM speech transmission lets up to eight streams of code share a single channel through interleaving or 'time-division multiple access (TDMA). This involves taking a short segment of each stream in turn and interleaving them, so that the channel first carries part of conversation 1, then part of conversation 2, and so on until a bit of each has been sent. Then it takes the next part of conversation 1 followed by the next part of conversation 2, and so on. At the receiver, it is then possible to take the interleaved signal apart again and reconstruct the conversations. Since noise or fading in the radio channel is likely to affect a few bits being sent next to each other, this technique means that noise or fading tends to do a small amount of damage to several conversations – from which the system can recover – rather than a lot of damage to a single conversation, which might not recover so easily. The other key function of multiplexing is to use spectrum efficiently. The digital channel can transmit information much faster than it is generated by speech, so it is possible to share the channel. Other tricks, such as identifying silence in speech and not transmitting it also improve efficiency.[28]

In a cellular system, therefore, many coexisting radio connections between bases and terminals share the same radio propagation medium and the same part of the radio spectrum - there is multiple access to the radio channel, which means mutual interference. Different methods can be used to eliminate this interference.

With FDMA (Frequency Division Multiple Access) each connection has an exclusive right to a narrow-band frequency slot (often so narrow that we can neglect time dispersion). With TDMA (Time Division Multiple Access) a wide-band radio channel is divided up in non-overlapping timeslots (in GSM 8 time slots) and each connection is allocated one slot. The date rate over the radio channel is increased correspondingly,

28 This roughly doubles the number of conversations than can be carried by a single channel. Since this technique means that the people having the conversation would actually hear periods of complete silence in the pauses between words and the breaks in conversation, the GSM standard in fact required the receiver to generate a little artificial background noise – otherwise the conversation would sound very strange

which also means increased channel bandwidth. This generally means that equalizers must be introduced to suppress time dispersion over the radio channel. In CDMA (Code Division Multiple Access) even higher date rates (and channel bandwidth) must be used, as powerful channel codes are used in order to handle the time dispersion. Still the total frequency economy is improved as the interference between nearby cells is suppressed to a large extent.

Analogue systems (1G) tended to use frequency division (FDMA), while 3G systems use code division (CDMA – Code Division Multiple Access), where different streams of information are encoded using incompatible codes and sent at different frequencies across quite a wide channel. CDMA is the most efficient way to use limited spectrum, but is power-hungry and for a range of reasons proved to be insufficiently ripe when GSM was standardised (see next section).

A problem with 1G analogue systems is that it is easy to listen in to phone conversations. 2G systems therefore encrypt or cipher radio signals, using a unique encryption key generated by the mobile phone and the base station for each conversation. This improves both privacy and data security.

Once information has been channel coded, interleaved and encrypted, extra bits are added to format the signal into short bursts for transmission. These extra bits have known characteristics and, like the 'training codes' referred to earlier; the receiver can use them to understand where it is in the sequence of information it receives.

The last step is to modulate the digital bursts onto radio waves – moving from the digital world inside the handset or base station to the analogue radio world in between them. Modulation works by taking a simple 'carrier' wave and combining it with the signal (such as speech) to be transmitted. The radio wave carrying the information is therefore a mix of the information and the carrier and the receiver can reconstruct the information by compensating for the presence of the carrier wave. Simple schemes for modulating digital signals involve big changes in the phase of the radio wave, and these are hard to achieve quickly, so the data rate for simple schemes is comparatively low. Efficient modulation schemes involve less dramatic changes in the modulated signal. However, increased data rates come at the cost of increased complexity. GSM uses Gaussian Minimum Shift Key modulation[29] (GMSK) to achieve a good trade-off between efficiency and complexity. Minimum Shift Key modulation has been known since the early 1970s, but adapting it to this application was one of the key technological achievements of the Swedish research community in the period leading up to the GSM standard.

29 For an explanation, see Michel Mouly and Marie-Bernadette Pautet, *The GSM System for Mobile Communications*, Paris: Cell & Sys, 1992

Once the digital signal is modulated onto an analogue carrier, it is amplified and transmitted. If it were simply to travel in a straight line to the receiver, it would arrive in reasonably good shape – perhaps a little distorted by noise encountered on the way – but the channel coding and burst formatting would mean that the receiver should be able to make a pretty good job of understanding the signal. As Exhibit 9 suggests, this would essentially be a matter of reversing the sequence of coding, encryption and modulation described so far. However, base stations and mobile phones radiate signals in many directions. As a result, the receiver is likely to get the signal via several different pathways, bouncing off buildings and hills on the way. These pathways will be of different lengths. The received signal will therefore be the sum of several different signals, which are out of phase with each other – a phenomenon called Rayleigh fading. It is complicated further by effects induced by the terminal moving about. Rayleigh fading causes 'inter-symbol interference': that is, some of the longer radio propagation paths introduce so much delay that bits arriving via different paths collide. Somehow the receiver has to untangle this interference – otherwise the data transfer rate has to be set so low that the system becomes extremely inefficient.

The solution is 'equalisation', which uses statistics to decide what the 'real' signal should look like. First the signals are demodulated and then they are analysed. One of the key insights in the development of GSM was the realisation that the Viterbi algorithm, first published in 1967, could be used to achieve this equalisation. Once the incoming signal is demodulated and equalised, it can be deconstructed as shown in Exhibit 9.

3.2 Standardisation

Standardisation in the three major generations of mobile telephony spans three very different regimes. Except in the USA, the 1G standards were devised under state monopoly conditions, while the 2G standards – especially GSM – marked the weakening of that monopoly, combined with internationalisation. The first two generations of standards were largely decided by the state monopolies. In contrast, 3G standardisation (which is still work in progress) is a wholly international process with increasingly liberalised telecommunications markets and with industry playing a significant role in negotiating standards.

These differences also mean that the direct influence of national policies over telecommunications standards has been declining: first, because of the increasingly international scale at which standards are defined and products developed; second, because liberalisation has altered the role of the PTTs. With the disappearance of monopoly, the PTTs'responsibility for trying to secure public goods also disappears. One can always discuss how effective the old-style PTTs were in securing the public good, and the answer undoubtedly varies amongst PTTs. As monopolists, they tended in many ways to be inefficient. However, on balance the Nordic PTTs did comparatively well, providing universal services at modest prices and taking a very active role in technology development. But after liberalisation, like other PTTs, they have largely closed their R&D facilities and become standard-takers rather than standard-makers.

In the past, PTTs – especially in the medium and large sized countries – had a tendency to define idiosyncratic standards and national equipment manufacturers made equipment in line with these. The need for international connectivity in telecommunications and the manufacturers' desire for international markets in practice put limits on how specific national standards could be, but the monopoly-monopsony relations in many markets meant that standards were not public. The mobile standards discussed here are all 'open': that is, they are published in order to encourage equipment manufacturers to compete and (in principle, if not always in practice) to allow telecommunications companies to mix and match equipment from different manufacturers.

3.2.1 1G Standardisation: NMT

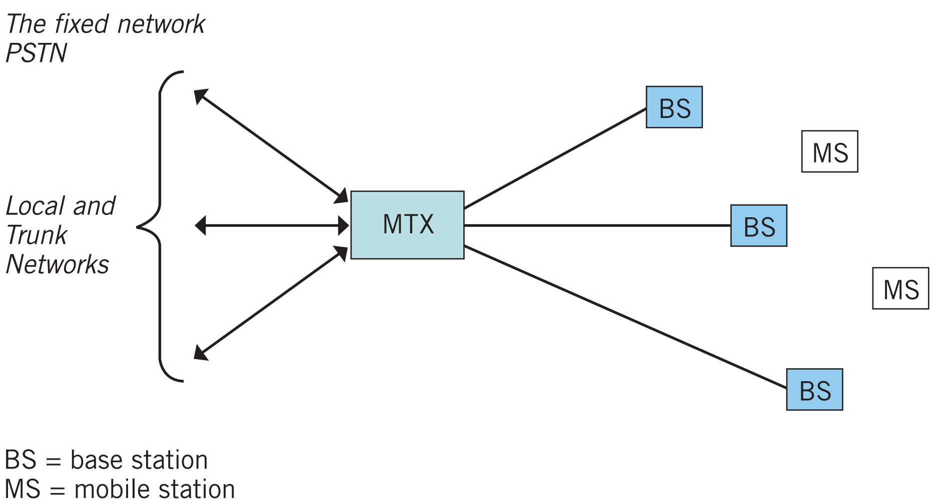
In its former role as a standard-maker, Swedish Telecom set up a mobile communications study group under Carl-Gösta Åsdal in 1964. People who can remember waiting years to get a telephone will recall that the old monopolists were rarely in a hurry, and it took three years for Åsdal's report to appear. It dealt with a wide range of intended mobile services, including paging and private mobile radio, but the key discussion was of the need for a new mobile telephone system – originally called MTC, following in the tradition of the earlier systems. MTC was to be cellular. The Swedish Telecom board approved the report in 1967 and its Radio Lab began work on the matter in 1968.

In 1969, at Kabelvåg in Norway, Åsdal reported on his work to the Nordic Telecommunications Conference – a conference organised under the Nordic Council cooperation that reflected cooperation in telecommunications dating back to the 1930s – and suggested that a Nordic cooperation in mobile telephony would be useful. The Nordic Mobile Telephone group began work in 1970. Any early issue was to agree on and allocate common frequencies in the 450 MHx band. The principle of 'roaming' – that customers should be able to move freely among the constituent national networks – was a radical difference between NMT systems and other 1G systems being developed elsewhere. However, it took until 1975 before key issues, such as the choice between automatic dialling and manual connection, were resolved.

The basic architecture of NMT was similar to that of other 1G systems (Exhibit 10). It was cellular, with several base stations grouped around each mobile telephone exchange

(MTX). The MTX contained the intelligence needed to control the base stations and provided access to the fixed telephone network. This was a bold move – deciding to use the power of the then new microprocessors in a decentralised way. But it also meant that the NMT system had almost no effect on the fixed network – it functioned purely as a way to access the fixed network and for calls via the fixed network to be routed to mobile terminals.

Exhibit 10 NMT Basic Architecture



Source: John Meurling and Richard Jeans, *The Mobile Phone Book: The Invention of the Mobile Phone Industry*, London: Communications Week International, 1994

However, unlike in other 1G systems, the requirement for roaming meant that the NMT system had not only to monitor where every connected mobile terminal was but also to keep track of terminals that were operating outside their 'home' territory. For example, for a Danish customer to use her terminal in Norway, the Norwegian network had to tell the Danish one that the roaming handset was in Norway, so that calls could be routed to it. In effect, the NMT network architecture therefore had most of the characteristics needed by the 2G GSM system in order to allow users to roam among networks and countries.

The NMT systems specification was completed and reported to the Nordic Telecommunications Conference in 1975. Swedish Telecom had assumed that in NMT the operators would own the terminals, but was overruled by the other Nordic operators, who wanted to create an open market in terminals in order to foster competition and technological change. Swedish Telecom and the Norwegian PTT volunteered to carry out systems trials over the two following years and successfully demonstrated the system in 1978. The NMT group met frequently with first Nordic and later other interested manufacturers, with the intention of fostering an open standard and open competition. On the systems side, however, Ericsson had a powerful advantage in that it had a strong installed base: all the Nordic fixed networks used its AKE analogue exchanges ('switches'), so for them it would be easy to buy Ericsson swithces. Ericsson and Swedish Telecom had just developed a new generation of digital switch (the AXE), which Ericsson began delivering in 1976. Initially, Ericsson was reluctant to supply its brand new AXE switches as MTXs, preferring to offer AKEs. However, when it became clear that Japanese manufacturers were offering cheaper alternatives to the AKE, Ericsson decided to invest in the needed applications engineering of the AXE – apparently winning the MTX business across the Nordic area on the basis that this gave the operators confidence that these would inter-work seamlessly with the existing fixed networks.[30] Buying the inherently modular AXE switches turned out to be a useful accident when the real level of demand for mobile services became clear. Smaller, non-modular switches would have proved a bottleneck.

The Nordic PTTs ordered base stations and MTX switches in 1978, with the intention of launching an NMT-based service in October 1981. Sweden, at least, was actually able to launch its NMT service on time and the other Nordic administrations were close behind. As a result, the Nordic countries were early users of cellular mobile telecommunications, and the household penetration of 1G systems quickly rose higher in the Nordic countries than anywhere else in the world.

One can of course ask whether the 17 years it took for NMT to move from idea to implementation is a reflection of the far-sightedness of Swedish Telecom and the other Nordic administrations or a reflection of their status as unhurried monopolists. Perhaps the best we can say is that NMT seems to have made good use of the technologies available at the time of its implementation. It is hard to see how a mobile telephone system using digital signalling and with so much intelligence placed in the MTX switches could have been built much sooner. A more primitive system using earlier technologies would probably have involved modifying the fixed network – an unlikely proposition, given the tiny size of the perceived mobile market compared with that for 'real' telephones.

NMT 450 was a runaway success. By 1986, the Danish, Norwegian and Swedish systems had reached their original design capacities while Finland reached this point in 1987.[31] Already in 1983, the NMT group approved the development of a version of

30 Manninen, Op Cit, p113

31 Ari T Manninen, *Elaboration of NMT and GSM Standards*, doctoral thesis, University of Jyväskila, 2002

NMT to operate in the 900 MHz frequency range in order to get greater capacity. Swedish Telecom in practice served as a reference user for the many other PTTs interested in building their own mobile systems, and this led naturally enough to an introduction to Swedish Telecom's main supplier.

Exhibit 11 NMT and GSM Standardisation Time Line, 1964 to 1992

1964	NMT Study group set up under Carl-Gösta Åsdal
1967	NMT Study Group report defines requirements for NMT specification
1969	NMT working party set up by the Nordic nations, following presentation of Åsdal's report at the Nordic Telecommunications Conference
1971	Manually switched mobile telephone systems established in Nordic countries (MTD in Sweden)
1975	Nordic working party submits NMT 450 specifications
1977-78	NMT 450 systems trials
1978	NMT 450 specification published
1981	NMT 450 networks launched in DK, N, SF, S and Saudi Arabia
1982,	CEPT establishes the Groupe Spéciale Mobile under Thomas Haug to define GSM
1986	NMT 900 launched in Sweden
1986	Permanent nucleus of GSM TC is established
1986	Evaluation of transmission prototypes for GSM at CNET in Paris
1987	Main radio transmission techniques are chosen for GSM, based on prototype evaluation of 1986
1988	ETSI created. Includes industry in addition to PTTs and other operators
1989	GSM becomes an ETSI committee
1990	Phase I GSM specifications (drafted 1987-90) are frozen
1990	DCS 1800 (ie GSM at 1800 MHz) specification work starts
1991	DCS 1800 specification frozen
1991	First GSM systems demonstrated at Telecom 91
1992	GSM launch in Europe

3.2.2 2G Standardisation – GSM

Östen Mäkitalo, one of the driving forces for mobile telecommunications within Swedish Telecom, the head of its Radio Lab from 1975 and Director of R&D at Swedish Telecom Radio from 1977 to 1991, told us that NMT used analogue speech because the technology for digital transmission was not ripe – but that otherwise GSM amounted to a digital reimplementation of the NMT architecture. In the light of the discussion of technical challenges above, this argument is plausible. However, GSM standardisation was a game in which Swedish telecom was one player among many others – unlike in NMT, where it clearly brought much more to the party than its partners.

Discussions on a common European mobile telephone system go back to the 1960s within the Conference of European Posts and Telegraphs (CEPT) but did not get far before GSM. Following the allocation at the World Administrative Radio Conference of parts of the 900 MHz band to mobile telecommunications in 1979, the French PTT convened an international meeting in 1980 to map national plans for mobile telephony and promote the idea of a common system. However, many countries felt that the French ambition to have a 900 MHz system in place by 1985 was unduly rushed. Some did not intend to exploit that band until the 1990s.

At the June 1982 telecommunications conference in Vienna, the Dutch PTT called[32] for standardisation work to begin on a pan-European mobile service. The Netherlands PTT argued "the 900 MHz band represents the last opportunity for the coming decades to achieve a form of harmonisation in the field of land mobile services for European purposes." In response, CEPT set up a study group[33] from 11 countries (later expanded to 13) called the Groupe Spécial Mobile (GSM) to start to define a standard. The group's plan was drawn up by the Dutch and Nordic PTTs and was chaired by Thomas Haug of Swedish Telecom, who had originally been the secretary and later the chairman of the NMT standardisation group. It seems likely that the experience of NMT standardisation gave the Nordic authorities relevant experience for the GSM work. Certainly Haug knew how to manage the complex diplomacy needed to manage an international standardisation process.

In practice, the work did not only proceed within CEPT but also through a COST project[34] (COST 207 Digital Land Mobile Radio Communications) in which the participants in the standardisation process shared the results of a large number of tests and measurements, tackling in particular

- Fading, taking into account the physical characteristics of the terrain in various countries
- Measurements of man-made noise in the 900 MHz band
- Modulation methods seen as possible candidates for the GSM system: GFTM'; PAM/FM and GMSK
- Adaptive baseband equalisation techniques
- Forward error-correction codes

32 Netherlands PTT Administration, "Public Mobile Communications Systems in the 900 MHz band," CEPT Telecommunications Commission, Vienna, 14-25 June 1982

33 CEPT, Commission "Télécommunications," XIe Session ordinaire, Vienne, 14-25 Juin 1982 (mimeo)

34 M Failli (chair), COST 207 Digital Land Mobile Radio Communications, Final Report, Brussels: European Commission, D-G Telecommunications, Information Industries and Innovation, 1989

- Specification of the speech coder/decoder (codec) and corresponding test sequences
- Aspects of the specifications that could minimise power consumption and the effects of interference

CEPT set out a several lists of criteria, which the GSM specification should satisfy and in further proposals by the Dutch, Danish, Finnish, Norwegian and Swedish authorities at the first meeting of the GSM in Stockholm in December 1982[35], the list became very long, but they essentially boil down to seven

- Good subjective speech quality
- Low terminal and service cost
- Support for international roaming
- Ability to support handheld terminals
- Support for a range of new services and facilities
- Spectral efficiency
- ISDN compatibility

The Integrated Digital Services Network (ISDN[36]) was the predominant concept for digital fixed telecommunications in the 1980s and was widely expected to transform telecommunications. It amounted to a set of protocols for switching digital telephone circuits in blocks of 64 kbps – with each block corresponding to a single high-quality speech circuit. Considered as broadband in its time, ISDN has largely been overtaken by higher bandwidth connections and the TCP/IP Internet protocols, which rely on different switching techniques[37].

Signalling System 7 (SS7), originally developed by AT&T in 1975 and adopted as a standard by the International Telecommunications Union in 1981, establishes a separate channel for communications between devices, in parallel with the main (speech) channel. For many of us, the most obvious use of SS7 is Calling Line Identification, where the handset shows us the number that is calling as the phone rings. While NMT put noisy bursts of digital signalling into the speech channel, GSM uses the parallel SS7 channel to communicate, for example to allow the mobile terminal to assist the base stations and MTX in managing a handover form one cell to another.

35 The Netherlands, Denmark, Finland, Norway, Sweden, "Proposal for a Study Plan on Question CCH 3," T/CCH (82) 21R, CEPT: December 1982 (mimeo)
36 Originally Integriertes Sprach- und Datennetz
37 ISDN uses traditional circuit switching, while TCP/IP employs a modified form of packet switching

The GSM work proceeded in two phases: a feasibility phase from 1982 to early 1985; and a true standardisation phase from 1985 to 1991, when in principle the system was supposed to 'go live'. Initially, the group met only annually, then more frequently. It split in 1984 into three Working Parties

- WP1 Services and facilities
- WP2 Radio transmission issues
- WP3 Network aspects

Most of the unresolved technical issues discussed in the previous Chapter were in the territory of WP2 and this was where there was most disagreement in the standardisation process.

In 1984, France and Germany agreed to promote their own technical solution for radio access (CDMA with slow frequency hopping) in the hope of persuading the others to accept it and accelerate the pace of implementation. They were joined by Italy in 1985 and by the UK in 1986. The GSM Group nonetheless persisted in moving to competitive trials of the alternative radio access and speech coding/decoding technologies.

The radio access trials were held in Paris in late 1986. Exhibit 12 shows the competing consortia and their proposed solutions. The Norwegian entry from ELAB in Trondheim did not have an industrial backer, but had been supported behind the scenes by Swedish Telecom, which provided a test vehicle and measurements in a series of trials in Stockholm, allowing the Norwegians to tune their proposal. The Nordic proposals used various implementations of TDMA – an approach that was of particular interest in the Nordic countries because it could efficiently accommodate both large and small cells, making it useful both in the cities and in the sparsely populated Nordic countryside.

The results of the trials clearly showed the superiority of narrowband TDMA. No individual TDMA implementation was chosen at the time[38] although Maseng says that his was shown to be the best[39]. Subsequently, at its meeting in Madeira in 1987, the GSM agreed to present the results of the trial in the form shown in Exhibit 13. Initially, France and Germany refused to accept the trial results but were eventually cajoled into line because the narrowband TDMA solution was technically superior and by arguments about the need for European unity.

38 Mouly and Pautet1994, page 37
39 Torleiv Maseng, Telektronik, 3.2004;; see also *New Scientist*, February 1987

Exhibit 12 GSM Access Methods Competing at the Paris Trials

Developers	ATR, SAT, SEL, AEG, Italtel	ANT, Bosch, Telettra	LCT	Philips/TRT MATS-D		Ericsson	Televerket Sweden	Mobira	Elab, Trondheim
System	CD-900	S-900-D	5FH-900	(MS-BS>	<BS-MS)	DMS-90	MAX		ADPM
Multiple access	wide-band TD/CDMA	narrow-band TDMA	nb/wb CD/TDMA	narrow-band FDMA	wide-band CD/TDMA	narrow-band TDMA	narrow-band TDMA	narrow-band TDMA	TDMA
Traffic rates (kbps)	12.8+3.2	9.6+1.4	16+25.6	16+2	16+2	16+8	16+4.6	16+8	16
Signalling rate	0.8+1.6	0.25	10.4	0.75	0.75	1+0.67	1.6+0.5	0.5+0.5	-
Multiplexed rate	18.4	11.25	52	18.75	18.75	25.67	22.7	25	-
Channel per carrier	63	10	3	1	64	10	11	9	10-160
TDMA-factor per carrier	63	10	3	1	4	10	11	9	10-160
CDMA-factor per carrier	1	1	1	1	8	1	1	1	1
Multi access rate (ksymb/s)	1496.25	128	201	19.5	39	340	302	252	256-4096
Modulation rate (kbaud)	3990	128	201	19.5	1248	340	302	252	256-4096
Gross bite rate (kbps)	7980	256	201	19.5	19968	340	302	252	256-4096
Carrier spacing (kHz)	6000	250	150	25	1250	300	300	250	200-4000
Modulation	QPSK	4-CPFSK	GMSK	GTFM	QAM	GMSK	GMSK	GMSK	OPM
Pulse type/filtering	15RC	2AC	0.30 gss	gss	-	0.25 gss	0.50 gss	0.25 gss	SRC
FM/PM	PM	FM	FM	FM	PM	FM	FM	FM	PM
Symbol alphabet	4	4	2	2	4	2	2	2	2
Modulation index	0.50	0.33	0.50	0.50	0.50	0.50	0.50	0.50	1.20
Double sided banwith (kHz)									
• -20 dB	-	130	200	20	2000	370	300	270	-
• -70 dB	-	260	600	50	2500	810	1000	600	-
Gross symbol duration (μs)	0.251	15.6	4.98	51.3	0.801	2.94	3.31	3.96	-
Time slot duration (ms)	0.4762	3.1875	1.3333	16	4	0.8	1	1.77	-
Speech frame duration (ms)	15	32	12	16	16	-	-	-	-
M acc frame duration (ms)	30	32	240	16	16	8	11	16	
M acc frame length (gr symb)	119700	2048	48240	312	19968	2720	3322	4032	-
Frequency hopping rate (s-1)	-	-	250	-	-	125	-	-	-
Diversity BS	-	yes	-	yes	-	-	yes	yes	-
Diversity MS	-	-	-	-	-	-	yes	yes	-
Speech coding	SBC	RELP	SBC	RELP	RELP	-	-	-	-
Channel coding	RS	-	RS	RS	comp	RS	-	RS	-

Source: Torleiv Maseng, Telektronik, 3.2004; cited from *Communications Systems Worldwide*, September 1986

Exhibit 13 Evaluation Criteria and Results of the Paris Trial

Criterion	Analogue vs. Digital	FDMA vs. TDMA	TDMA N-B vs. W-B
1. Speech quality	Comparable	Comparable	Comparable
2. Spectrum efficiency	Comparable	Comparable	N-B
3. Infrastructure & 4. Mobile cost	Digital	TDMA	N-B
5. Hand portable viability	Digital	TDMA	N-B
6. Flexible for new services	Digital	TDMA	Comparable
7. Risk	Analogue	FDMA	N-B
8. Spectrum management	Comparable	FDMA	N-B

N-B = narrow-band

W-B = wide-band

Source: GSM Doc 22/87, cited from Ari T Manninen, *Elaboration of NMT and GSM Standards: From Idea to Market*, PhD thesis, University of Jyväskylå , 2002 p188]

The GSM group (together with other members of the COST 207 project) also evaluated 26 proposals for speech coder/decoders ('codecs') and made trials of the 6 most interesting. The race was quickly reduced to four (French, German, UK and Swedish), with the final winner being a modified form of the German proposal (excited linear predicting code – LPT), refined through the addition of long-term predicting code – an idea borrowed from the French proposal.

The GSM group meeting in Madeira in 1987 finally confirmed that GSM would be a digital system, that it would use the modified German codec and that it would use narrowband TDMA for radio access, despite the objections of France and Germany.[40] Following further arguments and pressure from the European Council of Ministers, thirteen PTTs signed a memorandum of Understanding[41] (MoU) that underlined the need for common action in order to build the scale and common standards needed for a pan-European mobile service to be introduced by 1991. A key objective of the MoU was to demonstrate the commitment of the PTTs to the equipment industry – providing an assurance that there would be demand for systems and infrastructure built according to the GSM standard.

The GSM standardisation discussions took place in a context increasingly influenced by the European Commission. It had tried and failed to influence national telecommunications policies since the early 1970s (despite the fact that the Treaty establishing the Community gave it no mandate to do so), but managed to establish the European Strategic Programme of Research and Development in Information Technology

40 Outcome of the CEPT/CCH/GSM meeting in Funchal 16-20 February 1987 concerning the technical standard for a pan European digital cellular radio system (mimeo, supplied by Thomas Haug

41 Memorandum of understanding on the implementation of a pan European 900 MHz digital cellular mobile telecommunications service by 1991, CEPT, 7 September 1987 (mimeo)

(ESPRIT) from 1983, which focused on trying to improve the EU's weak position in computing and IT. The Commission's position in relation to telecommunications became stronger in the early 1980s, especially following the US decision in 1982 to break up AT&T. The Commission established the Information Technology and Telecommunications Task Force (IT3F) in 1983-6, which campaigned for increased intervention in IT and telecommunications, ran the early parts of ESPRIT and eventually established a pilot programme of R&D in Advanced Telecommunications for Europe (RACE) in 1985-6, which promoted R&D cooperation on what was intended to be next-generation telecommunications technology. The aim was to exploit the opening of telecommunications equipment markets to create a European-level telecommunications industry with global scale. In 1985, the Commission went so far as to try to take over the GSM standardisation process in order to accelerate it, but was rebuffed by CEPT, which however did strengthen the GSM working group.[42]

The Commission's Green Paper on telecommunications in 1987 was intended to be a major impetus towards liberalisation and the separation of the regulatory and operating functions of the PTTs. The Commission also gave GSM an important kick towards reality through Council Recommendation 87/371 that year, stimulating the development of a European handset industry, and 87/382, which required member states to set aside spectrum in the 900 MHz range for GSM.

