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BECOMING HIGH-TECH: THE REINVENTION OF THE MECHANICAL ENGINEERING INDUSTRY IN TAMPERE, FINLAND

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Becoming high-tech: The reinvention of the mechanical engineering industry in Tampere, Finland[1]

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1 Introduction

1.1 Background on the Tampere case

This case study explores how an old industry reinvented itself in order to enter the new economy. It profiles the transformation of the machinery industry in the Tampere region, and highlights how being in Tampere has affected the ability of local companies to innovate. The collapse of the industry in Tampere has been avoided by internationalization, specialization and the active introduction of new technologies. Employment in machinery-related companies has remained fairly stable during recent years.[1]

The case of the Tampere machinery-related industry can be seen as an example of the reinvention of a traditional industry. During the last few decades, the industry underwent a transformation from a relatively low productivity, labor intensive metal industry to a concentration of export oriented and highly specialized firms supported by strong focus on R&D and high technology. A typical characteristic of many of the companies in the area is that their roots are in highly-diversified industrial conglomerates like Tampella, Valmet and Lokomo that dominated the Tampere city-region in previous decades and have now disappeared. The know-how that existed in those companies, combined with new technical expertise provided by local research and education institutions was funneled to the more robust and promising fields that prospered and grew even as most of the traditional industrial base in the region –textiles, leather, and shoes, for example–disappeared. Sub-units of these earlier conglomerates still exist and are independently successful. Today Tampere is home to several companies that are world market leaders in mobile heavy machinery, as well as large-scale process machinery and automation. All of these companies concentrate their product development activities in Tampere.

The key to the survival of the machinery industry in Tampere has been the introduction of new technologies into traditional machine-building. This process includes upgrading basic capabilities such as materials, machining, design, and testing, and, most importantly, the infusion of electronics, control, and information technology into the machines. The technological transition has been brought about through a long-term process of building innovation capabilities in the companies, often in interaction with the local and national knowledge infrastructure. Tampere University of Technology (TUT) has played an especially important role in recent decades as a provider of skilled labor, technical know-how and problem-solving abilities relevant to the local industry. Also, national organizations like the Technical Research Centre of Finland (VTT) have been influential in generating new knowledge, building up a portfolio of cross-industry technology platforms, and transferring knowledge and technology across industries and disciplines of knowledge. The development of expertise in the local innovation system can be understood as a continuous, interactive co-evolution of the knowledge institutions and the industry.

From one perspective, Tampere can be seen as a case of creative destruction, in which the old industrial culture has given way to the new organizational forms and production models of the knowledge economy. However, although there has been a structural transformation and some sectors have disappeared, there are two distinctive features about this case. First, there has been continuity in the knowledge base. Machine-related expertise can be traced back to the industrial origins of the city and later to World War II and the industries that emerged in the post-war period, while automation can be traced to the arrival of aircraft manufacturing in the 1930s. The second interesting aspect of Tampere is the strong role played by information and communications technology, especially from the beginning of the 1990s onwards. The successful integration of automation and control systems has relied upon a synergy between the fields of mechanical engineering and information and communications technology.

At the regional level, Tampere is a good example of how a combination of a strong knowledge infrastructure, corporate vision and leadership, and active local development policy can succeed in avoiding the fate of so many old industrial regions. Even though most of the recent growth of the region occurred after the recession of the early 1990s, the building of regional capabilities began much earlier. It can be argued that local actors understood the need for change already in the 60s and 70s, which led to stronger interactions among the education, research and production sectors. What is especially noteworthy about Tampere is the important role played by the local network of public and private actors in turning the tide in the city's economic prospects.

1.2 The case study

The objective of this research is to elucidate how Tampere's local innovation system –with special emphasis on universities and research institutions– affects the ability of companies to innovate and assimilate new technology. We are seeking to understand, for example, how local innovation-related institutions and organizations affect the innovation process within firms – i.e. their effect on the ability of engineers and managers to come up with new ideas and transform them into new products and processes. Our inquiry focuses on the following three questions:

1. What is the nature of the industrial and technological transformation in Tampere's mechanical engineering industry?
2. What is the nature of the core innovation process behind this transformation and what are the conditions that are likely to facilitate it?
3. Why has the Tampere environment been conducive to innovation in the mechanical engineering industry? In particular, what has been the role of education and research?

In answering these questions, we have captured circumstances and transformations at the institutional level (the macro level) and how they affect the innovation process as observed in the evolution of specific products (the micro level). In other words, we are trying to discern the macro-micro link.[2] To do this, we approach the reality under investigation through several *entry points.* The first entry point is at the macro level (section 2), where we seek to understand the industrial history and culture of the Tampere region and the policy and institutional frameworks for innovation in place. The second entry point is mezzo level or firm specific, exploring the innovation histories of specific firms and the communities within them. Through this second entry point, we take a close view at the micro-level innovation process using products as the units of observation and their evolution (the technological change process) as the unit of analysis. Our analysis at this level is covered in section 3, where we provide accounts of the evolution of products in three companies in the mining, forestry, and process automation sectors. Through these three corporate accounts we illustrate the innovation process in the Tampere region. Each account concludes with the "story behind the history", where we describe the actors, processes, interactions, and events behind the evolution of products. In section 4 we bring out the technological transitions in these products, find that the core process at work is the integration of new technology into the machines and identify projects as the organizing units for innovation in the industry. Finally, in section 5 we discuss how this processes at the micro-level process of integration is affected by Tampere's environment.

Our views of technology are inspired by the research traditions in science and technology studies (STS), more specifically in the history and sociology of technology. From this perspective technology is not a black box. Technological artifacts are embedded in a network of social and technical relations, in which technological change and product outcomes are path-dependent and socially constructed as humans interact and make decisions around them. History and context matter.[3] This perspective is receiving increased attention as one of the most promising avenues to further our understanding of innovation research and technology policy practice.[4] A close analysis of artifacts and their evolution is thus central to our inquiry as we seek to discern these relationships and how history and context matter for technological change in Tampere.[5] Consistent with this view of technological change, we view innovation as a *process* that is inherently *social*.

Our investigation is regionally circumscribed, industry focused, technology specific, product centered and process oriented. Our research design is qualitative, historical and case-based and our explanations are inductive, localized, socio-technical and process oriented.[6] The building blocks of our argument have emerged form a series of in-depth semi-structured interviews with a variety of actors in the Tampere Region, ranging from policy and business strategists level to engineers and project managers working within firms. Our contribution is mostly empirical; we report the findings from our research in Tampere and offer an interpretation.

1.3 Policy relevance

From a policy perspective, this case study is of utmost relevance. It addresses the important question of survival of an industry, which is often tightly coupled with the economic well being of a whole region. Tampere's mechanical engineering industry is a remarkable example of how an old-economy industry reinvents itself by proactively assimilating new knowledge, new technology and adapting to an evolving business environment; and also of how a supportive environment affects the ability of industry to innovate, and ultimately, to survive.

2 The Region and the Industry

2.1 Definition of the region and the industry

Tampere is located in the southern part of central Finland, some 170 km northwest of Helsinki. Its roots as an industrial center date back to the early 19th century. The city of Tampere has about 200,000 inhabitants and the size of the whole urban region is around 300,000. It is the second biggest urban concentration after the Helsinki region and the biggest inland city in the Nordic countries. More recently, Tampere has also become known as a student city, having over 23,000 university students in several major educational institutions.[7]

Although nowadays a region with a diverse range of industries, Tampere still has a strong focus on mechanical engineering industry. Several overlapping concentrations can be distinguished that are focused on process automation and machinery and various types of mobile working machines. These fields are the strongest sub-fields of mechanical engineering and automation in the Tampere region. The industry consists of several world market leaders in what are typically highly specialized niche products supported by a concentration of sub-contractors and parts providers which together form a regionally functional cluster (see Figure 1). There are also smaller industry concentrations centered on glass processing machinery and stone crushing machinery. These core industries are embodiments of a long tradition in mechanical engineering, dating back to the 19th century. As production is mainly concentrated on investment goods and production machinery, most of the customers are other industries, most notably forestry and paper, electronics, mining, transport and a wide range of other manufacturing industries. Strong areas of expertise in the regional cluster include machine automation, mobile hydraulics, the control of dynamic systems, thermal and laser coating, flexible manufacturing and production automation and process control systems in the pulp and paper industry. The key technologies in these areas are hydraulics, automation, electronics and wireless technologies. Automation is a central competitive factor in various branches of industry.

The mechanical engineering and automation industry employs almost 17,000 people in the Tampere region. The annual turnover of this sector is over €2 billion (1999). When the active implementers and developers of process control and automation (the rubber and plastics industries) are included, the gross value of the production from this sector rises to €3 billion, or half of all the industrial output in the region. Correspondingly, the number of personnel in all related fields rises to 24,000. Growth and development are evident in the process and manufacturing industry, the tools and automation industry, and in private engineering, planning and consultation agencies.[8]

Recently, industry ownership has changed and many of the leading companies are now foreign owned (e.g. Tamrock by Sandvik, Timberjack by John Deere). The biggest drivers for this internationalization are the globalization of the markets in which the majority of the core companies and their customers operate. This has made many companies in Tampere attractive targets for multinationals. The attractiveness of the expertise in these companies is reflected by the fact that very few production operations in the region have moved abroad. Moreover, in some cases product development activity has actually become more concentrated in Tampere, which suggests the presence of a considerable amount of specialized local know-how in these companies that is difficult to transfer.

In the region there is a rather specific concentration of firms on different kinds of working machines. Despite serving different markets and customers they draw on the same technological and knowledge base. What is interesting is that while the companies are not directly competing with each other in the same markets, they nevertheless have similar needs when it comes to new innovation, parts suppliers, etc. This means that they share in the dynamics of concentration of similar activities seen in many regions while at the same time not suffering from the negative effects of co-location between competitors (information leaks, IPR issues etc.). The similarities in the innovation processes and requirements of these companies are illustrated in later parts of this paper.

Although we cover the whole field of machinery industry in this paper, our in-depth analysis of innovation (Section 3) is based upon a detailed examination of two mobile heavy machinery companies and one company in the process automation sector.

2.2 Importance of the regional economy

Tampere has traditionally been the industrial heart of Finland, dating back to the 19th century. Industry is still an important employer but during the past 30 years the local economy has experienced a profound structural change. The proportion of industrial workers has dropped from over 50% in 1970 to a little over 30% in 2000. However when taking into account the outsourcing of various industrial services and the change in the nature of jobs it is clear that industry is still a very strong sector in Tampere Region. A considerable number of new service jobs have been created in the public sector as a result of the developing welfare state. As a whole, the fastest growing areas in the region are both private and public services (see table 3).

The nature of work has changed tremendously since the 1970s and it can be argued that the employment base of the region has changed more as a result of intra-industry changes than because of a structural change towards a service economy. A good example is 3,800 jobs at Nokia Corporation, none of which are in production –all are in R&D– but are still counted as industrial jobs. As industrial activities have become more knowledge intensive and dependent on global marketing and service networks this has meant that instead of a city of blue collar workers Tampere has increasingly become a city of engineers. Between 1985 and 1997 the amount of people with high-level education doubled from 9% to 18% in the Tampere sub-region.[9] The education level in the Tampere region is nowadays above the average in Finland (see Tables 1 and 2.).

The industry base in Tampere is quite diverse, including textiles, paper, rubber, medical equipment, media, etc. Nevertheless the bulk of the production relies heavily on machinery and telecommunications. The manufacturing of machinery and equipment is the biggest employer and the second biggest producer in the region. It employs one fifth of all industrial workers in the region. (see Table 4). Within that category, the sub-categories of "other general-purpose machinery" (SIC292) and "other special purpose machinery" (SIC295) stand out.[10] The machinery industry is also very export oriented, with two thirds of all production exported.

Investments in innovation activities have increased tremendously during the 1990s (see Table 5). What can especially be seen is the dramatic increase in industry R&D. This is partly a result of Nokia expanding its activities in Tampere since opening an R&D center in 1987. Also, the education sector (universities, university hospitals) has almost doubled its R&D spending between 1995 and 2000. For example, the amount of external research funding in the Tampere University of Technology budget rose in that period from €25 million to €42 million.

2.3 How the industry got started in the region

The rise of mechanical engineering can be traced back to the pre-WWII period, when the whole metal industry started to grow. The introduction of the state airplane factory in 1931 was one of the factors that increased the need for engineering industry. During wartime, employment in the metal industry was already approaching that of the textile and leather industry and Tampere was the site of manufacturing of munitions and weapons. By 1943, largely fueled by the manufacturing of weapons, vehicles and components for World War II, the metal industry was the biggest industrial sector with nearly 27% of the workforce. The textile, clothing, footwear and leather industries were still a strong branch after WWII and in 1956 those industries still employed 18,000 people. Since then, employment has fallen dramatically, and in 2000 was only 2,900. Even so, in relation to the rest of the country the production of textiles, clothing, footwear and leather is still quite strong.[11]

After the war, a substantial share of Finland's industrial infrastructure was devoted to paying war reparations to the Soviet Union. Tampere was the production center of metal products and machines, boosting the development of machinery manufacturing and related fields of expertise in the city-region. Many machines and vehicles had to be put into production that had not been built in Tampere before. Tampella Ltd, in Tampere, made the largest contribution, producing over 14% of all machinery and devices manufactured in Finland for reparations.[12] Our interviewees suggested that the technical, production, and design skills of local engineers and technicians (in machinery in particular) were enhanced by the need to innovate and produce the machines demanded as reparations by the Soviet Union, which often were not previously manufactured at all in Tampere. There was also a shortage of all kinds of products in the country and new machinery had to be built to start new production of both industrial and consumer products. Later, many of the companies continued to sell the same machines to the Soviet Union that were previously provided as war reparations and in that sense, new markets were opened. The Soviet Union was the main market for Finnish machinery exports up until the Soviet collapse in 1989.

2.4 Evolution of industry structure in the region

At the beginning of the 1960s industry still provided over one-half of all employment in Tampere. The absolute number of industrial jobs was at its zenith in 1962 and the rapid decline only started in the mid-1970s. Employment continued to decrease until 1993 when the amount of industrial workers in Tampere was 16,776. After that it began to increase for the first time in decades and in 2000 the number of industrial jobs had risen to 21,770 in Tampere. In the whole urban region the number of industrial jobs was 31,244, 23.7% of all employment.[13]

The restructuring of industry can also be seen in the productivity numbers. In the machinery industry, for example, production increased by over 25% between 1975 and 1995 even as almost half of the jobs were being lost. This means that productivity increased over two fold in 20 years.[14] For industrial production as a whole, output rose slightly between 1975 and 1995 at the same time that employment declined from over 35,000 to about 20,000. Since 1995 production in the region has increased further but employment has also been on the rise. In machinery manufacturing the production increased from 955 million euro in 1995 to 1,173 million euro in 2000 (see table 4). These figures clearly suggest that instead of a collapse certain industries were able to make the transition.

Since the 1980s a new industry, ICT, has emerged and grown substantially. The main motor for this development has been Nokia Corporation, but also many other new companies have been established or have moved to the region. In 2002 there were approximately 300 companies related to ICT employing 8,500 people compared to some 3,000 people in 1994.[15]

Many external contributors to the industrial transition in Tampere can be identified. With the rapid growth after WWII came a very rapid increase in wage levels, which created incentives for industry to develop automation. The oil crises of the 1970s was a remarkable shock, which catalyzed a wide discussion about Tampere's future among city officials. The collapse of the Soviet market at the end of the 1980s and the general recession in the early 90s each had a large influence. For the export-oriented machinery industry all this has meant a continuous need to find new solutions in order to survive.

2.5 Leading firms in Tampere's mechanical engineering industry

The 20th century industrial history of Tampere is intertwined with the growth, diversification, and decline of Valmet and Tampella. From their early specialization in aircraft devices and paper machinery, respectively, these two companies grew into diversified industrial groups, often spinning off new ventures. Along with this diversification into new products and markets came a diversification of skills and knowledge base, while preserving the common foundations of mechanical engineering and automation. Many of the current companies are related in some ways to these groups.

Our interviews also showed that many senior engineers and company executives share an employment background in one of these companies.

Valmet illustrates this process. From the State Aircraft Manufacturing in 1936, its spin offs include: In 1941 – Kuorevesi Works, now Finavitec and part of Patria industries (electronics); 1943 – Linnavuori Works, later Sisu Diesel and now part of Kone (diesel engines); 1964 – Valmet Air Systems, now part of Metso Paper; 1968 – Valmet Instrument Works, now Metso Automation; 1984 – Valmet Logging, later Partek Forest and now part of Kone (forest machinery); 1986 – Valmet Otis Lifts, now Otis (elevators); 1991 – Railway Division, later Rautaruukki Transtek and now part of the Spanish group Talgo; 1992 – Valmet Factory Automation, now FASTEMS (flexible manufacturing systems); 1994 – SISU Terminal Systems, later Kalmar Industries and now part of Kone (container handling).[16]

Today, the leading industries in the Tampere region consist mainly of the ICT, machinery and forestry industries, of which the latter reside outside the urban core. ICT, especially, has developed rapidly during the 90s. Today Nokia Corporation is the biggest employer in the city and total employment in the ICT industry exceeds 10,000 workers. At the same time, the more traditional machinery industry has grown more slowly.

In the Tampere region there are more than ten industrial companies that are global market leaders in their field: for example, Kalmar Industries (now part of Kone), which has concentrated on container handling machinery in ports and large container terminals all over the world, and Timberjack (part of the John Deere Group) in the field of forest machinery (see Table 6 for market share information of these and other companies). The market leadership of the leading machinery companies appears mainly to be based on incremental innovations, combining technologies in existing and new products aimed at very specialized niche markets. With the help of top level production know-how and short development lead times, high end products can be manufactured at competitive costs in Finland regardless of high labor costs as well as higher freight costs and delivery times associated with distant markets.

Three main clusters have been identified in the Tampere machine building and automation industry: mobile work machines, process and production machinery, and process automation (Tampere Centre of Expertise program 1999-2006).

Some major companies in mobile work machines are Kalmar Industries (part of Kone), the world market leader in container handling machines; Sandvik Tamrock, the world market leader in hydraulic rock drill machines; Bronto Skylift, the world market leader in high lifting platforms; Metso Minerals, the world market leader in mobile stone crushing machinery; and Timberjack (part of John Deere), the world market leader in forest machines Other significant enterprises in the cluster are Patria Vehicles, Avant Tecno (mini loaders), Pinomäki (forest machines) and Liftec (container and cassette handling) among others. Outside the Tampere Region there are other Finnish companies belonging to the cluster and having close connections with the region, for example Ponsse, Loglift (hydraulic log loaders and cranes), Logset (forest machines), Velsa (mobile cabs), Normet (mining and farming vehicles) and Timberjack`s factory in Joensuu. The high expertise of the cluster companies can be found in the technological fields of mobile machinery, hydraulics, machine automation, design engineering, virtual technology, load handling, power transmission, automated production, rock crushing and supplier networks (ibid).

In the process and production machinery field, the major companies include Tamglass engineering, one of the world`s leading suppliers of safety glass machines; Kvaerner Pulping, one of the world`s leading producers of special boilers; Metso Stock Preparation, a producer of pulp handling equipment; and Fastems, leading supplier of flexible manufacturing systems in Europe. Among other production equipment suppliers there are Finn-Power (metal manufacturing machines), Nekomat-Belos (material handling solutions), Tammermatic (vehicle cleaning machines), Sunds (paper processing machines), PCE Engineering (production technology for construction). The strong know-how of this field can also be found in the companies utilizing production automation. Fields of expertise of these companies are manufacturing processes, planning techniques, project management, automated production, robotics, tooling technology and system control.

