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Three essays on major trends in a slow clockspeed industry: The case of industrial automation

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The case of industrial automation

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I Executive summary

The motivation for this research initiated from the abrupt rise and fall of minicomputers which were initially used both for industrial automation and business applications due to their significantly lower cost than their predecessors, the mainframes. Later industrial automation developed its own vertically integrated hardware and software to address the application needs of uninterrupted operations, real-time control and resilience to harsh environmental conditions. This has led to the creation of an independent industry, namely industrial automation used in PLC, DCS, SCADA and robot control systems. This industry employs today over 200'000 people in a profitable slow clockspeed context in contrast to the two mainstream computing industries of information technology (IT) focused on business applications and telecommunications focused on communications networks and hand-held devices. Already in 1990s it was foreseen that IT and communication would merge into one Information and communication industry (ICT). The fundamental question of the thesis is: Could industrial automation leverage a common technology platform with the newly formed ICT industry?

Computer systems dominated by complex instruction set computers (CISC) were challenged during 1990s with higher performance reduced instruction set computers (RISC). RISC started to evolve parallel to the constant advancement of Moore's law. These developments created the high performance and low energy consumption System-on-Chip architecture (SoC). Unlike to the CISC processors RISC processor architecture is a separate industry from the RISC chip manufacturing industry. It also has several hardware independent software platforms consisting of integrated operating system, development environment, user interface and application market which enables customers to have more choices due to hardware independent real time capable software applications. An architecture disruption merged and the smartphone and tablet market were formed with new rules and new key players in the ICT industry. Today there are more RISC computer systems running Linux (or other Unix variants) than any other computer system.

The astonishing rise of SoC based technologies and related software platforms in smartphones created in unit terms the largest installed base ever seen in the history of computers and is now being further extended by tablets. An underlying additional element of this transition is the increasing role of open source technologies both in software and hardware. This has driven the microprocessor based personal computer industry with few dominating closed operating system platforms into a steep decline.

A significant factor in this process has been the separation of processor architecture and processor chip production and operating systems and application development platforms merger into integrated software platforms with proprietary application markets. Furthermore

the pay-by-click marketing has changed the way applications development is compensated: freeware, ad based or licensed – all at a lower price and used by a wider customer base than ever before. Moreover, the concept of software maintenance contract is very remote in the app world.

However, as a slow clockspeed industry, industrial automation has remained intact during the disruptions based on SoC and related software platforms in the ICT industries. Industrial automation incumbents continue to supply systems based on vertically integrated systems consisting of proprietary software and proprietary mainly microprocessor based hardware. They enjoy admirable profitability levels on a very narrow customer base due to strong technology-enabled customer lock-in and customers' high risk leverage as their production is dependent on fault-free operation of the industrial automation systems. When will this balance of power be disrupted?

The thesis suggests how industrial automation could join the mainstream ICT industry and create an information, communication and automation (ICAT) industry. Lately the Internet of Things (IoT) and weightless networks, a new standard leveraging frequency channels earlier occupied by TV broadcasting, have gradually started to change the rigid world of Machine to Machine (M2M) interaction. It is foreseeable that enough momentum will be created that the industrial automation market will in due course face an architecture disruption empowered by these new trends.

This thesis examines the current state of industrial automation subject to the competition between the incumbents firstly through a research on cost competitiveness efforts in captive outsourcing of engineering, research and development and secondly researching process re-engineering in the case of complex system global software support. Thirdly we investigate the industry actors', namely customers, incumbents and newcomers, views on the future direction of industrial automation and conclude with our assessments of the possible routes industrial automation could advance taking into account the looming rise of the Internet of Things (IoT) and weightless networks.

Industrial automation is an industry dominated by a handful of global players each of them focusing on maintaining their own proprietary solutions. The rise of de facto standards like IBM PC, Unix and Linux and SoC leveraged by IBM, Compaq, Dell, HP, ARM, Apple, Google, Samsung and others have created new markets of personal computers, smartphone and tablets and will eventually also impact industrial automation through game changing commoditization and related control point and business model changes. This trend will inevitably continue, but the transition to a commoditized industrial automation will not happen in the near future.