During this period, the European Commission was campaigning strongly for liberalisation of telecommunications in Europe. In 1988, it succeeded in triggering the creation of the European Telecommunications Standards Institute (ETSI) to take over the standardisation role of CEPT, arguing that in a liberalisation telecommunications industry the PTTs could no longer be in sole charge of standards. ETSI therefore included representatives of industry as well as PTTs. (The GSM had in fact jumped the gun and invited informal industrial participation from 1987.)

The implications of the GSM standardisation process for Sweden were largely positive. The German RPE-LPC codec approach posed no problems. The choice of a narrowband TDMA solution was very helpful, because it permitted fairly large cells and therefore meant Swedish Telecom could reuse its NMT base station sites. The modulation approach chosen – GMSK – was in fact proposed on the basis of work by Tor Aulin, a Swedish academic. Both GMSK and the decision to use the Viterbi algorithm for equalisation (which was also suggested by ELAB) benefited everyone.

For Ericsson, the narrowband TDMA choice appears to have been vital. Not only did it give the company a lead in product development of about two years, it also meant

42 Manninen, Op Cit pp 222-4

that Ericsson had the capability to develop a different TDMA access solution that was built into the US 2G D-AMPS standard and Ericsson has been the dominant systems supplier for the D-AMPS markets. The choice of TDMA for the European Cordless telephone standard DECT also meant the company had a faster time to market in that product (which is also a contributor to the developing 3G standards).

Given the large size and comparatively early development of the US mobile market, it seems surprising that no US standard ever seriously challenged GSM at the world level. Timing was an important reason: in the USA, a technical committee to focus on future digital standards was only finally proposed in September 1987, by which time GSM was close to completion. Another key factor was that the US regulator initially insisted that 2G systems should be 'backwards compatible', so that they could be used by analogue AMPS subscribers as well as people using the new D-AMPS digital phones. This raised the handset cost and led phone companies to use the D-AMPS technology to extend existing capacity, rather than to build wholly new networks. Quickly, a second standard (CDMA) emerged and operators split between the alternative standards. It was only at the start of the 3G period that US subscribers could begin to use their phones nationwide and to roam abroad without specialised multi-standard handsets.

3.2.3 3G – Universal Mobile Telephone System

If the 1G systems were essentially defined at national (or in the Nordic case regional) level and 2G (GSM) at the continental level with PTTs essentially competing and cooperating to define standards, then 3G has raised standardisation to the global level, with regional standards definition organisations becoming actors on behalf of regional industrial interests. Unlike the earlier generations, 3G aims to be 'backwards compatible' (in this case with GSM). While 3G continues the interest in increased spectral efficiency, it does so in order to offer broadband services to users rather than to increase the number of subscribers who can use the network.

In the first phase of the RACE programme, project 1043 RACE Mobile, which ran from 1988 to 1992, provided an arena in which European operators and equipment suppliers could work on the principles of the 3G successor to GSM. This project introduced the idea of the Universal Mobile Telephone System (UMTS), with the ultimate ambition of defining a global standard. Subsequent RACE projects in 1992 to 1994 defined network aspects and provided test beds for both code division and time division radio access technology developments. The ACTS programme that succeeded RACE included some 30 mobile-relevant projects. In sharp contrast to its failure to contribute to the development of 2G standards, through the RACE and ACTS programmes the European Commission was a key enabler for UMTS, which was adopted as an ETSI standard in 1998, based on a Euro-Japanese wideband CDMA(W-CDMA) access scheme. The Euro-Japanese alliance (essentially between Ericsson, Nokia and the Japanese DoCoMo telecommunications operator, formerly known as NTT) was essentially a move to outflank the emerging US CDMA2000 standard, which was a development of a formerly proprietary standard developed in the USA by the Qualcomm company. In practice, 3G networks have largely converged on C-WDMA technology, which gives better results than TDMA but which can only efficiently be implemented using technologies that were not yet available when GSM was standardised.

The International Telecommunications Union (ITU) also promulgated a 3G standard – IMT-2000 – in 1998, which in effect defined 3G as a family of six different wireless access protocol standards. In effect, this ratified the de facto movement of initiative in standards making to the global level. The 3GPP Third Generation Global Partnership created by regional standards definition organisations similarly acknowledges this new dynamic, which effectively means that the standards making process in telecommunications not only has become global but more closely resembles the style of de facto standards-making that has prevailed in the computing industry in the past, where standards are effectively defined through market power rather than by regulation – now with the standards definition organisations effectively co-opted into that process.

4 The Role of the Public Sector

The focus of this study is on the interaction between STU/NUTEK-funded university research and mobile telephony development in Sweden. However, this story only becomes relevant because the 'development pair' of Swedish Telecom and Ericsson had been active for many years, though their relationship was changing during the 2G standardisation period. We therefore discuss Swedish Telecom and then the STU/NUTEK and wider national R&D support programmes that were relevant before touching on the international programmes that were to become important later on.

4.1 Swedish Telecom

From the middle of the Twentieth Century, Swedish Telecom and Ericsson enjoyed a partly symbiotic and partly competitive relationship. Televerket maintained switch design and manufacturing capabilities until the 1980s, but the increasingly demanding nature of the technology meant that it has increasingly to cooperate with Ericsson. In 1956, driven to a great extent by shortages of electronics engineers and the need not to duplicate effort, the two organisations formed a joint 'Electronics Council' (Elektroniknämnden) to work on electronic switching. However, they were interested in different technologies, so there was little practical cooperation. In 1963, it was agreed between Swedish Telecom and Ericsson that Ericsson would develop the AKE 12 exchange while Swedish Telecom worked on a larger machine in a deliberate division of labour. Triggered by the loss of a key order in Australia to ITT in 1969, Ericsson acutely needed a digital switch. Faced with a huge technical challenge that went well beyond its capabilities to act alone, Swedish Telecom set up a joint development company with Ericsson – ELLEMTEL – owned 50/50 and with a mission to develop what became the AXE switch. ELLEMTEL had to satisfy both the demands of Swedish Telecom for switches that would work well in the Swedish network and the requirements of Ericsson for a range of switches that it could sell worldwide. One result of this tension was that the original specification for a fairly small switch was abandoned in favour of a modular, scaleable switch with Stored Program Control[43] and the ability to support new services (it was intended to be 'future-proof'). While 20 years earlier, Swedish Telecom was capable of designing much of the equipment it needed, digital systems were so large and complex that their development were well beyond its resources and the technological capabilities of its existing staff.

43 ie it could be programmed like a computer

Swedish Telecom's role in type approval and regulation meant that it maintained quite large laboratory facilities. The Radio Lab, which was the key actor in GSM development, had about 100 staff in 1980. However, only about 10 of these worked in the 'narrowband office' that addressed NMT and GSM developments, a number that rose to about 15 by the middle of the decade. As was the case at Ericsson, the level of qualifications rose through the period. The office recruited its first MSc in 1985 and there were no PhDs working there until the late 1980s. Like Ericsson, Swedish Telecom recognised the need to increase the supply of digital radio engineers and the two organisations together invested in the expansion of KTH into the wireless area at Kista in the late 1980s,

Swedish Telecom had 'sectoral responsibility' for ensuring the availability of the knowledge it needed to conduct its business. In the early 1980s, it was – in addition to running its own laboratories – – spending about SEK 1-2m per year funding activities at KTH (Tele-Transmission Theory, Tele-Traffic Systems, Speech and Musical Acoustics), LTH (TeleTrafic Systems), LiTH (Systems Technology), IM, the Institute for Applied Mathematics, Institute for Optical Research, Karolinska Institutet, Åskled arkontrollanstalten[44] and the Corrosion Institute[45].

While Swedish Telecom's labs were heavily engaged in the development of NMT technology, apparently leading developments within the Nordic coalition, the greater complexity of GSM and its more international nature mean that Swedish Telecom's role was more closely tied to specifying requirements, evaluation and testing of prototypes than had been the case in NMT. The large number of working party meetings absorbed a great deal of the small narrowband office's time and its role often involved acting as go-between so as to connect findings from Ericsson's development work with the emerging requirements being discussed in the GSM Group. In this way, implementation issues such as the power consumption requirements of alternative specifications could be explored and were reflected in the final decisions made. Swedish Telecom played an important role by developing and hosting a number of pre-standardisation test beds. These test beds functioned as important 'focusing devices' – bringing together Swedish Telecom, Ericsson and various university people to address common problems and evaluate potential solutions.

While Swedish Telecom had the lead role in the development of NMT technology but by the 1980s its role in relation to technology development in Sweden was increasingly as co-developer, emphasising standards and usability aspects. The needs of Swedish Telecom as a systems specifier and Ericsson as a manufacturer did not always match

44 The lightning conductor authority!

45 Chefen för Televerket, Yttrande angående planering och finansiering av sektoriell forskning (letter), Farsta 13 January 1983

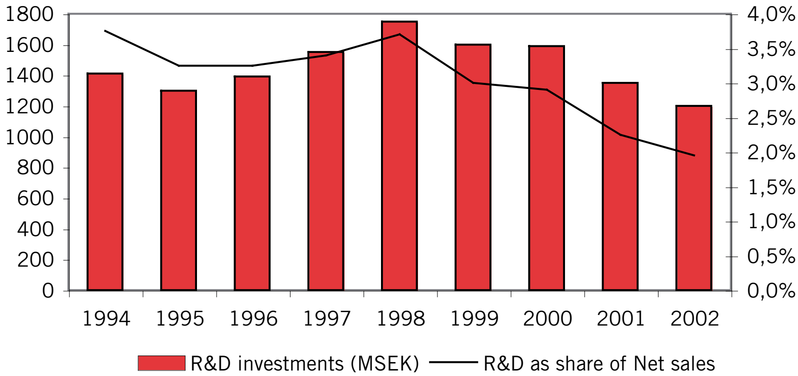
closely. While both were keenly interested in the FDMA and TDMA development test beds of the early 1980s, they disagreed about the usefulness of the IT4 GSM Test Bed project that – late in the decade – involved field tests of GSM prototypes. These were important to Swedish Telecom because they gave it quasi-operational experience of the system and let them to look at practical aspects of propagation. As one result, Swedish Telecom was therefore better positioned to design its base station network than its competitors in the Swedish market, who lacked this experience. For Ericsson, these questions were less immediately relevant, since they related to operational aspects of designing a GSM service rather than the equipment itself. However, against Ericsson's instincts, this and other implementation work with Swedish Telecom work turned out to be important to Ericsson's later success. It meant that it had the field experience to help new digital mobile operators deploy new networks, as part of the overall systems supplier package it offered.

While mobile telephony fuelled the dramatic growth of Ericsson and its technical staff through the 1980s and 1990s, it could not have the same effect at Swedish Telecom. Already in 1978, a internal project lead by Bertil Thorngren had identified that Swedish Telecom would come under increasing competitive pressure and that this would have implications for its behaviour and structure. The equipment market began to be deregulated in 1980 and was in principle completely open by 1989. The telephone monopoly was gone by 1988, under pressure from entrants like Comvik (Tele2) and after a determined rearguard action during which Swedish Telecom used the fact that it had no formal monopoly to try to counter demands for interconnection. Step by step the de facto monopoly was dismantled until it was complete in 1993.

The last director-general, Tony Hagström, initiated a process of corporatisation some years before Swedish Telecom finally became a state-owned limited company in 1993, when the Telecommunications Act completed the liberalisation process and placed temporary restrictions on Swedish Telecom's ability to use its market power to hinder entry.

As in other countries, mobile telephony ran ahead of this liberalisation process. With GSM in 1991 came regulated competition and the right for others to interconnect to Swedish Telecom's network. The writing had long been on the wall for the R&D function, and this was reduced in scale significantly and reoriented from its traditional role in equipment development to focus on services, since as an operator in a deregulated and globalising market Swedish Telecom got no advantage from subsidising equipment manufacturers' R&D, whether in cash or kind. The liberalisation also meant separating the regulatory function from Swedish Telecom, so the need for laboratory staff to do type approval and regulatory work dried up.

Exhibit 14 Swedish Telecom (Telia) R&D Investments 1994-2002



Source: Sven Lindmark, Erik Andersson, Mattias Johansson and Erik Bohlin, *Telecom Dynamics: History and State of the Swedish Telecom Sector and its Innovation System 1970-2003*, VINNOVA Analysis VA 2004:04, Stockholm: VINNOVA, 2004 p149

Exhibit 14 shows the decline in Swedish Telecom R&D investments through the liberalisation process. This was in fact far less dramatic than was the case for the major PTTs. In 1990, the three giant former monopolies AT&T, BT and NTT's R&D intensities were 7.3%, 3.8% and 2.1% respectively. By 1999 these figures had changed to 0.9%, 1.8% and 3.9%.[46] But liberalisation market the end of large-scale technical cooperation with suppliers in general and with Ericsson in particular.

4.2 STU/NUTEK

Since this study focuses on new kinds of university research in the 1970s and 1980s, this story necessarily focuses a lot on STU, which established funding practices and traditions that have to a considerable extent continued up to the present day via NUTEK and VINNOVA. Two aspects are especially important. First, STU developed a practice of investing quite widely in potentially interesting projects that came to it 'bottom up', but it did so generally in dialogue with industrial and academic stakeholders and on the basis of a good internal understanding of technology. So it was placing 'bets' that had had a basis in knowledge. Using signals from these projects and the stakeholders, it was able to identify cases where more formal programming would be helpful – as in the case of digital communications, where it became clear that this was a growing and important field and where the research and education effort needed to be scaled up. STU, in other words, operated as a change agent at a micro level. Second, and at

46 Sven Lindmark, Erik Andersson, Mattias Johansson and Erik Bohlin, *Telecom Dynamics: History and State of the Swedish Telecom Sector and its Innovation System 1970-2003*, VINNOVA Analysis VA 2004:04, Stockholm: VINNOVA, 2004 p149

a much more aggregated level, STU in the late 1970s and the 1980s was also a driving force for a much bigger change: namely, altering the shape of the national research and education effort to cope with the dramatically new needs of the electronic age. In this second role it was, in international terms, by no means alone; but it was decisive that some organisation should take on this role in Sweden.

4.2.1 STU and its role

STU was established in 1968, partly in response to a criticism from an OECD science review panel in 1964 that said the existing arrangements for funding research in Sweden were locked-in and bureaucratic and partly in response to the social democrats' campaign for a more active industry policy under the slogan *trygghet i utveckling* – security in development. If innovation was to be the motor of growth and welfare in Sweden AB, then an agency was needed that would bring together research and innovation. Important parts of the STU tradition remained present in its successor NUTEK and are still central to the way VINNOVA operates, notably the techniques used for programming and managing programmes as well as having the technical competence in-house to be able to respond to individual project proposals.

STU was not a new organisation but a merger of the technological research council TFR, EFOR, INFOR, The Swedish Foundation for Scientific Research and Industrial Development (Malmfonden) and the Swedish office for inventors. It was organised into a development department that funded projects, an information and advice department that focused on invention and dissemination, a planning department and an administration. A constant source of organisational stress was the need for STU at the same time to fund technological development and capacity building in the universities and to promote innovation in industry.

Sigvard Tomner – who was recruited from SRA to become the first head of the development department and, from 1975, STU's third director general – described STU as having three roles

- The societal role: to promote R&D within sectors of society not already provided with research resources and, in sectors where existing research funding arrangements are in place, to foster development
- The industrial role: to foster industrial innovation and quality, especially by assuming some of the risks of innovation in areas of importance for Swedish competitiveness
- The research role: to increase the scientific level and knowledge in selected areas47

47 Hans Weinberger, *Nätverksentreprenören*, Stockholm: KTH, 1997

Initially, project funding decisions were taken by research council-like committees (*nämnd* – a tradition inherited from TFR) but it became clear that this committee system tended to lock funding into a static pattern. The General Audit Office complained in 1972 that no reallocation took place between areas and that STU had no mechanism in place for doing such a reallocation. In 1973 the Board transferred the right to take project funding decisions from the committees to STU's project officers. From that point on, all expert committees in STU (and later in NUTEK and VINNOVA) became advisory. There was constant frustration, however, at STU's inability to change things. Director-General Bertil Agdur wrote in the daily newspaper *Dagens Nyheter* in 1974 that

> Our society is managed by an administrative apparatus. That may be appropriate for handling current issues of resource allocation and providing social services. When that same apparatus has to tackle the future, it naturally does so in the only way it can: it allocates money in the established patterns, using precise rules and comforting control mechanisms. A fundamental reason why we get stuck is that we are trying to use an **administrative apparatus** where we actually need a **change agent.**[48]

Such was the frustration with STU that a government commission (STU-utredningen 1978) investigated it. Many of the improvements in STU's processes and ways of working of the late 1970s were either suggested by that commission or developed in discussion with its members. (The secretary to the commission – Staffan Håkansson – subsequently joined STU and remained in the management of the organisation through the NUTEK period, become VINNOVA's international director.) A key conclusion confirmed that of the Audit Office that STU's system of budgeting across a large number of fixed areas caused lock-in. The commission proposed that STU should move to a system of flexible but fixed-term framework programmes with clear start and end dates. This would enable it to become the desired change agent.

STU's reaction was to ask the universities what the contents of the framework programmes should be. The universities' response was essentially a series of long lists of projects – proposing to continue what they already were doing. Tomner therefore asked his planning department to identify and prioritise key areas. Four framework programmes were launched in July 1979 in wood chemistry, genetic technologies, industrial food processes and a programme in speech, sound and hearing. A further ten were launched the following year.

Over the next few years, STU evolved a programming practice that built on close interaction with stakeholders and where programme design was supported, rather than

48 Our translation from Weinberger, 1997 p406

steered, by the planning department, which increasingly focused on overall strategy and on producing tempting budgets ('proposals' as Tomner called them internally) to offer to the industry ministry at three-year intervals. Programming came to involve a planning committee of academic and industrial experts in a field, which supported a project officer in writing a plan based on identifying technological and industrial needs and opportunities for Sweden. Once STU management approved a programme, the planning committee was dissolved. Programmes typically run for two successive 3-year periods and were overseen by a programme steering committee of knowledgeable but uninvolved industrialists and academics. They advised the project officer on project funding, but STU staff formally took these decisions.

STU had two kinds of programmes. From 1980, it ran so-called framework programmes (*ramprogram*) aimed to build capacity in the university system (*kompetensutveckling*). Programmes that involved industry were run from 1985 and were initially called action-areas (*insatsområden*), aiming to develop technologies (*teknikutveckling*). In later terminology, these became 'programmes'.

By the mid-1980s, STU was programming roughly half its project funding resources and awarding the rest in 'response mode' to projects proposed by the academic and industrial communities. Formally, this ratio has remained similar. However, VINNOVA increasingly stimulates non-programme activity by making calls for proposals in focused areas that it believes need to be stimulated[49]. As a result, the scope for bottom-up projects appears to have been reduced.

A second important process innovation[50] introduced in 1980 after the STU commission's work was periodic peer review evaluation by foreign peers. Later this was supplemented by 'usefulness' evaluations that aimed to understand and learn lessons from programmes' conduct and impacts. Weinberger argues that therefore STU was able to bring three vital resources to bear that help explain its success: money; a credible vision of future technological development; and the ability to judge quality in scientific terms.

4.2.2 ICT Programmes at STU/NUTEK

Through the 1980s and into the 1990s there were three fairly distinct strands in the funding of Information and Communications Technology (ICT) programmes at STU/NUTEK that ran over many years.

- One focused on electronic components and their underlying technologies. Between 1983 and 1987 these were treated as components of the National

49 Interview with Staffan Håkansson, 2008
50 STU/NUTEK undertook 105 such between 1980 and 2000

Microelectronics Programme (NMP3)

- A second focused on computing, computers and other electronic systems. Between 1987 and 1990, these were treated as part of the national Information Technology programme (IT3)
- A third, more diffuse strand handling various applications of ICT

STU's efforts in telecommunications were limited because Swedish Telecom took 'sectoral responsibility' for the development of that field. It operated its own large laboratories, funded university research and ran a joint-venture development company (ELLEMTEL) with Ericsson, developing switches. It was therefore only in 1993 – the year Swedish Telecom was privatised to become Telia and when it was clear that it would run down its technological capabilities and no longer look after the national interest in telecommunications research – that STU (by then NUTEK) set up a telecommunications research funding programme.

Exhibit 15 shows STU's framework programmes in electronic components (the first strand to which we refer) during the 1980s. The amounts spent varied but were generally about SEK 40m in total per year.

The Electronic and Electro-optical Components technology managed by Sven-Ingmar Ragnarsson, a former researcher and one of the key architects of the national electronics programmes and NUTEK and STU's subsequent IT strategies, was one of STU's first four framework programmes, running from 1979-1984. It spent about SEK 160m over these five years and represented a significant scaling up of the university-based research effort in these fields, from about SEK 5-6m in 1978/9 to some SEK 40m by 1983/4[51]. Achievements of that programme included establishing a number of university semiconductor laboratories. The number of university researchers in the field grew from 90 in 1979 to about 250 in 1983, of whom STU funded about two-thirds. The continuation of the programme as NMP3 is said to have further doubled the number of researchers to about 500 by 1990[52]. For the mobile telecommunications story, these programmes were important in that they established research capacity and capability in semiconductor design and manufacturing.

At the end of NMP3, a number of activities were transferred from STU programmes to the Institute for Microelectronics at Kista.

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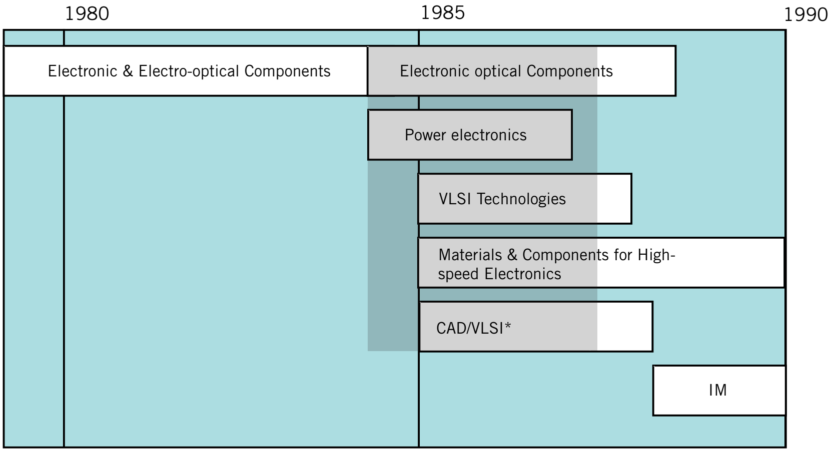
51 STU, *National Microelectronic Programme*, Information No 424-1984, Stockholm: Swedish National Board for Technological Development, 1984

52 STU, Vad STU gjort för utvecklingen av informationstekniken och dess användning, STU Info 838 - 1991

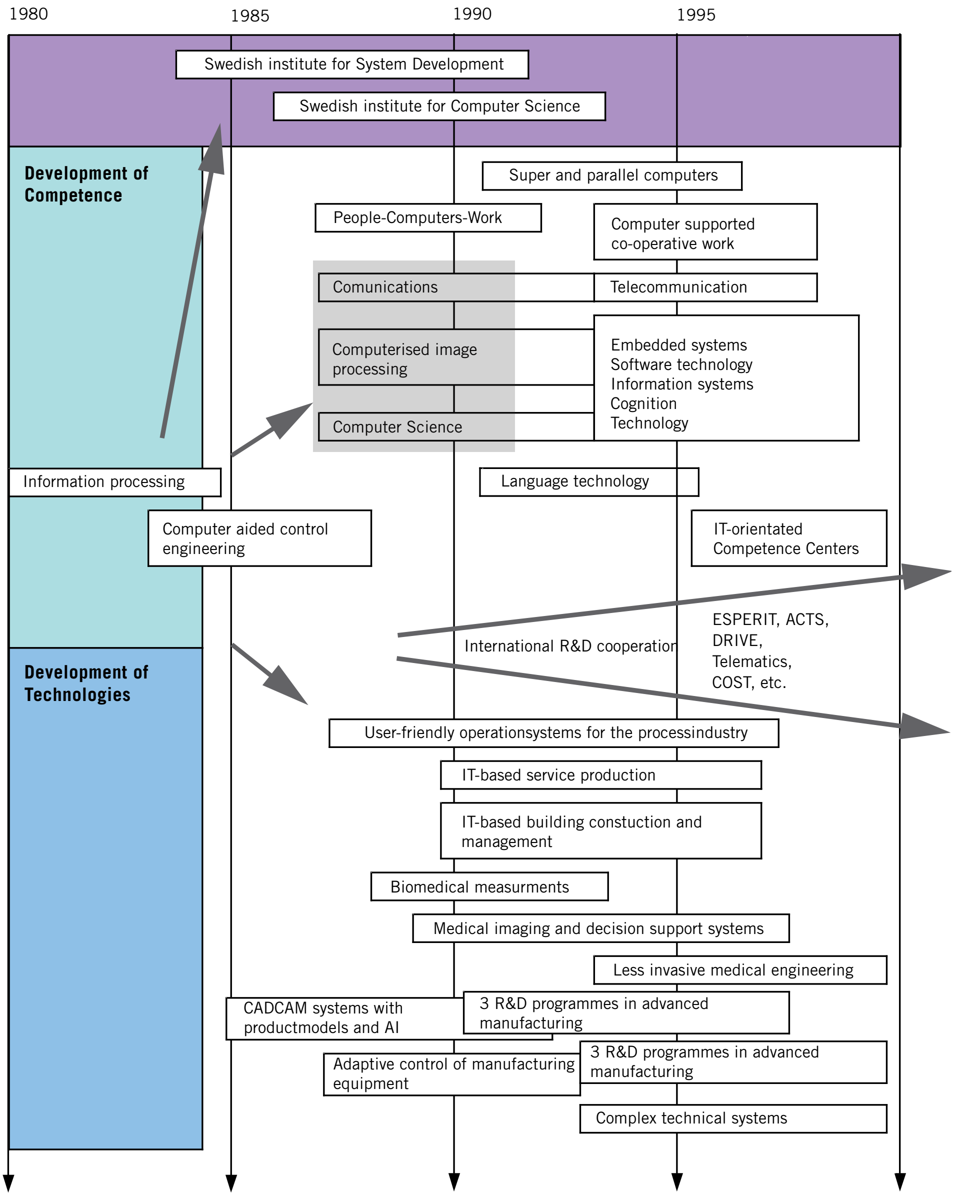
Exhibit 15 STU Programmes in Electronic Components, 1979-1990



*Partly continued in the Digital Communication programme
The grey area represents NMP3

The second strand began with the Programme for Research in Information Processing and Computer Science (1980-85, with a total budget of some SEK 80m). This identified and funded thirteen research groups in computer-focused research topics such as software systems, software engineering, artificial intelligence, industrial and distributed computing and computer-based learning. It was planned together with MIT and was peer reviewed annually. It also established a packet-switched network among computer researchers. It contained nothing orientated towards to telecommunications, although both Lars Zetterberg and Rolf Johannesson – important figures in the mobile telephony story – participated. Two research institutes – SICS and SISU – were set up in the wake of the programme, which made a considerable contribution towards building up national research and educational capacity in IT.