In the process automation segment some major companies are Metso Automation, world market leader in paper machine automation; Instrumentointi, a global supplier of data transmission and file protection systems; Labkotec, process automation directed toward environment protection.Equipment suppliers such as Sunds and Metso Stock Preparation also deliver process automation. There are also companies providing expertise of process automation to end users like the forest industry and the energy sector in the Tampere Region. The fields of expertise in process automation are automation, control systems, measurement technology, information technology, data protection and virtual reality.

In the Tampere region there is also a concentration of component and system supplier companies that are among the leading companies in their fields. The most notable of these are Nokian Tyres, Teknikum, Tammerneon, Sisu Diesel, Patria Finavitec, Katsa, Ata Gears and Tasowheel. Most of the component suppliers in the region act as parts providers for the local machinery companies and can therefore be included in the regional cluster. For example Nokian Tyres can be included in the mobile machinery cluster as they develop and provide special tires for heavy machinery. Some other fields in the area are aviation industry, electron beam welding, power transmission, material technology, design engineering, rubber technology, production technology and personnel participation.

2.6 Competitive standing and innovative performance of the industry

As a whole, the competitive standing of the Tampere machinery industry seems to be strong. Many of the leading companies operate in global markets and hold a strong and steady market position. There are several reasons for this. First, many companies operate in very narrow niche markets, manufacturing specialized products mainly for production activities. The main competitive advantage is based on an established global customer base and highly specialized engineering expertise, which is hard to transfer to other companies. The narrow market focus and high barriers to entry for new competitors keep the markets quite stable.

There are also threats to the industry, however. Many of the companies serve mature markets, which means slow growth or even declining demand base.[17] The future success of their customers is crucial for the machinery providers. Second, the companies are increasingly being sold to foreign companies, which may have competing or overlapping products. The acquisitions can mean rearrangements both in R&D and manufacturing. The headquarters of many of the main companies are already situated outside Tampere, which may weaken the position of local units in the continuous process of restructuring. Third, there is some concern about the current age structure of the manufacturing workforce and the future attractiveness of the industry for young engineers. In the future it will become increasingly important to get new trained staff not just for R&D activities but also for manufacturing. There is also some concern in the region about the ability to attract enough foreign researchers and engineers to support the innovation activities of the local companies.

The drivers of innovation and shifts in business logic have changed during the development of the industry. In the 70s and in the 80s external shocks in the marketplace forced local companies to invest in R&D in order to survive. After they had successfully established a strong market position, a new way to compete was by building closer co-operation with the customer in order to ensure an ongoing relationship. This meant a shift to deeper partnerships and co-operation. In the 2000s, many mature industries are facing small or zero growth and the question is no longer about competition but rather about the future of the markets. When the markets for new products decrease the question is where to generate the profit. The growing trend seems to be the move towards services. This means for example building whole logistic systems with the customer instead of just selling machines. It can also mean selling production capacity, annual service contracts or other means to move the source of revenues away from traditional product sales. More specific examples are provided in later chapters.

Many of the companies in our study base their competitiveness on innovative products, which give more value added to the customer even though the cost of the machinery can be higher than competing products. Very often each product is customized to the specific needs of the end-user. The companies in the region have been able to maintain their market position with this strategy, which is heavily dependent on the infusion of new technology and after-sales service. In some cases the need for rapid technological innovation is not as crucial, as customers might not be ready to put such innovations to use. Instead, in some branches the challenge is to move from technological innovation to organizational innovation e.g. improvements in the business logic. The other challenge is to continue introducing new technologies to established products, which requires new skills and interaction with other companies and research institutes.

2.7 Development spirit of the region

The creation of a regional environment that is supportive of innovation and industrial activities has been a very important mission of local actors in the region throughout the 20th century, but especially since the 1960s, when city officials and industrialists became clearly aware of the inevitable decline of the traditional manufacturing sector and the associated structural problems in industrial activities. Local activism to develop the city and especially the educational system started at that time and was very influential in building the competence base that has since been so important for the local industry to develop.

In Tampere there was a fierce will to get its own university and the transfer was finally realized in 1960 as a result of local mobilization and lobbying. Helsinki had had a private School of Social Sciences (YKK) that was established 1925. The basic idea of the school was to offer educational possibilities for people with limited means who had not graduated from high school. Its transfer to Tampere was influenced both by thrusting forces in Helsinki and appealing factors in Tampere. In 1966, the name of the institute was changed to the University of Tampere (UTA), and in 1974 it became a state university like all the other universities in the country.

The City of Tampere began to aspire to establish a technical university to fulfill the needs of local industry, and there was a local mobilization to achieve this. A side branch of the Helsinki University of Technology was opened in 1965. The branch finally achieved the status of an independent unit, the Tampere University of Technology, in 1972. The influence of the local environment was very clearly visible in the work of the university as co-operation with industry was emphasized from the beginning. This positive attitude towards industrial co-operation was in sharp contrast with the general opinion in the country at the time, which went so far as to forbid universities from cooperating with industry during part of the 70s. The Tampere University of Technology, however, continued cooperation and is today a central actor in the local innovation system.[18] During the 1990s, the share of external R&D funding for the universities in Tampere was the highest in Finland and TUT played an important role in this.[19]

The city of Tampere began to pursue a dedicated business development policy in 1970, when the first industry ombudsman was hired to take care of co-operation with industry. In 1993 a Business Development Centre was formed. The main task of the Business Development Centre is to plan and implement the city's business strategy, which creates a general vision for the city's business and industrial structure. The most recent projects include the eTampere and BioneXt projects, as well as initiatives focusing on the general promotion of expertise and know-how.

The city of Tampere is also actively involved in several development companies and the local science park Hermia, and was one of the founders of Tamlink, a buffer entity where university researchers can carry out proprietary research for local companies.

It seems that the active mission to develop the local conditions for industry has been more about coalitions of key people than a broad consensus among actors in industry, universities and public sector. Good examples of these small-scale coalitions were the cases of lobbying for universities, and infrastructure in the 60s and 70s, the formation of Technology Centre and

Tampere in the 80s and the development of local innovation environment in the 90s. In all these instances, a small group of active people from different organizations (universities, the city, industry, chamber of commerce etc.) discussed new possibilities and were active in launching new initiatives. The key people and their groups have been very active in Tampere also over a longer time than in many other cities. This has partly been explained from the point that Tampere has not been in the center of national politics (not an administrative center, small public sector, no regional policy support) and therefore there has been a need for local initiative.

Leadership has been fundamental. Local business leaders, often highly engaged in policy or in policy-corporate partnerships, have been instrumental in shaping Tampere's innovation systems and the resources that currently exist. They have both created and negotiated future visions and actively engaged in their pursuit.

2.8 The institutional set-up for innovation in the region

The core of the institutional setup for innovation in Tampere consists mainly of several internationally oriented companies, local research and education organizations, several local development organizations and local financial organizations. The regional system of innovation is tightly linked to national policy and many national level institutions like TEKES and Sitra (see Figure 5).

Regional innovation policy in the Tampere region reflects quite well the objectives and key areas defined in the local Centre of Expertise (CEP) program. There are four main fields in CEP: mechanical engineering and automation, and information and communication technology, which are both managed by the Tampere Technology Centre Ltd; health care technology managed by Finn-Medi Research Ltd; and media services managed by Media Tampere Ltd. The first two are focused on sustaining the main existing industries in the region while the latter two are trying to develop new industries. The city of Tampere is actively involved in all of these development companies.[20]

The Tampere Region Centre of Expertise is targeted on promoting the development of business activities in the region. As part of the national Centre of Expertise Program, it aims at promoting the development and transfer of knowledge and technology by developing cooperation between companies and between companies and educational and research organizations. Basically the CEP is a forum to build new networks and share information. In practice this is done by different kinds of working groups and development projects. Further discussion of the operation of the CEP is covered in Section 4.

In addition to the CEP there are other regional innovation initiatives, including eTampere and BioneXt. eTampere, a five-year development project costing 130 million euros, is a considerable project that links several activities and various actors. It has the bold objective of making Tampere a global leader in the research, development and application of issues related to the Information Society. In practice this is to be achieved by various new projects and organizations that are targeted on strengthening the knowledge base of the region, the creation of new business activities and the development of new public web services. The program consists of seven different sub-programs and its central implementers, in addition to the City of Tampere, are TUT, UTA, VTT and the companies in the region. The city of Tampere is actively involved in these development programs as well as financing different development companies.[21]

The local educational system is a very important part of the whole innovation system. The mobility of people in Finland is typically lower than, for example, in the United States. This emphasizes the need for local supply of highly educated people. In the Tampere region education is well-connected with local industry, especially in the relevant technical fields. In total there are around 23,000 university students in the region.

Tampere University of Technology has over 10,000 students, of whom almost 1,700 are graduate students. It has 10 departments and 33 institutes. The departments are: Architecture, Automation, Mechanical Engineering, Materials Engineering, Civil Engineering, Electrical Engineering, Information Technology, Industrial Engineering and Management, and Environmental Technology, Science and Engineering. The impact of TUT as a pool for the local labor market is considerable. In 2002 the university graduated over 700 students with graduate degrees, of whom 48 were PhDs.[22] TUT attracts students from all over Finland, and many of the graduates find a job and stay in the region.

Tampere University has over 14,000 degree students, of whom 11,900 are taking first degrees, 1600 are postgraduates and 800 are non-degree students. The university has six faculties: Faculty of Social Sciences, Faculty of Humanities, Faculty of Economics and Administration, Faculty of Medicine Faculty of Education, Faculty of Information Sciences.[23]

There are also many other educational organizations in the region. Tampere Polytechnic has about 5,000 students of whom 700 are in adult education.[24] The main fields are technology, business and administration, culture and natural resources. Pirkanmaa Polytechnic has over 3000 students in the fields of business administration, tourism, nutrition, tech and transportation, social welfare and health and culture. Tampere College (Vocational Institute) has about 1,750 students in various fields. The Vocational Adult Education Centre of Tampere is the biggest provider of adult education. It has around 2,700 students.[25]

The education system and especially the education of highly skilled and specialized engineers is viewed by the companies in the region as the most important contribution made by local educational institutions. The role of TUT has especially been highlighted by our interviews. This is consistent with Kautonen and Schienstock's analysis of the regional innovation system: "from the perspective of the innovation system, the most central organization in Tampere Region is the Tampere University of Technology. Nearly all other key support organizations have joint projects with the University."[26]

There have been co-operation projects between TUT and industry since the 1970s but the volume has increased considerably in the 90s. Between 1995 and 2002 external funding for the university increased from €25 Million to €46 Million.[27] The experience of university-industry cooperation from the 70s and 80s seems to have enhanced the ability to cooperate and manage interactions effectively (contacts, some project management experience, etc).

TUT is perceived by industry as the main source of highly-skilled workers, being the source of most of the engineers who stay to work in the region. TUT also has research, education and problem-solving capabilities in most of the fields of knowledge relevant to local industry, and there is continuous contact between university researchers and local companies. Another key form of interaction, constantly highlighted by industry, was a continuous flow of students who complete their diploma requirements (Master's thesis) by working on industry projects. In addition, TUT has served as a socialization mechanism. Many industry leaders and engineers working in the leading companies met each other at TUT as students. The role of the university is discussed more extensively in Section 5.

Although Tampere has a long tradition of research in the technical areas that are important for machine building and automation, direct interaction between industry and universities does not seem sufficient to explain the birth and development of now-dominant technologies or products. Most of the growth in co-operative research projects and in other formal interactions did not occur in the 1990s, but the industrial transition had started prior to this.

Another important player in the region is VTT Industrial Systems, part of Finland's national infrastructure of Technical Research Centres (VTT). VTT Industrial Systems is the product of the recent merger between the Automation and Manufacturing Technology units. In contrast to the universities, VTT is more focused on applied research, on project work with industry and on building up a portfolio of technologies that can be applied across industries. We further discuss the role of VTT in Section 5.

One of the key players in the region is the local science park – Hermia. The concept of a science park started to emerge in the late 1970s. A group of local leaders from the TUT and the City of Tampere started to make plans in the early 80s. Hermia was founded in 1986 and today has about 150 companies and houses 3,000 jobs. Hermia is located next to TUT and VTT. It is an expert organization, with an annual income of 7 million euros. Most of its work is carried out in various projects. Hermia has an important role especially for innovative SMEs. Hermia is managed by the Tampere Technology Centre Ltd. The same company also manages some other related activities like the Centre of Expertise program in the fields of mechanical engineering and ICT.[28]

2.9 Regional and extra-regional sources of innovation: from local to global

National integration in the field of innovation is quite developed. It is typical for companies to have connections to national R&D institutions like VTT, and many companies in Tampere are actively cooperating with other Finnish universities, especially Helsinki University of Technology. All in all, when looking at the support mechanisms for innovation it is actually more realistic to talk about a national innovation system with different regional dimensions.

Many of the local development organizations are partly financed by national level institutions like TEKES. Tekes is also a catalyst of cooperation between universities and industry through its Technology Programs, which provide seed funding for technology projects that require this kind of cooperation. Such cooperation often continues after programs are over, and thus there is a network-building effect involved.[29] TEKES technology programs also enable companies with similar interests to meet frequently, and to interact with universities and VTT units. In addition, it may be argued that Tekes Technology Programs highlight technology trends and serves as a "foresight agent" that is publicly accessible, and that mitigates risks by investing in technologies and projects that companies would not pursue on their own.

Within the region, the universities and VTT also provide access to national and global knowledge networks and in that sense they act as hubs to extra-regional sources of innovation. The local presence of VTT provides access to the national VTT network. Furthermore, VTT has changed from working just in Finland to an international R&D organization that sells R&D services to many foreign companies, which helps them to provide information to local partners. In 2001 9% of VTT's income came from international projects (VTT Annual Report). In the case of TUT, most of the core units have wide networks in their field and can be considered quite international. The Institute of Hydraulics and Automation, for example, is part of the Fluid Power Net, an international network of research centers in fluid power. Both VTT and TUT interpret knowledge created elsewhere and make it available to the local context in the form of education and of applied research. This interpretation happens typically through research contacts, publications, and joint projects with other companies and universities in Finland and elsewhere in Europe and, in some cases, around the world.

In a small country like Finland there are also many well-established informal networks ("weak ties") between engineers and managers, which can date back to studying in the same university or working previously in the same company.

> Tampere is a center for companies working with heavy machines. It is based on people knowing each other, who often worked in the same companies (TUT Professor).
>
> We are a small, homogeneous country, we share an engineering education and most of the people are in the same age group and know each other well. Making contact is easy, without need for formalities. You know each other personally, and that is a real strength (Center of Expertise).

More recently, a supra-national policy dimension has emerged. Finland's membership in the European Union has become a factor in promoting cooperation of local companies, universities and research institutes with their European counterparts. Several companies in Tampere have been involved in EU projects, and the cooperation usually keeps going even after the programs are over.

Major companies often have R&D activities elsewhere in Finland and often in other parts of the world, as well as connection with universities and research institutes outside of Finland. A general finding from our research is that bigger, more internationalized companies in the region assign less importance to local cooperation as a factor of success in their innovation performance. Larger companies work in global markets, have wide international connections and have the ability to access knowledge and monitor customer needs and markets in many places. The same applies to connections with other Finnish universities and with companies outside the region. Especially those companies that are foreign-owned or are parts of a larger international corporations have a strong international dimension in their R&D. This does not mean, however, that being in Tampere is not valuable even for these companies. The most important resource highlighted by all companies is a highly skilled workforce not available elsewhere. In addition, some companies distinguish between the kinds of things they can get from other locations versus what they can get by being in Tampere. There is a form of "deep cooperation", as one company executive called it, which involves continuous interaction and immediate access that cannot be had with distant partners. The ability to discuss technical issues locally, with companies that face similar technological challenges but that do not operate in the same markets, is also valued.

3 Innovation History in Tampere: A tale of three companies

In this section we take a closer look at innovation inside three companies in Tampere: Sandvik-Tamrock, Timberjack, and Metso Automation. To achieve this objective, we describe the evolution of one or several of their products and technologies since approximately 1970. These companies specialize respectively in mobile mining machines, mobile forest machines, and process automation applied to several industries. They all have a highly competitive position in the global market in their respective niche, and are all survivors of previous industrial conglomerates. In times of decline, they were able to change and successfully weather economic shocks. How did they survive?

Through these three stories we will illustrate how engineers, managers, organizations, artifacts and ideas in Tamepre have come together throughout the innovation process that has sustained the competitiveness of the three companies. Note how the narrative brings together all of these elements in the storyline, showing that innovation is a social process embedded in a network of social and technical relationships and that history and context matter for innovation. The three accounts illustrate how the institutional set up for innovation in the Tampere region (section 2.8) and the development and role connections with regional and extra-regional sources of knowledge and technology (section 2.9) played a central role in the product evolution of each company. The stories highlight connections with universities –TUT in particular– and with VTT, the technical research centre of Finland. In addition, they illustrate how certain policy interventions –like Tekes technology programs– foster collaboration. In short, these three tales show how the environment matters for innovation and how the ability of firms to reach out to innovation resources within and outside of the region matter for innovative performance *within* the firm.

Each account also illustrates particular aspects of the pattern of innovation in Tampere's mechanical engineering industry. Sandvik-Tamrock shows the role of leadership and how individual interventions impact innovation performance at the firm and regional level. This story also highlights the transition to hydraulic power systems, a core technology for all these companies, and the emergence of the Institute of Hydraulics and Automation, a related research institute in TUT that plays a central role for all machinery and automation companies. The Timberjack story illustrates in detail how the infusion of new technology into machinery has transformed not only the machines, but also the processes in the forest products industry. In addition, Timberjack illustrates a specific way of creating an environment for innovation. Finally, Metso Automation shows the evolution of automation devices, and illustrates the idea of *deep cooperation* that only happens locally.

Substantial parts of these stories that follow derive from the accounts of our interviewees in the three companies. References will only be made when other company reports and other sources that were consulted to construct the narrative.

3.1 Sandvik Tamrock: Mobile Mining Equipment

Sandvik-Tamrock specializes in mobile mining equipment. The company was founded in 1969 as the rock drilling division of the Tampella group. Today it is the most important business sector of Sandvik Mining and Construction, world leader in the supply of mining equipment, and part of the Sandvik Group, a Swedish engineering firm. All the research and development activities for mobile mining equipment are concentrated in Tampere. Tamrock has been at the center of several technological transitions that have characterized the market niches in which some local mobile machinery companies operate.

3.1.1 Evolution of Tamrock's mining equipment

Tamrock started producing hand-held drills in the 50s, and during the 60s there was a major deal to sell 50,000 drills to China, fueling the growth of the company and providing the resources to build the existing facilities in Tampere. Tamrock was a successful participant in the mechanization of mining by adopting new power systems. The two main obstacles for the mechanization of mining were labor, and the fact that mining processes had to be redesigned for the use of machines. During the process of mechanization, the initial power systems used in the machines were mechanical and Tamrock was one of the first companies in Tampere to implement hydraulic power systems, which could deliver more power more efficiently. The first percussion hydraulic drill was successfully tested in the mid 70s but at that point the market was not yet ready. In 1976 a customer returned a hydraulic drilling machine because it was too efficient: it could do an 8 hour job in 1.5 hours. This increase in efficiency meant a radical change in the business and required a new configuration of the process in the mines, which had to be redesigned in order to fit the capabilities of the new machines. In addition, early machine designs were big, heavy, and unreliable and there were no workshops underground to provide maintenance. Support systems also had to be changed for the new technology.