II Acknowledgements

Firstly I would like to thank my father, Prof. Eino Tunkelo for a mentally stimulating youth which implanted in me a permanent passion for learning and education. Secondly I would like to thank my Professor, Ari-Pekka Hameri for showing me the way to learn the required scientific methods and to construct and write academic papers. I also would like to extend my gratitude to other members of my colloquium, Prof. Yves Piqnuer and Prof. Alan Wegmann for their undivided support.

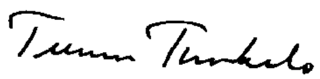
My thesis focuses on technology cycles in industrial automation, an area with relatively little prior research available. In order to get access to data and experienced people to collect the necessary artefacts I needed to ask help from numerous people. I want to extend my vast gratitude to the hundreds of people active in industrial automation as customers, incumbents and newcomers for supporting my research in the different phases of the technology lifecycles in industrial automation.

The academic community has enabled me to understand the way current time and future research can best be accomplished with the limited available historical artefacts. I want to sincerely thank Prof. Kari Lohivesi, Dr. Pekka Nikander, Dr. Tobias Scheele, Dr. Ravi Gopinath, Dr. Antero Putkiranta and others who have taken time to help me on my journey. From my earlier education I want to thank Leena Soivio for teaching me that I do not ever have to give up since every failure I face will eventually make me stronger.

I am pleased to be part of a vivid society and having a global network of friends I highly respect. In reference to my thesis I would like to thank Jaakko Karo, Juho Lipsanen, Petri Pöllänen, Fabrizio Orlando, Boon Kiat Sim, and James Foo alongside to many other friends who have given me the essential mental support I truly needed.

Finally I want to thank my wife Annatina for her perpetual patience, understanding and support and my brother Lauri for his always insightful advices and enduring support.

In Kaiserstuhl, January 23rd, 2014



III Foreword

The biologists use Drosophila Melanogaster (aka common fruit fly) for genetic analysis since it develops to an adult at room temperature approximately in a week. Similarly the studies of technology lifecycles focus mostly on fast clockspeed industries since there the lifecycle development signals can be quickly captured and researched. Nevertheless, Industrial automation, a slow clockspeed industry, is interesting for me due to its colossal impact on the well-being of our global societies. Among many other significant impacts it reduces blue collar workplaces, lowers carbon footprint and consumption of chemical and other raw materials. It also improves productivity and quality making industrial products more affordable.

It was interesting to reflect the vast research on technology disruption against a slow clockspeed industry in which I have personally been active for the major part of my professional life. I believe I can understand with a longitudinal perspective how things change and how the related 'zeitgeist' evolves in industrial automation. However, this thesis result was a revelation for me. I would have expected a swift disruption based on the gigantic change in number of Unix computers inside smartphones and tables leveraging a new kind of integrated real-time capable software platforms running on a hardware independent inexpensive RISC processor architecture, with many additional functions and further benefits like low energy consumption.

These technologies should have all the elements for a rapid architecture disruption in industrial automation. However, in any industry the best technology never wins but the most sold one. Purchasing decisions are done with emotions which have a bias on the management decision making even in a business-to-business environment. The personal legacy of earlier decisions and the foreseen risks and opportunities of the new decisions seem to have greater impact on the decision making than what I would have assumed before working on this thesis.

It has taken me a lot of discipline to return to the academic world and a long time to finally complete my thesis. During these years I have grown as a human and have learned to understand myself better than ever before. I feel great gratitude to life for having the opportunity to work on and complete my thesis.

IV Contents

1 Introduction

While the research on technology lifecycles and disruptions is mostly focused on fast clockspeed industries, this thesis takes an empirical and qualitative approach on industrial automation to highlight the current and foreseen industrial dynamics caused by technology lifecycles and related disruptions in the context of a slow clockspeed industry.