Exhibit 16 STU/NUTEK IT Programmes 1980-2000



Source Torbjörn Winqvist, VINNOVA. Grey area represents IT3

4.3 The National IT Programme

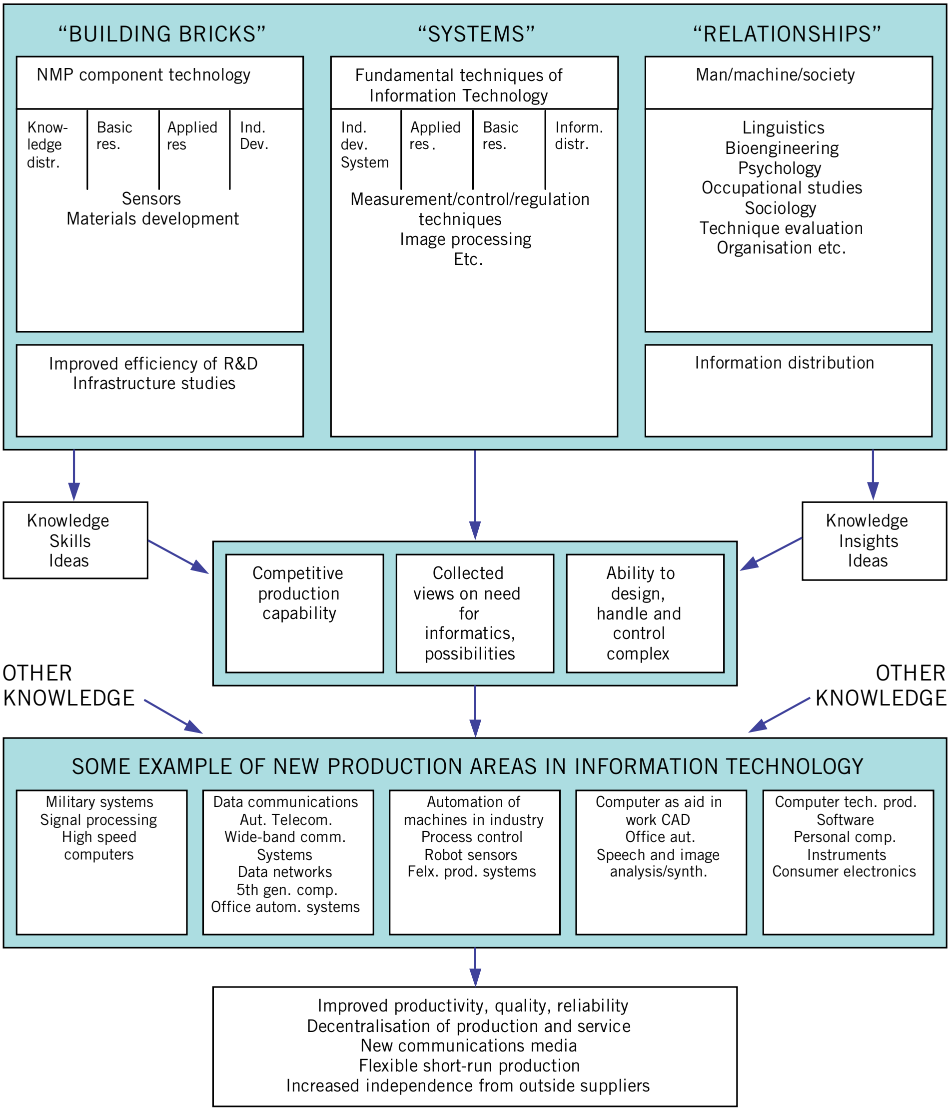
By 1980, it was abundantly clear to policymakers worldwide that a huge effort was needed in IT. Many OECD countries launched national IT programmes[53] of various kinds, often partly re-labelling existing efforts but always introducing substantial new money. The focus was generally on microelectronics and computing, reflecting concern at growing Japanese strengths in these areas and the apparent success of Japanese government R&D programmes in the 1970s. A concern with telecommunications took longer to develop in most countries – presumably because they felt this was already handled, where possible, in the interaction between the PTTs and their suppliers and partners in the equipment industry. In fact, the movement towards telecommunications liberalisation meant that these relationships were no longer adequate ways to protect national strengths in telecommunications, but in 1980 IT and telecommunications were largely seen as separate technologies and separate policy issues. It was only as the decade (and digitalisation) progressed that 'convergence' between the two made it clear that they were part and parcel of the same thing.

The early STU framework programmes in electronics reflected the international focus on IT, rather than ICT. STU took the initiative to start planning work on a national IT programme in 1982, developing the overall vision for such a programme shown in Exhibit 17. An initial proposal for a national microelectronics programme was put before parliament in 2003 and its more detailed design became a joint project between STU and several other agencies[54] in an unusual act of 'joined up' planning that effectively committed several ministries (industry, education and defence) to the idea.

53 Erik Arnold and Ken Guy, *Parallel Convergence: National Strategies in Information Technology*, London: Frances Pinter, 1986

54 Universitets- och Högskoleämbetet, Byrån för utbildning och forskning, *Nationellt informationsteknologiprogram – underlag för kanslidiskussion*, (mimeo) 1984-09-17

Exhibit 17 STU's Original Outline for a National IT Programme



Source: *STU, National Microelectronic Program*, STU Information No 424-1984, Stockholm: STU, 1984

As a result, in 1984 STU succeeded – in cooperation with the Swedish Defence Materiel Administration (FMV), Swedish Telecom, the Department of Higher Education and Universities (UHÄ) and the Swedish Natural Science Research Council (NFR) – in persuading the government to finance a National Microelectronics Programme (NMP)

– this extended and broadened the Electronic and Electro-optical Components programme to cover UHÄ-funded basic education at the universities (NMP1), NFR-funded research at the universities (NMP2), STU's goal-oriented research (NMP3) and an additional programme of industrial development, also to be funded via STU (NMP4).

NMP had a total state budget of SEK 560m, of which some SEK 250m was accounted for by STU's framework programmes. The Components of the NMP were

- NMP1 Education and awareness (SEK 20m) from HSÄ
- NMP2 Basic research (SEK 60m) from NFR
- NMP3 Goal-orientated research (SEK 315m from STU)
- NMP4 Industrially-orientated R&D (SEK 330m from STU, Swedish Telcom, FMV and ÖCB)

But NMP had a defensive as well as an competitive dimension. STU placed it within the context of other countries' national IT programmes, saying

> All these projects are pushing development forward very rapidly and something rather like a technological race is in progress, primarily in the field of information technology.
>
> The desire to provide employment results in a tendency to put the normal rules of business and free trade out of action. Protectionist tendencies and the requirements of security policies, particularly in the USA, are beginning to slow down the flow of information and are resulting in increasing restrictions on trade in high technology production equipment. These problems have, in fact, begun to be a hard fact of life for high technology industries and research organisations in Sweden.[55]

NMP4 in particular ensured the presence of a significant VLSI and ASIC process capability in Sweden, within Ericsson Components, in the second half of the 1980s[56].

While NMP4 had partly commercial and industry-strategic motives, it was not very important for high volume production of microelectronics, which never took place in Sweden. Ericsson secured its bulk components through an agreement with Texas Instruments. One of the key reasons why NMP4 was funded was the "increasing restrictions on trade in high technology production equipment" to which STU had referred. Specific pieces of US microchip production equipment had been denied to

55 STU, *National Microelectronic Programme*, Information No 424-1984, Stockholm: Swedish National Board for Technological Development, 1984

56 Sigfrid Wennerberg, *Nationella mikroelektronikprogrammet (NMP) och industriell utveckling*, Stockholm: 1989

Swedish customers on national security grounds. STU and FMV, which funded the NMP, saw this as a threat to the Swedish 'armed neutrality' doctrine. In practice, the increased ability NMP gave Ericsson to design and fabricate VLSI gave it huge bargaining power over Texas Instruments – a fact that it exploited in pressing down the price of the DSP chips it needed in order to implement GSM.

After NMP was up and running, planning continued on a national Industrial Information Technology programme (IT), which was agreed in 1986 and launched in 1987. IT has the same four-part construction as NMP. IT3 essentially was a collective label for STU's IT programmes.

STU planners hoped to complete an architecture for a national IT programme as shown in Exhibit 18 and the Research Act of 1986/7 created a legal basis for it, saying that its aim was

> ... to maintain and improve IT expertise in Sweden, and thereby to reduce our dependence in this field on other countries, and also to promote the good use of Information Technology. The goal is to sustain an internationally competitive capability in selected key areas and thereby maintain a base from which to take advantage of technological development in other fields in the rest of the world. (Prop 1986/7.24: p 107)

Exhibit 18 Architecture of the National IT Programme

	EDUCATION, AWARENESS	BASIC RESEARCH	GOAL-ORIENTED RESEARCH	INDUSTRIAL DEVELOPMENT
NATIONAL MICRO-ELECTRONICS PROGRAMME	NMP1 Technology transfer	NMP2 Basic research and higher education	NMP3 Applied Research	NMP4 Industrial development projects
INDUSTRIAL IT PROGRAMME	IT1 Extended education in computer science, etc.	IT2 Basic research and higher education	IT3 Applied Research	IT4 Industrial development projects
INFORMATION TECHNOLOGY APPLICATIONS	ITA1 Computer courses in higher education	ITA2 Basic research and higher education	ITA3 Research projects in the use of computers	ITA4 Demonstration projects, etc.

IT4 was a ‘billion kronor programme’ to which the state contributed SEK 495

- SEK 150m from FMV
- SEK 255m from Swedish Telecom
- SEK 90m from STU

Industry contributed a total of SEK 600m in cash and kind[57].

The third aspect of the National IT Programme - IT Applications - continued to be discussed for many years after IT was launched. It was never directly implemented, although two NUTEK programmes were later created which covered some of the ground: the DUP programme in process control technology; and ITYP which promoted the use of IT in the service sector, aiming to create products, services and software and to bridge the gap between automation aimed solely at rationalisation and issues about the quality of work and working life. Both were funded and managed in cooperation with the Swedish Work Environment Fund (Amfo).

4.4 STU/NUTEK Funding for Digital Mobile Communications

STU funded university research relevant to digital mobile telephony for several years during the late 1970s and the first half of the 1980s in response to individual project applications. Sven-Olof Öhrvik of SRA was lobbying STU to start a programme from about 1975, and there was considerable informal contact between SRA, Swedish Telecom and STU on the subject. Over time, the content of the discussion became very rich, with Ericsson sharing road maps of expected developments and discussing outstanding research problems with both STU and university faculty. STU was involved both in projects that tackled the new problems in coding and in VLSI implementation, especially via DSPs.

There was no formal programme, but – as the next Chapter makes clear – Ericsson and Swedish Telecom were very actively coordinating the university research effort and therefore the proposals that came to STU/NUTEK. Exhibit 19 shows the amounts of the grants STU funded in this way between 1978 and 1986. Exhibit 20 shows who the beneficiaries were. Ericsson estimates that it was investing about 20% of the amount that STU/NUTEK provided in kind by doing projects internally that mirrored and benefited from the university work.

57 Erik Arnold and Ken Guy, *Evaluation of the IT4 Programme*, Brighton: Technopolis and SPRU, 1992

Exhibit 19 STU Grants for Digital Mobile Related Research, 1978-86

	CTH	KTH	LTH	LiTH	Total
1978			50,000		**50,000**
1979		488,750	798,000	1,820,000	**3,106,750**
1980		729,910	2,485,000	307,808	**3,522,718**
1981		771,105	696,500	1,337,900	**2,805,505**
1982	605,980	1,111,292	283,560	2,354,340	**4,355,172**
1983		620,122	712,000	900,720	**2,232,842**
1984	1,050,200	1,542,000	1,024,300	1,150,100	**4,766,600**
1985	425,900	1,109,000	1,895,000	2,509,300	**5,939,200**
1986	706,000	1,198,300	2,480,000	741,000	**5,125,300**
Totals	**2,788,080**	**7,570,479**	**10,424,360**	**11,121,168**	**31,904,087**

Source Analysis of STU/NUTEK's 'Peanuts' administrative database

Exhibit 20 Recipients of STU Grants for Digital Mobile Related Research, 1978-86

CTH	KTH	LTH	LiTH
Tor Aulin	Gunnar Ahlbom	Göran Einarsson	Lars Ahlin
Holger Broman	Anders Forsen	Rolf Johannesson	Thomas Ericsson
Per Hedelin	Kåre Mossberg	Sven Mattisson	Tore Fjällbrant
Carl-Erik Sundberg	Svante Signell	Carl-Erik Sundberg	Ingemar Ingmarsson
	Jan Uddenfeldt	Sven-Olof Öhrvik	Lars Wanhammar
	Lars Zetterberg		Jens Zander

Source Analysis of STU/NUTEK's 'Peanuts' administrative database

STU/NUTEK ran the Digital Communications Programme from July 1987 to June 1994. It spent a total of SEK 63.7m[58] of its original SEK 74.7m total budget. Deiaco estimates that it involved sixteen research groups and trained some 64 PhD students. It represented a tripling of the effort compared with the early 1980s and a doubling of the annual level of funding that STU had provided in the two previous years (Exhibit 19). It extended the pattern of funding to include Uppsala University but this still left room significantly to increase mean funding per participating university so among its key effects were to scale up the production of PhDs in the area and to help generate critical mass in individual research groups.

58 Enrico Deiaco, *Ramprogrammet Digitalkommunikation, in VINNOVA, Effekter av VINNOVAs föregångares stöd till behovsmotiverad forskning*, Stockholm: VINNOVA, 2002

As a 'second-generation' framework programme, Digital Communications was planned in intensive cooperation with industrialists and academics with much of the discussion taking place by letter. Lennart Alfredsson, then head of R&D at Ericsson Radio Systems, wrote in March 1987

> The second mobile telephony generation will be digital … Sweden is playing a leading role in the development of this system. To a considerable extent, this is a result of STU's investments in digital mobile radio research at universities since 1977 and the fact that Ericsson and Swedish Telecom have been able to match the research in the universities with their own goal-oriented research.. It is vital for Ericsson Radio Systems that STU gives priority to a framework programme in digital mobile radio. As in the past, we are prepared to match the universities' efforts with our own internal research to support and complement them.[59]

The academic community was also very involved in the consultation about the potential framework programme. A group of professors wrote that they believed the programme was necessary so that the universities could build on the increased research activity in the area in recent years and establish more permanent research and educational capacity in digital communications. Deiaco remarks that the preparations for the programme reflected a very high degree of agreement about priorities between industry and the universities. He also points out that it did not involve fundamentally new knowledge.

> One cannot claim that the programme was a watershed in digital technology research. The aims and make-up of the programme followed well-trodden paths leading to specific industrial needs. Hence the research produced new knowledge and methods that helped to reduce uncertainties and set the directions of the industrial solutions.[60]

Once the programme was up and running, it was overseen by a steering Committee comprising

- Lennart Ljung, professor in control at the University of Linköping (chair)
- Jan Uddenfeldt, then head of research at Ericsson Radio Systems
- Östen Mäkitalo, head of the radio lab at Swedish Telecom
- Per Tjernlund, Infovox, who moved to Ericsson in 1989
- Torleiv Maseng, ELAB at the Norwegian University of Technology (NTU), Trondheim, who had been a collaborator with Swedish Telecom in the Paris GSM trials
- STU/NUTEK's project officer Björn Wasell, who was later replaced by Anders Hedberg

59 Translated and cited from Deiaco, 2002
60 Translated and cited from Deiaco, 2002

The programming document refers to the rapid growth of telecommunications, the quickly changing nature of the technology and Swedish research strength in the area of digital communications, which, however, was of too small scale and needed to be developed further. "The situation for Swedish R&D in telecommunications is favourable. The fundamental problems are well understood and described by good theory. That means that there is a good theoretical basis and an established methodology that can be used to tackle the new communications problems that information technology creates." The programme was developed with the intention of shedding light on integrated voice, image and data communications with potential applications such as

- Mobile telephony
- ISDN
- Satellite communications
- Hydro-acoustic communications
- Fibre-optic channels
- Military communications systems
- Speech recording

However, the first on the list was seen as the driving application in the Swedish industrial and academic context. The goals of the programme were to generate knowledge about how to

- Exploit communications channels efficiently
- Obtain an adequate level of security
- Efficiently combine different forms of information in a common digital channel
- Protect information from the effects of noise
- Develop physically small systems

The programme was peer reviewed in 1990[61] by one German and two US professors. The review praised the quality of the work and the hard work of those doing it. But is also found the work to be overly theoretical and that the researchers failed adequately to consider its long-term impact on Swedish industry. The review goes on to say

> The primary reason for this situation seems to be a lack of motivation for researchers to perform the additional work to enhance the usefulness of their results to the engineer or system designer. In many cases, this objective is overshadowed by that of academic recognition or of personal insight. In other

61 Robert Brodersen, Robert Gallagher and Peter Noll, *Report of the International Evaluation Committee on the Digital Communication Programme*, STU Info 785-1990, Stockholm: STU, 1990

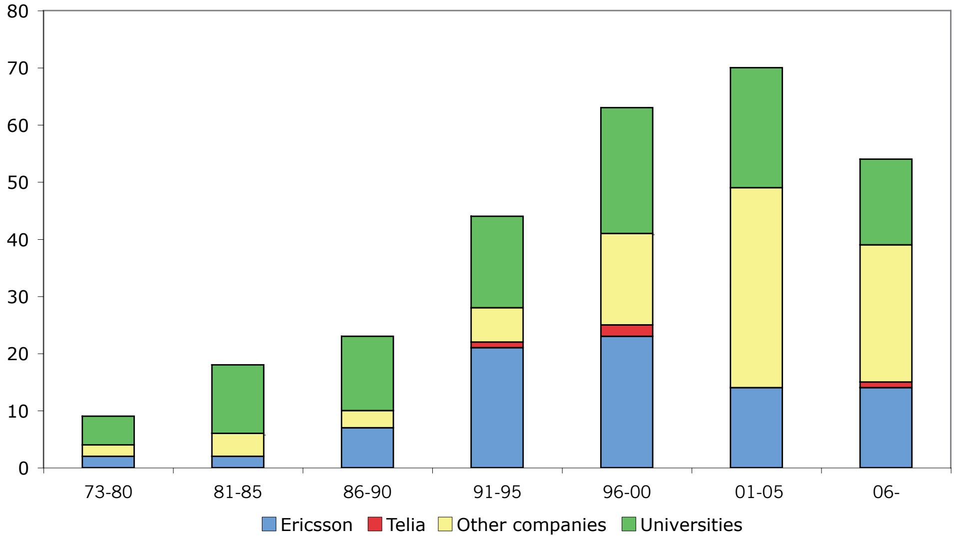
> cases, the problem is a lack of stable and continuing interest on the part of the industrial community. The industrial community seems to regards the academic community as something that can be tapped at will, rather than as long term liaisons that must be cultivated over the long term.

Further, it argued the Swedish university research in telecommunications was over-focused on the cluster of issues pursued by the programme (such as error-correction coding), leaving gaps in national capabilities across many other parts of telecommunications. In effect, the peers say that the researchers in the programme have excessive autonomy and that – despite STU's efforts at programming ᵒ– they inhabit an incentive system that insufficiently encourages working on matters with industrial relevance. In his remarks to the IT2000 Commission, Sven-Olof Öhrvik makes a related observation about the relations between this group of researchers (at an earlier date) and industry. "Significant communications problems arose … because of differences in working culture. In several cases, it proved appropriate to improve the interface by offering university researchers 3-6 month contracts at ERA."[62] NUTEK and VINNOVA have subsequently addressed this difficulty via the competence centres programme, 1995-2005 and more recently, VINN Excellence centres.

It is not possible to give a complete account of PhD production as a result of STU/ NUTEK.VINNOVA funding in mobile telecommunications relevant areas. However, we have been able to identify 281 PhDs produced in the relevant groups between 1973 and 2007 (Exhibit 21). The Exhibit shows that early PhD production increased university reseach and teaching capacity in relevant fields. From the mid-1980s, the industrial take-up increased significantly, with Ericsson taking the greater part. Telia (Swedish Telecom) took almost none of those we could identify. Following the Ericsson retrenchment at the turn of the century, the proportion of PhDs going to other companies significantly increased. Clearly, STU/NUTEK's funding set in train a very significant process of upgrading the R&D capabilities of Ericsson and other companies in the system. The minimal numbers going to Telia reflect its lack of a tradition of hiring PhDs in the earlier years and the decline of the R&D function there in the later period.

62 Sven-Olof Öhrvik, 'Svensk FoU inom digital mobilradioteknologi,' I*T 2000 Bilagor till Ds 1991:63 Svensk informationsteknologis möjligheter under 1990-talet med förslag till riktlinjer för en IT-politik inom det näringspolitiska området*, Ds 1991:64

Exhibit 21 Mobile-Relevant PhD Production, 1973-2007 By Current or Last Location



Source: Technopolis survey, interviews and Internet searches

4.5 International Programmes

International R&D programmes are becoming increasingly important in the European ICT industry and standardisation. GSM was influenced by the COST programme while 3G has been targeted by European Commission programmes since 1987.

4.5.1 COST

The European Cooperation on Science and Technology is among the oldest of Europe's science and technology cooperations. Unlike the European Commission, it does not finance research. It funds travel and meetings so that people and organisations working on common problems can benefit from exchanging ideas (and often graduate students) and coordinate their future work.

COST project 207 – Digital Land Mobile Radio Communications – ran from 1984 to 1988 and brought together many of the teams working on GSM standardisation. The project comprised three work groups. One worked on radio propagation, allowing the exchange of data from several locations across Europe where GSM signal propagation was measured. A second group on Baseband Processing looked at issues of channel coding and noise, and appears to have come up with the idea of introducing 'comfort noise' to compensate for the fact that GSM uses bandwidth efficiently by transmitting nothing during periods of silence in phone conversations. The third group compared and researched alternative modulation methods.

This cooperation undoubtedly contributed by increasing the amount of knowledge available to all involved in the GSM standardisation process and through coordinating the effort. The success of the project is evidenced by the fact that it was followed by COST 231, Evolution of Land Mobile Radio (1989-1996), which worked on the higher-frequency extension of the GSM standard to 1.8 GHz, to the DECT cordless phone standards and to the UMTS idea. That was in turn followed by COST 259, Wireless Flexible Personalised Communications. This worked more on UMTS and on the later HIPERLAN 2 specification and 4G mobile telephony.

4.5.2 The EU Framework Programmes - RACE

RACE - Research and development in Advanced Communications for Europe - was a European Commission funded programme to define technical directions and prepare the ground for early introduction of commercially viable Integrated Broadband Communications (IBC). The formal objective of RACE[63] was to prepare for the "Introduction of Integrated Broadband Communications (IBC) taking into account the evolving ISDN and national introduction strategies, progressing to Community-wide services by 1995" and it spent something over one billion Euro in R&D subsidies trying to achieve this. Sweden and, to a lesser degree, other EFTA countries participated in many projects, with national funding. IT4 served as the channel for Swedish funding of RACE participation.

RACE began in 1987. The Commission believed there were too many sub-scale telecommunications switching manufacturers in Europe to allow any one of them to fund the move to IBC and was therefore anxious to promote cooperations and mergers. Using the PTTs' tradition of cooperation (established through the ITU, the cartel responsible for setting prices, allocating traffic and therefore effectively regulating entry in international telecommunications), the Commission aimed to bring the equipment suppliers closer together to develop IBC and therefore to promote industrial restructuring. In parallel, the Commission began to apply pressure for liberalisation and deregulation of telecommunications across the Community, reducing the PTTs' ability to shelter favourite national switching suppliers.

63 European Commission, RACE '91, OTR 402, Brussels: European Comission1991

Exhibit 22 RACE Projects Funded by IT4

<table>
<tr><th>Connecting to the Network</th><th colspan="2">The Broadband Network</th><th colspan="2">Applications</th></tr>
<tr><td>CPN
RIC/BUNI</td><td>Architecture
Network
Management

Interconnection

Mobile
Video</td><td>ROSA
ADVANCE
NETMAN
TERRACE
BIPED
B-CPN
ACCESS
ATMOSPHERIC
PARASOL
OSCAR
MOBILE
FUNCODE
HIVITS</td><td>Banking
Medicine
Special Needs</td><td>DIVIDEND
TELEMED
TUDOR
APPSN</td></tr>
<tr><th colspan="2">Tools for Building the Network</th><th colspan="3">Services to Other Projects</th></tr>
<tr><td colspan="2">ARISE
PROVE
INTEGRITY
GUIDANCE</td><td colspan="3">CMO
ESP
BEST
EPF</td></tr>
</table>

In the first phase of the RACE programme, project 1043 RACE Mobile, which ran from 1988 to 1992, provided an arena in which European operators and equipment suppliers could work on the principles of the 3G successor to GSM. This project introduced the idea of the Universal Mobile Telephone System (UMTS), with the ultimate ambition of defining a global standard. Subsequent RACE projects in 1992 to 1994 defined network aspects and provided test beds for both code division and time division radio access technology developments. The ACTS programme that succeeded RACE included some 30 mobile-relevant projects.

The first RACE programme ran from 1987 to 1992. It comprised 94 projects and had a subsidy budget of € 550m[64]. It was run in three strands

- IBC development and implementation strategies: Related to the development of functional specifications, the systems and operational research towards the

64 In fact, a little more. SEK 60m from Swedish Telecom's part of the IT4 budget was used to pay the subsidy cost of Swedish participation, since Sweden was not a member of the European Community during RACE 1

definition of proposals for IBC standards and the analytical work to establish interoperability for IBC equipment and services

- IBC technologies: Technological cooperation in pre-competitive R&D addressing key requirements of new technology for the low-cost realization of IBC equipment and services
- Pre-normative functional integration: Relating to pre-normative cooperation in the realisation of an 'open verification environment' with respect to functional specifications and standardisation proposals

RACE II ran from 1991 to 1994, and was intended to move the more fundamental work of RACE I into applications and practice. It had a subsidy budget of €554m and 123 projects in eight strands

- IBC (Integrated Broadband Communications) R&D
- Intelligence in networks/flexible communications resource management
- Mobile and personal communications
- Image and data communications
- Integrated services technologies
- Information security technologies
- Advanced communication experiments
- Test infrastructure and inter-working

The unofficial aim of RACE was to encourage concentration in the European telecommunications industry in the face of liberalisation and this meant that it concentrated heavily on the fixed network. There was only one project in RACE I concerned with mobile communications. That continued the work on TDMA in the expectation that this would be the access technology for the future Universal Mobile Telephone System, in which people would have personal telephone numbers and could use these to access and be accessed via the network, irrespective of where they were. Both Ericsson and Swedish Telecom took part, but this project was rather peripheral to RACE as a whole.

By the time RACE II was defined, however the importance of mobile was becoming more evident, it was no longer regarded as a mere 'access' technology to the 'real' telecommunications network but as something important in its own right. The mobile strand had 9 projects and the scope of the radio access work had grown to include CDMA. These are listed in Exhibit 23, which makes it clear that the Swedish participation was highly selective. By RACE II, Swedish Telecom had been privatised to become Telia and had few R&D resources to devote to international research programmes. Ericsson was resource-constrained and had to be very discriminatory in its participations.

Exhibit 23 RACE II Mobile Communications Projects

Project	Title	Ericsson	Telia
R2027	PLATON – Advanced Cell Planning Methods and Tools		
R2020	CODIT – UMTS Code Division Test Bed	Leader	Participant
R2066	MONET – Mobile Network	Participant	
R2067	MBS – Mobile Broadband System		
R2072	MAVT – Mobile Audio-Visual Terminal		
R2084	ATDMA – Advanced TDMA Mobile Access		
R2108	TSUNAMI – Technology in Smart Antennas for Universal Advanced Mobile Infrastructure		
R2117	SAINT – Satellite Integration in the Future Mobile Network		
R2123	GIRAFE – Gigahertz Radio Front Ends		

5 The Role of the Swedish Research Community

Perhaps the central fact about the role played by the Swedish research community in GSM standardisation and in underpinning Ericsson's huge economic success in mobile telecommunications is that it was not random and it was not a result of researcher-directed R&D. Rather, it was carefully orchestrated by a small number of people in support of industrial needs. The key characters were Sven-Olof Öhrvik, Jan Uddenfeldt and Östen Mäkitalo – all graduates of KTH, the latter two having been supervised by Lars Zetterberg, who may in many senses be regarded as the 'father' of Digital Signal Processing (DSP) in Sweden. The first two worked for the Ericsson group, while Mäkitalo headed Swedish Telecom's radio laboratory. All three were involved in the development of radio **systems**. As a result, they were in the unusual position not only of having responsibility for generating new designs but being able to see the knowledge needs across the breadth of the systems they were trying to create. Because they could see the knowledge bottlenecks, they were not only able to supply university researchers with a stream of problems but also able to say which were the important ones for industrial development.