Tamrock was not the first mining equipment company to introduce hydraulics-based units. The technology –though not the products– had existed since the 1950s in the United States and a French company had tried to introduce it during the 60s, but the machines were not reliable and the market was not prepared. In spite of the lack of market acceptance and technical difficulties Tamrock continued to develop hydraulics-based products, and by the time the market was ready the company was a successful early entrant. Key to this success was the use of proper seals in the hydraulic systems which became available in the 70s; Tamrock was an early adopter and the application of hydraulic power systems in mining machinery started to work.

Mining equipment was a new business segment for Tamrock, whereas for competitors the new hydraulic technology meant competing with their own product line. According to a senior manager in the company, this allowed Tamrock to take more risks and experiment more than competitors. Tamrock was just a small division within the Tampella group, with the freedom to experiment and to make mistakes without much to lose.

Tamrock's business grew rapidly with the mechanization of mines, with its competitive position enhanced in part by superior technology. The transition from pneumatic to hydraulic power systems in mobile mining equipment finally took off between 1978 and 1980. By 1980 approximately 80% of the equipment sold was hydraulics-based and 20% pneumatic.

After the introduction of hydraulic power systems, product innovations focused on enhancing basic characteristics such as materials and machine design, and most importantly, on the integration of new technology within the products, specifically electronics, automation, and information technology. The early steps in bringing in these technologies were taken in the 70s, at about the same time of the transition to hydraulic power systems (which are better suited for to control systems than their pneumatic and mechanic predecessors).

Although automation and IT have allowed the company to expand its market position, these improvements don't necessarily translate into increased sales. Automation and information technology have progressively improved the productivity and the use of capital and equipment, and the mining industry is close to maturity and has slow growth. Even though there are opportunities for growth in the developing world –especially in China– the challenge now is to remain competitive and move into other product markets. At this point, Tamrock is making further efforts in automation. One field of opportunity is, for instance, unmanned mining, dependent upon the integration of wireless technology and intelligent systems. Opportunities in this area, though, are limited because automation is expensive and most mines are in some ways already automated and every product has microprocessors and control systems. In mines that are not yet mechanized –as in many parts of the developing world– labor poses a big challenge for mechanization and automation so growth prospects there are uncertain.

Tamrock's R&D manager suggested that the main challenge now is to remain competitive and to "stay awake." Besides expanding into new markets in the developing world, and continuing to rely on new technology, the company is expanding its service business. Already about two thirds of revenues come from after-sales services. Technology, in particular software and electronics, will continue to be a core of the company's strategy.

3.1.2 Story behind the history in Sandvik-Tamrock

The transition to hydraulic power systems in Tamrock was led by Rolf Ström, Tamrock's current General Manager for Research. After working for a brief period in the company during 1962, he returned to the company in 1972 to bring in hydraulic power systems. He first turned for help to the Tampere University of Technology, where he met Matti Vilenius, who was then a young researcher at the TUT. The meeting between Ström and Vilenius heralded the start of the cooperation between Tamrock and TUT; these were the early days of research on industrial hydraulics at the university. In 1982 Vilenius founded the Institute for Hydraulics and Automation (IHA), of which he is still the director. Today, the IHA is the only Center of Excellence designated by the Academy of Finland in the field of mechanical engineering, and it has extensive linkages with local machinery companies, many of which use hydraulic power systems and automation as core enabling technologies. Initially focused on education, cooperation between Tamrock and TUT soon expanded to research and since then, TUT has been the main source of knowledge and skilled professionals in the fields of hydraulics and machine technology not only for Tamrock, but for many other machinery companies in the region.

Ström has been an advocate of doing only development within the company while outsourcing research. This is reflected in the network of cooperation that Tamrock has built to access knowledge and research capabilities from various sources. Ström, for example, also promoted research on mechanics and structural optimization at the Lappeenranta University of Technology. Tamrock has also benefited from expertise in mining engineering from the Helsinki University of Technology. VTT has been a source of knowledge in automation.

Ström, like many other managers in the region, is an engineer, and has an extensive network of contacts with engineers that run other companies, many of whom share a background in the Tampere University of Technology or in the Helsinki University of Technology. “Speaking the same language” in his words, has facilitated cooperation and communication with managers in other companies and with universities and research institutions. This has been important in the process of bringing different fields of knowledge together and integrating technologies.

Ström points out that today, as throughout the history of the company, it is important to be “interested in the future.” Close contact with the customer is central since the company perceives its role as enhancing all the customer’s processes. Machines are, in the end, embedded in the chain of events that occur within a mine. Detailed understanding of these processes and the ability to identify opportunities to improve it is a source of ideas for innovation.

3.2 Timberjack: Mobile Forest Machinery

Timberjack is the world’s leading forest machine manufacturer, with a market share of approximately 30%.[30] Sales amount to about 500 million USD and production to somewhere between 2,500 to 3,000 machines per year. The product line of Timberjack include feller bunchers, skidders, log loaders, harvesters and forwarders. In addition, the company supplies information systems for optimization, management and logistics.

The roots of present day Timberjack go back to Canada and Finland. On the Finnish side the original company was Lokomo, a diversified company that had a forest machinery division founded in the 1940s. Lokomo was acquired by Rauma-Repola in 1983, together with the forest machines division. With the merger of Rauma and Valmet in 1999 Metso emerged, and Timberjack, a Canadian company bought the forest machinery division. Finally, in April 2000, Timberjack was sold to John Deere & Company and became a part of Deere’s Worldwide Construction & Forestry division.[31] Besides being one of two R&D centers around the world, Tampere is home to the company’s European market and service center and the management headquarters.[32] Production is carried out in Canada, the United States, and Finland. New concepts and fundamental engineering research and development is carried out by Plustech Oy, a separate organization that is part of the group and is in the same location as Timberjack in Tampere. Around 100 people work in the main engineering building and 30 in Plustech.

Because Timberjack has been built through acquisitions, engineering teams were dispersed in different places. Tampere used to have the forwarder engineering unit and harvester engineering was in Filipstad, Sweden.

> That location was not competitive, the city was small and not attractive to live and it was difficult to get engineers with the right qualifications. Tampere has a good enough image for people to move, and spouses are likely to find work, and Timberjack's products are attractive for engineers to work on (Senior Manager).

In 1996 all harvester engineering activities were moved to Tampere from Sweden. Some engineers migrated and many others were hired locally, mostly from TUT and especially from the Institute of Hydraulics and Automation. Usually one or two students a year do their thesis at Timberjack and are later hired by the company, and there is interaction between the company and researchers from the group. In the past decade the integration of hydraulics, automation, and information technology became pervasive in all products. Back in the 80s the company had 4 hydraulics specialists, and now there are about 15 engineers specialized in hydraulics and automation, four of them PhDs from TUT.

3.2.1 Evolution of forest machinery

In the SIC industrial classification, forest machinery falls under code 3523, "Farm Machinery and Equipment." However, forestry differs from other kinds of farming and the harvesting of wood is also different from other crops. The process involves marking the trees to be removed (in selective cutting), felling and processing of trees, and transportation of the wood from the felling site, or stump area, to a roadside storage or a central processing yard (landing) in the forest. There are two harvesting methods, and they differ on the amount of processing that is done on site, in the forest. In longwood harvesting, trees are only topped and delimbed at the felling site. In shortwood or cut-to-length harvesting, trees are completely processed at the felling site and the logs are then transported to a storage yard or site and eventually to the factory. Processing a tree includes top removal (topping), delimbing, crosscutting into logs (bucking), debarking, and sometimes chipping of residues or bad trees.[33]

In Finland, axe and handsaw were the major tools for felling trees until the early 50s, when the chainsaw replaced them, but this still remained manual work until the first machine harvesters were introduced in the 1970s. Hauling timber from the forest was done by horse until the 1930s, but machines replaced horses in the following decades. Tractors appeared in the end of the 1940s linking felling and long-distance transport, thus giving birth to the "wood transport chain." Later, tractors were replaced by especially designed forest machinery like caterpillars and skidders. Transporting logs to the processing site changed from floating or logs to truck as early as the 1930s. Rationalization of wood transportation began in the 60s. With the use of harvesting machinery, skidders and loaders for hauling became common, and then trucks transported logs to processing sites, creating a fully mechanized wood chain. This process is still being refined today.[34]

Mechanization has transformed wood harvesting as machines were introduced at all stages of the wood chain and now a great variety of machines are available for harvesting and processing of trees. Some perform separate operations like delimbing or debarking while others combine several operations. For instance, harvesters combine felling, delimbing, and bucking. Logs are then loaded on forwarders for transport to a landing. Processors top, delimb, and bunch felled trees and pile the logs after bucking.[35] With the introduction of harvesters and forwarders, shortwood harvesting is now the most widespread method in Northern Europe where virtually all harvesting is of this type, compared with only 15 to 20% in North America.[36]

Although initially rudimentary, forest machinery has been transformed by numerous innovations, further enhancing the wood harvesting process. Progress has happened in design, materials, power systems and other elements of the machine. And over the past 30 years the functionality and productivity of forest machinery has been enhanced by integrating electronics, control systems, automation, information technology and wireless communications. Over the past 10 years these technologies have also changed the management of the wood value chain in the forest industry by improving logistics and the flow and management of information.

Electronics and automation have been part of forest machinery for a long time. Back in 1972, when microcontrollers were relatively new, Timberjack (then Rauma) made early tests with the first electronic control system. According to an engineer in the company, the fact that Rauma's Forest division was small created more room for experimentation and innovation. At that time competitors were using relay controls but there was one small application niche: measuring the log with accuracy. This was difficult to do with relay controllers, while microcontrollers were simple to calibrate through software. By around 1978 the first machines with this feature were introduced, and customer demand for these kinds of features increased. Rauma was the first to enter the market with this technology. Technology penetration snowballed in the 80s, especially in Finland and Sweden. Germany, the United Kingdom and France are rapidly adopting technology. Among third-world countries, Brazil is rapidly mechanizing. North America is lagging behind.

Today all the machines, not only the harvester, are full of hydraulic power systems, and while computerized control systems have been controlling the machines since the 1980s, over the past decade automation and information technology have become pervasive. A revolution in automation came with the introduction of distributed digital control systems in the 1990s. In 1993 the Timberjack 3000 measuring and control system was the first one to distribute machine control tasks to several inter-communicating modules embedded in the machine, with a digital CAN (Controller Area Network), at its core. Also in 1993 TMC (Total Machine Control), made up of four independent modules was introduced in the Timberjack 810B forwarder. The most recent control system and successor of Timberjack 3000 is Timbermatic 300, a PC-based system measuring and control system, including as well e-mail, maps and GPS.[37] The system helps operators optimize wood usage, with functions like full tree prediction and value optimization. It also includes integrated control for stump treatment, color marking and electronic calipers. Work and repair statistics can also be analyzed. The operator can also use minigrip control levers and touch pads to navigate the machine. A color display is mounted in the cab in front of the operator, together with a keyboard.[38]

New product features are increasingly software-based, adding functions to the control systems and ultimately enhancing the performance of the machines. “The quality and speed of software development have, in fact, become one of the most important criteria for successful product development”, an interviewee said. The Timbermatic 3000 measuring and control system includes, for example, a software based adaptive feed control system that permits feed speed, and roller and delimbing knife pressure to be controlled automatically. The CD-ROM, floppy disk, USB port and serial ports enable software installation and updates.[39]

Software is also making possible the management of information produced and utilized in the whole wood chain. One example is TimberOffice, a combination of five programs.

TimberCenter, the core information and email management of the system, saves all the information collected by the harvester or received as an e-mail to relevant databases. SilviA, built in Timbermatic 300, helps create and manage price lists and bucking instruction files can be sent directly to a harvester working in the forest. These files include price and distribution and limitation lists, color marking, product groups and stem types. Production results, work and repair statistics, stem and calibration data can also be analyzed. TimberNavi is a Geographical Information System (GIS) designed for forest machines and utilizing the global Positioning System (GPS). In the machine it shows the machine position on a digital map display, and in the office different types of site information like borders, roads, strip roads, and biotypes can be added. The forwarder operator can find timber stacks by following the harvester's path marked on the digital map via GPS. TimberCalc is a cost, revenue and budget management tool. Finally, TimberMonitor monitors machine performance. Information is sent from the harvester by e-mail to Timber monitor where it can be processed, for example, to diagnose performance or productivity failures.[40]

Today, according to the interviews, more resources go into software development than mechanical design, changing the operation and the skill set required by the company. Although some software development takes place inside, the company has outsourced to other specialized companies in the software industry and from research facilities such as VTT and local universities.

In conjunction with information technology and automation, during the 90s mobile communication enabled the remote transfer of information between machines and contractors, changing the business by enhancing the management of the whole wood chain. According to our interviews, the presence of Nokia has made companies more aware of this technology and more willing to try it, and has fueled the birth of other wireless-related companies that are also used by other industries. However, wireless technology has been part of Timberjack products for about 10 years, linking the machine with the office of the contractor. This technology first took off in Finland and Sweden with the wide GSM network, and now all machines are connected through GSM. Wireless communications also enable the use of GIS, GPS, and e-mail capabilities to keep the harvester up to date with mill requirements and location information, and provided the contractor with production and performance figures. In the summer of 2002 Timberjack introduced the first harvester with a wireless Internet connection that allows for all remote monitoring, diagnostics and process management through the web. Bringing this information to the Internet may revolutionize information flow because you can use the information in different places at the same time: management, dealer, pulp mill, etc.

In the wireless area, the company does not do any software coding or hardware design in house. In general, when it comes to information technology (including GIS and graphics) and electronics the focus internally is on developing specifications and outsourcing hardware and software development to a network of small specialized companies mostly in Finland and Sweden. There is also cooperation with a company in California in the area of satellite communications, used to network machines in remote locations or as a backup. Satellites are not necessary in Finland and Sweden because the GSM network is pervasive and is the cheapest method of networking.

The use of wireless communications and IT integrates the machine and generates a vast amount of information. This technological combination is enabling Timberjack to move from selling machines towards focusing more on selling services. The company sees itself as improving the customer's process from the forest to the factory, and a key has been to know the whole information flow. This will change the business model and the company is adapting to the idea of selling information instead of machines. Improving technology is no longer an end per se, but an enabler to add value to the customer's process.

Today's forest machine is working autonomously in the forest but is linked to the logistics chain and to the office of the pulp mill or the paper mill via a cell-phone modem connection. Each log has a custom value and the trees are cut in the forest according to what is being sold. The sawmill already knows what type of lumber has been sold to the customer –to build houses for example. The machine operator gets a proposal of how to minimize the driving distance and when he goes out to the forest he already knows what kind of log is needed, including for example diameter and length. The harvester performs an optimization process on site: measuring the tree, felling, bucking, and color-marking the logs according to the final customer. Managing all this information greatly increases the value of the tree. Since logs at one site are not going to the same place, logistics and transportation is also optimized with all the information at hand. When logs are left on site the harvester sends GPS location information to the forwarder operators, who know with enough accuracy the size and type of the wood. GPS allows forwarders to come and pick up the logs wherever they are, in the dark or in sites covered in snow.

Automation keeps moving forward, but even if it were possible to build a fully automated machine, Timberjack does not plan to go that way. The operator will always need to be there but his role is changing; he now manages and controls the process on site, and his presence is important for quality control and accountability. The operator is controlling and managing the process on site. However, the rapid development of automation and information technology brings up the question of whether operators will be able to keep up. Timberjack makes them part of the development process by constantly monitoring what they are saying and testing new products with them. Knowledge about the human-machine interface is increasingly important and covers issues like user-friendliness to keep the machine easy to use for the low-end operator, aesthetics and occupational safety. Graphic designers and experts in ergonomics work besides electronic and software engineers. Different types of knowledge are coming together in this. “The key is connecting people to figure out the best solution”, an interviewee said.

3.2.2 Story behind the history in Timberjack

Our interviewees in the company emphasized the relevance of knowing the customer well. Timberjack monitors the current work processes of the customer and analyzes them to detect opportunities for intervention and improvement. To discern development trends, the company has connections with the forest industry and builds a total picture of the business where Timberjack operates, because machines are just one small part of the whole and what the company is selling is solutions and services. The product offered needs to be not only technically effective, but also needs to look good to the customer. If there are two forest machines that perform the same functions, are equally reliable and have the same price and features, the customer starts looking at other details like color and looks.

Timberjack separates product development into three levels, each with a different focus and level of risk. Present Product Improvement activities focus on reducing costs and making small improvements in existing products. In the Product Delivery Process the end result is always a product within a 2-year time frame, beginning from paper and going through several production prototypes, and is always 100% sure of delivering a product. The third level is long term concept development and testing, which is carried out by Plustech. In this case there is no certainty about the end result. The walking forest machine is the kind of concept technology that is very long-term; it took almost 10 years to develop and has been in prototype for three years. This kind of development is important to test new ideas and different kinds of technology, often transferable to the Product Delivery Process and the Present Product improvement.

In the late 1980s Plustech was the Rauma-Repola Technology Center and operated as a small scale business, partly owned by management, selling advanced R&D services. According to our interviews, Plustech is separated from the rest of Timberjack's product development activities to keep it free from the pressures of daily activities. In Plustech people work with new ideas without tight schedules and no short-term delivery work. that is not trying to manage the process, but about bringing together people with the right skill sets and competences. When talking about the activities unfolding in Plustech, our interviewee said that

> The kinds of experts working here are like artists. You have to know what kind of people they are and give them freedom… You cannot order people to do something. You have to organize the environment so that people can go on… If you are facing a problem without solution you cannot order, unlike a factory floor where you can order to move something. This is not about management, it is about leadership, about creating the space for others (Manager).

In the office of Plustech's manager there is a big sign with the initials "NIH", which stands for "Not Invented Here" syndrome. Dealing with internal resistance and being open to new ideas has been important for Timberjack's ability to innovate, keeping a positive attitude towards new information. These ideas might come from within, such as occurred in the 70s when the idea of using microcontrollers came from "a bunch of crazy guys." To get new ideas Timberjack recognizes that all the stages of R&D are needed, from long-term to short term product improvement, because by focusing only on the short term, the manager said, "you totally miss new ideas." Often these ideas are not commercial successes, but can be the beginning of something important. Even testing new ideas is difficult sometimes, because there is also internal resistance, often with the excuse that the customer does not need such a feature or that it will only increase costs. But being able to test new concepts has been important, starting with talking about the idea, and then physically testing the idea depending on the case. Back in the 1970s, when Timberjack was a small-scale operation within Rauma and projects were small, engineers had the freedom to test new ideas in products.