The thesis consist of three essays, two published and one submitted: The first research essay (Hameri and Tunkelo, 2009) was based on a one company case study with interviews and descriptive data collection. The second essay (Tunkelo et al., 2013) was a case study combined with action research, where a support process was documented, key control variables were identified and measurement processes were implemented, which led to a significant improvement in throughput times. The third research essay (Tunkelo and Hameri, submitted) used Delphi method and surveys to systematically assess forthcoming technology disruption occurrences in industrial automation based on System-on-Chip (SoC) technologies and related software platforms.

Within the field of industrial automation this thesis focuses specifically control systems which use computers to automate production processes. This is a global industry, dominated by six major incumbents controlling approximately half of the total market. The key incumbents and selected describing data are presented in Table 1. The data has been estimated to reflect the business directly related to control system industry since there is no public information available due to the reporting practices of these conglomerates.

	Employees ca.	Revenues BUSD	EBIT margin	Annual Growth	EBIT multiple
Siemens Industrial Automation	40’000	11.2	14%	3%	19
Honeywell Automation and control systems	12’000	2.4	4%	0%	15
Rockwell Automation	22’000	6.4	19.5%	1.5%	21
Yokogawa	10’000	2.8	6%	8%	19
ABB PA division and partially DM division	20’000	6.4	11%	7%	13
Emerson	14’000	6.1	20%	9%	17
Top six total	118’000	25.3B$			

Table 1: Top six incumbents key data 2012

Mechanical, pneumatic and electrical technologies have been used in industrial automation for more than a hundred years. Today industrial automation uses computers to control production processes or industrial machinery and related processes to reduce manual work and improve quality and productivity of the production process. Minicomputers, once widely used in business process automation applications, were used in first computerized industrial automation systems some fifty years ago. In mid 1970s dedicated automation control systems based on less expensive microprocessor technology were deployed in industrial automation applications with tightly integrated hardware and software platforms to better fulfil the real-time and other application specific requirements with more distributed processing architecture. This architecture and technologies dating back over thirty five years are still deployed today in most control system applications.

Industrial automation is a vertically integrated large global slow clockspeed industry which is currently in a mature phase of its technology lifecycle. The previous disruption was based on microprocessor technology and hardware independent operating system. This disruption occurred with a five to ten years delay compared to mainstream IT industries but only in the operator and engineering station hardware and operating systems.

Industrial automation is now facing a possible technology disruption from System-on-Chip (SoC) technologies and related software platforms currently widely used in the lower cost and higher performance ICT industries. This thesis studies incumbent suppliers' current key activities and whether the current Status Quo will continue or industrial automation will face its next technology disruption.

In this thesis industrial automation control systems are grouped into four main application areas each with their own specific technology variations. These are Distributed Control Systems (DCS) for continuous process control, Programmable Logic Controllers (PLC) for discrete manufacturing, Supervisory Control and Data Acquisition (SCADA) and Industrial Robots (Groover, 2007). SCADA applications are geographically distributed control applications managing for example oil pipelines or electricity distribution networks. This thesis views industrial automation today as one industry using different kinds of computers and software platforms to control various industrial processes currently with vertically integrated proprietary systems.

We investigated industrial automation (Table **1**) in the context of Schumpeter (1939) cycles. Industrial automation is currently dominated by the competition between incumbents with ever increasing cost pressures as defined by Marshall (1898) in his principles of economics theory. Industrial automation and also adheres to the theory of competitive forces (Porter, 2008). To research technology lifecycles in industrial automation two research projects studying the Status Quo of industrial automation within its present-day mature technology lifecycle phase; Firstly an one company case study on offshoring of engineering work (Hameri and Tunkelo, ibid.), secondly an action research study on business process improvement of a globally distributed support of fault tolerant industrial automation applications which control the uninterrupted production of physical goods (Tunkelo et al., ibid.).