5.1 Research in Interaction with Industry

The organising spirit in the relations with the universities seems to have been Öhrvik, who took his licentiate in radio technology and an MBA in 1954 and spent 1955 in the USA working on a doctorate about the industrial development of transistor circuits. This practice of going to the USA, where new technology was being developed and working with the developers recurs at other points in this story.

Öhrvik joined SRA (the Swedish Radio Company, originally owned by Marconi, Ericsson, ASEA and Aga, but over time successively taken over by Ericsson until it was eventually renamed ERA) in 1956, and became head of R&D in 1963. In the early days the company's focus was on military radio, but it successively became more interested in civil applications. By the 1970s, one of the difficulties SRA faced was a shortage of radio engineers. This became particularly acute from 1976, when Öhrvik refocused the research effort at ERA on digital transmission via mobile radio channels. Mobile telephony was not the only application ERA had in mind, but there was a cluster of potential markets that would depend upon making good use of such channels.

SRA's role in military radio meant that it was among the pioneers of digital radio (though Öhrvik was not himself involved in military work). The military needed digital technology so that it could encrypt speech and in order to use techniques like spread spectrum and frequency hopping to prevent jamming and interception. Crucially, the military was prepared to pay for expensive solutions, so ideas that later found civil application sometimes started as challenges in the development of military technology. After the initial GSM standardisation process, when it became clear that some markets such as the Japanese would require CDMA techniques originally developed for military communications, ERA transferred substantial numbers of engineers from the military to the civil side.

However, Öhrvik's preoccupation was the prospect of large civil digital radio markets and he notes65 that the Swedish National Board for Technological Development (STU) began funding research relevant to digital mobile radio from 1976, probably as a result of his discussions with people at universities of technology triggering research interest in the topic. However, few universities were interested in the subject and the leading Swedish professor Gösta Hellgren at KTH apparently regarded the invention of FM as the last important development in radio and appears to have been of the opinion that radio as a subject for research was worked out: there was nothing left to do. Correspondingly, there were few university courses in radio engineering and the provision of training fell for many years (apparently from the 1950s to the 1980s66) to the Swedish Association of Engineers (Teknologföreningen). Öhrvik therefore began a campaign to increase the amount of radio research and education done in the Swedish universities. He approached STU at various levels to discuss the future importance of digital radio communications. He launched discussions with several professors at Swedish universities of technology in 1977. As a result, Thomas Ericsson at Linköping, Lars Kristiansson at Chalmers and Gunnar Einarsson at Lund started research projects in various areas related to digital mobile radio transmission, based on STU project funding. However, his efforts to encourage work in the area at KTH were rebuffed. At Lund and Chalmers, the baton quickly passed to doctorands but Thomas Ericsson remained a key figure in the area until his retirement in 2007. The three research groups obtained significant project funding from STU in the following five years or more.

Öhrvik argues that this intervention was decisive in establishing Swedish leadership.

> Fundamental research in various areas of technology related to civil digital mobile communications began at a serious level in Sweden in 1977. This was several years earlier than corresponding civil research in other countries. In other European countries, larger scale industrial R&D began in 1982, when the West European PTTs decided to develop a systems concept for a future pan-European

65 In a short paper presented at the Radiovetenskaplig Konferens in Linköping, 10-12 April 1984
66 Source: ÖstenMäkitalo

digital mobile telephony system. The GSM (Groupe Spécial Mobile) was created to undertake this study.[67].

To establish unofficial communications among those doing research on digital mobile radio, Öhrvik set up a 'radio club': *gruppen för digital mobilradio*. This met twice a year. After a few years, ERA made contact with British Telecom and the UK Department of Trade and Industry and these meetings began to alternate between Sweden and the UK, with STU funding the Swedish costs. The club was informal, there were no written minutes of meetings and almost all the documentation presented at the meetings has disappeared so our account is sewn together from the memories of those involved. The composition of the club was not fixed but varied over time, not least because graduate students came and went, but doctorands seem to have been vital to the group. Key members included at various times

- Lund, Signal Processing: Professor Göran Einarsson and his doctorands Carl-Erik Sundberg and Tor Aulin, working on modulation and channel coding for the mobile radio channel
- Lund, Applied Electronics: Professor Göran Lind, later Öhrvik himself, with doctorands Sven Mattisson, Mats Torkelsson and Lena Pettersson, focusing on microelectronics (especially ASICs), radio components and characterisation of the radio channel
- Linköping, Signal Processing : Professor Thomas Ericsson and two doctorands: Lars Ahlin and Jens Zander, working on channel coding and field tests on mobile radio channels
- Chalmers, Signal Processing: Professor Lars Kristianson with doctorand Per Hedelin, working on speech coding and digital processing of encoded speech
- Linköping, Microelectronics: Professor Christer Svensson and doctorand Lars Wanhammar, working on ASICs for DSP
- From about 1984, KTH Signal Processing: Professor Lars Zetterberg and doctorands

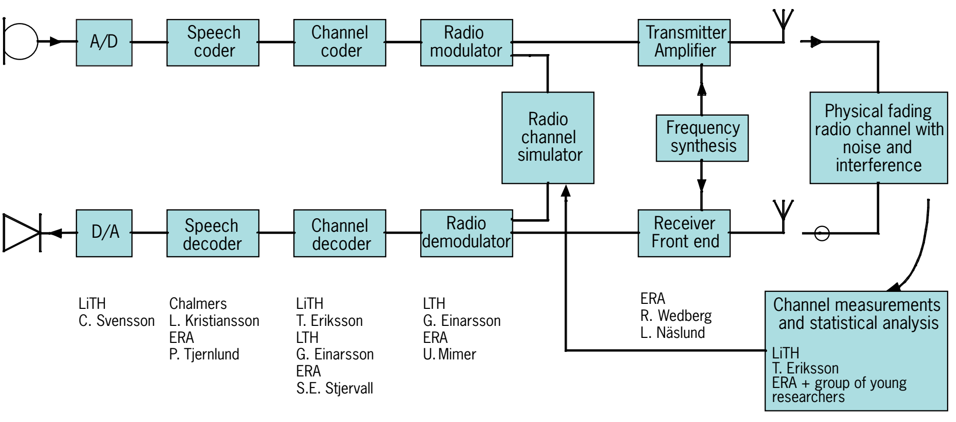
FOA was initially involved in the radio club but quickly dropped out. In later years, STU project officers attended some of the meetings. This club functioned as an 'arena' where research ideas and results were exchanged. People from both Ericsson and Swedish Telecom told us that they shared results of their work in a much more open way in the club than was possible in any other forum. As a result, there was rather

67 Sven-Olof Öhrvik, 'Svensk FoU inom digital mobilradioteknologi,' I*T 2000 Bilagor till Ds 1991:63 Svebnsk informationsteknologis möjligheter under 1990-talet med förslag till riktlinjer för en IT-politik inom det näringspolitiska området*, Ds 1991:64

tight coupling between the topics addressed inside and outside industry. The universities' research was funded on a project basis by STU, with few proposals apparently being rejected and the club came to foreshadow the 'arena' role of the later Digital Communications programme steering committee – though probably with a rather higher degree of flexibility than was possible once there was a formal programme.

Swedish Telecom's interest in mobile telephony was growing at this time, and in 1981 the radio club began work on a test bed for FDMA at Ericsson (Exhibit 24). This was a necessary step in developing the capabilities to develop digital radio access, since theoretical approaches and designs need to be tested against reality. The diagram also shows which researchers were involved in the various parts of the test bed, indicating how Öhrvik in effect orchestrated and integrated the research effort between the universities and industry.

Exhibit 24 FDMA Test Bed for 25KHz Radio Channel



Source: Sven-Olof Öhrvik, 2008

Even before the FDMA test bed was completed in 1984, it became clear to those involved that this technique would not produce adequate performance. A TDMA test bed was therefore built in 1984 that gave Swedish Telecom much of the basis for its submissions to the GSM Paris trials. From a development perspective, it was not all that important that the Swedish Telecom entry failed to win the competition. The key was that working with TDMA and building upon the developing knowledge of the research community, Swedish Telecom and especially Ericsson had a good grasp of TDMA and were strongly positioned to build systems following the particular version of TDMA that was finally chosen. It was also not a disadvantage that Torleiv Maseng from ELAB, who led the development of another TDMA solution, worked closely with, and used facilities belonging to, Swedish Telecom. By the time of the Paris trials, he was in any case an honorary member of the Swedish team.

The radio club appears to have stopped meeting in the middle of the 1980s, partly because the field was then expanding to become mainstream. Other universities, such as Uppsala, began to enter the field. Crucially, STU launched the Digital Communications programme in 1987 that scaled up the level of research in the area, taking over the organising role that Öhrvik, Mäkitalo and Uddenfeldt had played from outside the funding agency in previous years. (In fact, Mäkitalo and Uddenfeldt continued to act as organisers through their membership of the programme board.)

Another factor was probably that by the mid 1980s, the technical problems that needed resolution for the GSM standardisation process were largely solved, Ericsson employed a growing body of PhDs and it was able to be more autonomous in technology development.

5.2 The Universities

Exhibit 25 summarises the view of our interviewees about who were the key academic contributors to the transition from 1G to 2G in Sweden.

Exhibit 25 Key Researchers in the GSM Standardisation Period

	Speech coding	Channel coding	Modulation	Propagation, equalisation	Components
Per Hedelin	X				
Lars Zetterberg	X	X			
Tomas Ericsson		X			
Rolf Johannesson		X			
S-O Öhrvik		X			X
Jens Zander		X		X	
Lars Ahlin		X		X	
Björn Gudmundsson				X	
Carl-Erik Sundberg			X		
Tor Aulin			X		
Arne Svensson			X		
Mats Torkelsson					X
Sven Mattisson					X
Claes Hammar					X
Lars Wanhammar					X

In the following sections we sketch the activities in the key university research groups during the GSM standardisation period. Except for the work at Uppsala (which began during the Digital Communications programme), the activities described were funded project by project by STU. We treat the people in Exhibit 25 as 'first generation' researchers in the illustrations in the next few sections. These show the production of doctors in technology in 'generations' where the first generation supervised the second one and the second generation supervised the third.

There is a general pattern in these graphics, where a large part of the second generation stays in academia – usually the university where they did their PhD – and build the capacity of the university to do research and teach in the area. The third generation is more prone to go and work for industry after doing their PhD – especially to go to Ericsson. This pattern illustrates well the build up of not only research but crucially also the teaching resources needed by the universities to cope with the massive increases in demand for electronics and communications engineers at masters level triggered by the growth of the electronics industry in general during the 1980s and of Ericsson in particular.

5.2.1 Lund

The relevant research groups at Lund in the early 1980s spanned Theoretical Automations, Tele-transmission Theory and Applied Electronics.

An attraction of Lund for Ericsson was that Professor Lennart Stigmark had in the 1970s been reluctant to move from analogue radio to digital research, so there was a strong radio tradition still in place compared with other Swedish universities, which had largely abandoned radio.

Öhrvik had contacts with Carl-Henrik Sundberg about modulation during the 1970s and became adjunct professor at Lund from 1983 before himself taking the chair in Applied Electronics in 1985. One of his aims was to build up the equipment needed to create test rigs and test benches, allowing the theoretical and simulation work to be connected with reality. This also required finding ways to fund minicomputers needed for computation-intensive simulation. Another was to expand the relevant education in order to supply the new Ericsson mobile handsets business in Lund – run by Nils Rydbeck, himself a Lund PhD – with skilled people.

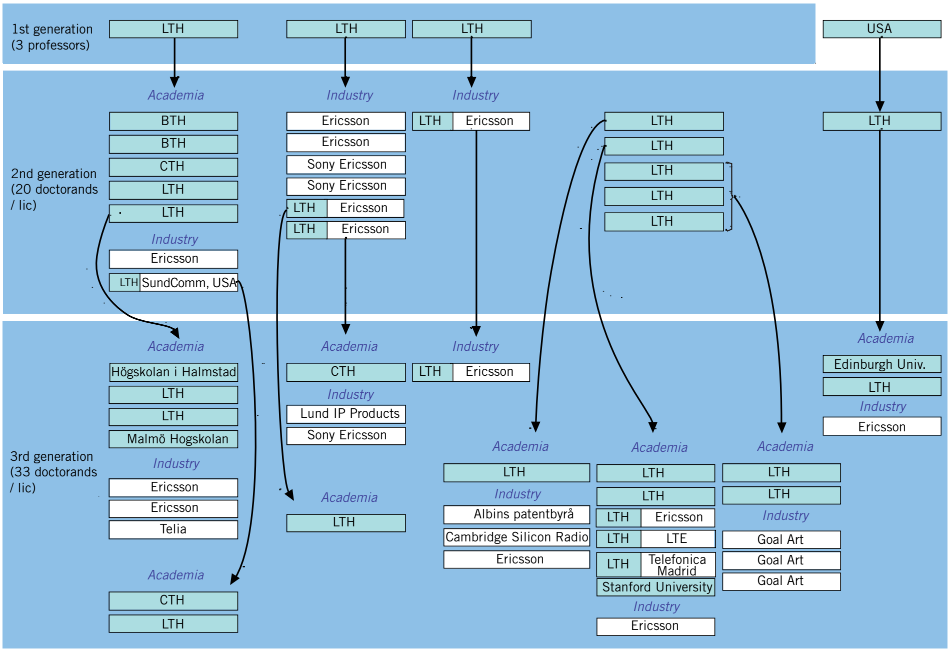
One of Öhrvik's concerns was VLSI implementation of various DSP techniques so that they could actually be used in mobile systems. Among others, he worked with Sven Mattisson on circuit design. Mattisson himself spent a period at CalTech in 1983/4, acquiring know-how about how to simulate circuits using parallel computers. Mattisson took over the chair from Öhrvik in 1993 and two years later moved to Ericsson – where he designed Bluetooth. Mats Torkelsson was another doctorand who went to the USA – in his case to Berkeley – in order to acquire DSP design technology, writing a thesis on the design of algorithm-specific DSPs. He eventually moved to Ericsson but remains an adjunct professor at Lund. Mattisson and Torkelsson's experience in the USA was an important technology channel for Ericsson. Today, the company has direct links with these universities but, especially in the 1980s, such links needed to be made via Swedish universities because the number or R&D workers working on mobile radio questions at Ericsson was so small.

Other members of the group at Lund such as Lars Wanhammar worked on DSP – in his case in relation to building digital filters. As with most of the researchers, the links with Ericsson were indirect – even where there were joint projects, Ericsson would run a 'shadow' project more directly aimed at development.

Rolf Johannesson did and still does rather fundamental work on coding, specialising on the convolutional codes that were adopted (in a simple form) in the GSM standard as part of the channel coding process. More complex convolutional codes are used in 3G. Johanneson's links with Ericsson are through his students – many of his doctorands end up at Ericsson – for example Johan Nyström, who works on channel coding at Ericsson Kista. Other colleagues such as Göran Lindell worked on communications theory as a basis for channel coding, supervised by Carl-Erik Sundberg. Here, too, the basis was laid for Aulin's work on phase continuous modulation, which he continued at Chalmers and which underpinned the choice of GMSK modulation in the GSM standard.

Exhibit 26 shows the flow of people we have been able to establish from the early 1980s at Lund into other academic institutions and industry. Each box represents a person (details are in the Appendix). It underlines that a significant part of the flow of human capital went to universities, underpinning the later scaling-up of the research and educational effort. Discussions with the faculty at Lund show that in the recent past, the flow of new PhDs is overwhelmingly towards industry.

Exhibit 26 Human Capital Track - LTH

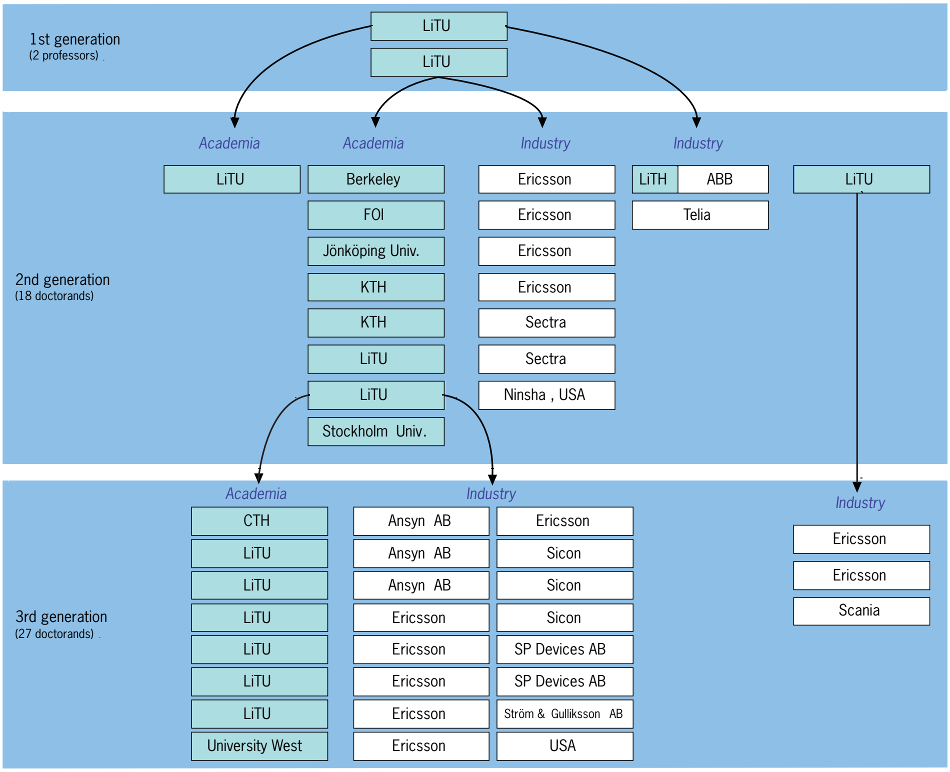


5.2.2 Linköping

Three groups at Linköping were involved in early research: Information Theory; Systems Technology; and Control Technology. The key professor at Linköping, Thomas Ericsson, worked in Ericsson's transmission division on the last generation of analogue coaxial cable carrier technology to be developed before the arrival of optical fibre then became professor at Linköping in 1973. His work on interference and multiplexing in wire-based analogue systems was a good basis for tackling the much more difficult problems in radio transmission, using more sophisticated equalisers. He also worked on channel coding and error-correction, with much of the work in the 1980s being on error-correcting codes. Among his doctoral students were Håkan Ericsson (now Ericsson's head of R&D, who moved to the company before completing his PhD), Jens Zander (now professor at KTH, whose chair was endowed by ERA) and Lars Ahlin, who works at FOI. Both did key work in channel coding, with Zander working especially closely with Ericsson. His current position as head of KTH Wireless places him in a key position as a high-volume deliverer of engineers and PhDs to the Swedish industry.

Exhibit 27 shows that about half the second generation of doctorands moved to industry, with the remaining ones largely staying in Swedish universities.

Exhibit 27 Human Capital Track – Linköping

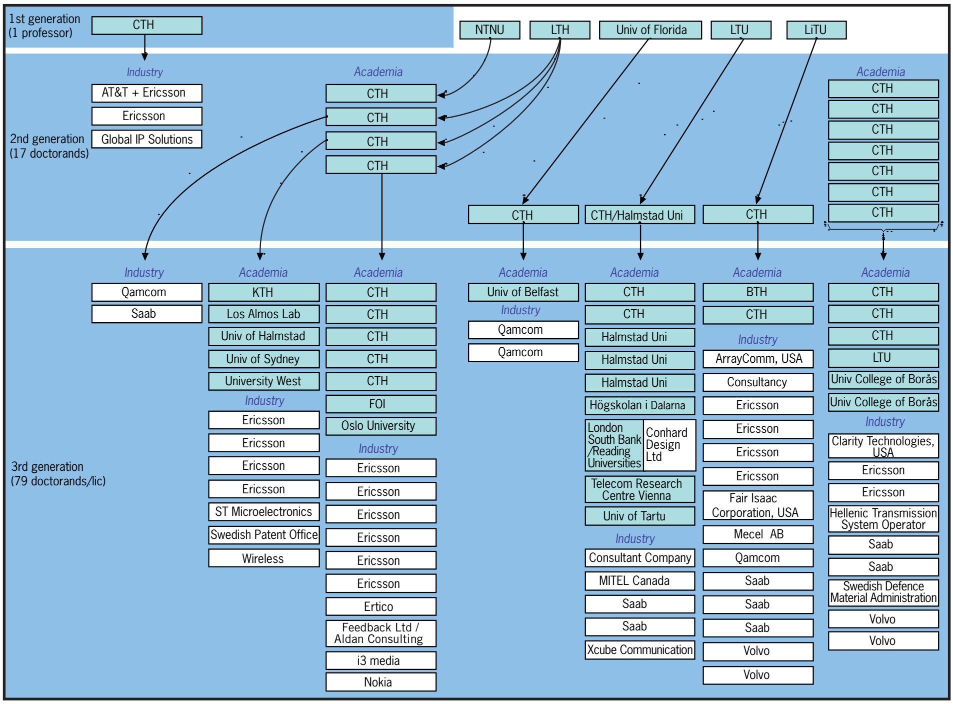


5.2.3 Chalmers

Chalmers was initially less involved in digital mobile telephony issues than Lund or Linköping. The role of Professor Lars Kristiansson, who was initially part of the radio club, was taken over by his doctorand Per Hedelin, who was the key researcher originating at Chalmers and was primarily concerned with speech coding. While the Swedish codec proposals were not accepted in the GSM standardisation process, Hedelin's work helped generate the needed capabilities at Ericsson in this area. From 1984 to 1987 he was partly funded by Ericsson and together they produced and evaluated a range of prototype codecs.

Tor Aulin moved to Chalmers from Lund. He, together with Arne Svensson at CTH (who also moved from Lund) and their supervisor Carl-Henrik Sundberg were key developers of phase continuous modulation, which was implemented in the GSM standard as GMSK. Svensson has built up a group of 20 researchers in the Communication Systems department. His work remains focused on digital radio and he is increasingly involved in EU-level research. Of his 14 graduate students who have completed their theses, half have moved to Ericsson and another two work elsewhere in the telecommunications industry.

Exhibit 28 Human Capital Track - Chalmers



Chalmers had a less focused research group in the area than Linköping or Lund in the early 1980s, though it has since established significant capabilities. It is noticeable that the pattern of movement by graduating PhDs is more dynamic at CTH than elsewhere, with quite a few people moving to the vehicles industry.

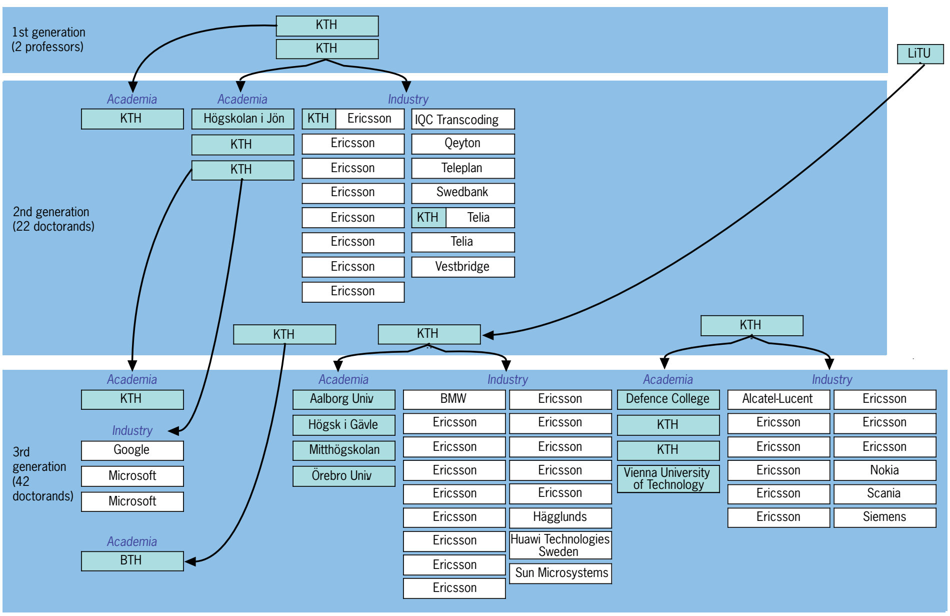
5.2.4 KTH

At KTH, the key figure for the development of mobile telephony in the GSM period has been Professor Lars Zetterberg, who headed the Tele-Transmissions Theory group. Through his work, KTH was key both before and after the GSM pre-standardisation period – for example, he supervised both Uddenfeldt and Mäkitalo. In addition to educating a fair proportion of Ericsson's senior management, he has been key to the development and maintenance of DSP skills in Sweden. Zetterberg and his group, however, were partly focused on other DSP applications in the early 1980s and played a smaller role at that time.

More widely, of course, KTH has expanded enormously in the radio communications area since the early 1980s – part of the bigger scaling up of the ICT research and education effort to support the new and growing industry, promoted by STU and NUTEK.

Exhibit 29 illustrates the flow of people from Zetterberg's group across the period considered. This group was already well established before the 1980s and was functioning as a 'PhD factory', especially for Ericsson, before the newer groups, so we see a significantly bigger flow of second generation people to industry than in Lund or Linköping.

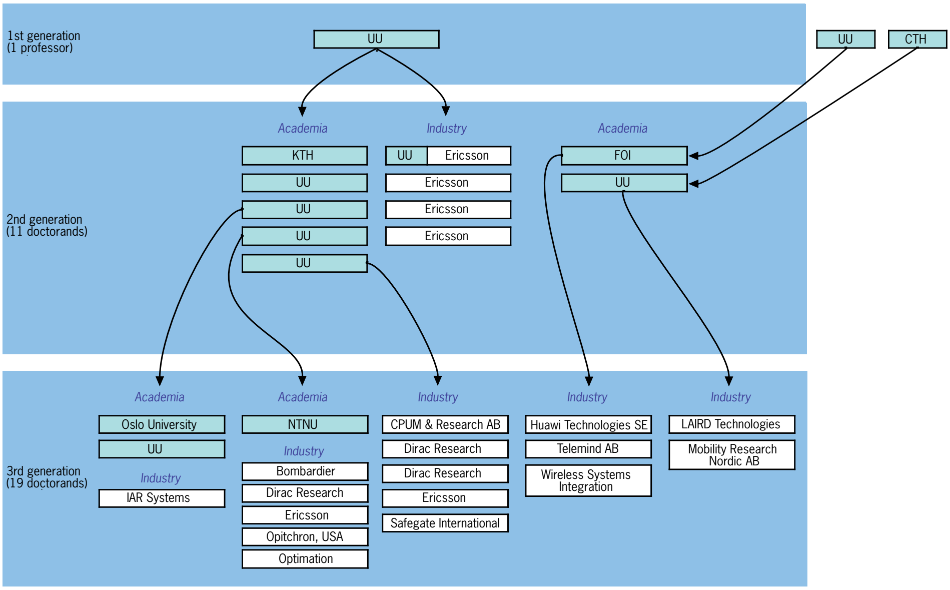
Exhibit 29 KTH Human Capital Flow from Zetterberg's Group



5.2.5 Uppsala

Uppsala started doing relevant research during the Digital Communications programme – after the GSM standardisation period. Thomas Söderström is treated in Exhibit 30 as a first generation researcher, but the late entry of the already established group from Uppsala into the area means we see a quite rapid growth in production of PhDs for industry as well as to grow the group at Uppsala.