A number of the technologies and design principles in Timberjack's current product line were developed in the early 1990s. A team of engineers was in charge of redesigning the machines. An interviewee suggested that it was important to include people with experience but also new people that had had nothing to do with harvesters previously. If only experienced people had been included, it would have been difficult to break with tradition and established mental models. If, on the other hand, only new people had taken part, experience would have been wasted. Among the technologies developed by this group are the sophisticated control systems of the harvesters. They were developed "somewhat secretly" and until there was some progress, senior management became aware. Having that space to experiment "on the side" was important to develop a technology that is now integral to all machines.

A senior manager in Timberjack stated that another important reason to have Plustech as a separate operation is to put critical technologies together, and this happens in the context of development projects. Whereas the Product Development Process always has clear goals, deadlines, and risk is minimized, putting technologies together is more risky and freedom to fail is necessary. In this process different corporate units come together, as well as reaching out to universities and suppliers to connect the technologies. This is the case in current work on the human-machine interface, where many fields of expertise need to come together to figure out where to go. This kind of project, where the goal is not clear, is guided by a vision –usually a business target– and the sense that the technology is the right one to study. Often this vision emerges after the project has started, and other unexpected insights emerge along the way. That was the case with the walking forest machine, whose development started more than a decade ago. It took 10 years to have a prototype, but in the short term there were spin offs, ideas and technologies that were transferred to existing products and projects.

The main areas of expertise that come together within Plustech are the closely-related fields of mobile machine hydraulics and automation and control for mobile machines. There is also mechanical engineering and structural analysis, and one person in manufacturing technology. Expertise in materials is not present in house, but is available outside. Virtual prototyping is used to analyze systems before actually making them, and TUT often cooperates in this. Plustech has also developed a training simulator technology for virtual testing of equipment, including a simulator environment to test new software for harvesting machinery before loading it into the machines. There is also expertise in testing and evaluation.

Besides in-house expertise Plustech uses external resources extensively, "but in order to cooperate you have to have your own knowledge…you cannot utilize external resources if you do not know what to do", according to our interviewee. Plustech cooperates mainly with TUT, HUT, Lappeenranta University of Technology and the University of Oulu. The easiest interaction is with TUT because of its strength in mobile hydraulics and automation, and in other areas like control and virtual prototyping. Many TUT students do their theses at Plustech. Timberjack values the differences between the ways universities and companies do R&D. "Universities need to focus on R&D and not product development", and that is a reason to invest in basic research in universities, because "technology development cannot happen without it."

VTT is also an important partner, often through Tekes projects that require cooperation. When necessary there is also cooperation with some universities and companies in Sweden, Germany, the United Kingdom and the United States. Within Europe, the cooperation network has been extended by Plustech's involvement in European Union projects. Although most R&D is funded internally, Timberjack/Plustech is one of the companies in Finland that receives external funding through Tekes projects for example.

More recently, Timberjack's ability to access external resources has been enhanced by belonging to John Deere, as similar trends in automation are occurring in other products within the group in the agricultural and construction machinery sectors. There are now groups of experts representing the three machinery groups to share knowledge, experience, and extend cooperation networks. Timberjack is more advanced in distributed control systems, but has obtained useful insights from Deere for the development of software processes.[41] However, according to the interviews, cultural differences often make cooperation difficult. In the case of Plustech, for example, "we are used to do what we say; we say less things but what we say we do. In the U.S. people can say something but not really mean what is said… In U.S. organizations it is important to have exact definitions for everything, clear processes… That is not so important here. We have more flexibility in the organization. The bottom line is important here but many other things are important too." And although belonging to a big group brings new opportunities, the decision making process is slower, there is more bureaucracy and making decisions is more difficult.

Our interviewees said that within Finland and in Tampere more specifically, personal relations with people in companies that follow similar paths and operate in a similar business environment facilitate cooperation. Timberjack often cooperates through suppliers, rather than directly with the other mobile machine companies, and in this way what companies learn is spread around through the supplier. It is not shared with competitors, but applying the technology in different applications – like mining and forestry – is not a problem. There is also a widely shared view that those suppliers that serve several companies get new ideas by working in different applications that can be transferred across these customer companies. In general, having national focus areas for cooperation between universities and companies also facilitates cooperation within Finland, where there are not so many universities or companies.

3.3 Metso Automation: Process Automation

In 2001 Metso Automation was the world's third largest supplier of pulp and paper industry automation and information application networks and systems and the sixth largest supplier of power plant automation. Operations cover three main areas of process automation: process automation and information systems, automation and control valves, and process measurements and analyzers. The company's main customers are the pulp and paper industry, power generation, and hydrocarbon and chemical industries. The company is part of Metso Corporation, and along with fiber and paper technology (Metso Paper), and rock and mineral processing (Metso Minerals), Metso Automation is one of the core businesses. In 2001 it accounted for 15% of the total sales and 15% of the personnel of the corporation.[42]

The roots of the company –and of the automation industry in Finland– date back to 1921, when a workshop for repairing aircraft instruments was founded by the State of Finland in Helsinki. This became the State Aircraft Factory, which moved to Tampere in 1936. In 1945 this company evolved into the State Metal Works. Around this time, in 1944, the development of measurement and control systems for the process industry began, a line that would remain the main expertise of Valmet Automation. In 1951 the State Metal works was named Valmet Oy, and within it, in 1968 Valmet Instrument Works became a separate part of the group. Later this was incorporated in 1988 as Valmet Automation Inc. During the 1980s most of the expansion of Valmet Automation in Europe and North America happened through mergers and acquisitions. In 1999 Valmet Automation merged with Neles Controls Inc., giving birth to Neles Automation. Neles Controls had developed expertise in control valve manufacturing since its origins in the mid 50s, and in 1997 focused on control valves and digital flow control technology. In 2001 the company was renamed Metso Automation.[43]

3.3.1 Evolution of Metso's automation technology

The product history in what is today Metso Automation illustrates the evolution of automation technology over the past 20 years in the context of process machinery for the paper industry. In the 70s Metso Automation (then Valmet) had a product called AIRMATIC, which was a pneumatic measurement and control system. This product was transformed by the arrival of electronics, and ELMATIC was introduced. Instead of using air, it used electrical signals for measurement, changing the operating logics from measurement and opening the door to control systems. With the arrival of microprocessors in 1979 came DAMATIC. It was a distributed control system which required networks, software applications, a programming language and graphical user interfaces. Higher level computer-based controls were on top of it, constituting what was called a Mill Information System. A substantial part of the technology for DAMATIC was transferred by VTT Automation in Espoo (Helsinki Metro area), which had the expertise in communications and functional blocks.[44]

In 1987 came DAMATIC XD, an automation system whose development had begun in 1983. With it came the need for expertise in configuration because product delivery at this point was more about configuring the systems to specific customer applications than programming new or enhanced features. As it is always the case, R&D focused on programming while engineering focused on configuring customer-specific systems. The engineers are the ones who go out and install the systems. In Damatic XD there was a graphical configuration system to support the work of customer project engineers.

The 1980s focus on processes, high-level control and machine control, evolved into distributed control systems. Damatic XD combined with ordinary automation, high-level controls and machine controls and evolved into a distributed control system.

The next product generation came in 1995, called PaperIQ, used to take on-line paper quality measurements and enabled by a variety of sensor technologies. The company did not have expertise in-house, so in the early stages of development of Paper IQ the question was whether there was expertise in sensor physics in Finland, because measuring paper quality requires many kinds of sensors: beta radiation, x-rays, microwaves, and others. It happened that VTT in Oulu had background in optical measurements, VTT in Espoo was good at electromagnetic fields and the Technical University of Lappeenranta and the University of Joensuu were good at color measurements.

DAMATIC XDi came in 1997, incorporating information and knowledge management systems. In 2000 this system evolved towards metsoDNA (Dynamic Network of Applications), supported by embedded automation into the process machinery itself.[45]

Recently Metso Automation worked with VTT and the TUT on a project to embed a wireless technology into automation systems. For example, the configuration of the valve can be changed from the mobile phone, and it is possible to monitor how the valve is working and change its settings during set up. The idea for the project emerged during an informal meeting where people from companies, the university and VTT came together to discuss wireless applications. There were several meetings and discussions back and forth. "During the first conversations we did not have a clear idea in mind, but by the end this emerged as a clear candidate for a new product." Hermia helped bring together the engineers from Metso, VTT and the university at the start of the conversations.

Today Metso Corporation as a whole is transforming itself from an equipment supplier into a knowledge-based technology company, expanding from a traditional machine supplier to a comprehensive supplier of know-how and aftermarket services. Metso created the FutureCare business concept to move in this direction, and is relying on previous deliveries—about 800 pulping lines and 2,000 paper machines–to grow this line of business. The idea is to bring together equipment, solutions, software and services to form a comprehensive business concept to plan, develop and maintain customers' core processes throughout their life-cycle. New technology is central to this corporate transformation, and Metso Automation is playing a key role by providing enabling technology for Metso Paper and Metso Minerals. The development of wireless devices and communication and information networks, embedded intelligent measurements, open automation application networks and Internet and extranet technologies are central to the company's ability to provide new services. In addition, they are transforming the relationship with the customers, which will be based on long-term partnerships between the supplier and the customer. As Metso takes over responsibilities for managing the customer's process, continuous connection with the customer's processes becomes essential. Besides new technology, strong process know-how throughout the value chain is important.

3.3.2 Story behind the history in Metso Automation

Supporting this product evolution has been a large internal R&D operation, and the acquisition of knowledge and expertise through cooperation with universities, R&D organizations, suppliers, and sometimes by buying other companies. As an international corporation, the company has looked for expertise wherever it can be found. Usually, for IT the company cooperates with other companies that make tailor-made products for Metso. The company has been buying software from US companies and central Europe, and in 1985 it licensed software from Stanford University. In the past it acquired a sensor firm in Germany and today it is working with firms in Northern Italy. In all these cases, when there is cooperation with foreign organizations local presence has been important: "to really cooperate you need local presence, or it's impossible", our interviewee said. He added that communication in these cases is always a challenge. Not only the language is different, but distance is also a factor. Tools like the Nokia Communicator facilitate this cooperation at a distance –mostly within Finland. Metso has also taken part in tests of e-Meeting software used by VTT. At the national level VTT is an important partner, and whenever there is a technical issue, it is a company policy to look at VTT first because they often know the answer.

Locally there had not been much cooperation, partly because many companies in Tampere are machinery companies, while the expertise of Metso Automation is process control and automation. Recently, however, more cooperation is occurring with the local machinery and automation companies and the company values more local cooperation and the people and know how that is available locally. From being mostly international in the 80s, in the 90s local ties took on more importance. Being in Tampere has mattered mostly for the workforce, since most of the employees are hired locally and many of them come from TUT. Control theory is a central field of expertise for the company, and there is a lot of cooperation with the automation and control laboratories at TUT. Wireless technology and micro systems are becoming more important and the company is also cooperating with TUT in these fields.

Our interviewee talked of a kind of "deep cooperation" that can only take place locally and sometimes nationally, so it only occurs within Finland. He stated that whereas from foreign organizations the company usually buys products or parts, deep cooperation usually means some kind of joint development and people interacting on a continuing basis. Being close is useful for clarifying things immediately, and for bouncing ideas around as soon as something comes to mind. When buying things this kind of involvement is not necessary. A shared language and culture within Finland also facilitates deep cooperation. Additionally, there is not so much competition with other companies within Finland, and it is easy to talk to people about things.

As with other companies in Tampere, the combination of ideas and technologies from different fields has been key to product innovation throughout the recent history of the company. Metso's slogan nowadays is in fact "Linking Innovations." DAMATIC, for example, is a major innovation that emerged by bringing together the group of instrumentation and the group working with computers. Something similar happened in Metso Paper with paper machinery when Valmet was the only company that successfully incorporated automation. It took about 10 years to make it happen and the main challenge was for automation people to understand machine building and vice versa. "It takes time for people to understand what they are speaking."

Our accounts from the company pointed out the relevance of projects as a good way to achieve integration. The senior manager in the company pointed out that projects are useful because they provide a clear objective, an idea that people move towards. The challenge, he said, is for a common language to emerge and an open attitude to facilitate discussions. When these projects involve other companies, lack of competition among them facilitates cooperation.

New projects start when technological opportunities emerge or something that seems important appears on the horizon. Usually a visionary comes up with the idea and convinces others to begin something. The fact that management is knowledgeable about technology facilitates undertaking risky projects that might not make immediate economic sense, but could be important in the future. In the past, having the space and the time to experiment with new ideas was important. "If it is something that must be done, you do not make a risk analysis." Tekes plays a role here putting some of the risk money, and additionally, bringing together companies and research institutes in projects and stirring groups to discuss technologies. If Tekes has approved a project, management often supports it. Though Metso participates in these kind of cooperative efforts, internal development is still fundamental for the company. Still, Tekes can provide some signals of new research through technology programs, and often gives the extra push for companies to take internal risks.

Major development projects have been motivated by the survival of the company and of the business. "We understood that we needed to change to survive, and this has nothing to do with costs", the manager said. Cost-benefit analysis would have precluded moving in risky directions, but being about survival, cost did not matter as much. The engineers involved in these projects understood the importance and that was a motivator. Metso engineers and mangers were not necessarily the originators of the new ideas. Rather, they became aware that something was going on in other companies elsewhere. But while other companies –in the United States for example– had already started marketing something they still did not have, Metso mobilized immediately towards implementation. The senior manager in the company said that "when we look at what happens in the US, people talk a lot; we take their talk seriously. We don't speak much until we do. The feeling that we are late gives us an extra push. We are late, we must work hard."

FutureCare, which entails a change in business logic from machines to services, had an economic motivation. The paper business is cyclical and so are the revenues, and when selling machines the cycles are deep. In contrast, the customers are always buying services so it is a more stable business. In a way it is also a survival strategy, a way to keep the business going because investments in machines are low and Metso needs some kind of business to survive. This is happening in the three business units of Metso Corporation, not only in the paper business. Metso Minerals is starting to sell production capacity of the rock crushing machines, and that is the next step in the paper business also. In the process automation business where little maintenance is required, the cycles are smoother and the lifetime of systems are shorter, service is usually about upgrading and configuration. In the 80s the company noticed small engineering companies near the customer making small configuration changes, and created small service centers near the customers to enter this business.

Throughout the technological and business transitions of Metso over the past few decades, it always took "people interested about the future." Today, when "there is so much information available about the future", the challenge is to select among the options and to know what to believe and whether it makes technical sense. There are groups within Metso looking at future technologies, emphasizing those that could provide more value to the customer. "Nowadays people talk about big trends, but you must understand what the trend means to you." It is important to distinguish between technology fashions and whether these fashions can become dominant technologies or platforms. Will it just be a niche or have high penetration? Right now, for example, wireless technology is emerging as a platform with multiple applications, likely to have high penetration in many businesses. In the 80s many advocated for using Windows for automation systems, but the software was not reliable enough back then.

According to our interviewee, Metso has been more a technology than a marketing driven company. When engineers and people knowledgeable about technology are confronted with something new, they always wanted to test before acting. In the US marketing often makes the decisions and technology gives the solutions. Testing is important. In Metso it is important to continue looking and continue testing new ideas.

4 The innovation process: integration

The story of innovation in Tampere's machinery companies is one of reinvention through the infusion of new technology. The ability to integrate measurement devices, control systems, software, and wireless technology into the machines has been the core process of innovation and the key to the survival of these companies. The stories of Tamrock, Timberjack and Metso illustrate how interactions and activities leading to the recombination and successful integration of knowledge and technologies from various fields of expertise is a driver for innovation. Engineers, managers and policy makers are aware of this. A policy maker said that "it is about translating and combining, and in the future there will be a need to combine things even more than today."

The machines produced by leading companies in Tampere are at the intersection of three spheres of knowledge (Figure 6). First and foremost, the foundation is mechanical engineering. Over the years, Tampere's institutions, including companies, have supported the upgrading of knowledge that supports the wide range of skills required to make a machine. The second sphere of knowledge is information technology. During the last two decades mechanical engineering companies –and the engineers working within them– have successfully acquired the skills to integrate electronics, control systems, information technology into the machines. All of these, together, have evolved into sophisticated automation systems that intersect mechanical engineering and information technology. Information technology has, in addition, enhanced design, simulation, and testing capabilities throughout the product development process. When companies do not have expertise in house, they have developed linkages with university research labs and specialized IT companies. Finally, the third sphere of knowledge is expertise about the business logic and processes of the client industries where the machines and devices end up. Sustaining this expertise depends upon close interaction and a continuous conversation with the client industries. All of our interviewees pointed to the user as a source of innovation, and explained how having deep knowledge of their customer's process is central to come up with new ideas and modification for the machines. Such detailed knowledge of the customer's process has allowed local companies to design products and interventions that make sense in the overall process. Timberjack is aware of what goes on in forestry, Tamrock in mining, and Metso in the paper industry.[46]

The integration of the three spheres has been gradual, and in this our findings concur with other studies of innovation in mechanical engineering that have found that mechanical innovations are largely incremental.[47] The usually incremental nature of innovation in machinery is related to what a machine is: a system. Machines are decomposable, they can be broken up in tangible parts, each one fulfilling a specific function within the system. A change in one part, or the addition of a new one, alters the functionality of the machine. The parts vary in complexity, from nuts and bolts to intelligent control systems, and the knowledge and skills associated with making each of these parts vary accordingly. What is required to innovate in machines are a series of innovations that added together lead to an improvement in the machine's functionality. The ability to integrate the parts is fundamental. This is the story of Tampere's machinery.

4.1 Technological transitions in the industry

In this section we describe the different layers of technology that have been added to the machines over the past three decades. This process of technological change in machines has been illustrated in the three corporate accounts, but is not limited to the three cases above. Our research shows that the story is very similar across mechanical engineering companies in the region, including, for instance, Tamglass, the world's leading manufacturer of safety glass machinery, and Metso's paper machinery division. The addition of these layers is a common innovation characterized by a set of relatively well-defined technological transitions, each one bringing new technology to the machines, and yet always building upon a stable platform that has itself been upgraded over time (Figure 7). We can also see how these companies have drawn from local resources during the innovation process.

4.1.1 Improving the platform

From the three spheres of knowledge described above, this improvement has taken place mostly within the mechanical engineering sphere. There are certain attributes inherent to all machines, such as materials, engines, form and function, and some processes and the associated skills required to make a machine and its components, like design, welding, prototyping, machining, etc. In Tampere, there has been a continuous improvement in all the components of a machine. There have been improvements in engine technology and materials science, while design capabilities have been enhanced with CAD, CAM, and simulation and testing through methods like virtual prototyping and finite element analysis which are now standard in the life of every machine. Different levels of technical sophistication and kinds of skills, ranging from artisanship to engineering science are required to make it.

Local educational and research institutions have supported this upgrading. The educational experience of technicians and engineers has supported the acquisition of the knowledge and skills required to sustain the mechanical engineering sphere at the cutting-edge. Equally important have been the company's own initiatives to improve their knowledge base through in-house research as well as through cooperation with research and educational institutions throughout Finland and, in the case of global companies, in locations elsewhere in Europe. What we gather from our research is that this upgrading process has taken place along a *continuum* of engineering knowledge ranging from craft to science. We expand on the relevance of this finding in section 5.