In the third essay (Tunkelo and Hameri, ibid) we apply Moore’s (1991) Chasm theory on Roger’s (1962) technology lifecycle curve, Christensen's (1992) theory of disruptive technologies, the theory of increasing returns (Arthur, 1996) and the behavioral theory of the firm by March and Cyert (1992). We study the possible discontinuity points of the technology S-curves in industrial automation through a combination of Delphi and survey research methods to gain insight into future technology leadership and business model developments in industrial automation: We assess the potential technology disruptions in industrial automation caused by SoC technologies and related software platforms, which are right now widely deployed with significant growth in mainstream ICT markets. We explore the industry seeking answers to strategic assessments and impacts of managerial strategic decision making rationales. We assess the forthcoming technology disruption from three angles: the Customers, Incumbents and upcoming contenders; the last of which are defined as Newcomers. Newcomer can be part of a current actor, a challenger arising from another industry already familiar with the disruptive technology, a customer changing its business model, a repositioned unit of an incumbent or a start-up.

The overview of the thesis structure is presented in Table 2.

<table>
<tr><th colspan="3">Motivation</th></tr>
<tr><td colspan="3">Industrial automation is a vertically integrated large global slow clockspeed industry currently in mature technology lifecycle phase.

Personal computers initiated the previous technology disruption with microprocessor based industry standard hardware and an independent operating system. These replaced vertically integrated minicomputers which use proprietary processor, hardware technologies and Unix operating systems. This disruption occurred with a ten years delay compared to the mainstream ICT industries but only in operator end engineering station hardware and operating system.

Industrial automation is now facing a technology disruption from SoC technologies and related software platforms currently disrupting lower cost and higher performance ICT industries with tablets and smartphones.</td></tr>
<tr><th colspan="3">Research questions and hypothesis</th></tr>
<tr><th>Essay 1</th><th>Essay 2</th><th>Essay 3</th></tr>
<tr><td>Q1: How does low-skilled off-shoring differ from traditional local and high-skilled outsourcing, i.e. what are the managerial challenges related to off-shoring?

Q2: How are organizational capabilities developed in the off-shoring entity and to be able to educate and train low-skilled workers to maintain, develop and deliver complex system products, while at the same time protect the intellectual rights?

Q3: How to can outsourced operations support long product life cycles and customer service for years to come?</td><td>Q1: What are the key workflow performance indicators for a process improvement project in a distributed, heterogeneous and multi-tier software development and support organization

Q2: How should change be initiated in such an environment towards more efficient processes and to sustain continuous improvement?</td><td>H1: Technological disruption will eventually take place in industrial automation.

H2: SoC hardware and related software platforms are strong contenders to trigger the next technological change in industrial automation.</td></tr>
<tr><th colspan="3">Methods</th></tr>
<tr><td>One company case study</td><td>One company case study and action research</td><td>Delphi and Survey</td></tr>
<tr><th colspan="3">Data</th></tr>
<tr><td>Quantitative data from the off-shored unit: number of workers and expats, production volumes, output in R&D and how these have evolved over six years

Qualitative data, i.e. how different managers perceived the evolution of the unit

Management level people in the off-shored unit interviewed multiple times over a period of two years

Access to a vast amount of global business documents</td><td>Action: BPR[*] project implementing new lead time based KPIs and related management process to improve customer experiences

Longitudinal analysis of three years problem ticket data related to the support of 10’000+ active control systems

Field trips to Sweden, Singapore and India with interviews among 32 experts and managers with country, regional or global responsibilities</td><td>Total of 78 customers, incumbents, and newcomers interviewed

Delphi method in-depth interviews with 27 executives and experts in 2011 and longitudinal update in 2013 with eleven of them

Survey method in 2012 with 71 executives, managers and experts</td></tr>
</table>