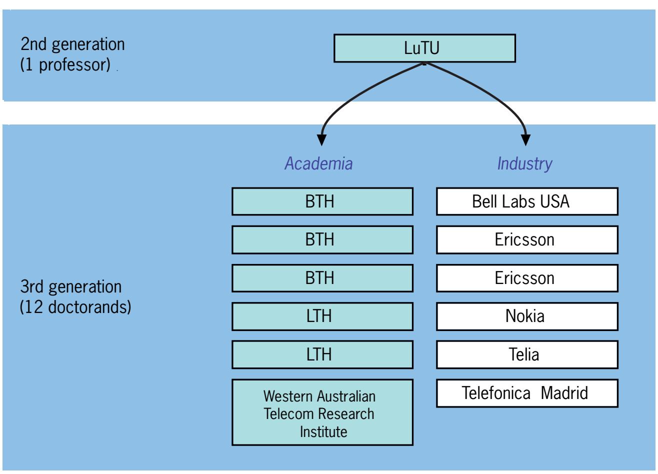
Exhibit 30 Human Capital Flows from Uppsala



5.2.6 Luleå

Luleå was a still later entrant. PhD production there feeds not only industry but the new group established (as a spin-off from Lund) at the new university of Blekinge.

Exhibit 31 Human Capital Flows from Luleå



5.3 Publications and Patents

We were interested to find out whether the pattern of publications and patents confirms the quality and emphasis of the work done by those researching in the early GSM generation and among the subsequent generations of PhDs.

Our human capital track of the first three generations of researchers (illustrated in the preceding sections) covers 121 people. In total, these people hold a total of 965 patents (8 patents each). We used the 'Publish or Perish' software to explore publications – an especially useful tool for this field because it covers more publications within the quality 'grey' literature than the traditional bibliometric indicators, which is typically an important publication channel for engineers. This involves therefore a wider publication basis than is used by the conventional bibliometric databases. (Publish or Perish scans Google Scholar, rather than using the Thomson-ISI databases.) The total number of publications is 4 318, giving an average of 36, so this is a highly productive group (see Exhibit 32).

The h-index referred to in Exhibit 32 is an index designed to distinguish influential scientists from those who simply publish many papers. It is defined as follows: A scientist has index h if h of his/her N papers have at least h citations each, and the other (N - h) papers have at most h citations each. In other words, a scholar with an index of 40 has published 40 papers with at least 40 citations each. Thus, the h-index is the result of the balance between the number of publications and the number of citations per publication.

Exhibit 32 Publications and Patents – Some Analysis

Total number of patents (n=121)	**965**
Total number of publications (n=119)	**4,318**
Total number of citations (n=119)	**28,825**
Average h-index (n=119)	**5**
Number of publications (industry n=49)	641
Number of publications (academia n=52)	3,540
Number of publications (residual category, no affiliation known, n=19)	137
	4,318
Number of citations (industry, n=49)	3,641
Number of citations (academia, n=52)	24,208
Number of citations (residual category, no affiliation known, n=19)	976
	28,825
Number of patents (people in industry)	612
Number of patents (people in academia)	259
Number of patents (residual category, no affiliation, n=19)	94
	965

Number of Publications and Patents According to Affiliation of Researcher

	Industry (n=49)	Academia (n=52)	Total
Publications	641 (15%)	3,540 (85%)	4,181
Patents	612 (70%)	259 (30%)	871

n=101

We have limited our investigation of the h-index to researchers who received their PhD up to the year 1993, thus covering the relevant period till the end of the Digital Communications programme and including the most important actors from the point of view of the study.

While many people involved have moved between academia and industry, we have used a simple classification based on their current positions. Academics have an average h-index of 8 while those in industry have an h-Index of 3. The other data in Exhibit 32 are consistent with this pattern. This shows that – as one would expect –those in academia communicate more through publications and those in industry through patents. The less trivial part of this finding is that the research related to the GSM standardisation process has developed a large body of intellectual property. Our method is not able to capture all the relevant people, so the total number of patents is certainly undercounted.

6 Effects of the Public Research Effort for Sweden

In the previous Chapter, we showed some of the human capital effects of the research at the level of individual universities. Here we paint a broader picture of the human capital development that resulted from the research funding before looking at the way the various public funding arrangements affected Ericsson. Ericsson itself is of course a central actor is the story, so we also describe some of the ways the universities and programmes linked to Ericsson's actions. Finally, we discuss the social and economic benefits that come from the research funding.

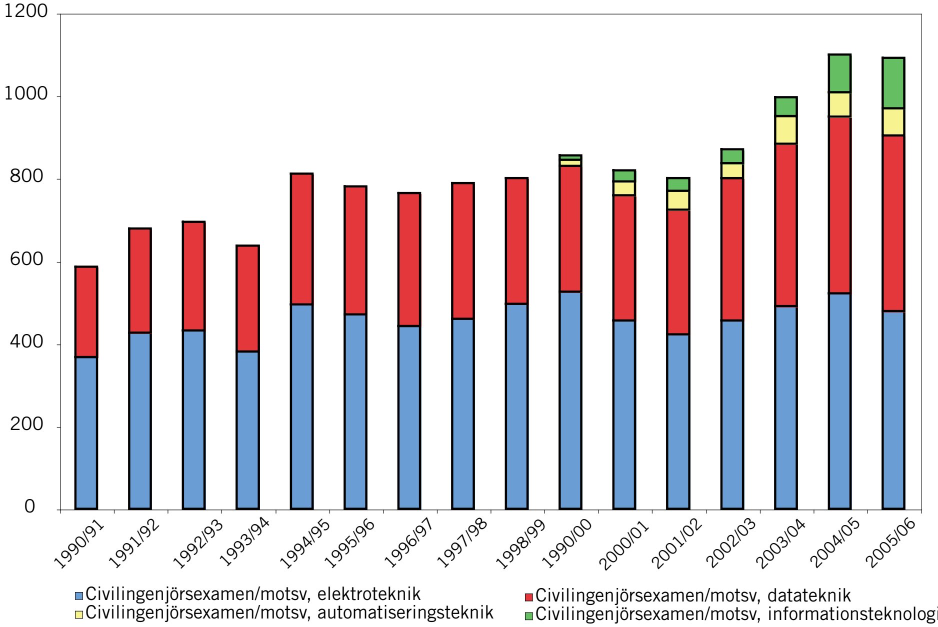
6.1 The Universities and Human Capital

The STU/NUTEK ICT programmes shown in Exhibit 15 and Exhibit 16 were key in triggering the huge expansion in ICT higher education since the 1970s. In 1980, there were about 25 professors in IT subjects at Swedish Universities. By 1989 there were 55[68] and the number has continued to rise. Correspondingly, levels of doctoral and graduate education rose in response to STU ICT programmes[69].

68 Ulf Keijer, *STUs Programsatsningar inom Systemteknik och Informationsbehandling under 1980-talet och vad de lett till*, Stockholm: TEDAB AB, 1992

69 Peter Åsell and Björn Bäckström, *Industrirelevanta Effekter av STUs Långsiktiga Insatser för Kunskapsutveckling*, (preliminär), Stockholm: STU, 1985

Exhibit 33 MSc (Civilingenjör) Graduations in Mobile-Relevant Subjects, 1990/91 to 2005/6



Source: SCB

Exhibit 33 shows total annual ICT-related graduations at MSc level for all the Swedish universities and suggests that this rising trend has continued.

The ICT programmes were also important in that they encouraged the formation of two new research institutes – SISU, and SICS – and reshaped and extended the microwave institute into the Institute for Microelectronics (IM).

Not surprisingly, there are no statistical sources that track graduations or other useful growth indicators at the level of research and education relevant to mobile telephony. However, when Sven-Olof Öhrvik was looking for research capacity to support digital radio communications in the latter 1970s he was able to find only four relevant professors (Lars Kristiansson, Gunnar Einarsson Thomas Ericsson and Lars Zetterberg). Currently, we can identify some 40 professors dealing with the types of issues tackled by the radio club (Exhibit 34). They work with a total of 94 other faculty members (including post-docs) and 162 doctorands, so teaching and research capacity in the area appears to have increased by about ten times in the intervening period, starting with the scaling-up effect of the Digital Communications programme and continuing based on universities' own resources and funding from STU, NUTEK, VINNOVA, the

Strategic Research Foundation, Ericsson, Swedish Swedish Telecom and international programmes, notably the EU Framework Programme.

Exhibit 34 Swedish University Capacity in Areas Relevant to Digital Mobile Telephony, 2008

	Group	Profs	Other Faculty+	Doctorands	Course Coverage
BTH	Signal Processing	1	10	15	Telecoms and radio eng. Signal processing
CTH	Comms Systems & Systems Theory	4	5	10	Telecoms theory, datacomms, wireless comms, digital comms, antennae, signal processing
	Signal Processing & Antennae	3	9	17	
	Telecoms Theory	1	1	1	
LiTH	Communications Systems	1	4	4	Signal theory and processing, error-correction, coding, radio comms, info theory, data transmission, codecs and filters, DSP, systems design, comms electronics, VLSI design, radio electronics, RF ICs, IC design and evaluation
	Electronics Systems	3	6	9	
	Electronic Devices	2	1	9	
	Computer Technology*	1	2	7	
LuTH	Signal Processing	1	2	3	Wireless and other networks, Computer science, VLSI design
	Computer Comms	0	1	5	
LTH	Circuit Design	5	6	13	Digital comms, secure systems, cryptology, error-correction, digital transmission, spread spectrum/wideband comms, VLSI, DSP, analogue and radio and systems design, antennae, channel coding and modelling, field theory and propagation, codecs
	Electromagnetic Theory	2	4	4	
	Radio Systems	2	5	7	
	Signal Processing	1	2	4	
	Information Technology*	9 (2)**	8	7	
KTH	Communications Theory	1	2	10	Network services and systems, wireless systems, DSP, radio and radio comms, wireless networks and transmission, mobile networks and architectures
	Signal Processing	2	5	16	
	Communications Systems	4	11	15	
UU	Signals and Systems*	4	10	6	Microwave technology and systems, DSP, digital and analogue electronics design, digital modulation and coding, digital communications
7	19	40	94	162	

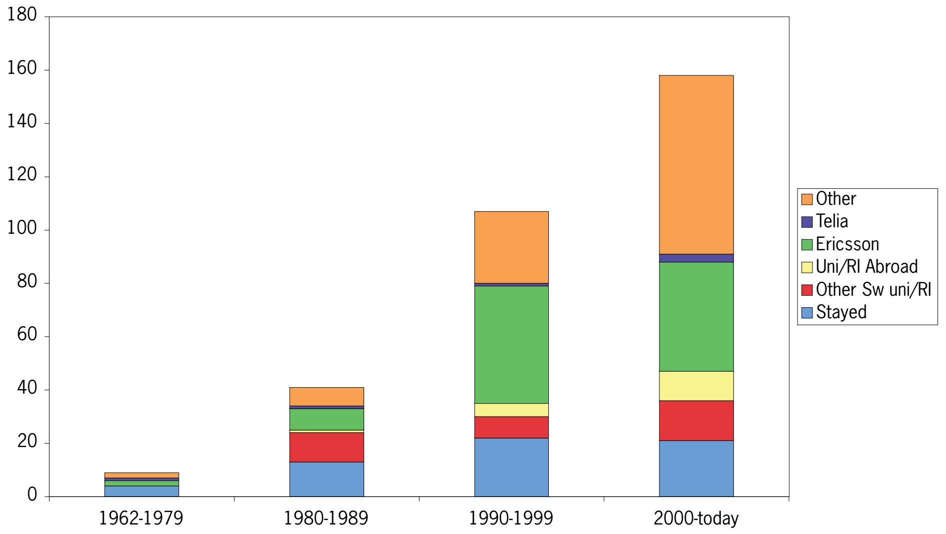
* Group only partly relevant ** Only 2 professors entered in column total + Includes post-docs

Source: University web sites, accessed 080219

An evaluation of STU's activities in information processing, image processing and control technology undertaken in 1985[70] conducted a questionnaire survey of recently qualified PhDs in these areas, following a period of significant expansion of STU funding through framework programmes and project by project funding. In each of the fields, about half the PhDs stayed in the university sector (primarily where they had taken their PhD) and half moved to industry.

Our track of PhDs 'produced' by the research groups established by the members of the radio club and others involved in the Digital Communications programme has identified 315 people as doing PhDs or licentiates in or close to the fields considered by the radio club (Exhibit 35 and Exhibit 36). Their destinations are similar to those of PhDs from the information, image processing and control technology programmes during the 1960s to 1980s. About half the digital communication related PhDs ended up in university careers (mostly in Sweden). More recently, the proportion of PhDs going into industry (or in a small number of cases, such as the current Director-General of VINNOVA Per Eriksson, public service) has risen to two thirds.

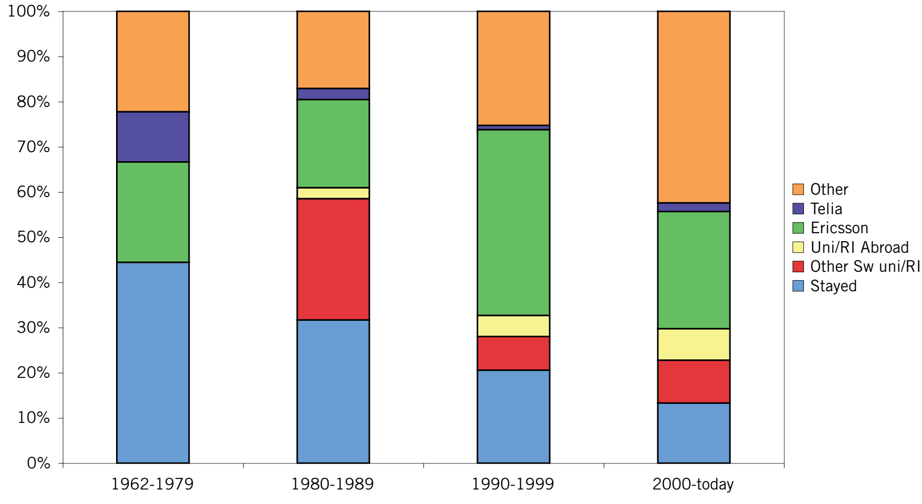
Exhibit 35 Current or Final Destinations of PhDs and Licentiates Graduated in Mobile-Relevant Areas by Date of PhD Defence (Numbers)



n = 315

70 Peter Åsell and Björn Bäckström, *Industrirelevanta Effekter av STUs Långsiktiga Insatser för Kunskapsutveckling*, (preliminär), Stockholm: STU, 1985

Exhibit 36 Current or Final Destinations of PhDs and Licentiates Graduated in Mobile-Relevant Areas by Date of PhD Defence (%)



Some 50% of those people going into industry or public service end up in SMEs. About one in five of these SMEs is located outside Sweden. Over the whole period, Ericsson has absorbed 95 of the PhDs (30%) but Swedish Telecom/Telia only 6 individuals (2%). During the rapid expansion of the 1990s, Ericsson took 41% of the PhDs and even in the context of the wider lay-offs of the first half of this decade Ericsson has still taken a 26% share of the growing PhD output from the universities.

We can confidently conclude that STU/NUTEK funding triggered a very considerable expansion of doctoral education and a very large supply of highly qualified people into both industry and academia. Further, the institutional structure is in place in the universities that should assure the continuation of this supply.

6.2 Effects of Public Funding at Ericsson

The efforts of Swedish Telecom were crucial to Ericsson's position at the start of the GSM story. As we have shown, the NMT history had by that time already generated a strong position for Ericsson in 1G mobile telephone systems. To a considerable extent, this history involved the Nordic PTTs – and especially Swedish Telecom – in developing NMT technology and handing it over to Ericsson for implementation.[71] Despite top management's initial lack of interest in mobile markets SRA/ERA was able to capitalise upon this technological advantage to build a dominant position in 1G

71 Interviews; Meurling and Jeans, 2004

mobile systems technology markets. Thanks to the joint effort with Swedish Telecom at ELLEMTEL, Ericsson also had a brand-new computerised switch (AXE) that it could offer so as to interconnect the GSM 'access' technology to the PSTN.

The national IT programme – encompassing NMP and IT – was also significant. The importance of the NMP for digital mobile communications in Sweden was primarily the VLSI research, design and manufacturing capabilities it created. These enabled Ericsson to implement the new ideas emerging in digital mobile telephony in components, especially DSPs. Having its own capabilities (and the ability to reach out to university and IM capabilities in these areas) meant not only that it could design these components earlier than others in the market but also that it could exert leverage over its component-producing partners. This affected the speed with which they would deliver components and the price at which they would do so – both important factors in Ericsson's ability to deliver handsets and systems in a timely way.

The IT programme was of immense importance for digital mobile communications in that the Digital Communications programme was a component of IT3. IT4 also contained two projects of significance: the GSM Test Bed; and it was the channel through which Swedish participation in the EU RACE programme was funded, before Sweden joined the EU.

The GSM Test Bed project involved ERA, Ericsson Mobile Communications and Swedish Telecom, beginning in 1987. It had a budget of SEK 45m, of which IT4 contributed half and at its peak occupied 80 people. Unlike the pre-standardisation test beds, this was a rather large-scale effort and was needed to flesh out some of the details of the GSM standard, to design handsets and base stations, and to optimise the location of base stations given the new radio propagation requirements of a digital system.

The project had three stages

1. Familiarisation with GSM through parallel testing against NMT analogue technology (Swedish Telecom)
2. Constructing a test network to explore the characteristics of GSM and to help design a functioning system (Swedish Telecom and Ericsson)
3. Designing key components of the system, including miniaturised components (Ericsson) that allowed Ericsson to announce the smallest-in-market handset when GSM launched

Ericsson was able to file a small number of patents based on the work. Swedish Telecom gained early technical experience with GSM, ahead of its Swedish competitors, who had to wait for equipment to become commercially available before they could work with it. It therefore had a head start in the measurement and characterisation work required to build a GSM mobile telephony network.

STU/NUTEK funding of digital communications research in the universities was, as we described in Chapter 4, split into two stages. The first period, from 1978 to 1986, involved coordination of an informal research programme by Ericsson and Swedish Telecom in discussion with the research community. Operating in parallel and sometimes in cooperation with internal Ericsson and Swedish Telecom projects, the research community effectively explored technological options and transferred not solutions but an understanding of how to get to solutions. This was only possible because Ericsson itself had started to employ a small number of PhDs, who could define research questions in this way and who provided Ericsson with the absorptive capacity to understand and make use of the opportunities the academics researched.

The same did not happen to a significant degree in Swedish Telecom. Up to the late 1970s, Swedish Telecom had tended to train its technical people internally at 'Teleskolan' so its technological capabilities were in fact much greater than would be suggested by the rather modest formal qualifications of many of the staff. While there was an increase in the educational level and the research capabilities of people in the Radio Lab through the 1980s, this growth was blocked by the impending privatisation and the eventual reduction in the organisation's research role.

These early PhDs in Ericsson were important but stretched. There were only 5 PhDs among the 50 or so people in Ericsson's Radio's research department in 1988. Moving from a GSM standard to building real products required a much greater effort. In the ten years to 1998, the number of PhDs grew from 5 to 50 and the number of MSc-level researchers from 50 to 500.

R&D staff as a whole in Ericsson Radio grew from about 1,000 people in 1988 to 10,000 in 1998. About 60% of these people were in Sweden; almost all had at least an MSc degree; and very many of them had to be recruited straight from university[72]. Others were transferred from AXE and military work elsewhere in the Ericsson group. Of course, by no means all these people needed the radio access focused skills tackled by the radio club, but an important fraction did. The Digital Communications programme was crucial here because it was one element in the scaling up of the R&D effort to enable Ericsson's meteoric expansion in digital mobile telephony markets. It produced PhDs needed for the research department and through the research it influenced the content of MSc-level university training, helping to secure the engineers needed. Without the stimulus of the programme, there is no reason to think that the universities could have achieved anything like the expansion of capacity illustrated in Exhibit 34.

72 Jan Uddenfeldt, personal communication, February 2008

The close cooperation between Swedish Telecom, Ericsson and the universities during the GSM standardisation process meant that Ericsson had intimate knowledge of the competing technological approaches, especially narrowband TDMA, reducing the risks of development and allowing it quickly to work with the range of access techniques relevant in different markets. This was not a matter of luck but of good judgement in the 1970s that led to the formation of the radio club. The importance of STU was that it was willing and able to support this kind of initiative through bottom-up project funding and that it developed the programming mechanisms that let it go on to support the needed scaling up of effort, once it was clear that there would be significant digital mobile communications markets.

The result of the internal and external effort was that Ericsson could demonstrate to customers a functioning GSM base-station technology capable of executing hand-over in 1990, ahead of Motorola (Ericsson's chief competitor in base stations). It had the switching technology and the systems and deployment understanding needed to deliver packaged systems to those customers who needed them. It could announce a smallest-in-market GSM handset and deliver it ahead of most of the competition. (And the high level of component integration and production automation achieved meant that this product could be made in Sweden. Previously, the mobile phone handset production business had been seen as 'lost' to the Far East.) Close contacts and feedback between developers and the lead customer allowed Ericsson to go to market with a system that had already been adapted to meet the requirements of one of the world's toughest service providers.

It was imperative for the future for both Telia and Ericsson to be involved in RACE, because the standardisation arenas were becoming more international, equipment suppliers were gaining more influence over standards and there was a need for alliances to avoid getting trampled in this new competition. Swedish Telecom was involved in the RACE definition phase as early as 1986, indicating its strategic commitment to the programme. Ericsson was already expanding within the European Community and could not afford to be excluded from the developing equipment suppliers' 'club' or from the technical advances that might be made in the programme. Having already a clear understanding that the future would be competitive and would involve international alliances as well as significant changes in technology, Swedish Telecom clearly understood the need to work more closely with other PTTs and to demonstrate the capabilities of what could otherwise easily seem to be a small operator from a peripheral country of little importance on the economic fringe of Europe.

6.3 The Link to Ericsson[73]

Ericsson was traditionally a company that focused on practical engineering and skipped the intellectual stuff. John Meurling explains the culture amusingly in the introduction to his book about developing the AXE exchanges[74] by saying that in 1951 when he was appointed as an engineer at Ericsson before being awarded his MSc (civilingenjör) degree, he was firmly told that his degree was not worth much at his future place of employment. Our interviewees suggest that, in general, the perspective of 30 years ago was that Ericsson needed just a sprinkling of MSc engineers within a mass of BSc-level people. Since the world became a digital place, Ericsson has had to raise the game and now works with a sprinkling of PhDs across a large body of MSc engineers. By the late 1990s, in fact, Ericsson was globally recruiting some 900 MSc's per year[75].

SRA seems to have had more use for technologists. Öhrvik was recruited as a PhD in the 1950s. Nils Rydbeck, who joined SRA in 1976, was another early PhD, as was Jan Uddenfeldt who joined about 5 years later.

SRA (Svenska Radio Aktiebolaget) was originally set up in 1919 by ASEA, Aga and LM Ericsson. to build radio transmitters. In 1921, the British Marconi company exploited its patents to persuade the other owners to let it buy a stake in the company. By mid-century, Ericsson had bought out the other Swedish owners. SRA started building equipment for transmitting voice calls over long lines, but this activity was then moved into Ericsson, leaving SRA making radio (and later television) sets for consumers and – from the 1940s – developing a land mobile radio business for the police, fleets of trucks, taxis etc. The company started to develop international markets in mobile radio and Åke Lundqvist – head of the mobile radio division – became managing director in 1976, just after SRA moved to Kista. Another key SRA activity was military radios, and in 1982, Ericsson bought out Marconi's share (apparently at the insistence of the Swedish military, which wanted to have a fully national supplier for the radio equipment in the new JAS fighter aircraft). SRA's name was changed to ERA in 1983.

73 Important parts of the industrial mobile telephony story took part in SRA, when it was part owned by Ericsson and part owned by Marconi. Several of our interviewees have been rather vehement in distinguishing SRA from the Ericsson group more generally. They argue that up to 1983, when Ericsson abandoned its adventure in trying to become a PC manufacturer, mobile telephony was regarded as irrelevant by top management and at best tolerated provided that it remained invisible. This appears to have been especially the case for the terminals operations. John Meurling and Richard Jeans, *The Ugly Duckling, Mobile Phones from Ericsson – Putting People on Speaking Terms*, Kista: Ericsson Mobile Communications, 1997

74 John Meurling and Richard Jeans, *A Switch in Time: An Engineer's Tale*, Chicago, Illinois: Telephony, 1985

75 Mauren McKelvey, François Texier and Håkan Alm, *The Dynamics of High Tech Industry: Swedish Firms Developing Mobile Telecommunications Systems*,report to the TSER programme, Contract No SOE1-CT95-1004, DG XII SOLS, University of Linköping, 1998

Meurling and Jeans delightfully capture the attitude of 'big' Ericsson to its subsidiary.

> We looked on SRA, and then ERA, as something of a backyard operation, run by cowboys. Admittedly, by the end of the 1970s they did have an impact on sales and earnings (mostly positive), but still, they were not really one of us. They looked different and behaved differently.
>
> And in any case, during the first half of the 1980s, we in Public Telecoms were more concerned about being overtaken by the new Ericsson comet, Information Systems. This was the attempt which Ericsson, like so many other companies in the 1980s, made to build and market systems in which the technologies of computing and telecommunications converged… So we didn't really know much about Ericsson Radio Systems. And we didn't care! [76]

In 1977, when the Nordic PTTs called for proposals to build the NMT 450 system, SRA was focused on supplying handsets and could offer neither the base stations nor the mobile telephone switches (MTX) needed to control them. Another Swedish company, Magnetic, together with Mitsubishi became the suppliers for the base stations. Ericsson won the MTX order for all the Nordic countries – but only after Swedish Telecom insisted that Ericsson should offer its new AXE digital switch technology rather than an older analogue switch. This insistence turned out to be crucial for Ericsson because digital switching was needed for fast hand-overs between base stations and the AXE technology was highly scalable. Unlike the small analogue switches Ericsson originally proposed, AXEs could cope with the much bigger than expected demand for mobile telephony. And this capacity proved crucial in the UK market - initially supporting Vodafone (the first mobile competitor to British Telecom) and later establishing the AXE as a high-volume switch for use in BT's own networks.

While NMT was an open specification, so that operators could buy base stations and switches from different suppliers, SRA rapidly appreciated the advantages of offering a packaged solution, which it originally did by becoming the sub-contract manufacturer of the Magnetic base station and offering this together with the AXE switch and its own hand sets. It therefore had a double advantage: offering a system that was in established use by the Nordic PTTs and becoming an integrated systems supplier, reducing the perceived risk of purchase to new operators who therefore would avoid endless arguments among equipment suppliers about whose responsibility problems were. In 1981, Ericsson management gave SRA full responsibility for mobile systems, providing a single customer interface, although the mobile switches continued to be developed and made the main Ericsson divisions. Ericsson bought Magnetic in 1983, giving it control over base station technology and adding to its development capabilities.

76 John Meurling and Richard Jeans, The Mobile Phone Book: The Invention of the Mobile Phone Industry, London: Communications Week International, 1994

Ericsson had another product – MiniLink –that proved useful in offering turnkey solutions. MiniLink was an all-in-one-back microwave link that had many communications uses. It was especially interesting for mobile operators because it let them quickly set up low-cost microwave links between base stations and with the MTX switches that bypassed the terrestrial telecommunications network. Over time, the operators learnt to use microwave and leased-line links to build networks that were increasingly independent of the fixed network. Mobile systems were no longer **only** 'access' technology but started to become networks in their own right.