4.1.2 From mechanic to hydraulic power systems

Also within the mechanical engineering sphere, In the 70s the first major transition in Tampere's machinery companies was a change from mechanical power systems to hydraulic power systems. Such systems have several advantages over their predecessors and are well suited for mobile machines. Hydraulic power systems are compact, light weight, and deliver more power more efficiently than mechanical or electrical systems of equal size. Hydraulic power transmission is key to moving many parts of mobile machines, depending on the application: cylinders, stirring, belts, arms, attachments, and others. It provides accurate responses to controls, and as a result, is extensively used in modern aircraft, automobiles, heavy industrial machinery and many kinds of machine tools.[48] Hydraulic power systems have been one of the foundations for the integration of control systems into the machines. This is, in other words, an important platform for the integration of the mechanical engineering and IT spheres.

Hydraulic power systems have been central to the success of local mobile machinery companies. In all the conversations that we held with these companies hydraulic power systems appear as one of the core enabling technologies. At the same time that hydraulic power systems became important for local companies, research and education in the field began in TUT, motivated and funded by a local corporation. This research initiative became the Institute of Hydraulics and Automation, one of the most important educational and applied research units within TUT. Local companies that use a combination of hydraulics and automation systems rely on the IHA as a source of engineers, and often for research and development initiatives.

4.1.3 Integrating control systems and automation

Over the past two decades the integration of control systems and information and communications technology has also transformed the functionality of the machines. This has been important not only for mobile machinery, but for all the machines that are embedded into any activity or production process: forest harvesting, paper making, container handling, flexible manufacturing, rock crushing, and others.

This transition and type of application has taken different forms depending on the product, and automation technology itself evolved over the last 20 years. Early systems were based upon pneumatic devices, and the arrival of electronic control systems and the application of microcontrollers improved the performance of devices. Later on, in the 80s, computer-based control systems appeared. The last major innovation was the application of distributed control systems in the early 90s, such as the CAN bus used in the forest harvesting machine. Along with this change, the emphasis moved from hardware to software-based control systems.

Automation technology is sustained by other fields of expertise and core technologies, in particular control theory, information and communications technology, electronics, and sensors. At this point, the major trend in the development of automation technology is a movement towards autonomous and intelligent systems, applying concepts from artificial intelligence. In addition, there is a move towards embedded automation within the machines. In call cases, these fields are prominently sustained through research and education by both TUT and VTT, as we shall illustrate in section 5.

4.1.4 Advent of wireless communications

A change that is currently underway is the integration of wireless technology into control, measurement and automation systems. Wireless technology is now widely available in Finland through GSM networks and more recently, BlueTooth technology has enabled new applications of wireless technology. In some instances, managing the processes and functions in which the machine is embedded is moving towards the Internet and web applications. This is the case of some paper machine automation equipment, and more recently, of forest harvesting machinery.

As with the other transitions in this storyline, TUT and VTT have been important players in sustaining the knowledge base and the problem-solving capabilities required by the companies to integrate wireless technology into the machines. Researchers from both institutions have often been participants in the initial conversations that lead to a project.

4.1.5 Towards technology-enabled services

The rise of software-based control systems and other forms of information technology that have become part of the machine, together with wireless technology and embedded automation are now serving as the technical platform for a transition in business logics: from selling machines towards selling services. Local companies, faced with a mature industry and, in some sectors, highly cyclical business environments, are now moving towards selling after-sales services and integrating machines and automation systems into their customer's processes. Besides the opportunities offered by technology, the need for a continuous and larger stream of revenues is motivating this transition. Instead of selling machines, companies will be selling output or capacity of specific characteristics according to customer needs.

This transition has been driven by the marketplace, and it is common to all the companies in our sample seems to be the major challenge for right now, since they have been used to dealing with technology more than services. Movement in this direction relies on "softer" fields of knowledge and technologies, like process analysis and logistics, supply chain management, maintenance, optimization, human factors engineering, management, and marketing. Some professor in TUT pointed out that this will be a challenge, while VTT has already undergone a major reorganization and has created a group on intelligent systems and services.

4.2 From conversations to projects: organizing for innovation

One of the main findings from our research in Tampere's mechanical engineering industry is that the organizing unit for innovation is the project. Engineers, technology managers and policy makers pointed out that it is in projects where innovations occur. Projects are also the settings of integration as individuals, knowledge and technology from different fields come together. Our research shows in addition that the starting point of a project is usually a conversation. In Tampere's mechanical engineering industry there are a number of conversations unfolding all the time. These conversations may take several forms and occur in a variety of settings. They may be an informal meeting among R&D, engineering, and marketing personnel within a company; a relatively structured discussion about technology trends; a forum organized by the Centre of Expertise; a phone call; or a meeting in the context of one of Tekes' Technology Programs. The back and forth exchange of ideas between engineers, students, and researchers in universities, companies, and research centers, may also be seen as another form of conversation, even though it does not take place in a seminar room or an auditorium. Some of these conversations become projects, and some of this projects conclude in new products.

Two quotes from our interviews in Tampere illustrate the centrality of conversations and projects for the innovation process in the industry:

> [The] idea emerged during one discussion that we had and we concluded that it was a real need. We were discussing with several companies during a meeting of a very lose and informal group of people that came together to discuss wireless applications. It was us [VTT], the companies and people from the university... Initially there was wandering during the meeting, and we had several meetings like this and we kept discussing ideas back and forth. The first conversations didn't have a clear goal in mind, but by the end the idea emerged as a clear candidate for a new product. Hermia was promoting this kind of activity. We discussed this issue which ended up in a new project (VTT).

> The project started about 4-5 years ago after a scenario session that we held with some professors and outside people... The topic of the meeting was "Traffic of the Future." There were about 15 persons involved, our people and people form HUT and VTT. Half were from us, and we convened the meeting. We have these scenario meetings with specialists from outside about once a year or so; we look for people with connections and who have an idea of what the future might look like. We did it with HUT and VTT because they are involved in research projects at the cutting edge, and know what is likely to happen. We also cooperate with them because they have connections with industries that interest us [...] so they also know what users are thinking about. In the meeting there were also advertising specialists and customer behavior specialists; so there were both technical people and market specialists […] In the meeting it became clear that in fact this was a good idea, and that we needed more resources put into this product. Before the meeting the idea was very raw. It was there that the vision crystallized and that this might become a big thing. So we emerged with a "yes, push the product." So one man in the company started to concentrate in this idea and started to work with this thing. (Nokian Renkaat).

Several aspects of these accounts are worth noting. In the first place, the initial ambiguity and openendedness of the conversations. As the first quote illustrates, initially there was "wandering." Such ambiguity seems important because it leaves the discussion open to a variety of topics. A clearer definition might have closed off avenues of discussion and some conversations might not have taken place at all. Notice the variety of interlocutors in the conversations. Participants in the meetings came from different backgrounds –representing universities, research institutes, marketing, and others. Some of them were selected because they were the cutting edge of related fields and also "what the user is thinking about." In addition, the organizers of the meeting were aware that each participant brought with him or her connections to other people. In both cases the conversations were oriented towards the future: it was a "scenario session", dealing with traffic "of the future" with people that had "an idea of what the future might look like."

In these two examples an unstructured conversation became a project. What distinguishes a project from the early unstructured conversation is a sense of direction given by a vision and a clearer idea of the tasks to be accomplished, even if they are reformulated over the course of the project. Besides qualified individuals, technology, and resources, the ability to create and reformulate visions of the future is fundamental to keep conversations going and projects alive. The process is in addition contingent upon the history (past) and the context (present) of the project: What is the background of the participants? Are we looking at Present Product Improvement or at Long-Term Concept Development? Is the project backed by the CEO or not? Have similar projects taken place inside the company? What resources are available? As project members interact they construct and reconstruct a vision until the product reaches functionality and stability in a way that is plausible to both the project members and the customer. The meaning of what the team is tying to achieve emerges and becomes clearer over time and an initially "raw" or fuzzy idea "crystallizes" after going "back and forth."

A very important source of new ideas and conversation topics in this industry is the customer, hence the relevance that all of our interviewees ascribe to knowing the customer's process well, of having very close contact with the customers and involving them in the early conversations for new products. The customer might be the trigger of the conversation when coming to the company to ask for a new feature. Another important source of ideas for products are the engineers in industry, universities, and research centers.

Our research also points to "a bunch of crazy guys" or "one person" as sources of a new idea. In the case of universities and research centers, part of what motivates the conversation is inventiveness, curiosity and a desire to apply new concepts or technology. If these interactions and conversations were not taking place, perhaps these projects would have not gotten started.

Besides knowing each other informally, two background conditions seem to have facilitated these conversations and projects in the past. First, what we would call a "culture of experimentation." In the days of Valmet and Tampella there was space within the large company to "do your own thing", as an interviewee said. It was possible for a "bunch of crazy guys" (see Timberjack's story above) to get together and pursue their own project, something that was often completely outside the existing business lines of the large company. In several cases, these experiments became the core of current businesses. The second condition relates to management style. Such opportunities to speculate and experiment would not exist without a particular management style that grants them legitimacy in local organizations. One of our interviewees said that management is "lose" and that if it were too focused on the bottom line some conversations would not take place at all; they would be seen as a "waste of time" or "too risky." Our research shows that such conversations are no waste of time. Many innovations in the mechanical engineering industry have started with conversations that in the beginning had no clear objective and that made little sense in the business environment of the time when they took place. The crazy conversations of today expand the business opportunities in the future.

Our interviewees repeatedly pointed out that integration takes place in the context of projects. For example, our interlocutor in Metso Automation said that "most innovations happen between technologies, and what matters is to have projects that will combine them." People come together in interdisciplinary teams to work toward a common goal. Engaging in practical, concrete problems is fundamental to bring them together. When entering a project, engineers and managers cross the many boundaries associated with their professional and organizational backgrounds and are exposed to interdisciplinary situations. Integration happens, for instance, through the implementation of electronics and information technology in an applied machine situation, in which engineers bring together the spheres of information technology and mechanical engineering and experience how mechanical engineering and IT interact in a machine. Since these projects are most of the time associated with an industry, engineers are exposed to the third sphere of knowledge associated with a specific industry, like forestry or paper.

This view of projects as organizing units for innovation, together with the evidence from the three corporate accounts in section 3, highlight what we call the *interpretive dimension* of innovation.[49] From an interpretive perspective, the product development project is a conversation, or rather, a set of intersecting conversations unfolding in time and space. An interpretation process unfolds as all of the elements just described converge in a project and are transformed into ideas, symbols, words and artifacts. Project members engage in an extended "question and answer" session as they hold conversations, solve problems, test ideas and artifacts, and gain new insights as the project unfolds. They make choices as the project evolves and, if the process is successfully sustained over time, an artifact –a finished product– gradually emerges. As project members interact they iteratively construct and reconstruct a vision until the product reaches functionality and stability in a way that is plausible to both the project members and the customer. The meaning of what the team is tying to achieve emerges and becomes clearer over time and an initially "raw" or fuzzy idea "crystallizes" after going "back and forth." We will elaborate more extensively on this view of projects and product development in a subsequent LIS working paper.[50]

Coming together in projects and undertaking the forms of interdisciplinary collaboration central to the success of the industry in Tampere is not a trivial undertaking. We are led to ask if there is something about Tampere that allows projects to flourish and integration to occur. We have already pointed out at two background conditions –experimentation and management– that facilitate this. In the next section, we elaborate on further circumstances in Tampere's environment that facilitate integration and hence, innovation.

5 Tampere's Innovation Environment

We have shown that the ability of local companies to integrate knowledge and technology from different fields to improve products and processes has been central to innovation and ultimately, to survival. The integration of sophisticated control systems and information technology into the machines has transformed their capabilities, and the transition towards technology-enabled services is deemed strategic for the long-term viability of local companies

However, this process of integration is not a trivial undertaking. The machine tools industry in the United States, for example, was not able to successfully compete with Japanese, German, and other European machine manufacturers in the 1980s, and an important impediment was the inability of American manufacturers to integrate control systems, the most significant technological development in the machine tools industry between 1960 and 1990. According to the analysis of the MIT Commission on Industrial Productivity in the late 1980s, a number of factors played into this failure to assimilate new knowledge and technology. These factors included inadequacies in engineering research and education at universities, a federal government policy biasing support towards research on large-scale complex engineering systems, a short-term economic logic on the corporate side, and an underestimation of the need to innovate on both producers and users.[51] A similar story emerged from the inquiry into the textile industry. In that case, besides low investment in R&D, firms maintained levels of secrecy that limited communication with the engineering professions. According to this study "the US lacked the regional institutions, supported jointly by government and industry, to provide training for industry personnel from machine operator to research engineer. Just as critical was a lack of broadly trained engineers working on process development and evaluation."[52]

A pattern observed in both the machine tools and textile machinery industries in the United States is *fragmentation* and *lack of coordination* in the disciplinary foundation and practice of the engineering profession; in federal government policies; in the interactions among the industry and supporting institutions, especially engineering research and education; and within the players in the supply chain of the industry. Though some of these factors are endogenous to firms and the dynamics of the industry, most of them are exogenous: they have to do with the environment in which these firms existed.

The fragmentation that accelerated the demise of the US machine tool and textile machinery industry is in sharp contrast with our findings in Tampere's mechanical engineering industry and the local innovation system. What we observe at the regional and sectoral level are coordination and communication patterns among local actors and institutions that support innovation. These patterns facilitate interactions and integration. From our research we can discern that in Tampere (1) regional and national policies related to mechanical engineering are coherent, are formulated with industry involvement, and facilitate the detection of technological opportunities and the adoption of new technology by the industry, (2) there are close and long-term relationships between the industry and supporting institutions, including universities and the engineering profession, (3) there are formal and informal communication and coordination among players in the industry, (4) there is a close relationship between machine builders and their client industries, and (5) there is a "continuum" of engineering research and education in local universities, colleges and research institutions, bringing together the craft and science sides of engineering. What all of these aspects have in common is that they reflect mechanisms of formal and informal coordination, communication and integration among the various players involved throughout the innovation process in the machinery industry. We focus our discussion on interaction patterns, education and research, and policies.

5.1 Interaction patterns in Tampere's innovation system

The macro-level interaction patterns that we observe among organizations in Tampere's innovation system are similar to other mechanical engineering clusters. To describe and explain these patterns in a more generalizable way we will draw from a particular body of literature in the field of political economy called Varieties of Capitalism (VoC). We are not attempting to fit Tampere in a box; instead we find that the language and ideas in this body of scholarship illuminate our observations well. We combine this with some insights from the innovation systems literature that describe patterns similar to Tampere in other places.

The patterns of coordination and interaction observed in Tampere and the mechanical engineering industry echo what the VoC literature calls a *coordinated market economy* (CME). In coordinated market economies, "firms depend more heavily on non-market relationships to coordinate their endeavors with other actors and to construct their core competencies. These non-market modes of coordination generally entail more extensive relational or incomplete contracting, network monitoring based on the exchange of private information inside networks, and more reliance on collaborative, as opposed to competitive, relationships to build the competencies of the firm."[53] These modes of coordination, evident by our analysis of Tampere's mechanical engineering industry, contrast with liberal market economies where firms rely on hierarchies and market competition. What we find in Tampere are similar patterns of university-industry interactions, skill-formation, and practice of the engineering profession to patterns observed in Germany, the idealized coordinated market economy. These patterns conform a "social system of production" that has been central to sustain the competitiveness of the world-class German engineering industries.[54]

The VoC literature suggests that the kinds institutional frameworks that characterize CMEs are effective to sustain incremental product and process innovations in established technologies such as machinery. These frameworks encourage cooperative, long-term investments, and industry-specific relationships "that develop organizational competencies and skills across internal and external organizational boundaries to develop continuous but incremental innovations."[55] Firms in the machinery industry need to coordinate technological and market knowledge from different sources, both within and outside the organization, to commercialize innovations. This includes collaborations between firms and the public science system which are industry and technology specific, and entails an active engagement between researchers and organizations usually focused on particular technologies relevant to firms.[56] These forms of coordination and boundary crossings are deemed necessary for technical change to take place in system-product technologies in which change proceeds through a combination of improvements in components and modifications in system design. The integration process is fundamental.[57] Our research shows that all of these interaction patterns are present in Tampere and support integration, the core innovation process in the mechanical engineering industry.

In the case of machinery and other mechanical engineering industries, the knowledge base involves high degrees of tacitness and specificity and is not easily codifiable through formal education and off-the job training. Learning-by-doing as well as extensive and tight relationships and communicative channels among suppliers and users are important. The search for new knowledge in mechanical industries is, in addition, heavily dependent on a local pool of know-how: specialized labor, other producers with the tacit and application-specific knowledge, and users operating in specific application domains. Informal mechanisms such as interpersonal contacts and talks, local mobility, and on-the-job training are central to sustain innovation. It has been suggested that a spatial clustering of innovators will emerge in those geographical areas where effective codes of communication and coordination mechanisms among firms have been established, and where firms, collectively, can acquire a competitive advantage over competitors in other regions. For all these reasons, clustering in common in mechanical industries.[58] This is the case of Tampere.

A central element of the interaction patterns just discussed is the skill formation and knowledge transfer systems associated with coordinated market economies and mechanical engineering industries. In Tampere, we find that these systems are indeed a keystone of the ability of local companies to innovate.

5.2 Education, research and Tampere's "engineering continuum"

At the beginning of section 4 we pointed out that what is required to innovate in machines are a series of innovations that added together lead to an improvement in the machine's functionality. Because of the diverse tasks and complexity of the parts in a machine, the ability to bring together craft and science, to think across disciplines and to integrate the parts is fundamental.

We find that in Tampere the craft and science sides of engineering knowledge and practice are blended along a *continuum*. At the science end of the spectrum we have abstract engineering science and the associated techniques. This is the kind of knowledge needed to make, for example, a finite-element analysis, the mathematical component of a sophisticated control system, or the optimization of an industrial process. In contrast with abstract engineering science, we have the type of engineering knowledge that is hands-on and is more an art or craft than a science. This knowledge tends to be more tacit and is acquired and deployed in practice. The skills are associated with the direct manipulation of things and the experience with artifacts in real life. Think, for instance, of the skill required to make a precise manual welding or bending of metal for small machines.

As we hinted above as we described technological transitions, the educational and research infrastructure in Tampere has been instrumental to sustain and upgrade knowledge and skills *across the engineering continuum*. We find that two main contributions of educational and research institutions to the innovation process in the mechanical engineering industry are (1) education and (2) enhancing integrative capabilities between craft and science and across fields of knowledge and technology domains.

5.2.1 Educating technicians and engineers

Our research suggests that educating engineers is one of the main contributions of TUT –and the Polytechnic– to local industry, if not the most important. Without "engineers with good skills and qualifications" the mechanical engineering industry could not survive.

The Tampere region has a differentiated educational infrastructure related to mechanical engineering ranging from vocational schools to the Tampere Polytechnic to TUT. These institutions support innovation by educating technicians and engineers, by doing research that ranges from basic to applied and by solving problems of diverse levels of sophistication. Most importantly, they do so across the engineering continuum. This diversity of institutions educate engineers and technicians that collectively and individually bring together the wide range of skills required to innovate in the mechanical engineering industry. We heard, for example, of a training program implemented by the Tampere Polytechnic for "mechatronics artisans," designed to upgrade the knowledge of those technicians whose work is at the craft side of engineering. In Tampere the craft of engineering is infused with science and the science of engineering is infused with craft.