Results		
Better results in leveraging emerging markets for complex systems engineering are achieved by giving full product management responsibility of a subsystem to the offshore unit rather than outsourcing various detailed engineering activities Focus on off-shored units employee satisfaction, career outlook and understanding local culture will improve employee commitment and thus case company success	On the basis of new KPIs and related management attention the case company turned its focus away from number of open cases towards time-to-complete and focused on reducing time consuming bottlenecks in the global support process of continuously operating production control systems 50% reduction in lead times for customer issue resolutions and implementation of new features	SoC technologies can have a major impact on industrial automation Recognized signals and surveys however indicate that the disruptions will not take place in the near future due to the slow clockspeed of the industry caused mainly by Customers' high risk leverage, i.e. their opportunity cost vs. risk cost Incumbents' strong profitability and efficient lock-in leveraging their proprietary technologies and resources supporting a vast installed base of systems with years of productive lifetime ahead Newcomers' offerings are currently proven only in a very limited number of installations with simple applications and they lack the recurring revenues for installed base maintenance Defined a quantification model, Disruption Ratio, based on five key drivers used by three key actors to resist or accelerate a disruption. Applying it to the gathered data results showed that resisting factors were stronger than the accelerating factors

Table 2: Thesis overview

Industrial automation control systems are operated through a Human Machine Interface (HMI). Initially HMIs were purpose-built vertically integrated hardware and software systems which were disrupted by technologies leveraging portable software platforms, namely Unix workstations in 1980s and subsequently personal computers in 1990s. After the disruption the operator, instead of an integrated HMI system, uses a general purpose computer which is based on a hardware independent software platform running a HMI software application. One of the topics explored in thesis is that conceivably in the next disruption Unix will return as the operating system for industrial automation HMIs and other control system modules but this time embedded in a SoC computer with an open software platform.

A PLC, DCS, SCADA and robot control system basically consists of seven tightly interconnected modules: 1) a HMI, 2) a Control system application, 3) Controller(s) each with their control application and 4) I/O units, 5) a Historian database, 6) an Engineering station and 7) Communications to communicate between the modules and other systems (Figure **1**).