The decision to offer systems solutions was shown to be a good one when bidding for the US AMPS system licenses began in 1982. Some 40 out of 130 bidders specified SRA systems. These were largely the new entrants with no strong ties to existing US equipment manufacturers and a greater need for the security offered by a single supplier. Building on its Nordic base and its ability to offer systems solutions to new entrants in 1G mobile telephony, Ericsson therefore quickly established a strong position in systems for all three major Western 1G standards: NMT; the US AMPS; and the modified version of AMPS adopted in the UK (TACS). In Europe, Ericsson became the dominant supplier of 1G systems – a fact that triggered substantial Franco-German R&D investment by four government-subsidised consortia in the lead up to GSM standardisation, in the hope of breaking Ericsson's position during the transition to a new technology.

The choice of narrowband TDMA was crucial to Ericsson, because it allowed it to continue to exploit its leadership position in the transition from 1G to 2G mobile telephony. According to Mäkitalo, "The key advantage of winning the GSM standardisation race was that Sweden was **to be** first – this is not a matter of lead time, it is about generating a lead with which no-one can catch up."[77]

At the launch of the GSM system in Europe, there was an acute shortage of handsets. Ericsson's ability to provide these became an important competitive advantage for a period, until other manufacturers caught up and began to produce in volume. However, it was Ericsson's systems capability and track record that proved decisive: 10 of the first 14 European GSM licence holders used Ericsson systems.

Ericsson had struggled with handsets since the early days of mobile telephony. The production of high-volume consumer goods went against the culture and internal disciplines of what had been a slow-moving systems maker. There were constant production and quality problems from the NMT days and through to the late 1990s, and wothot strong support from top management, a lot had to be achieved by 'muddling through'.[78]

77 Reference group meeting, 080125

78 John Meurling and Richard Jeans, The *The Ugly Duckling, Mobile Phones from Ericsson – Putting People on Speaking Terms*, Kista: Ericsson Mobile Communications, 1997

Once Nokia had firmly established the handset as a 'throw away' consumer fashion item in the mid-1990s, Ericsson saw its handset market share decline to about 10% and went into an alliance with Sony in 2000. But by this time its weakness in handsets no longer mattered so much. It had and still has upwards of one third of the market worldwide for mobile telephone infrastructure. The proliferation of handset manufacturers and the fact that network operators did not themselves buy the handsets meant that the need for systems manufacturers also to ensure a handset supply that was crucial at the launch of GSM had disappeared.

SRA's TDMA experience also proved decisive in the US standardisation process for digital mobile telephony that led to the D-AMPS system. In competition with FDMA systems from AT&T and Motorola, Ericsson was able in 1989 to demonstrate a working TDMA access system that could easily be grafted onto the existing AMPS base stations. As had been the case in Sweden, the choice of TDMA meant that new base station sites were not needed, so D-AMPS could 'piggy back' on the infrastructure already in place for AMPS. Ericsson has established and maintained a presence in all major 2G standards and continues this strength as 3G evolves. As a result, from the early days of GSM and onwards, the company has maintained a market share of digital mobile telephony systems in the range 30-40%. In handsets, it has not done so well. Despite creating a joint venture with Sony in 2002 (with the intention both of building scale and exploiting Sony's stronger consumer electronics brand and market understanding) Ericsson's share of the handset market has tended to oscillate between 5% and 10% since the early 1990s. Nokia has tended to be the market leader in handsets over the same period, typically taking about one third of the global market.[79]

There was little direct carry-over of products or techniques from military markets civil mobile telephony. However, its military history provided SRA with an important general advantage: namely that it was exposed earlier to new generations of technology that those of its competitors who only had civil experience. The military was, for example, willing to pay to use transistors in troop radios at a time when they were prohibitively expensive for civil applications. SRA's and Ericsson's military history was important in providing some of the skills on which 2G systems were developed. At the start of the 1980s, SRA already had strong capabilities in encryption and coding. One reason was that Ericsson transferred a subsidiary called Transvertex into SRA in 1980. Transvertex had been working on both military and civil encryption since the 1950s. Ericsson had originally bought Transvertex in order to use its encryption skills in mili-

79 Information about market shares is taken from a range of sources including Ericsson annual reports and press reports of findings of various market research companies

tary radios (a project called SN210)[80]. SRA had independently built up coding and cryptological skills for its own military products and was familiar with frequency hopping – a technique for jumping quickly between frequencies so that it would be hard for enemy listeners to hear more than a small part of a radio message and that made radio signals hard to jam, because the prospective jammers would not know what frequencies to target. While frequency hopping is an optional part of the GSM specification, it is not especially difficult to do at the level demanded by the standard. However, frequency hopping is a basis for CDMA, so SRA's understanding of it gave SRA an important lead into what became the radio access technique for 3G telephony. Elsewhere in the Ericsson group – notably the MI division that later became Ericsson Radar Electronics and eventually Ericsson microwave – relevant skills were also developed, for example in advanced radar, DSP and antenna technology. Nils Rydbeck, who headed the new handsets operation in Lund from 1985, brought nine years of experience of military radio and encryption to bear.

SRA's skills base was crucial in allowing Ericsson to achieve strong positions not only in GSM but also in the other major 2G markets. At the end of the 1980s and into the early 1990s,the company had to develop and deliver in quick succession: GSM systems in time for the 1991 launch; D-AMPS system for the 1992 launch in the US market; and PDC systems for the Japanese launch in 1993. The massive increase in the size of ERA's R&D department needed to achieve this was enabled in part by the fact that AXE engineers could be transferred from the fixed telecommunications division and ELLEMTEL while others could move form military work into mobile telephony, based on the similar skills involved[81].

The fact that in the 1970s mobile telephony was seen as a minor activity in Ericsson that had a limited future meant that little manpower was initially available for R&D. However, an important side effect of the huge success of the NMT system was that SRA had money to invest in research as well as development, and this proved vital in building its strong position in GSM. In 1982, the SRA radio research group in Stockholm was about a dozen people, rising to 15 a couple of years later. In 1983, when ERA was formed and decided to locate handset manufacturing opposite the Technical University of Lund, a second R&D team was built in the South of Sweden to tackle handset design and absorbed a steady stream of engineers and PhDs from across the road. Setting up shop next to technical universities became a key policy of ERA because of its massive demands for manpower.

From Ericsson's perspective, a key to making use of the research community's interest

80 John Meurling and Richard Jeans, *The Ericsson Chronicle: 125 Years in Telecommunications*, Stockholm: Informationsförlaget, 2000
81 Meurling and Jeans, Op Cit, 2000

in technologies relevant to mobile telephony was to be asking the community questions based on its own internal development. Despite the many interactions between the company and the community, we have identified only one case of significant knowledge moving more or less directly from research idea to industrial application, and that was Maseng's insight that the well-established Viterbi algorithm could be applied to equalisation, so as to minimise inter-symbol interference. Ericsson therefore was always running internal projects in parallel with those where it asked researchers to contribute.

Often the university research projects were highly theoretical while Ericsson's projects aimed to be simpler, producing robust solutions that used the minimum of electric power and that could eventually be implemented in components or software. There was a constant dialogue with the universities, which ensured that Ericsson understood its technological options. Especially in the period up to the mid-1980s, Ericsson did not recruit all that many PhDs from the universities: it was better that they stayed in place and taught new generations of engineers and PhDs, to supply Ericsson's growing appetite for personnel. But knowledge was transferred through dialogue and by asking academics to act as consultants. More than one of our interviewees recalled being invited to consult with Ericsson for a few weeks after completing their PhD, during which time they worked on a subject related to their research and effectively transferred their knowledge to Ericsson.

With the dramatic increase in Ericsson's mobile business and the corresponding large increases in R&D staff, the company is now able to maintain a much bigger 'contact surface' to the universities than SRA could in the 1970s and 1980s, not only in Sweden but also across the world. The company now, for example, participates in US competence centres in its own right, rather than needing to use Swedish academics to build the needed links.

The ERA radio research group in Stockholm (quaintly known as the 'development' department) was important for Ericsson not only as a source of absorptive capacity and new technology but also of management. People from the department would often be sent out to oversee the development of components and products after researching their early stages. Others moved quickly into functions such as marketing and sales. As a result, the research group was able to manage a rapid flow-through of people, often recruited after a PhD or some few years of research experience, who constantly refreshed the group's knowledge of the state of the art in research.

While this story focuses a great deal on radio access techniques, which was where some of the great challenges were in moving from 1G to 2G, Ericsson was also faced with the major task of implementing the new techniques via componentry. As our account of the key research associated with the radio club shows, part of this involved mastering the emerging component design techniques coming form the USA and building experience in the new art of DSP design using Application-Specific Integrated Circuits (ASICs). Ericsson benefited from other public interventions, notably NMP4, in order to build capacity in this area. Mastering the non-standardised design tools needed was one key agenda – it was only in the early 1990s that generally available commercial design tools could be routinely used for circuit design. But key to Ericsson's success was also its internalisation of component manufacture during the 1980s.

Ericsson's fabrication capability came through the transformation of RIFA[82], which had for many years produced various radio and telecommunications components. It established a cooperation agreement with National Semiconductor as long ago as 1971, allowing it to understand transistor technology. After relocating to Kista in 1977, it struck a long-term know-how deal with AMD that enabled it to start making integrated circuits in Kista – initially a pilot run of 4k static RAMs[83]. In 1983, the AMD agreement was extended to give Ericsson a CMOS process and establish an LSI design centre at Kista. Work on the CMOS process and design tools continued in the National Microelectronics Programme, focusing on line circuits for the AXE exchange. In 1987, RIFA established a cooperation agreement with TI that gave it access to TI's 0.5 micron BiMOS process and the associated design systems.

ERA built considerable experience in designing ASICs in partnership with GEC-Plessey during the 1980s while building its own fabrication capability at Kista. In the build-up to manufacturing GSM systems and handsets, this gave the company the power to persuade Texas Instruments considerably to lower the prices of its DSPs, saving Ericsson many millions of bought-in cost.

The transition of Ericsson from being a fixed to increasingly a mobile telecommunications company had important consequences for its choice of locations. The SRA doctrine of wanting to locate only in university towns and cities came to influence Ericsson's increasing focus on Kista, in North Stockholm. ERA, IBM and RIFA (late Ericsson Components) were among the first companies to locate there and were strong champions of the Electrum science park, set up in 1985. The Institute of Microelectronics (later renamed ACREO) located at Kista as did SICS and a range of other IT-related research institutes.

Unlike the foreign multinationals (and unlike the old Ericsson of fixed network times), ERA's history of close interaction with Swedish universities now makes it a strong

82 Originally Radioindustrins Fabriksaktiebolag – the Radio Industry's Factory Co. Renamed Ericsson Components in 1988

83 Random Access Memory (RAM) chips were often used to test and prove processes as they are large structures with many components but a very simple architecture, so it is easy to identify process problems

champion of close university relations. According to Lennart Alfredsson[84] Ericsson sought to develop radio technology but KTH was "absolutely against" promoting further developments in that area during the first half of the 1980s. They believed the research challenges in radio were "trivial" and that the technology was "mature" and that no "science" was needed. KTH was an ageing university, old fashioned and "not a very good university" because it lacked investment. Ericsson "decided to really change KTH". They proposed moving mathematics, electronics and physics to a new location south of Kista "to come closer to where things happened". This failed, and Ericsson turned its attention to fostering activities in the new Electrum science park that today houses ACREA, SICS and KTH Wireless as well as numbers of small electronics firms.

As KTH ran out of space on its city centre campus and was unable to expand into electronics and biotechnology as fast as it wanted, so it was persuaded by ERA and the City of Stockholm to grow its electronics activities at Kista, culminating in the creation of KTH's 'IT University' at Kista, which has substantial clean room facilities as well as a large number of other IT-related activities. ERA then defined and initially funded a new chair in Radio Systems Technology (held by Jens Zander, who took his doctorate under Thomas Ericsson at Linköping and who was an early member of the 'radio club'.)

Ericsson has continued to maintain close links with the universities. It has financed chairs at KTH, LTH, CTH and elsewhere, but the bulk of its effort with universities – not only in Sweden but also abroad and in international programmes – is cooperative, linking internal and external research.

6.4 Mobile Telephony and the Socio-economic Benefits of Public Funding

The major benefits of the public funding for Ericsson and its shareholders are pretty clear. But what does the Swedish taxpayer get out of this?

- A major body of new knowledge, visible in the form of publications and patents
- A university system adapted to the technologies and needs of the 21st Century
- Employment at Ericsson – and in the (voluntary and involuntary) spin-offs it generates and the transformation of a key company from the traditional fixed line telecommunications business into the more rapidly growing mobile sector
- The creation of significant value, which contributes through GDP to social and economic welfare

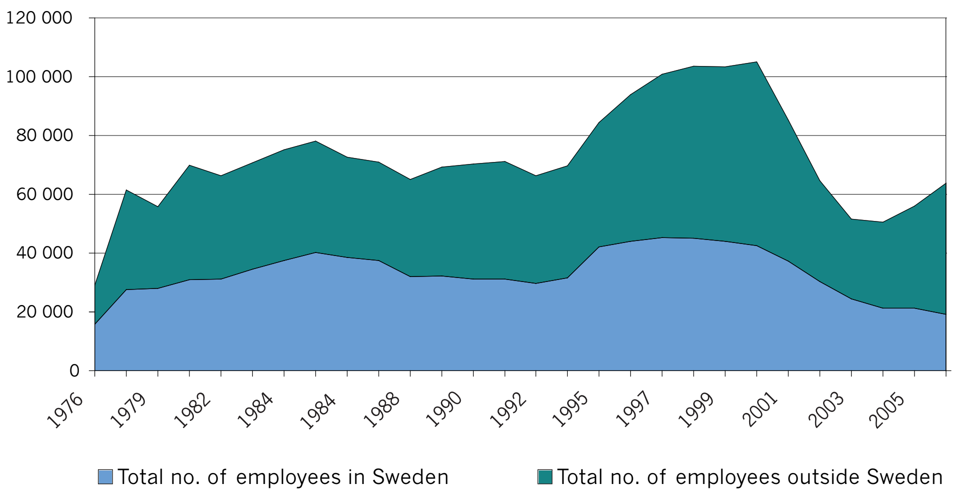
84 Cited from Jonathan Feldman and Daniel Högberg, *History of Immigration, Ethnic Enclaves and Housing Policies in Sweden*, Swedish National Institute for Working Life, working paper, 2004

- A healthy, positive contribution to Sweden's balance of trade
- Public benefits (consumer surplus), through access to and use of mobile telephone services

We sketched some indicators of the new knowledge created in Section 5.3 and the changes to the capacity of the university system in Section 6.1.

Just as it quickly moved from NMT to AMPS and TACS, Ericsson very quickly generalised the capabilities that gave it a strong position in GSM into the other digital mobile markets. This involved it increasingly in setting up development and manufacturing capacities outside Sweden, but – despite the well-known retrenchment in the early 2000s – the volume and quality of employment Ericsson provides to the Swedish public remains high.

Exhibit 37 Ericsson Employment: Overall and in Sweden, 1976-2006

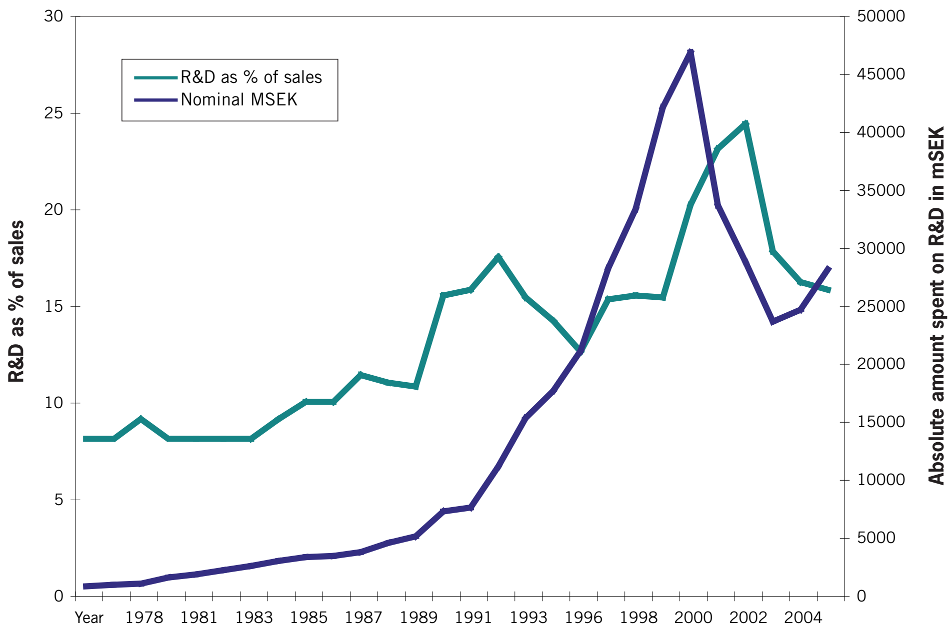


Source: Ericsson Annual Reports

Like other large technology-based organisations, Ericsson spins off many firms. This is a reflection of the skills and capabilities of its highly educated people and while the early 2000s saw quite a number of companies spin off involuntarily as Ericsson cut its workforce in order to reduce costs, the spin-offs also demonstrate the robustness of the Ericsson engineering community and the fact that it can survive beyond Ericsson itself.

The growth of mobile telecommunications has transformed Ericsson as a company from a rather traditional and slow-moving supplier of Public Switched Telephone Network (PSTN) equipment to PTTs to a very dynamic global player in mobile telephone systems. Exhibit 38 shows this change in turnover terms.

Exhibit 38 Ericsson R&D, 1976-2006

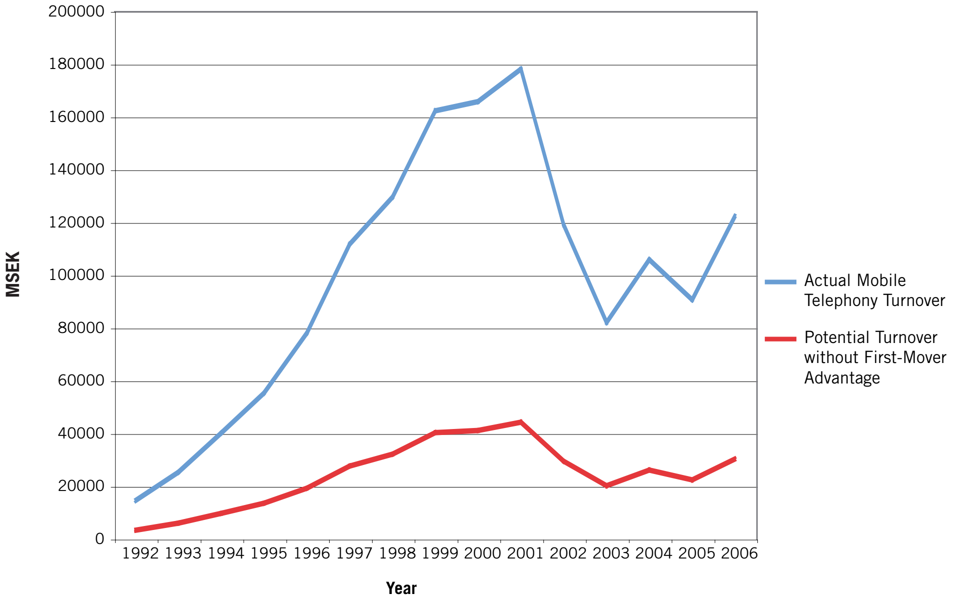


Source: Ericsson Annual Reports

The story of Ericsson's positioning in the GSM market told here (and confirmed by our interviewees in Ericsson and elsewhere) is that Ericsson was able to capture a strong position by being first with an integrated and credible systems solution. Being second would not have delayed Ericsson's growth in mobile telephony – it would largely have prevented it. While this is undoubtedly true, it makes the net effect of Ericsson's position hard to model in value terms because the counter-factual – what Ericsson would have looked like if it had not achieved this strong position – is not obvious. One possibility is that Ericsson would have gone the way of NorTel, the Canadian telecommunications equipment supplier that in the mid-1980s was in as similar position to Ericsson – a global but comparatively small switch manufacturer – but which failed to climb on the mobile bandwagon, suffered even more than Ericsson when the Internet bubble burst and is today about half Ericsson's size, having been driven increasingly into services.

We can, however, do a simple thought experiment. Certain of our interviewees have guessed that Ericsson's mobile business might have been a quarter of its current size, if the company had not had such a strong position at the start of GSM. This would undoubtedly have knocked on to the rest of the business because with smaller mobile systems sales Ericsson would probably have sold fewer AXE switches. But one possible estimate of the value of being first is therefore three quarters of Ericsson's mobile telephony sales since, say, 1992, when GSM was introduced. That would make the value of the first-comer position some SEK 1,115 billion.

Exhibit 39 Possible Net Effect of First-Comer Position for Ericsson in Terms of Mobile Telephony Revenues, 1992-2006



Deiaco[85], like some of our interviewees, suggests that Ericsson's early positioning can be thought of as producing up to a five-year lead over its competitors. We can model this by looking at the difference between Ericsson's actual mobile systems revenue and what it would have received if those sales had been delayed by five years. To be very conservative, we could also consider a shorter delay – say, two years. These calculations produce estimates of net effects of SEK 522 billion and SEK 214 billion.

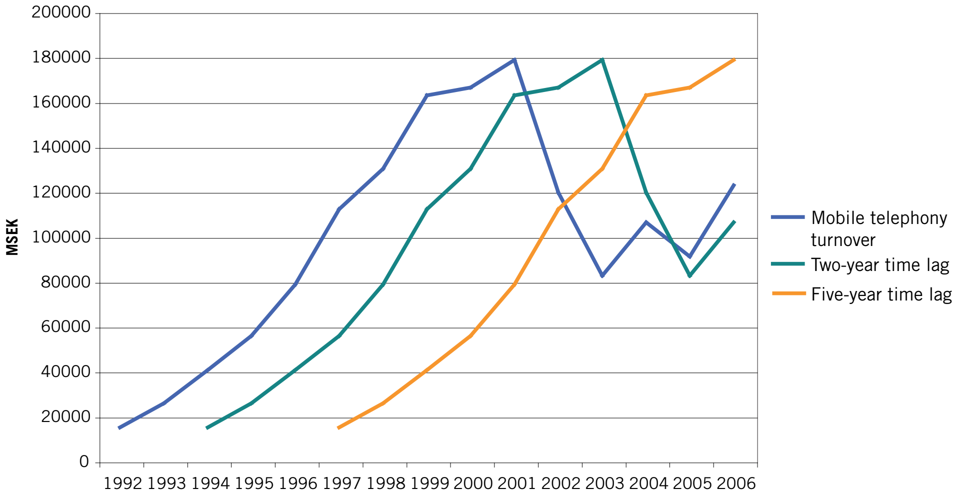
Of course these numbers are so ridiculously large that there is no point even to try to sophisticate them by adjusting for inflation of trying to calculate net present values.

85 Enrico Deiaco, 2001

The serious issue **is** that while the range of uncertainty about the economic benefits of Ericsson's first-comer position is large, equally it is clear that the value of these benefits is itself very big.

What proportion of these benefits to **attribute** to public funding in general and to research funding in particular is of course problematic. The research funding appears to have been a necessary condition for SRA/ERA to develop the capabilities needed to establish its GSM position. But then so too was probably the strong position that NMT had given Ericsson as a mobile systems supplier, and a large number of other factors such as the skills and application of Ericsson management and staff, the availability of capital and the fact that the education systems in Sweden and other countries were increasing their output of electronics engineers.

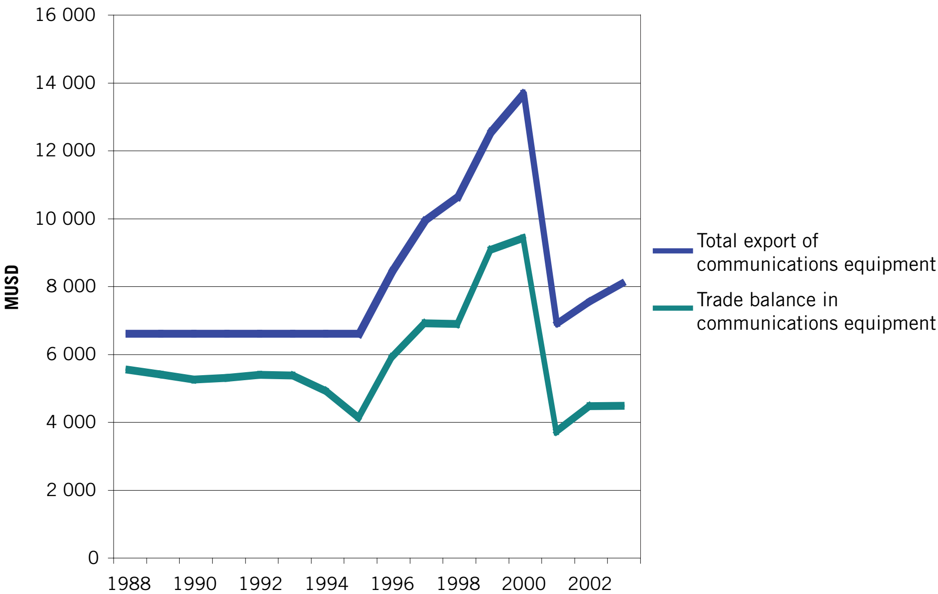
Exhibit 40 Possible Net Effect of a 2- and 5-Year Lead Time Advantage for Ericsson in Terms of Mobile Telephony Revenues, 1992-2006



The fact that there are so many necessary but not sufficient conditions drives us towards the innovation systems view of the world that underpinned the formation of VINNOVA. This implies that a large number of sub-systems of the national innovation system need to function well and to be well interconnected if the system as a whole is to perform well. In this view, we cannot attribute success to any one factor, but we can rather clearly say that if a component of the national innovation system fails then performance will fall. We have demonstrated in some detail how the links between publicly funded R&D and Ericsson's capabilities and success operated. Without the publicly funded R&D it is clear that there would not have been the same success.

Whatever we think about value creation, Ericsson's success translates into a major trade surplus for Sweden in telecommunications (Exhibit 41).

Exhibit 41 Swedish Exports and Trade Surplus in Telecommunications Equipment, 1988-2003



Mobile telephony brings benefits not only to equipment suppliers but also to those who use the equipment. Analysing the contribution of mobile telephony to national productivity, a study by the UK consultancy CEBR found that mobile phone use has been responsible for an increase of just below 1% in UK national labour productivity. In other words, everyone would have to work for an additional 20 minutes per week without mobiles to produce the same amount.[86] In an earlier study, CEBR estimated that by 2013 total UK productivity would be between 0.8% and 4.7% higher than it would have been without mobile communications.[87] Similarly, a Finnish study calculated that wireless connectivity boosts labour productivity by 6%, while underlining that wireless connectivity remains relatively rare at work and is expected to have potentially large productivity effects once work practices have fully adjusted to their presence[88].

86 O2, "I can't imaine working without my mobile." An analysis of how mobile phone use contributes to business productivity, study conducted by CEBR, 2006
87 O2, The Changing Economic Impact of Mobile Telephones, study conducted by cebr, July 2004
88 Mika Maliranta and Petri Rouvinen, Informational Mobility and Productivity – Finnish Evidence, ETLA Discussion Paper No. 919, July 2004

An alternative way to consider the benefits of mobile telephony is through the idea of consumer surplus: the difference between what consumers would be willing to pay and what they actually paid. It is estimated that the mobile services in six Latin American countries (Brazil, Chile, Colombia, Mexico, Peru and Venezuela) generated a consumer surplus of around $30 billion in 2004.[89] For the UK, the consumer surplus for mobile telephony[90] was £19 billion in 2006 as compared to £13,6 billion in 2002 (+40%). Furthermore, the consumer surplus for wireless broadband was £292 million in 2006.[91]

A third approach would be to consider the added value created by the mobile communications industry across the economy. The added value is captured by a multiplier that measures expenditure in subsequent rounds. The following table shows the values of multipliers that have been calculated in various studies.