The availability of highly skilled and specialized personnel is viewed by companies in the region as the most important contribution of local educational institutions to the mechanical engineering industry. In fact when we asked one of the interviewees about the reasons to concentrate product development in Tampere he answered that:

> [We] had different engineering teams in different places… But Tampere has the best location to get people with the skills and background. We had to close [a facility elsewhere], which was a small location, not competitive and with no engineers with good skills and qualifications… [Tampere] is a good place to get people with experience and expertise. We hired a lot of engineers from TUT.

Engineers are the key participants in every product development project in Tampere. Usually engineers come from the Tampere University of Technology or the Tampere Polytechnic. Historically, the establishment of the Tampere University of Technology as an independent university in 1972 has been regarded as one of the most important factors in the renewal and sustained competitiveness of the industry.[59]

Besides industry-specific and specialized courses over the course of their studies, there is an apprenticeship system that provides the learning-by-doing so central to the educational experience of engineers in Tampere. This is a remarkable example of how Tampere's engineering culture values both craft and science –theory and practice– and how the engineering continuum is preserved and contributes to local industry. There is a constant flow students between industry and universities, and engineering students often complete their requirements by doing a thesis in an industry situation working on interdisciplinary projects. Students serve as vehicles for transferring knowledge between industry and the university and in the process, acquire the industry-specific practical knowledge and the interdisciplinary and team capabilities required to work in the industry.

Both industry and educational institutions –TUT and the Polytechnic– place great value on this continuous exchange. University professors, for example, take for granted that it is necessary for students to be in industry, expose them to practice, and develop a set of skills and habits of thought that cannot be acquired in the classroom, including engineering knowledge that is industry-specific. This type of knowledge is in part acquired through advanced courses in engineering, but most importantly through direct involvement of the students in industry projects, which often becomes their Diploma thesis requirement. On the industry side, engineers and managers repeatedly highlighted the contributions of engineering students who made their thesis working in a project and how it helped them become acquainted and committed to a specific industry in ways that the classroom experience cannot provide.

5.2.2 Enhancing integrative capabilities

Our findings suggest that educational and research institutions enhance integrative capabilities in the region through educational and research initiatives that support the specific nature of innovation in the mechanical engineering industry. They support integration by bringing together theory and practice and by engaging on interdisciplinary projects in education and in research. Such integrative capabilities have been a central factor to support innovation in the local mechanical engineering industry. An interview in one of the firms highlighted the relevance of integration in Tampere:

> Mechanical engineering is everywhere, but Tampere has an engineering culture and history and is strong on hydraulics and automation, and specially mobile hydraulics. Only Tampere has such expertise and this kind of integration (Senior Engineer).

We discussed above how the educational experience of engineers enhances their ability to integrate craft and science. In the realm of research, an example of craft-science integration is the work history and experience of senior engineers in TUT and VTT. Many professors have substantial industry experience and later moved into a research and teaching position at a university but continue to be heavily involved with industry. They hold two identities and can speak the language of industry and the language of academia; the language of practice and the language of theory. In their minds and experiences these two forms of knowledge come together, and the appreciation for theory and practice is present in their research and in what they convey to their students. They act as translators between the world of abstract engineering science, in which they are embedded by virtue of their academic position, and the world of engineering craft and practice, familiar to them by virtue of experience and involvement with industry. Many TUT professors move back and forth between the industry and the university as they work on applied research and problem-solving projects.

From an interdisciplinary perspective, an example of integrative research in TUT is the Institute for Hydraulics and Automation or IHA. As we described in the story of Sandvick-Tamrock, the origins of the IHA date back to the early 70s and relate to the transition to hydraulic power systems in the company and the emergence of a relationship with TUT. Today the IHA is one of the most important resources for all machinery companies in Tampere. The contribution of the IHA to the education of engineers at TUT is very relevant for industry and like all TUT's engineering departments, education entails close engagement with industry. Besides offering advanced courses in specialized fields that are related to local areas of expertise in industry, most IHA-affiliated engineering students complete their education by doing their Master's thesis working in a project in industry.

During our conversations at the IHA, we learned that the strategic research areas are related to the needs of local industry and range from basic to applied. Research in the IHA is interdisciplinary, bringing together concepts and technologies from different fields. In fact, a researcher in the IHA emphasized that one of the distinctive features of the IHA when compared to other research groups elsewhere in Europe is its focus on systems. He said that "what companies need is systems and ideas about systems, not just about components… we make system technology because companies need systems."

Another important integrative capability supported by TUT is design. Several interviewees in the companies highlighted the relevance of engineering and industrial design for their ability to develop competitive products. We also learned from a conversation at the University of Arts and Design in Helsinki that many mechanical engineering companies place high value on design and are involved in conversations and projects about it. In TUT, the Institute for Machine Design (IMD) was founded in 1974 and since then it has had extensive cooperation with industry in both research and education. Graduates from the Institute hold high-level management and engineering positions in several local companies. Our interviewee at the IMD highlighted how design involves analytical and synthetic abilities, and how design is both art and science at the same time. Projects are a central part of education and research at the IMD.[60]

In the case of VTT, the first evidence of integration is the fact that VTT Industrial Systems is a result of the recent merger between the Automation and Manufacturing Technology units. A closer look into the research portfolio highlights the integrative approach of VTT and its relevance as a resource for local industry. In Tampere VTT has about 300 employees working on six technology themes: life cycle management, intelligent systems and services, enterprise networks, human-technology interaction, machines and vehicles of the future, and safety and reliability. The largest research group in VTT Industrial Systems is intelligent systems and services, with about 80 people altogether. Within this group, research is focused on three areas: vibrations and noise in all kinds of machines, embedded electronics and control systems, and services.

The fields of embedded electronics and control systems are a good example of integrative research in VTT. In the three corporate accounts we illustrated that the ability to embed or integrate electronics and control systems is a cornerstone of the innovation process in Tampere's machinery companies. The intelligent systems and services group and VTT has a strong focus on innovating by bringing technologies together. A senior R&D manager from this group said:

> I think that having multiple application areas within our group is very good because most innovation happens not within a single technology area, but between two technologies… I believe in combining technologies and resources, and that is what I encourage in this group. Projects will combine them (Senior R&D Manager at VTT).

The presence of an area focused on services is also noteworthy. According to a senior manager in VTT Industrial Systems this is a new focus area for VTT. He added that the move is taking place because of the pervasiveness of IT and wireless technology, which enable the provision of new kinds of services by companies that are able to incorporate these technologies. As we illustrated in our examples, this field brings together technological competence and business know-how, supporting an additional dimension to the integration process that is so crucial for local mechanical engineering companies.

5.3 Incentive-compatible policies in Tampere

In addition to a relevant skill formation system, the Varieties of Capitalism literature (section 5.1) suggests that information exchange among actors is fundamental in coordinated market economies, so institutions that provide opportunities for deliberation and encourage relevant actors to engage in collective discussions are very important.[61] It suggests in addition that policies are effective only if they are *incentive compatible*. On the one hand market-based incentives operate by reinforcing market competition, and they work best in settings in which firms rely on market mechanisms. On the other hand, coordination-oriented policies address firm needs with more precision and enhance the capacities of actors for non-market coordination. Market-based incentives would not work in settings in which firms interact mostly via non-market coordination, and vice versa. We find in Tampere two prominent examples of policies that are incentive compatible and promote deliberation: the Tampere Region Centre of Expertise and Tekes Technology Programs. These policy instruments rely heavily on bringing industry, university, and government together to deliberate. They motivate conversations across disciplinary and organizational boundaries, further enhancing integrative capabilities. The fact that all mechanical engineering companies share a similar knowledge base, coupled with the lack of competition in the market is an important background condition enabling actors to respond to these policies and incentives.

5.3.1 The Tampere Region Centre of Expertise

As part of the national Centre of Expertise Program, the Centre fosters the development and transfer of knowledge and technology by developing cooperation between companies and between companies and educational and research organizations. Facilitating the operation of the

CoE is the fact that “we are unbiased, and this allows us to arrange for competitors to meet each other”, our interviewee said.

At the core of the success of the Tampere Region Centre of Expertise is to bring people together. The CoE has an advisory council of about 35 members from industry, education, research, and also policy makers. In this way, it helps members from different organizational background to communicate. There are four main fields in the Tampere Region Centre of Expertise: mechanical engineering and automation, information and communication technology, health care technology managed and media services managed. The first two are focused on sustaining the main existing industries in the region while the latter two are trying to develop new industries. Each thematic area has its own advisory board, composed mainly of specialists in the field. About 150 people and 70 companies are involved in advisory boards. Three main activities take place in each area: match-making, project preparation, and marketing of expertise and investment promotion. Substantial efforts go into upgrading the knowledge base of existing companies through training programs.

The CoE promotes multiple fora and spaces for interaction among local actors that bring together experts from different fields and kinds of organizations, and multiple conversations occur across knowledge and organizational boundaries. Each thematic area organizes forums and working groups focused on specific topics. Under the *Tampere Engineering City* name, which is the mechanical engineering and automation group, there are several forums. At the time of our inquiry there was one on product development, involving ten managers, two professors, one member of the polytechnic and two from Hermia. Other groups are on CAD, CAM and product data management. These groups are somewhat loosely organized and are mainly a tool for knowledge management and for transferring knowledge within the cluster. Sometimes these forums and workshops evolve into specific initiatives that become institutionalized. Examples of these are the Rubber Institute and the Foundry Institutes, which started as discussion groups and became specific research initiatives housed in the region.

5.3.2 Tekes Technology Programs

Tekes Technology Programs (TTP) are public initiatives that support the development of the private sector. TTP may be seen as forums where individuals from different professional backgrounds and kind of organizations come together. In the context of programs too, Tekes funds projects that require multidisciplinary cooperation and organizational-boundary crossings. By bringing people together TTP helps sustain and expand the interaction patterns that are so crucial for the mechanical engineering industry in Tampere. Beyond bringing people together, TTP highlight new technology areas relevant for an industry or a group of companies. In this way, Tekes seems to play an important role in diversifying the range of technological options available to companies and sustaining a portfolio of projects that may be applied across industries. In addition, TTP mitigate risks by bringing Tekes as a co-investor in industry projects.

6 Conclusions

Tampere's mechanical engineering industry is a remarkable example of upgrading an old-economy industry by proactively assimilating new knowledge, new technology and adapting to an evolving business environment. Our findings highlight the deceivingly incremental nature of an innovation process that over an extended period of time has led to radical progress in the performance of machines. Different technologies and innovations that by themselves may mean little, add up to remarkably advanced products and processes. Upgrading has occurred throughout a continuum of technology: from nuts and bolts to artificial intelligence. At this moment these companies are becoming service providers and process integrators for their client industries. Being in Tampere has clearly supported the ability of these companies to innovate and survive.

The organizing unit for innovation in Tampere is the project. Many of the projects that led to the products that are today the basis of successful companies began with unstructured conversations. Through a process of refinement that involves reading the world of the customer, testing and experimentation, these conversations advanced towards a vision of the product. The ability to entertain conversations, even if in the beginning they seemed unrelated to existing product lines, has thus been central to the ability of the industry to innovate. The integration of knowledge and technology from three different spheres –mechanical engineering, ICT, and industry-specific knowledge– also takes place in projects. Our research shows that cooperative efforts, knowledge sharing and interdisciplinary collaboration are fundamental mechanisms for the recombination of knowledge, the key mechanism for innovation in mechanical engineering. Projects are affected by the history and context of Tampere. Further discussions about this finding suggest that it is of utmost relevance and perhaps the most generalizable to emerge from this study: *projects are organizing units for innovation.* We shall explore and elaborate on this finding in a subsequent LIS working paper.

Education and research have been key to sustain the mechanical engineering industry. This case study highlights the kinds of contributions that a university and other institutions can make to the survival of an old-economy industry. While currently most emphasis is placed on patenting or entrepreneurship in high-tech fields, Tampere shows other forms of university-industry interaction that have contributed to innovation the machinery industry. Education is a central contribution. The role of the university as a source of knowledgeable interlocutors that engage in the many conversations and projects taking place in the industry is equally important. Having cutting-edge research in fields related to the industry enables interlocutors to contribute to local projects.

An engaged, practical form of engineering science is at work in Tampere in close contact with the needs of industry and the craft side of engineering. The forms of engagement of the university, VTT and the kinds of policies enacted in Tampere support the nature of the innovation process. In this, the ability to cross organizational and disciplinary boundaries to bring different types of knowledge and technology together is at the core. The renewal of the engineering profession in the region is one of the key challenges in the future of the industry. A two-way, continuous dialectical process between research and educational institutions, rather than one-time transactions have been essential for the transfer of knowledge and technology in ways that have contributed to industry. The engineers and their firms are not only aware of their own business line, but key to their success has been an understanding and engagement with their client.

Our research design has highlighted the macro-micro link in the innovation process. We do this by capturing rich narratives and circumstances at the micro and macro levels of analysis and bringing them together. Getting close to the phenomenon and those involved in innovation –from engineers to managers to policy makers– has been fundamental. In this way we bring a *process* understanding of the innovation process and link it to the background conditions and institutional support for innovation in the Tampere region. This perspective that brings together the industrial history of the region, the innovation history of specific firms, and the technical history of products has allowed us to further our understanding of the co-evolution of products and institutions in Tampere. We have in addition opened the black-box of technology and respected the complexity of innovation as a heterogeneous sociotechnical and path-dependent process situated in time and space.

From a policy making perspective, our research suggests that it is important for policy-makers to go into the industry, understand the technology, and learn in some detail what those involved in the product development process actually do, how they come up with new ideas, and where they reach out to for assistance, knowledge, and technology over the lifetime of a project. It is also fundamental to understand the history and background conditions –such as culture, competitive dynamics, personal networks– that exist in the industry. In this way, unrealized potential and opportunities for interventions that are compatible with the specific nature of the industry can be enacted. In Tampere these policies are coherent among themselves. There is awareness about the innovation process in the industry and a shared understanding of what needs to be done to support it. Industry leaders and policy makers know the background conditions and the interaction patterns in the industry well. This awareness and knowledge of the industry serves as a framework to enact a coherent set of interventions that do not contradict each other and are compatible with the innovation process in the industry. Cooperation and communication spanning the members of the industry and the institutions and public agencies involved, has been central to achieve compatibility and coherence.

We conclude by emphasizing that this case study highlights the social, situated and contingent nature of the innovation process. Innovation is not a timeless, placeless truth.[62] Although the frontiers of knowledge and technology are advanced globally in networks of industry and educational and research institutions, and the evolution of technology is an industry-wide phenomenon, we started this research under the premise that location matters. Our engagement with Tampere furthers this argument and has allowed us to elicit how local conditions matter for innovation. Tampere is one of those *places* in which an industry has been able to create new products, to absorb new knowledge and technology, and to adapt to evolving technology and business trends. Although there are policy instruments that are widely applicable, there are aspects of the innovation process that are industry-specific –such as technology– and others that are particular to a region –such as background conditions and integrative capabilities. A grounded, situated understanding of the industry, the innovation process and the interaction patterns among the actors involved from the macro to the micro levels is central for the enactment of policies that work.

Table 1

The development of education levels from 1985 to 1995

		Population over 15	Population with a degree	All higher level	The lowest higher level	Bachelor level	Master level	Post graduate
Finland	1985	100,0	45,7	8,2	3,2	1,8	2,9	0,3
	1990	100,0	50,4	9,7	3,9	1,9	3,6	0,4
	1995	100,0	55,0	12,3	5,1	2,3	4,4	0,5
Tampere Sub-Region	1985	100,0	49,0	9,0	3,7	1,9	3,1	0,3
	1990	100,0	54,5	11,2	4,4	2,1	4,2	0,5
	1995	100,0	59,4	14,4	5,8	2,7	5,1	0,7

Source: Statistics Finland

Table 2

Level of education in the Tampere sub-region and Finland in 2000

	Population over 15	Population with a degree	All higher level	The lowest higher level	Bachelor level	Master level	Post graduate
Finland	100,0	59,4	23,3	12,5	4,8	5,4	0,5
Tampere Sub-Region	100,0	64,5	26,5	13,4	5,8	6,6	0,8

Source: Statistics Finland. The education statistics from 998 onwards are not compatible with those from previous years.

Table 3

The employment base in Tampere sub-region in 1990 and 2000

	1990	2000
Agriculture, hunting and forestry	2263	1085
Fishing	8	8
Mining and quarrying	36	79
Manufacturing	33896	32092
Electricity, gas and water supply	1223	915
Construction	9868	8875
Trade	16853	16264
Hotels and restaurants	3985	3860
Transport, storage and communications	8170	9242
Financial intermediation and insurance	3723	1656
Real estate and renting activities	11226	16853
Public administration and defense	5318	5250
Education	6832	9073
Health and social work	14978	19743
Other community, social and personal service activities	7048	6915
Private households with employed persons	1	3
Extra-territorial organizations and bodies	50	-
Industry unknown	2796	2170
Total	128274	134083

Source: Statistics Finland

Table 4

The industrial structure of Tampere sub-region in 2000

SIC	Industry	Employment	%	Production 1000€	%	Export 1000€	%
15	Food products and beverages	1913	6,0	252151	3,4	7759	0,2
16	Tobacco products	-	-	-	-	-	-
17	Textiles and textile articles	1388	4,4	137349	1,8	62529	1,3
18	Clothing and footwear	815	2,6	59078	0,8	11988	0,3
19	Leather and leather products	571	1,8	39987	0,5	12729	0,3
20	Wood and wood products	183	0,6	20666	0,3	1342	0,0
21	Pulp and paper products	2381	7,5	724670	9,7	485901	10,2
22	Printing and publishing	1808	5,7	255852	3,4	27976	0,6
23	Petroleum products and fuels	-	-	-	-	-	-
24	Chemicals and chemical products	920	2,9	159256	2,1	55985	1,2
25	Rubber and plastic products	2809	8,8	396880	5,3	221157	4,7
26	Mineral products	1689	5,3	191847	2,6	101266	2,1
27	Basic metals	442	1,4	45154	0,6	7947	0,2
28	Metal products	3096	9,7	488922	6,5	131896	2,8
29	Machinery and equipment	6420	20,1	1173445	15,7	782969	16,5
30	Computers and office machinery	x	x	x	x	x	x
31	Electrical machinery	362	1,1	34557	0,5	4129	0,1
32	Communication products	4131	13,0	3085056	41,3	2674872	56,4
33	Medical and precision equipment	1701	5,3	225561	3,0	78641	1,7
34	Motor vehicles and parts	902	2,8	139403	1,9	66282	1,4
35	Transport equipment	x	x	x	x	x	x
36	Manufacturing n.e.c	168	0,5	22757	0,3	5205	0,1
37	Recycling	16	0,1	6942	0,1	232	0,0
	Unclassified	3681	11,5	477398	6,4	134679	2,8
	Total	31886	100,0	7471660	100,0	4744535	100,0

Source: Statistics Finland

Table 5

R&D spending in the Tampere region in 1995 and 2000

Million Euro	Total	Companies	Public sector	Education sector
1995	211	134	25	52
2000	634	491	42	102

Percentage	Total	Companies	Public sector	Education sector
1995	100,0 %	63,5 %	11,8 %	24,6 %
2000	100,0 %	77,4 %	6,6 %	16,1 %

Source: Statistics Finland

Table 6

Market share of machinery and other mechanical engineering companies in the region