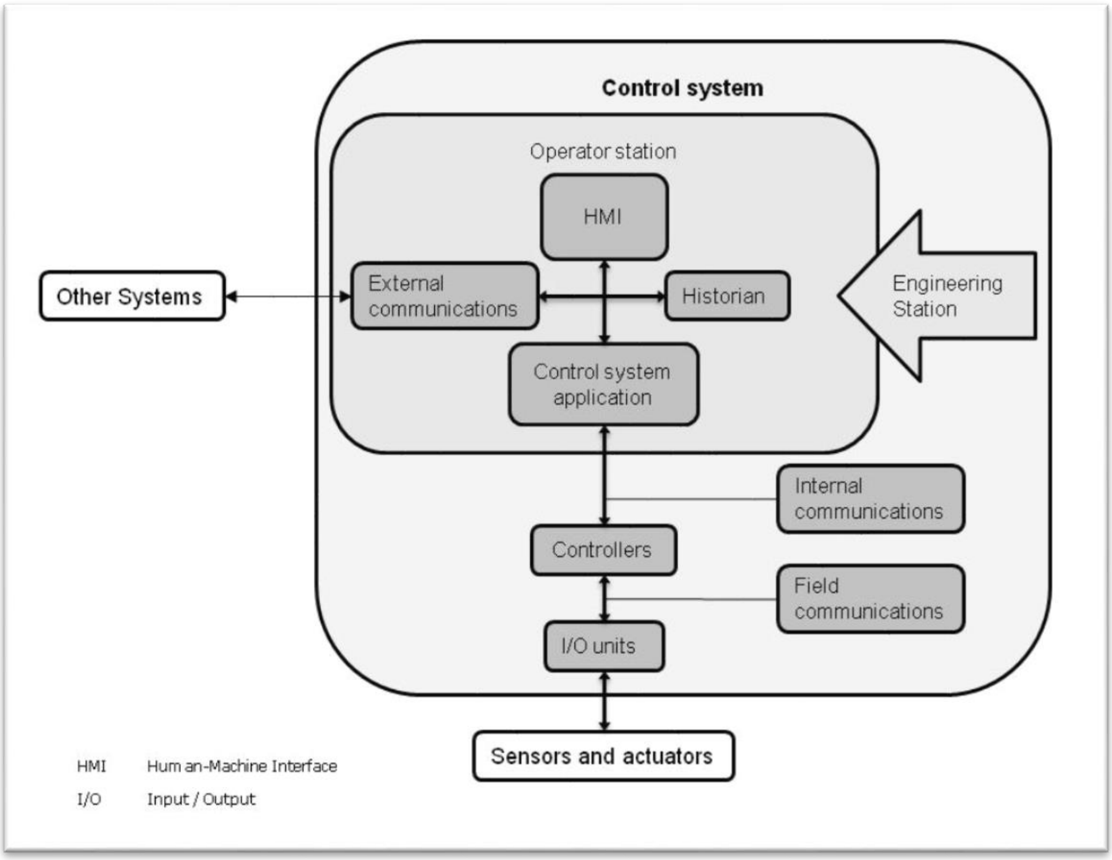


Figure 1: Control system modules

HMI is an operator station module visualizing the controlled production and enabling the operator to adjust the control system parameters for the control and optimization of the production process. Control system module receives real-time control point value series as well as alarms from controllers which are sent to the HMI for visualization and in parallel to its database module called historian. The HMI modules, historian database structure, control system application and controller applications are developed with a control system specific engineering application module, i.e. its software development environment.

As noted above, the HMIs in industrial automation have been impacted twice by mainstream ICT technology. However, key proprietary system modules are the HMI application, control system and engineering applications, controllers and I/O units. Each of them has their embedded software. The control applications are running on proprietary platforms as well as most of the system internal communications, which are however gradually starting to use standard Ethernet cables as the physical communication media. In SCADA applications controllers and I/O units are packaged together for remote control modules called Remote Terminal Unit (RTU).

The controllers are currently single board microprocessor based computers running proprietary real time operating systems with a downloaded control application developed in an engineering application module. The control application controls a set of feedback control loops each controlling a control point with a defined set point value and its upper and lower control limit values. The set point is the optimal value of the control point and is derived from the underlying production process characteristics. The upper and lower control limits define the accepted operating range for the control point. The application consist of repetitive endless loops for each control point which read input values from a group of sensors, comparing the values to set point variables and their respective upper and lower control limits defined by engineering for the control application. Based on a comparison between sensor value, set point and the upper and lower control limits, the application selects a control algorithm which controls relevant actuators to keep the control loop’s input value steadily inside the control limits at the proximity of the set point value. If the control point value exceeds the upper limit or is below the lower control, the controller application deploys appropriate control algorithm and sends an alarm to the operator station to alert the operator of a possible need for a manual intervention.

The I/O units are embedded microprocessors with the purpose of connecting controllers to sensors and actuators. They are either hardwired to the controllers and communicate with them using manufacturer’s proprietary protocols or use industrial communication protocols like

Highway Addressable Remote Transducer Protocol (HART), FOUNDATION Fieldbus, and Profinet. MODBUS and CANBUS are widely used in vehicles and industrial analyzers. To improve the interoperability in this myriad of protocols an Open Platform Communications (OPC) standard specification was developed in 1995 to improve real time data communication between control devices from different vendors.

This thesis focuses on the current status and possible evolution of industrial automation. Today industrial automation is a mature industry dominated by a handful of incumbents each with their own vertically integrated proprietary technologies. The research focus is on two distinctive points: 1) the current actions of the incumbents which maintain their profitability through internal efficiency improvements and 2) the strategic choices made by the industrial automation customers, incumbents and newcomers to leverage the foreseen radical technology disruption by SoC and related software platforms.

The three research essays investigate different phases of the industrial automation technology lifecycle as described in Figure 2. In the next three chapters we present the research essays in detail and continue to the conclusion chapter of the thesis. *Chapters 2* and *3* focus on analyzing case company’s two operational excellence activities in its current mature technology lifecycle phase: 1) The outsourcing case is about offshoring complex systems development and support activities and 2) the continuous improvement study examined the case company through participating in an improvement project targeting the re-engineering of a complex systems globally distributed support process.