Exhibit 42 Mobile Telephony Multipliers Found in International Studies

Study	
The contribution of mobile phones to the UK economy, O2 for ONS	1.13
Ovum studies on economic impact of mobile telephony in Bangladesh and USA based on review of various other studies*	1.6
Association Française des Opérateurs Mobiles *	1.7
Economic impact of spectrum use in the UK, Europe economics, based on ONS	1.1
Sicrana, R., and de Bonis, R.: ”The Multiplier Effects of Telecommunications Investments on Economic Growth and Restructuring**	1.5
Radio authority, UK 1995, Economic impact of radio	1.4

* on employment, ** on GDP

Source: GSM Association, *Global Mobile Tax Review 2006-2007*

These results suggest a range of 1.1 to 1.7 may exist, i.e. the added value created by network operators and other parts of the value chain is multiplied by this number to capture the total impact of this expenditure.[92]

To use any of these approaches in Sweden would require a special study. However, the international literature clearly points to mobile phone use generating value beyond the money paid for mobile services. Swedish mobile services revenues over time are shown in Exhibit 43. It seems reasonable to suppose that, without the interaction with the Swedish research community and Swedish success in influencing the access method

89 David Lewin and Susan Sweet, The economic impact of mobile services in Latin America. A report for the GSMA, GSM Latin America and AHCIET, December 2005

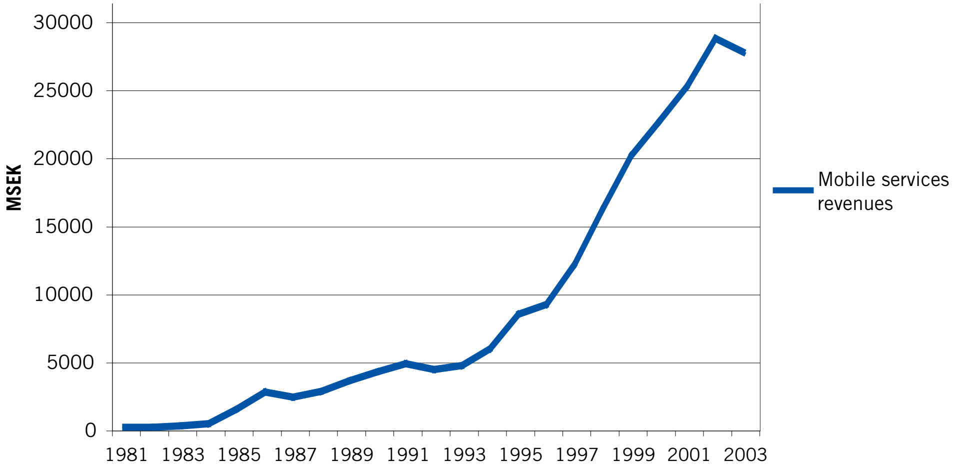
90 including celluar mobile, paging, public mobile data networks, and public access mobile radio

91 Europe Economics, Economic impact of the use of radio spectrum in the UK, report for OFCOM, November 2006

92 GSM Association, Global Mobile Tax Review 2006-2007, study conducted by Deloitte

used in the GSM standard, costs in the mobile telephone services business would have been higher, since without TDMA more investment would have been needed in base station infrastructure. However it is not obvious that, had Ericsson not held such a strong position, the growth of mobile services in Sweden would have been much slower. In the NMT period, Sweden already enjoyed one of the world's highest penetrations of mobile telephones, based on the marketing policies of Swedish Telecom. We conclude that there was probably only a modest positive effect from the public research funding on the benefits the Swedish public and industry got from mobile telephone services.

Exhibit 43 Swedish Mobile Services Revenues, 1981-2003



7 Conclusions and Policy Implications

This study has shown that there were crucial links between public R&D support in Sweden, during and immediately after the period when the GSM digital mobile telephone standard was being developed, that help explain the huge success of Ericsson and the Swedish mobile telephony industry in the period since then. These links were non-linear: research did not develop knew knowledge that industry then gratefully implemented. Rather, the interaction of industrial and research agendas focused university research and education on problems whose solution in theory and in industrial development enabled Ericsson's huge success and all the employment, trade and income benefits that has brought to Sweden. While the study focuses on one particular history, it suggests some general lessons about how to design public R&D policy and how companies and other producing organisations can fruitfully interact with the knowledge infrastructure.

This final Chapter has three parts. First, we summarise the **effects** of the public funding on Ericsson, the universities, Swedish Telecom and Swedish society more broadly; second, we draw a number of **lessons** from the history as described in the study; finally we draw out some **policy implications** that are relevant today.

7.1 Effects

Our conclusion in this study is that public research funding, especially that of STU/NUTEK, had a major effect in enabling Sweden's huge success in mobile telephony, bringing benefits to Ericsson, the university system, Swedish Telecom and many other parts of Swedish society. There is always a problem of **attribution** in making such a claim, however, because while the research funding appears to have been necessary it was by no means alone sufficient to cause the success: many other factors were also important. While in an earlier Chapter, therefore, we did some simple data-based thought experiments that convinced us the effects were big, it makes no sense to try to say exactly **how** big. What we can say is that in the absence of the public intervention it seems very unlikely that Swedish industry and society would have benefited anything like as much from the global explosion in mobile telephony.

Ericsson

The Ericsson group is the most obvious winner from the research funding. Ericsson's economic success in the latter 1980s and the 1990s was massive, as a result of its transformation from a fixed-lines to a mobile telecommunications company. Employment peaked at over 100,000 before the crash of the early 2000s, from which Ericsson has now begun to recover. Ericsson has generated many billions of kronor of economic activity, which benefits the Swedish economy and makes a major contribution to Sweden's large trade surplus in telecommunications.

Ericsson's successful relationship with the knowledge infrastructure was not a matter of luck but of good judgement because the company understood its needs and made them clear to the researchers and funders who could help. Most obviously, SRA's initiative in forming the 'radio club' amounted to a clear statement of need coupled to careful identification of relevant researchers. Only a company that already had considerable technological capability or 'absorptive capacity' could have done this. Equally, the company was able clearly to express its needs in relation to the development of LSI and VLSI technologies and the National Microelectronics Programme.

Based on its existing skills, SRA was in a strong position to understand the technological requirements of the transition from the first to the second generation of mobile telephony. Through the members of 'radio club', it was able to increase its knowledge about how to tackle these problems. What it got from the researchers was not solutions but knowledge about how to get to solutions and over time it also acquired growing numbers of PhDs and MScs trained by the researchers, allowing it to build its internal understanding further. This technological learning covered not only theory and algorithms relevant to digital radio access but a great deal of understanding about how to implement those principles via electronic components. The fact that a Nordic narrowband TDMA approach was chosen as the access method for GSM was very helpful for SRA, since it played to the company's existing strengths, but by the time that decision was taken SRA already had a strong technical understanding of the alternatives, which allowed it to take leading positions in all three major 2G markets.

The story of Ericsson's positioning in the GSM market told here (and confirmed by our interviewees in Ericsson and elsewhere) is that the company was able to capture a strong position by being first with an integrated and credible systems solution. Being second would not have delayed Ericsson's growth in mobile telephony – it would largely have prevented it. Technically, that success depended in part on Ericsson's radio access skills, in part on its components capabilities (including the ability to threaten to make its own unless suppliers were willing to offer acceptable prices and deliveries) and in part on the AXE switch developed in collaboration with Swedish Telecom and implemented using technology acquired through the NMP. All three aspects benefited substantially from state research funding.

Ericsson faced the prospect of acute skill shortages in the 1980s – both in specific radio-related areas and in ICT more generally. Its ability to exploit its strong position in GSM depended upon the increasing output of PhDs and MSc resulting both from STU/NUTEK's digital communications programme and from the bigger national effort to expand IT research, training and education that STU had helped trigger in the early 1980s. Given the supply of manpower, Ericsson then had the capacity (just![93]) to build on its TDMA/GSM capabilities and quickly to develop systems for two other important standards. Its leading global position in 2G systems then provided the basis for strength in 3G.

Thus, some of the importance of STU was that it was willing and able to support the radio club initiative through bottom-up project funding and that it developed the programming mechanisms that let it go on to support the needed scaling up of effort, once it was clear that there would be significant digital mobile communications markets. This was a case of responding to industrial signals and investing risk money in a number of projects then being able to spot that something important was happening. But STU was also important for its role in the national IT programme, which was altogether a much more planning-based affair.

We can safely say that without STU/NUTEK's role as change agent in the research and innovation system, Sweden would not have been able to take advantage of the opportunities afforded by mobile telephony and in the best case Ericsson would have had to pursue its expansion to a greater extent outside Sweden.

Universities

The public research funding led to a body of knowledge and publications but its more important effect in the university sector was to launch a trajectory of growth in the capacity to do research and teaching in subjects relevant to digital mobile telephony: at least a ten-fold increase in the ability of the university system to do research and teaching in the area. We were able to track 281 relevant PhDs and 34 licentiates, and have certainly under-counted. The number of relevant research groups has gone up from 4-5 in the early 1980s to some 20 in 7 universities. The expansion has both social benefits and career benefits for those involved. Without the stimulus of the digital communications programme and its successors, there is no reason to think that the universities could have achieved anything like this expansion of capacity. Given the huge recruitment needs of the industry at both MSc and PhD level, this was an important achievement that also needs to be understood in the context of the bigger expansion of ICT research and education capacity triggered by the national IT programme and its successors.

The universities were both enablers of Ericsson' success through their research and education activities and also beneficiaries of it – not only through research and teaching to

93 Meurling and Jeans, *Op Cit*, 2000

meet the growing needs of the mobile telephony industry but also because there is positive feedback from Ericsson in particular in the form of funding, collaborative projects and a continuing flow of information about emerging problems. Problems are the lifeblood of applied science and engineering. Odd as it may sound, a supply of problems is one of the most valuable things one can have in such disciplines, not only because they underpin day to day research and education (especially in final year projects and for higher degrees) but because they can define new research trajectories. And just as in industry, timely knowledge of what the important problems are is often key to competitive success in academia.

We can confidently conclude that STU/NUTEK funding triggered a very considerable expansion of doctoral education and a very large supply of highly qualified people into both industry and academia. This is a structural shift: the institutional structure is in place in the universities that should assure the continuation of this supply.

Swedish Telecom

While Swedish Telecom can reasonably be credited with creating one of the world's most advanced mobile telephone markets in the NMT era and was a crucial enabler of Ericsson's success through cooperation over AXE and in the GSM standardisation process, it has perhaps itself not benefited as much as other sectors from the expansion of ICT research and education – either at the general level or in the specific case of digital mobile communications. The use of narrowband TDMA in the GSM specification meant that Swedish Telecom could use its existing NMT base station sites to deploy GSM rather than having to set up new ones to create the smaller cell sizes implied by other access methods, and this has produced a significant saving compared with alternatives. However, the change in Swedish Telecom's role with corporatisation and liberalisation means that it no longer makes so much use of highly qualified R&D manpower, though we did identify 4 PhD-holders from our database who got their PhDs after 1990 and who now work at Swedish Telecom (Telia).

Sweden

The Swedish taxpayer more broadly has benefited significantly from the Swedish success in mobile telephony and to which public research funding has contributed.

One of the most important aspects from the national perspective is the creation of a large cadre of people in industry and in the knowledge infrastructure who understand and work with digital communications – what Bozeman and Rogers[94] call a Knowledge

94 Barry Bozeman and Juan Rogers, 'A churn model of scientific knowledge value: Internet researchers as a knowledge value collective,' *Research Policy*, (31), 2002, pp 769-794

Value Collective. By this they mean a social configuration able to produce knowledge value. Conventionally, we try to count the benefits of an intervention such as a research programme in the industrial world by looking at its effects on individual companies. In this study, we have focused heavily on the Ericsson group. But to a considerable extent, the community of people who work with a technology persists more strongly than individual companies. Thus, when Digital and Apple left Ireland to move computer production to the Far East, they left behind a population of people, some of whom migrated to other companies and others of whom set up their own businesses, using their knowledge of computer design and production. The effects of the Knowledge Value Collective persisted longer than the particular companies in which some of its members had worked. In the same way, when Ericsson downsized in the early 2000s, many people set up their own businesses in related areas of telecommunications and electronics.

The research programmes studied here also triggered significant changes in the university system, making it much more adapted to the needs of the 21^{st} Century than it had previously been. This is also an important effect for the taxpayer.

In Chapter 6 we looked at the amount of economic activity generated solely through the lens of Ericsson. We have not explored the effects on the company's suppliers. Neither have we looked at the belatedly positive side of Ericsson's rapid downsizing in the early 2000s, which includes the creation of a large number of new small firms. But even without considering these things, it is clear that there are huge benefits for Ericsson in Sweden – and that these result in the employment of large numbers of Swedish workers and the payments of large amounts of Swedish taxes as well as a healthy contribution to Sweden's balance of trade.

7.2 Lessons

A number of lessons can be learnt on the basis of this study. We should, however, also note that this study relates to a very particular situation and take account of this in drawing conclusions. The phenomena we investigate took place in the last operational years of a strong 'development pair' – an arrangement that is no longer easy to support, in the light of WTO and other international rules. It relates to a particular time and to an earlier stage of development of the electronics trajectory. It deals with large organisations in a very concentrated and regulated industry where standards are important. And it relates to technologies that, while disruptive, are based on fundamental principles that are reasonably well understood.

It is clear that, when GSM was launched in 1992, Ericsson had achieved a market-leading position on the basis of the strength Swedish Telecom had helped it develop in first generation systems, its internal competences, its interactions with the research community, the growth in the education system that it had helped trigger and a substantial list of other factors. The research was a necessary but not sufficient condition for Ericsson's success.

The fact that there are so many necessary but not sufficient conditions drives us towards the innovation systems view of the world that underpinned the formation of VINNOVA. This implies that a large number of sub-systems of the national innovation system need to function well and to be well interconnected if the system as a whole is to perform. In this view, we cannot attribute success to any one factor, but we can rather clearly say that if a component of the national innovation system fails then performance will decline – potentially in a catastrophic way. We have demonstrated in some detail how the links between publicly funded R&D and Ericsson's capabilities and success operated. Without the publicly funded R&D it is clear that there would not have been the same success.

In Chapter 2, we listed seven 'Channels' through which Martin and Tang's review of the literature suggests research and other parts of society interact. This study has found examples of most of these channels in operation and therefore provides evidence to support the much more complex 'innovation systems' view of the relation between research and society than is offered either by the naïve linear model of knowledge transfer or by the simple human capital model.

Exhibit 44 Knowledge Exploitation Channels in Digital Communications Research: Findings of This Study

Channels'	Examples From This Study
Channel 1: increase in the stock of useful knowledge	This is evidenced by the significant quantity of publications and patents identified for the people in our PhD database
Channel 2: supply of skilled graduates and researchers	The PhD-holder database shows that many people have been trained and have moved into industry, especially Ericsson
Channel 3: creation of new scientific instrumentation and methodologies	We are aware of no examples of instrumentation. To the extent that methodologies have transferred these are essentially cases where established methods have been re-used or incrementally developed
Channel 4: development of networks and stimulation of social interaction	The radio club was such a network. Later, participation in EU projects, for example in RACE, has allowed the Swedish research community to build more international networks
Channel 5: enhancement of problem-solving capacity	Industrial problem-solving capability has been increased through the movement of people but also through 'parallel working' between industrial and academic researchers and by industry hiring recent PhD graduates as short term consultants in order to transfer their knowledge
Channel 6: creation of new firms	Not a focus of this study
Channel 7: provision of social knowledge	This Channel involves knowledge relevant for policymaking. In so far as the public research has provided information used in setting standards this Channel has clearly been used in this case

In an exploration based on earlier work by Martin, we identified access to unique facilities[95] as a further research-industry communication and cooperation channel. In the digital communications area, test beds fall into this category and have been an important source of communication and focusing device for academic-industrial cooperation – an eighth 'Channel'.

The GSM case clearly illustrates that the role of R&D in this innovation was as something that had to be done on the way to achieving an innovation goal. Digital mobile telephony did not happen because someone did some research and realised they could build a GSM handset with the results. It happened because organisations understood that digital technology was the key to mass mobile telephony and set about solving the problems in the way of achieving this innovation. Some of those problems were solved via R&D. Others needed re-regulation. Yet others required changes in distribution channels and the invention of new pricing strategies. Early attempts did not all succeed in going digital – had it been technically possible at the time, NMT would have been an all-digital standard, but that had to wait for various component technologies to mature.

One question we tried to resolve in this study was whether there were 'critical events': points at which it is possible to see a particular research result passing into practice. There turn out to be almost no such events in this area. The possible exceptions – which really amount to insightful use of existing knowledge – are Maseng's identification of the Viterbi algorithm as the basis for equalisation to eliminate inter-symbol interference and Aulin's perception that GMSK would be a good option for the choice of modulation technique in GSM. It seems that it is competence and understanding of how to do things, not individual facts, that move between university and industrial researchers – at least in this case. (Many similar examples can be observed in competence centres, where university and industry researchers work closely together.[96]) Operating in parallel and sometimes in cooperation with internal SRA and Swedish Telecom projects, the research community effectively explored technological options and transferred not solutions but an understanding of how to get to solutions. This was only possible because SRA itself had started to employ a small number of PhDs, who could define research questions in this way and who provided the company with the absorptive capacity to understand and make use of the opportunities the academics

95 Erik Arnold and Ben Thuriaux, 'The contribution of basic research to the Irish national innovation system,' *Science and Public Policy*, Volume 28 Number 2 April 2001, pp 86 - 98

96 Arnold Erik, John Clark and Sophie Bussillet (2004), *Impacts of the Swedish Competence Centres Programme 1995-2003*, VINNOVA Analysis VA 2004:03, Stockholm: VINNOVA

researched. SRA therefore was always running internal projects in parallel with those where it asked researchers to contribute.

The study illustrates the importance of absorptive capacity in industry as a way to create the initial capabilities needed to move into disruptive technologies, the opportunities available through long-term collegial relationships between researchers in companies and universities and the opportunities to use problems – defined, for example, in relation to a standard or a test bed or a road map – to focus university research on industrially relevant questions.

SRA's proactivity is an extremely important part of this story that was only made possible by its small core of research-capable people. The radio club was a focusing device: an arena where research ideas and results were exchanged. People from both Ericsson and Swedish Telecom told us that they shared results of their work in a much more open way in the club than was possible in any other external forum. As a result, there was rather tight coupling between the topics addressed inside and outside industry. SRA's proactivity went well beyond the radio club, however. It decided to locate its plant only next to universities of technology – not only so that it could conveniently pick up new recruits as they graduated but also so that it could influence the direction of research and education in directions that helped meet the company's needs. It invested a lot of effort in understanding who did what in the academic research scene and in lobbying STU to fund projects and programmes in areas of interest to it. SRA therefore had an acute awareness of the potential value to it of close links with the higher education sector.

The creation and movement of human capital turns out to be extremely important in the mobile telephony story. Without the scaling up of the research and higher education effort Ericsson would not have been able to exploit the opportunities in digital communications. But not any old human capital would do: for some things the company needed people with particular skills; for others, it could benefit from the more general ramping up of IT research and education. Just as a focusing device was needed to excite researchers about research directions relevant to the problems in developing GSM, so that same device pointed the way towards the need for PhDs and MSc courses.

Overall, the study confirms the picture we painted in our discussion of Exhibit 5 of a set of relationships supporting industrial and academic development and of the tensions between different incentive systems being able to keep industrial and academic needs in balance. However, in a system where the state intervenes to take on some of the risks of innovation (as all developed countries do), this balance depends in part upon the skills and competences of the R&D funders.

The history shows that STU/NUTEK's skills and competences were very important in enabling the mobile telephony success. The interaction between SRA, the radio club and STU was fruitful partly because STU had the technical competence to be a discussion partner and to be critical of proposals. As a result, STU received access to companies' and academics' views about technological needs, likely trajectories and road maps and to an understanding of industrial development that could not have been understood by a purely administrative apparatus. The fact that STU's project officers themselves took funding decisions enabled them to negotiate and participate even in the process of project development, where necessary, and they were therefore welcome at the table when the radio club met even if they did not always attend.

The STU people involved were thus not 'bureaucrats' but were often former researchers from related fields. They generally had no need to go and consult a committee of experts in order to understand and decide about a proposal. The first programme officer of the Digital Communications programme later used his research background to good effect and became a technology entrepreneur after leaving STU. STU was willing to let the project officers make a number of project-level bets – normally rather modest in size – in the expectation that some would pay off and the certain knowledge that many would not. In the case of the radio club, this meant that some of the doctorands and junior researchers were able to get STU funding despite their complete lack of an academic track record because STU was able to put faith in them and their context. Avoiding the normal funding Catch-22 for new fields seems to have been a useful contribution to launching the research field quickly.

At the time when the radio club started, STU was just beginning to think about how to programme its activities in response to the criticisms of the STU Commission. In practice, STU was able to deal with the radio club through response-mode project funding and to monitor developments in the field. Once it became clear that digital communications would be important and that there would be a high demand for people with R&D skills in that area, STU/NUTEK was able to launch a specific R&D programme – one of whose explicit aims was to scale up the operation. At that point, STU/NUTEK's organisation took over the network coordination function previously played by the radio club and expanded the size of the network. STU's ability to move from a responsive/monitoring mode to a programming mode was key to developing the field and to creating the supply of mobile-relevant relevant manpower needed to underpin Ericsson's expansion.

However, STU's analytical capacity and close contact with industrial needs also underpinned its role in promoting the idea of a national IT programme and orchestrating it across multiple agencies and their ministries. This 'top down' strategic capacity, together with its lower-level and partly more responsive actions such as in digital communications, appears to have been a winning combination.

Another important lesson to draw from the mobile telephony history is the role of Nordic cooperation in the early stages. The combined efforts of the Nordic PTTs were crucial to establishing not only Ericsson but also Nokia as major players in world markets. Since EU accession, there has been increased scepticism about the value of the Nordic cooperation but – while there are of course a number of special circumstances that are hard to repeat – this is a clear demonstration of the value of building a Nordic platform from which to take on the world – an idea that has recently reappeared in Nordforsk's virtual Nordic Centres of Excellence and the new NordicNets.

7.3 Policy Implications

This study illustrates the complexity of the relationship between innovation and research and the role of many conditions that are necessary for innovation but none of which is sufficient. In the absence of sufficient conditions, a crucial policy implication must be that interventions must have a systemic perspective, taking account of bottlenecks and opportunities as these arise. Simplistic interventions based solely in ideas like the linear model or the naïve human capital model are unhelpful, however attractive their simplicity may be. It is the growing appreciation of the need for a systemic understanding of innovation and the need for more complex interventions that is driving the EU and OECD discussion today about 'policy mix'.

The mobile telephony history points to the need to think about policy mix on two levels. One is the mix between the research-council style of funding, dominated by concerns about quality and track record, on the one hand and on the other more explicitly use-oriented research funding, with its concern to establish links with innovation processes in order to generate social and economic benefits. The tension described in our discussion of Exhibit 5 illustrates some of the reasons why both styles are needed in a system that is intended both to do fundamental research and to link to society: essentially that the research community needs incentives to do both these things.

At the level of the innovation agency, the history suggests a need to balance response-mode project-by-project funding and programmed funds. The point of the response-mode funding is not only to react to isolated good ideas but also to act as a kind of 'search engine' to look for needs and opportunities. To do these things requires substantial technological competence and the authority to make funding decisions; bureaucracy and the mechanical application of standardised assessment criteria cannot accomplish it. It also requires a portfolio approach because no matter how good the intelligence applied, innovation projects are highly prone to failure. Neither a research council nor an administratively driven agency could have reacted to, fostered and eventually scaled up the radio club in the way STU's internal intelligence let it. Indeed, a study[97] of mobile telephony development in the USA concludes that National Science Foundation – the US research council – made no contribution to its development.

One example does not let us say what the right ratio between response-mode and programmed funding should be. Researchers were emphatic that VINNOVA allocates too little of its budget this way and while that response is a little stereotypical it nonetheless suggests the question of balance may be worth investigating at VINNOVA.

The success in mobile telephony naturally prompts the question: How can we do more of this?

The point of departure of our story was SRA's internal technological capability and its 'absorptive capacity'. This underlines the importance of the research policy emphasis in recent years on PhD education and graduate schools, and especially on the competence centre style of school, where industry is closely involved and where PhDs become focused on matters of industrial importance (whether in applied science or use-oriented fundamental research) while still being conducted with the normal rigour of university research. Instruments like 'industry doctorands' that encourage the injection of research skills into companies are also important, in order to raise the level of absorptive capacity and to form an 'advance guard' of research capability. Once such people are inside the firm, they start to suck in others.

The 'focusing mechanism' of the radio club and later the digital communications programme operated not only at the level of research but also in education. If the knowledge becomes important then there will also be a need for knowledge-bearers at both first degree and PhD levels. In a university system with research-based teaching, first-degree education will tend to follow directions established at PhD level, but large-scale changes will nonetheless require coordination, as was the case in the national IT programmes.

In VINNOVA's world, there are projects and there are programmes. There are few intermediate-level focusing devices like the radio club. VINNOVA could usefully explore the opportunities for enabling actions at this exploratory level, for example by funding network meetings, small-scale foresight and road mapping exercises that help set agendas and thereby encourage others to set up their own radio clubs'. The European Research Foundation's Exploratory Workshops have some of these character-

97 David Roessner, Robert Carr, Irwin Feller, Michael McGeary and Nils Newman, *The Role of NSF's Support of Engineering in Enabling Technological Innovation*, Arlington, VA: SRI, 1998

istics and could serve partially as a model but industry's role in these activities must be central. This could be achieved, for example, by insisting that only industry can apply for the relevant funding. At a slightly larger scale, VINNOVA could consider funding test beds and similar small-scale shared facilities that act as focusing devices. There is scope for experimentation with a range of small-scale focusing devices.

STU/NUTEK, like VINNOVA, had the twin instruments of bottom-up and programmed funding at its disposal. This meant that it had the flexibility in the early years to respond to developments while in the later period to formalise the activity into a programme that was able to scale it up and meet national needs. Maintaining such flexibility to use appropriate instruments was necessary in order to support development of the field. It also implied planning and budgeting mechanisms that were tuned to the industrial wavelength – that could receive and amplify signals from groups of industrialists and researchers and use these to trigger programmes. An innovation agency needs to combine such responsiveness with its own strategic intelligence. It needs a radio, it should be switched on and someone should be listening!

Weinberger suggested that STU's key success factors were: money; a credible vision of technological developments; and the ability to judge quality.[98] This required technological and industrial vision both at the level of project officers and, via the analysis function, at the level of the organisation as a whole. Such an organisation should clearly be interdisciplinary in character but, as the mobile telephony example and the wider IT programme illustrate, a significant part of the capability must be technological in character and that means the personnel should have a high proportion of technologists.

The money was also important. We have looked at a case where STU's bet succeeded, but there were others that did not. One of the strengths of project funding is that it lets the agency search for opportunities while containing the cost of failure. In uncertain circumstances, it is better to bet a couple of projects than a whole programme. (The motto should be 'Lose small; win big'.) Crucially, the portfolio of projects has to be large enough to let the winners win through and the culture has to understand failure as part of the search process, not as poor performance *per se*. Such portfolio thinking is difficult to maintain in the face of the growing demands of the New Public Management for predictability, detailed quality control and management by results. VINNOVA could consider whether it adequately communicates this aspect of its work. You should not run an innovation agency in the same was as you run a municipal bus company. (Certainly, a venture capitalist who employed the principles of the New Public Management would have a short career.)