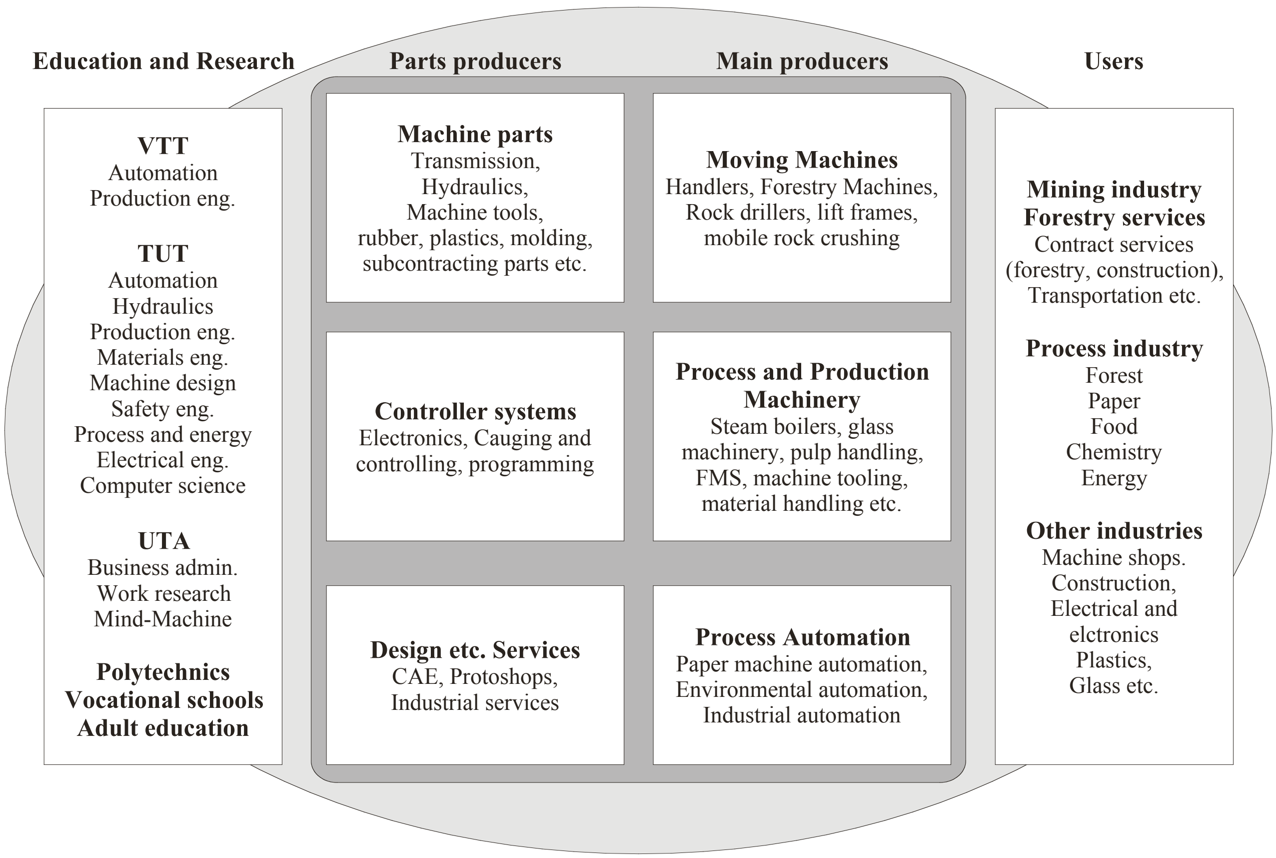
Company	Product	Global market share (%)
Ata Gears	Spiral bevel gears for marine applications	50
Avant Tecno	Mini loaders (max. one ton)	40
Bronto Skylift	Fire and rescue platforms	60
Fastems	Multilevel FMS	70
Gardner Denver	Ship compressors (Tamrotor)	50
Kalmar Industries	Container handling machinery	50
Kvaerner Pulping	Boilers	10-50
Metso Automation*	Automation for process industry (paper industry)	15
Metso Minerals	Mobile rock crushers	15
PCE-Engineering	Hollow core slab machinery	15
Sandvik-Tamrock*	Mining and construction machinery	35
Tamglass	Safety glass machinery (architectural and automotive)	70
Timberjack*	Forest machinery	30

*Discussed in section 3.

Source: Tampere Engineering City. Tampere Region Centre of Expertise.
http://www.tec.fi/english/information/global_market_leaders/

Figure 1

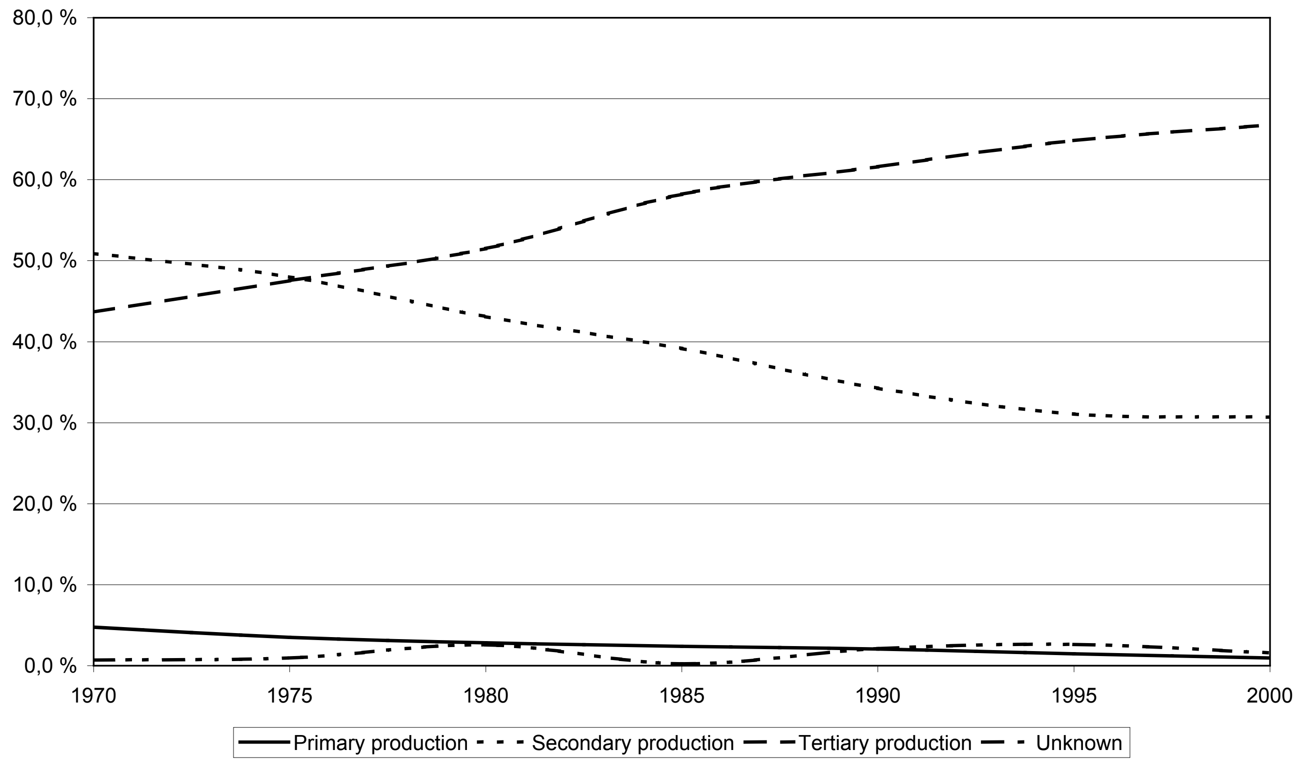
The regional cluster in mechanical engineering and automation



Source: Adapted from the Tampere Center of Expertise programme 1999-2006

Figure 2

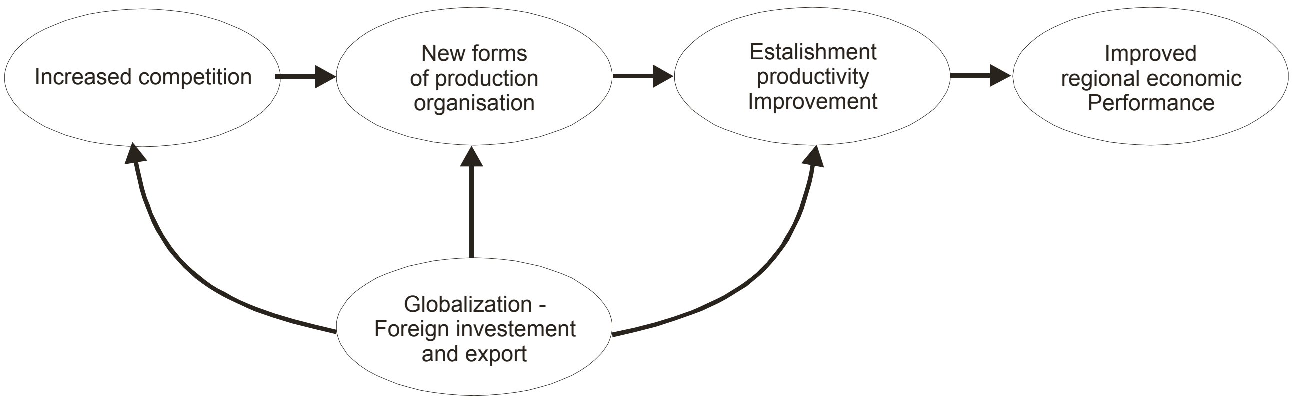
The development of jobs in the main sectors from 1970-2000 in the Tampere Sub-Region.



Source: City of Tampere

Figure 3

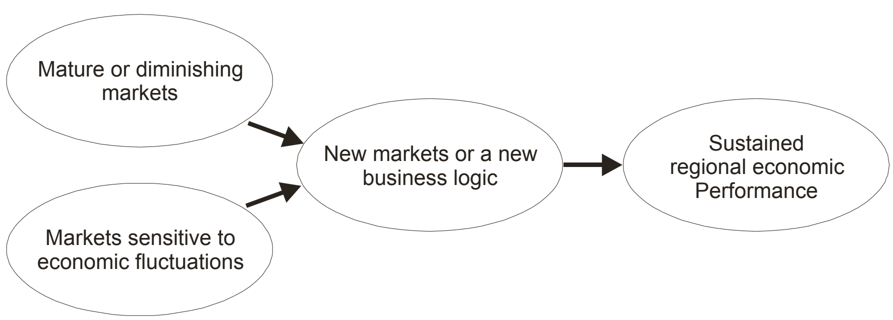
Industrial transition typically in the 70s, 80s



Source: Based on Florida, 1996

Figure 4

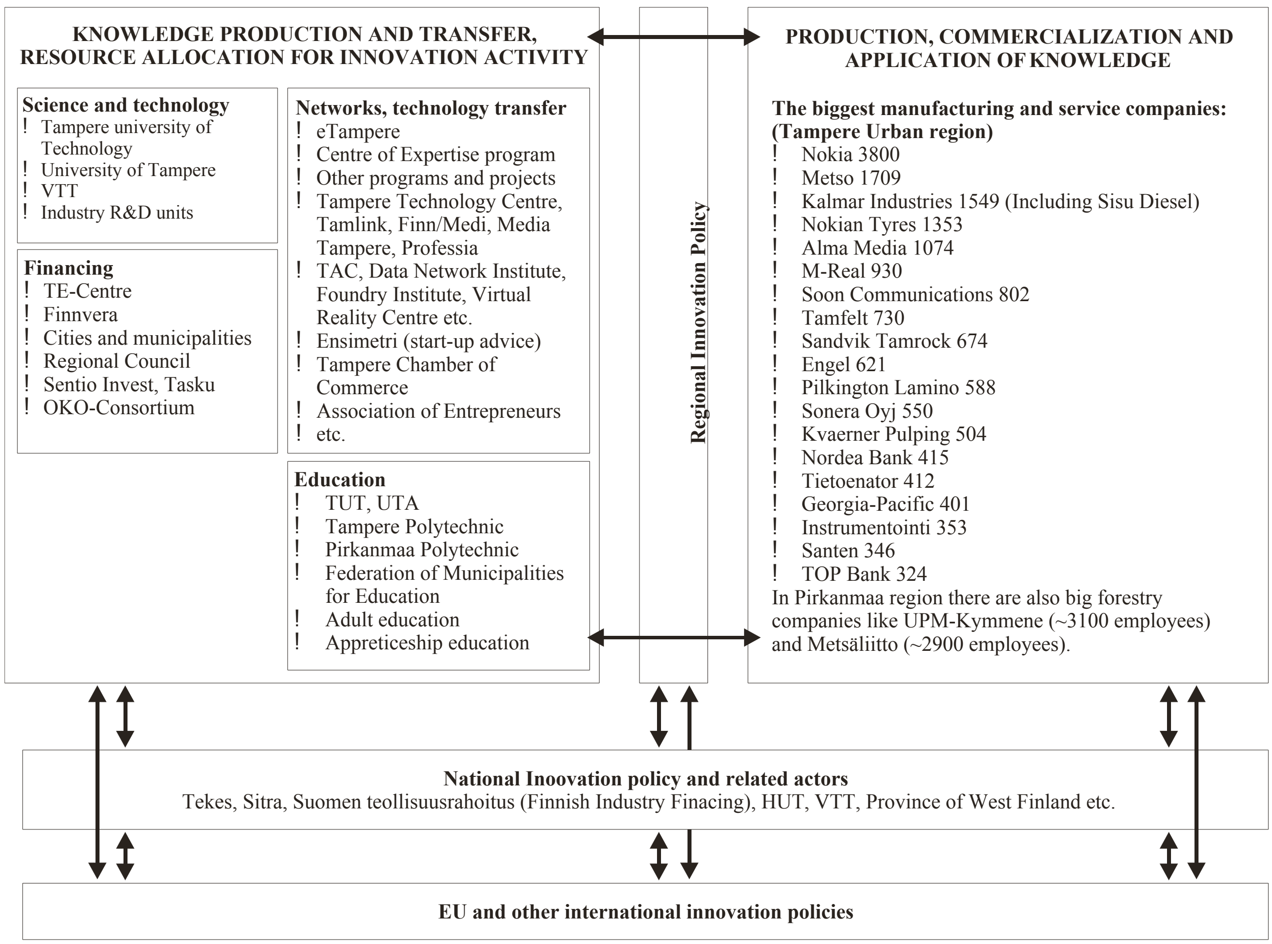
Ongoing transition in many companies since the 90s



Source: Author's scheme

Figure 5

The Tampere Innovation System

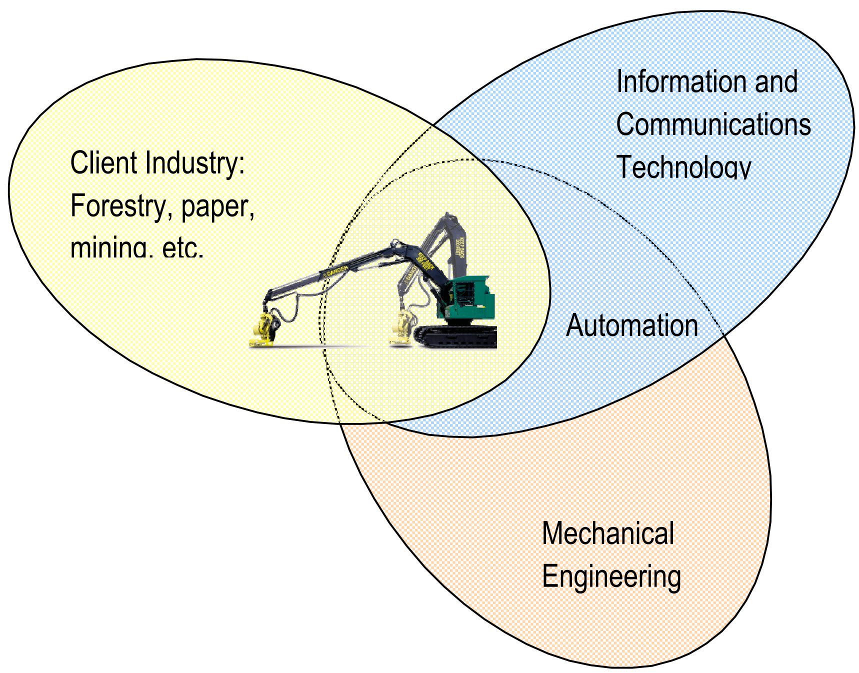


Source: Adapted from Kautonen 2000

Figure 6

The innovation process in machinery and automation

Tampere's mobile machines are at the intersection of three spheres: (1) mechanical engineering, (2) information and communications technology, including automation, and (3) the processes of the client industry. The innovation process in the leading machinery companies in Tampere is characterized by upgrading of inherent machine features (like design and materials() and, most importantly, by the ability to integrate knowledge and technology from the three spheres.

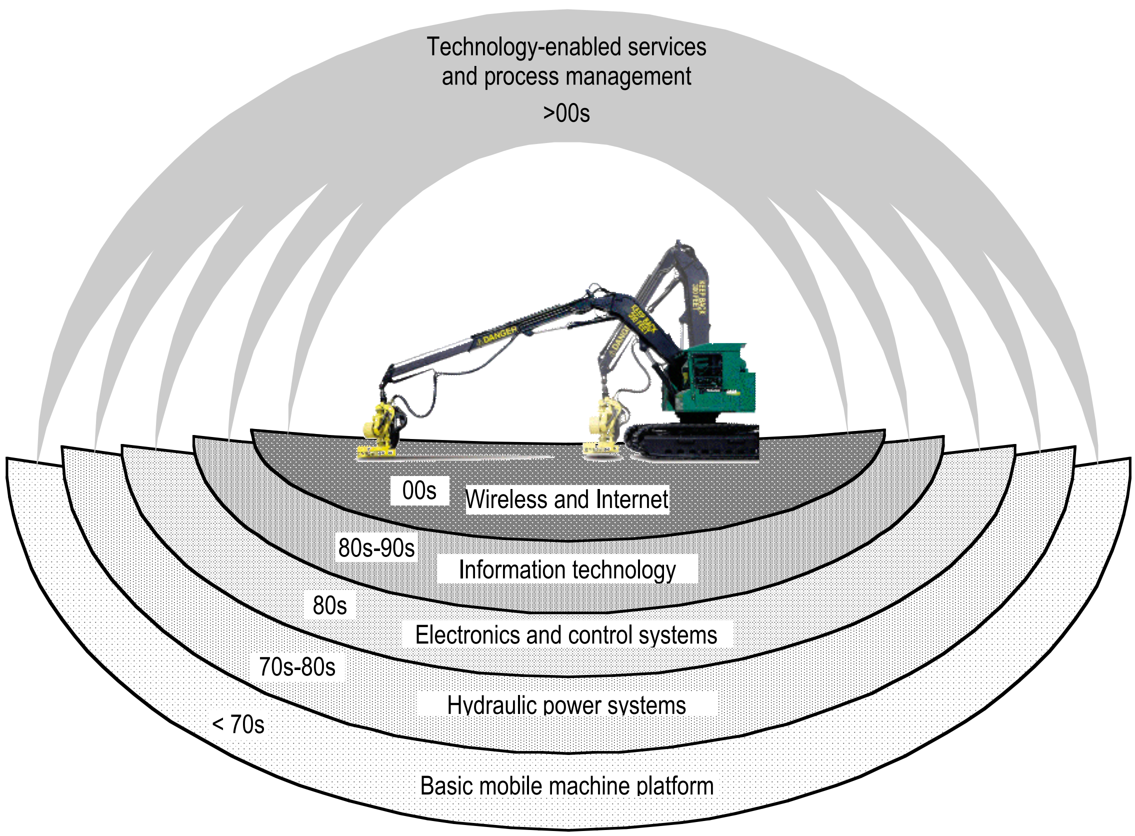


Source: Authors' conceptualization

Figure 7

Technological transitions in mobile machines

Since around 1970, the capabilities of mobile machines been transformed by the integration of several layers of technology: hydraulic power systems, electronics, control systems, information technology, wireless technology, and internet capabilities. Today, these technologies are enabling leading machinery and automation companies on Tampere to become service providers and process integrators for their client industries.