98 Hans Weinberger, *Nätverksentreprenören*, Stockholm: KTH, 1997

Weinberger's description of STU as a 'network entrepreneur' is a good one and a good description of its activities in relation to digital communications and ICT more generally. The observation of STU's second director-general, Bertil Agdur, that STU should not be an administrative apparatus but a **change agent** goes to the heart of the role of an innovation agency.

At isolated points in our story, we have identified individuals who spent a year during their PhDs or as post-docs in the USA, deliberately acquiring knowledge of a new technique or research area and bringing that home to Sweden. Despite their clear value, these appear to have been funded from rather diverse sources. This kind of 'Viking raid' on developing areas of technology did not occur only in digital communications. A well-known example is of a former director of IVF who was sent (by ASEA) to spend time at MIT's Servomechanisms Lab in the early 1950s and effectively imported numerical control into Sweden. The value of this kind of expedition is easy to overlook in the current context of widespread EU cooperation. VINNOVA might usefully consider whether a small number of grants targeted at taking post-docs outside the EU to key centres of excellence with the intention of acquiring technologies would be a useful way to strengthen national technological capabilities.

Despite the policy focus on SMEs in recent years, the example of digital mobile telephony shows both that large companies can benefit from support in establishing focusing devices and the massive rewards that can result from success when large firms are involved.

A number of policy implications for industry also emerge from this study.

- The story of SRA/ERA as a small, almost semi-official island of high technological capability within a large company with a focus on other things illustrates the importance of absorptive capacity. Without an initial few research-capable people, it would have been much harder to see the developing importance of digital radio communications, to identify the technological bottlenecks and to encourage researchers to work on these. Maintaining a core of research capability was important, at least in this case
- The interactions with the universities were selective, focused on current and future development issues and backed up by internal projects. The capacity to interact in this way, as well as to do internal research, needs to be maintained across long periods, in order to tackle successive product and technology cycles. It is not a one-time requirement but a permanent one that should drive the kind of long-term relationships that Ericsson has developed with Lund, KTH, Berkeley and other universities

- These links are needed not only in order to obtain and absorb knowledge form outside but also in order to maintain the supply of skilled and specialised R&D labour needed by influencing the activities in the university system. SRA's idea of setting up shop outside the gates of the universities of technology was in this sense absolutely the right thing to do
- Another success factor for Ericsson has been the ability clearly to distinguish research from development and to organise these differently. The outputs of research are knowledge and uncertainty-reduction, not products and processes
- The examples of the radio club and the various test beds that were key to the GSM story suggests that these kinds of arenas should actively be developed by industry where it needs to focus research interest on matters of importance to it. In the absence of development pairs these days, such arenas need to be comparatively open. The risks of openness are contained, however, by the fact that the ultimate benefits for the company are learning how to do things (and what things not to do) and manpower; generating product or process secrets is unlikely

Appendix A

Reference Group for the Project

From industry and academia

- Lennart Alfredsson
- Bengt-Göran Bengtner
- Conny Björkvall
- Östen Mäkitalo
- Jan-Erik Stjernvall
- Jan Uddenfeldt
- Lars Zetterberg

From VINNOVA

- Sven-Ingmar Ragnarsson
- Eva Westberg
- Anders Hedin

Appendix B

List of People Interviewed

Lennart Alfredsson
John B Andersson
Tor Aulin
Bengt-Göran Bengtner
Christian Bergljung
Conny Björkvall
Henrik Börjesson
Per Ola Börjesson
Gunilla Bratt
Peter Brauer
Peter Butovitsch
Staffan Carlsson
Steinar Dahlin
Lars Dahlman
Gunnar Edwall
Björn Ekelund
Nabiel Elshiewy
Thomas Ericsson
Lars-Erik Eriksson
Henrik Floberg
John Graffman
Björn Gudmundsson
Fredrik Gustafsson
Tony Hagström
Claes Hammar
Thomas Haug
Anders Hedin
Torbjörn Holmberg
Staffan Håkansson
Rolf Johannesson
Erlandur Karlsson
Kurt Katzeff
Göran Lindell
Lennart Ljung
Östen Mäkitalo
Torleiv Maseng
Sven Mattisson
Hans Nässla
Mats Nilsson
Jan-Erik Porath
Sven-Ingmar Ragnarsson
Per Runeson
Nils Rydbeck
Bernard Smeets
Torsten Söderström
Bo Stenviken
Mikael Sternad
Jan-Erik Stjernvall
Erik Ström
Arne Svensson
Bertil Svensson
Per Tjernlund
Mats Torkelsson
Jan Uddenfeldt
Mats Viberg
Ulf Wahlberg
Lars Wanhammar
Björn Wasell
Eva Westberg
Lars Westberg
Johan Wickman
Per Willars
Jens Zander
Olof Zander
Lars Zetterberg
Tommy Öberg
Per Ödling
Sven-Olof Öhrvik
Erik Örnulf
Viktor Öwall

Appendix C

Ericsson

C.1 Location of Mobile Communications in the Ericsson Organisation 1976-2006

Year	Product Groups/Business Areas							
1976	Public telephone exchanges	Private exchanges, telephone instruments, intercom systems	*Transmission equipment for telecommunications, radio systems*	Other systems and pro ducts	Military electronics and development projects	Cable, wire, line equipment	Other products	
1978	Public telephone exchanges	Subscriber exchanges, telephone instruments and intercom systems	Telex and traffic signalling systems	*Transmission equipment and radio communications systems*	Military electronic equipment and development work	Cable, wire and network equipment	Components and other Group products	Miscellaneous
1979	Telephone and telex exchanges	Subscriber exchanges, telephone instruments and intercom systems	*Transmission equipment and radio communications systems*	Military electronic equipment	Cable, wire and network equipment	Traffic signalling systems, components and other Group products	Miscellaneous	
1981	Telephone and telex exchanges	Data equipment	Subscriber exchanges, telephone instruments and intercom systems	*Transmission equipment and radio communications systems*	Military electronic equipment and development work	Cable, wire and network equipment	Traffic signalling systems, components and other Group products	Miscellaneous
1982-1986	Defence Systems	Components	Information Systems	Public telecommunications	Cable	Network Engineering and Construction	*Radio Communications*	Other Operations
1988	Defence Systems	Components	Business Communications	Public Telecommunications	Cables	Network Engineering and Construction	*Radio Communications*	Other Operations
1989	Defence Systems	Components	Business Communication	Public Telecommunications	Cable and Networks	*Radio Communications*	Other Operations	
1990-1991	Defence systems	Components	Business communications	Public Telecommunications	Cable and networks	*Radio Communications*		
1993	Defence systems	Components	Business networks	Public telecommunications	*Radio Communications*			
1997	*Mobile Systems*	*Mobile Phones and Telephones*	Infocom Systems					
1998	Network Operators and Service Providers*	Consumer Products	Enterprise Solutions**	Other Operations				
1999	Network Operators and Service Providers*	Consumer Products	Enterprise Solutions**	Other Operations				
2000	Network Operators and Service Providers*	Consumer Products	Enterprise Solutions**	Other Operations				
2001	Systems (Mobile Systems, Multi-service networks)	Phones (Sony Ericsson Joint Venture 50-50 from Oct 2001)	Other operations					
2002	Systems (Mobile Systems, Multi-Service Networks)	Phones (Sony Ericsson)	Other operations					
2003	Systems (Mobile Networks, Fixed Networks, Professional Services)	Phones (Sony Ericsson)	Other operations					
2004	Systems (Mobile Networks, Fixed Networks, Professional Services)	Phones (Sony Ericsson)	Other operations					
2005	Systems (Mobile Networks, Fixed Networks, Professional Services)	Phones (Sony Ericsson)	Other operations					
2006	Systems (Mobile Networks, Fixed Networks, Professional Services)	Phones (Sony Ericsson)	Other operations					

* one unit active in fixed networks ** one unit active in wireless telecommunication

C.2 Chronology of Mobile Communications at Ericsson, 1976-1993 Ericsson' radio communications history 1976-1993 (from Ericsson Annual Reports)

1976	Svenska Radio AB and other Group companies develop a broad range of radio communication systems and equipment. This includes mobile radio equipment for various civilian and defence purposes, marine radio equipment etc.
1978	SRA Communications AB and other Group companies develop a broad range of radio communications systems and equipment. This includes mobile radio equipment for various civilian and defence purposes, marine radio equipment etc. The acquisition of Sonab Communications AG, a sales an installation company, resulted in an increased activity in the field of radio communications systems. Substantial successes were scored with mobile radio telephone systems and the wireless ERICALL CONTACTOR personal paging system, which was introduced during the year.
1979	SRA Communications AB is one of the leading companies in the European market for radio communications systems and equipment. The Company develops, manufactures and markets a wide range of products for non-military applications in the fields of land-based radio communications, paging systems and mobile telephone systems. Other products include mobile radio links and portable radio systems for tactical military communications. The use of land mobile radio communication in both private and public networks is increasing. SRA Communications AB has developed new, advanced mobile radio equipment for use in the Nordic mobile telephone network. The system employs digital frequency synthesis and microcomputer control functions, which makes it simple for the operator to use.
1981	SRA Communications has recorded substantial success in its sales programme during the past year and the company will double its turnover during the next two years. Notably in the field of land-based mobile radio, SRA Communications recorded very high order bookings, not least as the result of success with its mobile telephone systems and its equipment for tactical communications, developed for customers within the defence sector. New products in the field include two automatic mobile telephones, personal pagers for Swedish Telecommunications Administration's nationwide mobile paging network, and ciphering equipment for police and military radio communications. Comprehensive development work is also under way on a new line of radio exchanges for both small and large mobile radio networks. The Group commands substantial resources in the field of land-based mobile radio communications radio and personal paging systems. The Group is strong in the civil market, with advanced radio systems for both transport control – a taxi fleet control system with central computers, for example – and automatic mobile telephone systems. The Group has a unique position being able to supply an integrated complete system with radio stations, mobile units and computer-controlled telephone exchanges.
1982	A new Group structure was developed in 1982, with operations organised in Business Areas and transfer of operational responsibility to the Business Areas. 'Radio Communications' became a new Business Area, comprising *microwave systems, mobile radio, mobile (cellular) telephony, personal paging systems.* On January 1, 1983 SRA Communications became a wholly owned subsidiary of LM Ericsson and its name was changed to Ericsson Radio Systems AB. As part of the reorganisation of commercial operations within the Group, the Parent Company acquired the minority interest in SRA Communications AG which had been held by General Electric Company plc of England. Mobile telephony, which differs from mobile radio in that a subscriber has direct access to the public telephone network, is our fastest-growing product field. The world market is expanding very rapidly and was of the magnitude of several billion Swedish kronor in 1982. Ericsson has received contracts to participate in the development of nationwide mobile telephone networks for the Nordic telecommunications administrations, as well as the Netherlands, Spain and Saudi Arabia. These orders total one billion Swedish kronor. In mobile radio, Motorola, an American company has about 40% of the world market and 60% of the business in North America. General Electric (U.S.) and Philips (NL) also compete in the world market. Ericsson has a relatively small portion of the world market but is the largest supplier in the Nordic countries and among the largest in the Middle East. Motorola is Ericsson's foremost competitor in the field of mobile telephony but access to AXE technology is giving Ericsson a distinct competitive advantage. Ericsson's share of the world market in this sector is substantial. Sales of the Radio Communications Business Area have risen at very rapid rate in recent years – an average of 30% annually during the most recent five-year period – with most of the increase attributable to volume increases.

1983	Major sales successes were recorded with Ericsson's mobile telephone (cellular radio) systems in 1983. The largest contract was obtained in Great Britain, where Ericsson will deliver one of two nationwide systems. In Ireland, a small system has also been ordered for the city of Dublin and two contracts were received in the U.S., for Chicago and Buffalo. Mobile telephony is by far the area of greatest expansion in this Business Area. The Business Area is a world leader in the systems field, with installations in service or on order in 12 countries. The AXE exchanges and the Business Area's know-how in radio communication constitute the base for the success of Ericsson's mobile telephony system. Ericsson's delivery of equipment for the Nordic Telephone Network (NMT) has provided important experience. During 1983 Ericsson purchased Magnetic, a Swedish company that manufactures base station equipment for mobile telephony. Ericsson also sells mobile telephone instruments (handsets) but the competitive factors in this sector are totally different from those in the systems sector. Long-series production and efficient distribution are decisive. Competition from around 20 manufacturers is severe. The Business Area has 20% of the Nordic market today. Ericsson's systems know-how is of great importance to the Business Area. Ericsson is one of the few companies in the world with immediate access to know-how in the fields of both radio and telecommunications. In this respect, Ericsson has a distinct lead over most of its competitors. The rapid growth of the Business Area is increasing the need to supplement Ericsson's R&D through access to other sources. A pre-requisite for this is a greater cooperaton with universities and colleges. As part of this type of cooperation, a development department for radio communications has been established in southern Sweden. The site was chosen to facilitate cooperation with engineers at the Lund Institute of Technology.
1984	The Radio Communications Business Area includes four product areas: - *Mobile telephony:* base stations, exchanges and terminals ("telephones") for vehicles - *Mobile radio:* mobile stations (portable or mounted in vehicles), control units, base stations, relay stations and link stations. - *Personal paging equipment* for local and regional networks. - The new product area *Radio transmission sector,* having replaced 'microwave communication' and responsible for Ericsson's operations in the field of satellite technology. It has substantial sales of 'mini link' microwave equipment. The Swedish Telecommunications Administration has ordered substantial quantities of this equipment in connection with the expansion of the NMT system. Sales of the Radio Communications Business Area in 1984 amounted to Skr 1,992m, 25% higher than in the preceding year. Mobile telephony showed the greatest relative increase, with a near-doubling of sales. Ericsson now has contracts to supply systems for mobile telephone networks in 16 countries, including the U.S., Canada and Great Britain, and is one of the leaders in technical development in this field in the world market. Large competitors include Northern Telecom, At&T and Motorola. Despite the rapid increase in sales, operating results, after depreciation, declined by Skr 63m, resulting in a loss of Skr 32m. The causes lay primarily in the mobile radio and personal paging equipment sectors. A programme to raise the efficiency of operations within the Radio Communications Business Area was begun in early 1984. A concentration of the product line, now under way, involves the allocation of increased resources to mobile telephone system operations, among others. Demand for mobile telephony is growing at a rate of about 25% a year. Ericsson has initially concentrated on the construction of networks in which its AXE switching system is the vital base. In Scandinavia and other countries where the NMT system has been introduced, Ericsson also sells telephone terminals (handsets) for vehicles and is one of the market leaders in this area.
1985	Radio Communications comprises the following areas: - *Mobile Telephony* including base stations and terminals (50% of sales) - *Mobile Radio*, including systems with stationary and mobile units for closed networks (15% of sales) - *Personal Paging Systems* for local networks (15% of sales) - *Radio Transmission*, including radio link systems and space projects (12% of sales). Sales in 1985 were 33% higher than in the preceding year. The largest increase, more than 80%, was in the mobile telephony product area. Orders received in 1985 included a contract from the Swedish Telecommunications Administration for a test network for digital mobile telephony that will make it possible to obtain basic data for standardising the next-generation Western European systems.

1985	Ericsson has now contracts in 22 countries. During 1985 Ericsson further strengthened its position as the world's leading supplier of systems for mobile telephony (cellular radio). Ericsson is also expanding its capacity to produce terminal equipment. Competition, notably from Japanese manufacturers, is severe. The field of mobile telephony is one of the most important, strategically, for Ericsson. It is based on Ericsson's systems know-how in telecommunications, with AXE as the core technology.
1986	The Business Area comprises the following product areas (% of total sales in parentheses) - *Mobile telephony*, including systems and terminals (65%) - *Mobile radio*, including systems with stationary and mobile untis for closed networks (15%) - *Personal paging systems* for local networks (15%) - Miscellaneous operations (5%) Product area 'Radio transmission' moved to Business Area 'Defence Systems' (product area 'Microwave communications', including radio links and satellite operations) Ericsson, which leads in the development of systems for mobile telephony, had a 45% share of the world market in this field at year-end 1986. The NMT network, the largest in the world with 310,000 subscribers, is largely based on Ericsson technology. During 1986 this network was expanded through the introduction of a new system - NMT 900 – to further increase capacity. Deliveries of base stations in the Nordic market increased 50%. 15 more mobile telephone systems were delivered to customers in the U.S. Ericsson now has 35% of the U.S. market not served by telephone operating companies. A new generation of mobile telephones was developed for NMT 900. The new technology, based on surface mounting techniques has made it possible to design a hand-held mobile telephone that is no larger than a conventional telephone receiver.
1987	- *Mobiltelefoni*, sysem och terminaler (67%) - *Mobilradio*, system med fasta och rörliga enheter för slutna nät (13%) - *Personensökare* för lokala nät (15%) - Övrigt (5%)
1988	The Business Area comprises the following product areas (% of total sales in parentheses): - *Mobile telephone systems* (51%) - *Defence communications* (16%) - *Mobile telephones* (13%) - *Personal paging systems* (11%) - *Mobile voice and data systems* (7%) - Miscellaneous operations (2%) There was a reorganisation of product areas in 1988. Defence communications operations were transferred from the Defence Systems Business Area to Radio Communications. Again in 1988, despite the exceptionally strong growth in volume in the sector, Ericsson maintained a 40% share of the world market for systems used in mobile telephony. One mobile telephone out of four in the highly competitive U.S. market is connected to an Ericsson system. Ericsson's principal competitors where systems are concerned are Motorola and AT&T. The two share the greater part of their domestic market in the U.S. and Motorola even has a share of the European market. In the Far East, Ericsson competes mainly with NEC. The BA's Swedish factories in Gävle and Kumla were expanded parallel with the increasing order bookings for mobile telephony equipment. The purchase of Radiosystems Sweden AB not only strengthened production capacity but reinforced R&D capabilities in the radio field. Ericsson in partnership with Matra, a French company, was selected as a supplier for the new "GSM" digital Pan-European mobile telephone system. Successful demonstrations of Ericsson's digital mobile telephone system based on TDMA technology were carried out in Los Angeles during 1988 and in January 1989 this technology was selected as the American standard. This is the same principle that will be used in the Pan-European mobile telephone system in the 1990s.
1989	The Business Area comprises the following product areas (% of total sales in parentheses): - *Mobile telephone systems* (56%) - *Mobile telephones* (14%) - *Mobile radio* (15%) - *Mobile data systems* (1%)

1989	- *Personal paging systems* (7%) - *Defence communications* (7%) - Miscellaneous operations (2%) Product area 'Mobile radio' reappears. Ericsson maintained its leading position in the world as a supplier of systems for mobile telephony. As of January 1, 1990, 40% of the 6.5 million mobile telephones in service were linked to Ericsson systems. Ericsson's position in the U.S. and Canada were strengthened through a joint-venture agreement with GE in the field of mobile communications. Ericsson will have access to GE's sales and service network for mobile telephones. Ericsson GE Mobile Communications, in which Ericsson holds a 60% interest and GE 40%, makes Ericsson the world's second-largest supplier in the field of mobile communications, after Motorola. Ericsson has nearly1/4 of the market for mobile telephone systems in the U.S. and more than half of the market in Canada. Procurement of equipment for the Pan-European digital mobile telephone system that will begin to be placed in service in 1991 started during 1989. In January 1989, the TDMA technology proposed by Ericsson was selected in the US as the American standard for digital mobile telephony. In autumn 1989 Ericsson launched 'HotLine Pocket', a new generation of pocket-format mobile telephones. The excellent talk time effect, the ration of call time to weight (420g) resulted in rapid marketing success. Deliveries of the new, advanced '8000' digital tactical radio to the Swedish Defence Forces were begun during 1989. The radio contains a ciphering system based on 'frequency-hopping' that is very difficult to break and which will also be used in the new commercial mobile telephone systems in the Nineties.
1990	Product areas remain the same. No percentages (sales) available. During 1990, a succession of telecommunications network operators in Europe selected Ericsson to supply equipment for the new GSM digital cellular mobile telephone system. Ericsson with a 40% market share continues to be the world's leading supplier of mobile telephone systems. Ericsson will continue to have a strong role in European research projects, most notably in RACE (Research in Advanced Communications for Europe), which is focused on the development of broadband communications.
1991	Product areas remain the same. No percentages (sales) available. Following several years of strong expansion, the market for mobile telephony softened in 1991. It was affected by the international recession and by the wait for the changeover from analog to digital technology that has just begun. At the end of 1991, Ericsson's share of the market for mobile telephone systems was more than 40%, with 6% of the market for mobile telephones. There are a large number of players in the market for mobile telephones, while the principal competitors in the systems segment are Alcatel, AT&T, Motorola, NEC, Nokia, Northern Telecom and Siemens.
1993	Following increases of 57% in order bookings and 73% in invoicing, the Business Area 'Radio Communications' is now Ericsson's largest. This is largely attributable to the very substantial successes with digital mobile telephony. Mobile telephone systems account for nearly 80% of the Business Area's sales and is thus the dominant operation within Radio Communications. During the latter part of the 1980s large resources were invested to develop the technology for the digital systems that were then beginning to be discussed. Its active involvement in standardisation work, as well, explains how Ericsson during the past 2 years became the dominant supplier of both systems and terminals for GSM. SMS, a new facility for mobile networks introduced by Ericsson during 1993, is a function by means of which brief text messages can be distributed via mobile telephones. Several GSM networks delivered by Ericsson were enhanced with this service in 1993. Sales of mobile telephones were 2-and-a-half times larger than in 1992. As a result, Ericsson's share of the market for analog mobile telephones rose sharply, with an even larger increase in the market for digital instruments, where it was the largest supplier in 1993.

Appendix D

Glossary of Acronyms

1G	First generation mobile telephony (analogue)
2G	Second generation mobile telephony (digital)
3G	Third generation mobile telephony (higher bandwidth digital)
3GPP	Third Generation Global Partnership
4G	Fourth generation mobile telephony
ACREO	Swedish electronics research institute, now part of SWICT
AKE	Last generation of Ericsson analogue switches
ALI	National Institute for Working Life Research
Amfo	Swedish Work Environment Fund
AMPS	US 1G system
ASIC	Application-Specific Integrated Circuit
AT&T	US telephone company, former monopolist and owner of Bell Labs
AXE	Ericsson digital switch
BiCMOS	Integration of bipolar junction transistors and CMOS
BTH	Blekinge University of Technology
C-450	German 1G system
CAD	Computer-Aided Design
CADCAM	Computer-Aided Design and Manufacturing
CDMA	Code Division Multiple Access
CEPT	Conference of European Posts and Telegraphs
CMOS	Complementary Metal Oxide Semiconductor
Codec	Coder-decoder
COST	European Cooperation on Science and Technology
CTH	Chalmers University of Technology
D-AMPS	US 2G system
DECT	Digital Enhanced Cordless Telecommunications stadard for cordless telephone handsets
DoCoMo	Japanese telephone company, formerly Nippon Telephone and Telegraph (NTT)
DSP	Digital Signal Processor
DUP	NUTEK R&D programme on IT in control technologies and work
EDGE	3g standard - Enhanced Data Rate for GSM Evolution
EFOR	One of the agencies merged to create STU in 1968

ELAB	Electronics laboratory of the SINTEF research institute in Trondheim
ELLEMTEL	50/50 telephone switch developer owned by Ericsson and Swedish Telecom
ERA	Ericsson Radio division - formerly called SRA
ESPRIT	European Strategic Programme of Research in Information Technology
ETSI	European Telecommunications Standards Institute
EU	European Union
FDMA	Frequency Division Multiple Access
FMV	Swedish defence procurement agency
GMSK	Gaussian Minimum Shift Key modulation
GPRS	General Packet Radio Service
GSM	Groupe Spécial Mobile - more recently Global System for Telecommunications
HIPERLAN/2	2g mobile standard
IBC	Integrated Broadband Communications
ICT	Information and Communications Technology
IM	Institute for Microelectronics; originally the Microwave Institute; later ACREO
INFOR	One of the agencies merged to create STU in 1968
ISDN	Integrated Services Digital Network - first-generation digital standard for the PSTN
IT	Information Technology
IT3F	Information and Telecommunications Task Force of the European Commission
ITA	IT Applications programme - part of the national IT programme plan, never launched
ITU	International Telecommunications Union
Itx	Phase of the national IT programme (IT1, IT2, IT3, IT4)
ITYP	NUTEK R&D programme on IT in services
JAS	Last generation of Saab fighter aircraft
KFB	Swedish National Board for Transport and Communications
KTH	Royal Institute of Technology, Stockholm
LiTH	Linköping University of Technology
LPT	Linear Predictng Code
LSI	Large-Scale Integration (Large Scale Integrated Circuits)
LTH	Lund University of Technology
LiTH	Linköping University of Technology
LuTH	Luleå University of Technology

MCCDMA	3G mobile standard
MNC	Multinational Corporation
MoU	Memorandum of Understanding
MTA	Mobile Telephone System A
MTB	Mobile Telephone System B
MTC	Mobile Telephone System C
MTL	Mobile Telephone Lauhréen - original name of MTA
MTX	Mobile telephone exchange
NIWL	National Institute for Working Life Research (ALI)
NMP	National Microelectronics Programme
NMT	Nordic Mobile Telephone - 1g standard
NTT	Nippon Telephone and Telegraph (NTT) - now called DoCoMo
NUTEK	Swedish National Board for Industrial and Technological Development
OECD	Organisation for Economic Cooperation and Development
PDC	Japanese 2g mobile telephony standard
Peanuts	Administrative computer system at STU and NUTEK
PHS	2G mobile telephony system
PSTN	Public Switched Telephone Network
PTT	Posts and Telecommunications authority
R&D	Research and Development
RACE	R&D in Advanced Telecommunication for Europe - EU R&D programme
RALF	Swedish Fund for Working Environment
RTMS	Italian 1G system
SEK	Swedish Crowns
SICS	Swedish Institute of Computer Sciences
SIND	Former state business support agency - now part of VINNOVA
SINTEF	Technological research institute in Trondheim
SISU	Swedish Institute for Systems Development
SME	Small or Medium Sized Enterprise
SOU	Swedish official publications series
SPC	Stored Programme Control
SRA	Svenska Radioaktiebolaget - former part-owned subsidiary of Ericsson, now wholly owned
SS7	Signalling System 7
STEV	One of the agencies merged to create STU in 1968
STU	Swedish National Board for Technological Development
TACS	UK 1G mobile standard (a variant of APS)
TDCDMA	3G mobile telephony standard

TDMA	Time Division Multiple Access
TEKES	Finland's innovation agency
TFB	Predecessor of KFB
TFD	Predecessor of TFB
TLA	Three-Letter Acronym (expression widely used to mock telecommunications engineers)
UHÄ	Department of Higher Education and Universities
UMTS	Universal Mobile Telephone System
UU	Uppsala University
VINNOVA	The Swedish Agency for Innovaton Systems
VLSI	Very Large Scale Integration (integrated circuits)
WATM	4G mobile telephony standard
WCDMA	3G mobile telephony standard
WLAN	Wireless Local Area Network
WTO	World Trade Organisation

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Effects of research on Swedish Mobile Telephone Developments: THE GSM STORY

Ericsson's development of mobile telephony is one of Sweden's outstanding industrial successes of recent years in terms of turnover, employment and exports. This impact study focuses on the role of Swedish government research funding in the development of technology for mobile telephony, especially GSM, and the subsequent Swedish success.

The study shows that a number of factors were important. These included the dialogue between the supplier Ericsson and the customer Swedish Telecom and their mutual support in the international standardisation process. Another factor was the technological capabilities and market strength already built up under the Nordic cooperation that created the NMT system.

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VINNOVA´s mission is to promote sustainable growth
by funding needs-driven research
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