Source: Author's conceptualization

NOTES

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[1] Kautonen, Mika. 2002. “Opening the Regional Innovation System from the Perspective of Technological Trajectories”. Published in Spanish as “Sistemas regionales de innovación desde la perspectiva de las trayectorias tecnológicas” in *Sistemas Regionales de Innovación*. Publishing Service of the University of the Basque Country, Leioa, Bilbao.

[2] Discerning the macro-micro connection is often a problem of research design and data availability. For a discussion on the subject, see Diane Vaughan “Theory elaboration: the heuristics of case analysis” in *What is a case? Exploring the Foundations of Social Inquiry*. C. Ragin and H. Becker, eds. (Cambridge University Press, 1992) A suitable context to observe this link is the context of practice. See J. Coulter (2001). “Human practices and the observability of the ‘macro-social’. In *The Practice Turn in Contemporary Theory*, Schatzki, Knorr-Cetina and Von Savigny (eds.). (Routledge, 2001). In addition, institutions are best observed through their effects. See Immergut, E. M. (1998). “The Theoretical Core of the New Institutionalism.” *Politics & Society* 26(1): 5-34.

[3] Several research traditions have pursued an intellectual agenda that has already generated a vast amount of studies, usually historical and sociological, and sometimes political, emphasizing the role of history and context in the shaping of technology. This tradition has long been pursued by historians of technology, particularly in what John Staudenmaier calls the ‘contextualist’ approaches to the historical research of technology. See John Staudenmaier, S.J., *Technology’s Storytellers: Reweaving the Human Fabric* (MIT Press, 1985), for an account of the various research approaches in *Technology and Culture*, the journal of the Society for the History of Technology. Over the past three decades, another more sociological line of research has been advanced. An early synthesis of this work can be found in Wiebe E. Bijker, Thomas Hughes, and Trevor Pinch; *The Social Construction of Technological Systems*, (MIT Press, 1987). More political perspectives can be found in Wiebe E Bijker and John Law, *Shaping Technology / Building Society*, (MIT Press, 1992). This approach, which emphasizes that technology is open to human intervention, contrasts with the ‘technological determinist’ approach, which posits technology as a determinant of social processes, and evolving somehow outside of human control. For a substantive reflection on this perspective, see Merritt Roe Smith and Leo Marx, *Does Technology drive History?: The dilemma of technological determinism* (MIT Press, 1994).

[4] For discussions on these subjects see Ketith Pavitt, “Knowledge about knowledge since Nelson & Winter: a mixed record”. Electronic Working Paper Series #83. (Science Policy Research Unit, University of Sussex, UK, 2002) and Andrew Barry and D. Slater. (2002). “Introduction: the technological economy”. *Economy and Society*. Vol. 31. no. 2. May 2002. pp. 175-193. Two examples of innovation research inspired to some extent by this tradition include Van den Ende, J. and R. Kemp. (1999). “Technological transformations in history: how the computer regime grew out of existing computing regimes”. *Research Policy*. VoL. 28. PP. 833-851.], and Geels, F. W. (2002). “Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study”. Research Policy 31, pp 1257-1274. There is also an emerging body of work bringing this perspective to the realm of policy. See Sørensen, K. H. and R. Williams (eds.) (2002). *Shaping Technology, Guiding Policy*: *Concepts, Spaces and Tools*. Edward Elgar. Cheltenham, Northampton.

[5] In this study we do not focus the other side of the equation; that is, how technology has affected the historical and social processes unfolding in Tampere. We would like to suggest, however that the fact that the technology under investigation is related to mechanical engineering and machinery, affect the social processes and forms of interaction taking place in Tampere’s industry. This has been a central topic in historical and social studies of technology. Also, over the last decade a *structurational* perspective on technology is bridging the positions of whether “technology drives history” or history (and context) drive technology. From this view, technology at the same time shapes and is shaped by social processes in a recursive way. This research has mainly taken place in the realm of information technology. See Wanda Orlikowski, “The Duality of Technology: Rethinking the concept of information technology in organizations” in *Organization Science* Vol. 3 No. 3, pp. 397-472. This research builds upon Giddens’ theory of structuration. See Anthony Giddens, *The Constitution of Society: Outline of the Theory of Structuration*. (University of California Press, 1984).

[6] The characteristics listed in this sentence come from a presentation made by Prof. Pablo Boczkowski (MIT Sloan School of Management) about the contributions that science and technology studies can make to the management of technological innovation.

[7] Ministry of Education. KOTA Database.

[8] Source: Tampere Region Centre of Expertise

[9] High level refers to a degree from university or a polytechnic.

[10] All 3-digit industrial statistics are from the regional level (Maakunta) while most of the other statistics are from the sub-region level, which more closely corresponds to the urban area of Tampere.

[11] Jutikkala, E. 1979. Tampereen historia III [History of Tampere III].Tampereen kaupunki.

[12] Source: Kostiainen, J. & Sotarauta, M. 2002. Finnish City Reinvented: Tampere's Path from Industrial to Knowledge Economy. MIT IPC Working Paper 02-007. Cambridge: USA.

[13] Source: Statistics Finland

[14] Source: City of Tampere 1999. Background statistics for the Economic Development Strategy of Tampere. Unpublished.

[15] Tampere Region Centre of Expertise Programme 1999-2006; Tampere Region Centre of Expertise Programme 1999-2006 homepage: http://194.89.205.3/suom/oske/fi/osket/tampere.html

[16] This information is drawn from a chart prepared by the Tampere Region Centre of Expertise. It includes updated information about company ownership, as discussed during an interview at the Centre.

[17] In some cases there is potential new customer base existing in third-world countries, but factors such as poor infrastructure, technological gap, cheap labor and lower environmental standards impede the entry of high-tech, high-productivity but high-cost machinery and systems.

[18] Kautonen, M. and Shienstock, G. (1998). Regional Innovation System in Tampere Region, Finland. Final Report.

[19] Kostianen, Juha (2000). “

[20] Tampere Region Centre of Expertise Programme 1999-2006

[21] eTampere: eTampere suunnitelma [eTampere Plan] http://www.etampere.fi/kuvapankki/pics/89.pdf

[22] Ministry of Education 2001. KOTA-database. http://www.csc.fi/kota/kota.html

[23] Universities: Ministry of Education 2001. KOTA-database. http://www.csc.fi/kota/kota.html

[24] TAMK pähkinänkuoressa [TAMK in a Nutshell] http://www.tpu.fi/tiedostot/301656__liite__TAMK%20pahkina%20elokuu2002.rtf

[25] Finland 2002. Oppilaitostilastot 2002 [Educational Institute Statistics].

[26] Op. Cit. 27, p. 35.

[27] Ministry of Education. KOTA Database; TUT External funding: TUT Internet Statistics 27.3.2003. http://www.tut.fi/public/index.cfm?MainSel=6&Sel=213&Show=214&NoSel=1&Siteid=0.

[28] Tampere Technology Centre 2002. Daring dreams: Tampere technology centre Hermia 15 years. Tampere.

[29] The same kind of mechanism can be found in many regional development initiatives like eTampere

[30] Tampere Engineering City 2002. http://www.tectampere.net/english/information/global_market_leaders/

[31] Source: Interviews and Company History in Timberjack’s web site. http://www.timberjack.com/company/history.htm

[32] Timberjack has two R&D centers. Tampere concentrates on forwarders, wheel harvesters, harvester heads and measuring systems. Woodstock, Ontario, Canada focuses on track feller-bunchers and harvesters, skidders, forwarders and felling heads.

[33] Based on: “Wood” Encyclopaedia Britannica. Retrieved January 25, 2003, from Encyclopaedia Britannica Online. http://www.search.eb.com/eb/article?eu=119326

[34] Source: *Finland's vast forests – a short history of forest use*. European Forest Institute. Forest Information Services Network for Europe. Retrieved on Jan 31, 2003 from http://www.efi.fi/fine/Finland/history.html

[35] Source: Encyclopaedia Britannica, ibid.

[36] Source: "Training for the future" in Timberjack News 1/2002. Issue downloaded from Timberjack's website at http://www.timberjack.com/news/magazine/2002-issue1.htm

[37] Source: "Smarter machines!" in Timberjack News 1/2002.

[38] Source Timbermatic 300 brochure, downloaded from http://www.timberjack.com/products/measuring/300.htm

[39] Sources "Smarter machines!" in Timberjack news 1/2002.

[40] Source: "TimberOffice –a powerful decision-making tool for logging contractors" in Timberjack News 1/2002.

[41] Timberjack News 1/2002

[4242] Metso Corporation emerged from the merger of Valmet and Rauma in 1999. Sources: Metso Corporation website (http://www.metso.com), Metso Corporation Annual Report 2001 and 2002, and the Tampere Region Centre of Expertise.

[43] Sources: Interviews and Metso Automation History, in http://www.metsoautomation.com/

[44] In 2001 VTT Automation and VTT Manufacturing merged to form VTT Industrial Systems.

[45] Sources: Interview; Metso Automation website (www.metsoautomation.com). "The Dynamic Network of Applications is based on the free networking of knowledge and information, control automation and embedded field control applications. metsoDNA is a network where diverse applications based on different hardware and software solutions cooperate together allowing the plant to flexibly select automation and information applications in response to its prevailing needs." (ibid).

[46] In the particular case of Timberjack, forest machines are at the intersection of the three world-class industries of Finland: forestry, mechanical engineering, and information technology. In these machines expertise from the three industries converge.

[47] Francesco Lissoni, 2001, "Knowledge codification and the geography of innovation: the case of Brescia mechanical cluster." Research Policy Vol. 30 No.9, 1479-1500.

[48] Interviews and Encyclopædia Britannica. "Hydraulic Power." Retrieved July 5, 2003, from Encyclopædia Britannica Online. http://www.search.eb.com/eb/article?eu=42652.

[49] As we bring in the idea of the *interpretive dimension*, we build upon several years of research on the organization of product design at the MIT Industrial Performance Center. For an early synthesis of these ideas see Michael J. Piore, Richard K. Lester, Fred m. Kofman and Kamal M. Malek, "The Organization of Product Development", *Industrial and Corporate Change*, Vol. 3. No. 2 (1994). For an extension to how these ideas apply to the management process, see Richard K. Lester, Michael J. Piore and Kamal M. Malek, "Interpretive management: what general managers can learn from design" in *Harvard Business Review* Vol. 76 No. 2 (1998) pp. 86-76. For views on the behavior of the firm, see Richard K. Lester, "Companies that listen to their inner voices" in *Technology Review*, May-June 1998. pp. 54-64. An extensive elaboration of theoretical framework underlying the interpretative perspective appears in the early chapters of Kamal M. Malek, *Analytical and Interpretive Practices in Design and New Product Development*, Unpublished dissertation, MIT Department of Mechanical Engineering, 2001.

[50] The interpretive dimension contrasts with what these scholars (see 49) call the analytical dimension, which refers to what is captured by dominant theories about product development, design and management. More generally, it is am way of looking at the world that dominates discussions about innovation and economic activity and is founded on a specific definition of rationality. This view would posit that the activities of the member in a project are guided by clear, stable goals pursued by following a set of pre-determined steps in the most time and resource efficient way. These goals and the way to pursue them are independent of time and place. Such perspective leaves

little room for ambiguity or deviation from stated objectives. Actors within such project act in a rational way and that they come into the project to apply knowledge that they know a priori and to process information that is solely related to the project's initially stated objective. The project manager leads the process by ensuring timely completion and coordination of tasks that have been clearly divided among team members. From the analytical perspective, the kind of integration that we see in the products emerging from Tampere would be a "natural" process: it is about setting goals and projects that are pre-defined in a way that ensures such an outcome, putting together the pieces of a puzzle, all of this facilitated by a good manager and a set of resources. The interpretive and analytical dimensios are not mutually exclusive; rather, they describe a different of processes that coexist.

[51] These findings come from the analysis of the decline of the machine tools industry in the United States, prepared by the working group on the machine tools industry of the MIT Commission on Industrial Productivity in the late 80s. See Artemis March, "The US Machine Tool industry and its Foreign Competitors" in *The Working Papers of the MIT Commission on Industrial Productivity*, Volume 2, MIT Press, Cambridge and London, 1989. A synthesis of this analysis appears in *Made in America* by Michael L. Dertouzos, Richard K. Lester, and Robert M. Solow (MIT Press, 1989).

[52] Commission Working Group on the Textile Industry. "The US Textile Industry Challenges and Opportunities" in *The Working Papers of the MIT Commission on Industrial Productivity*. Volume 2. MIT Press, Cambridge and London. 1989. Quotation comes from page 9.

[53] See Peter A. Hall and David Soskice, *Varieties of Capitalism* (Oxford University Press, 2001), p. 8.

[54] See Otto Keck, "The National System for Technical Innovation in Germany" in *National Innovation Systems: A Comparative Analysis* (Oxford University Press, 1993) pp. 115-157. On Social Systems of Production and a description of the German system and its effect over engineering industries, see J. Rogers Hollingsworth, "Continuities and Changes in Social Systems of Production: The cases of Japan, Germany, and the United States, in *Contemporary Capitalism: The Embeddedness of Institutions* eds. J. Rogers Hollingsworth and Robert Boyer (Cambridge University Press, 1997), pp. 265-310.

[55] David Soskice, 1997, "German technology policy, innovation and national institutional frameworks" in *Industry and Innovation*, Vol. 4, pp. 75-96. As cited in Richard Whitley, 2002 "Developing innovative competences: the role of institutional frameworks". *Industrial and Corporate Change*, Vol. 11, No. 3, pp. 497-528. Se also Hall and Soskice, 2001.

[56] Richard Whitley, 2002 "Developing innovative competences: the role of institutional frameworks". *Industrial and Corporate Change*, Vol. 11, No. 3, pp. 497-528.

[57] Richard R. Nelson and Nathan Rosenberg, "Technical Innovation and National Innovation Systems" in *National Innovation Systems: A Comparative Analysis* (Oxford University Press, 1993) pp. 3-21.

[58] See Charles Edquist (ed.). *Systems of Innovation: Technologies, Institutions and Organizations*. Science, technology and the international political economy series. (Pinter, 1997).

[59] Kostianen, Juha, and Markku Sotarauta (2002). *Finnish City Reinvented: Tampere's Path from Industrial to Knowledge Economy*. MIT IPC Local Innovation Systems Working Paper 02-002. Online at: http://ipc-lis.mit.edu/working.html

[60] For a discussion on the integrative role of design and the relevance of engineering and industrial design for innovation see Vivien Walsh, 1996, "Design, innovation, and the boundaries of the firm". *Research Policy* Vol 25, pp. 509-529.Design is acquiring increasing importance for the mechanical engineering industries in Finland, as reflected by the Design 2005 Technology Program organized by Tekes. The program brings together a variety of universities and firms related to design and the Technology Industries of Finland. One of the objectives of this program, according to our conversations, is to further integration of technology, human factors, and business factors across industries. We also learned of interactions between the University of Art and Design in Helsinki, the Helsinki University of Technology, and the Massina Technology Program (Mechanical Engineering) organized by Tekes. This group is engaged in discussions about the future of machinery.

[61] See Hall and Soskice (2001), p. 11-12 for a discussion on the relevance of deliberative institutions.

[62] We borrow this idea from a paper presented by Bruce Mazlish at a conference on *The Future of the City of Intellect*, at the University of California – Riverside in February of 2000. Mazlish described neo-classical economics as advocating “timeless, placeless truths”.

The Local Innovation Systems Project

The Local Innovation Systems Project, an international research partnership based at the Industrial Performance Center (IPC) at MIT, is addressing a central issue now confronting industrial practitioners and economic policymakers throughout the world: How can local economic communities survive and prosper in the rapidly changing global economy?

Our particular focus is on the role of innovation – in products, services, and processes – in promoting productivity growth and competitive advantage at the local and regional levels. National and local governments around the world, as well as other institutions with an interest in economic development, are greatly interested in creating and sustaining local environments that are attractive for innovation. Firms, too, recognize that their innovation performance is affected by their location.

The policy debate has been dominated by a few outstandingly successful centers of technological entrepreneurship, notably including Silicon Valley and the Boston area in the United States, and the Cambridge region in the U.K. But most locales do not have clusters of high-technology ventures of such scale, nor are they home to research and educational institutions with world-class strengths across a broad range of disciplines. Many, on the other hand, do have distinctive industrial capabilities and vibrant higher educational institutions, and some of these locales have been quite successful in harnessing new technology to revitalize their economies or even to reinvent themselves as centers of innovation and competitive advantage.

The Local Innovation Systems Project is investigating cases of actual and attempted industrial transformation in more than 20 locales in the United States, Europe, and Asia. Our research is aimed at developing new insights into how regional capabilities can spur innovation and economic growth. We seek ultimately to develop new models of innovation-led industrial development.

We are currently completing the initial year of a projected multi-year study. In the first phase of research, we are investigating the roles of universities and other public research institutions as creators, receptors, and interpreters of innovation and ideas; as sources of human capital; and as key components of social infrastructure and social capital. Later phases of our research will explore the process of enterprise growth and the ability of different locations to attract and retain innovating firms. We are also investigating different approaches to individual and institutional leadership in locally-based systems of innovation.

The founding research partners of the Local Innovation Systems Project consist of an interdisciplinary team of faculty, graduate students and research staff at the MIT Industrial Performance Center, together with their counterparts at the University of Tampere and the Helsinki University of Technology in Finland, the University of Cambridge in England, and the University of Tokyo, Japan.

Current research sites include several locations in the United States (Boston, MA; Rochester, NY; Akron, OH; Allentown, PA; Youngstown, OH; New Haven, CT; Charlotte, NC; and the Greenville-Spartanburg area of SC), Finland (Helsinki, Turku, Oulu, Tampere, Seinajöki, Pori), Japan (Hamamatsu, Kyoto), and the United Kingdom. Additional research is being carried out in Ireland, India, Taiwan and Israel.

At each location, teams of researchers from the partner institutions are studying innovation trajectories and developing comparative case studies of growth and transformation in several industries, mature as well as new, including polymers, ceramics, optoelectronics, industrial machinery and automation, auto/motorsports, medical equipment, biotechnology, and wireless communications.

The outreach activities of the Local Innovation Systems Project will include the preparation of discussion papers and books, executive briefings and informal workshops, international conferences, and executive education and training programs for policymakers, research managers, and industry executives.

Current sponsors of the Local Innovation Systems Project include, in the United States, the Alfred P. Sloan Foundation and the National Science Foundation, Tekes (the National Technology Agency of Finland), the Cambridge-MIT Institute, and the University of Tokyo.

For further information, please contact the Project Director, Professor Richard Lester (617-253-7522, rklester@mit.edu).