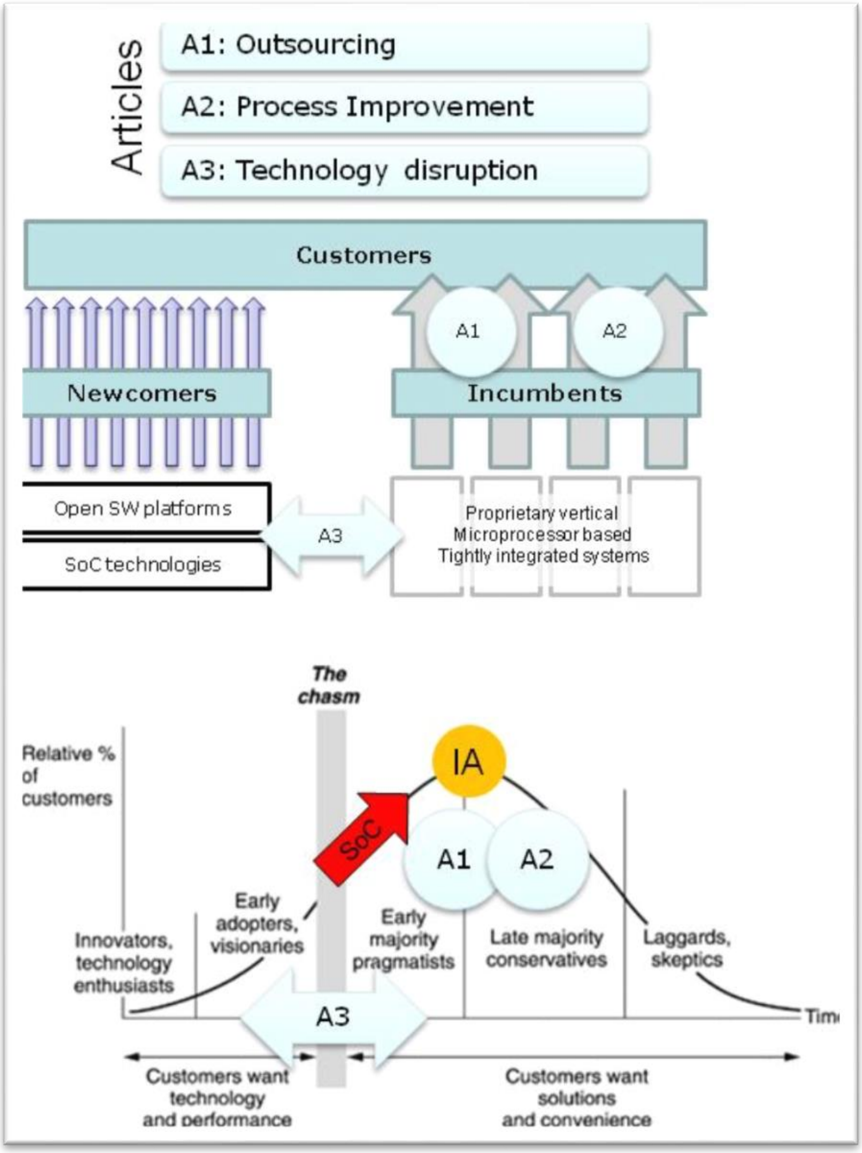


Figure 2: Research essays

Chapter 2 is a case study based on operational data in which the underlying case concerns a multinational, globally operating engineering company delivering complex system products used as part of industrial and social infrastructures, its entry to captive offshoring business model and the subsequent development from a green field operation to a sizeable center over six years.

The case advocates that the companies which recognize that building permanent, knowledge-based and proprietary presence with full product management responsibility in lower labor cost countries will be best equipped in serving customers and achieving cost efficiency in maintaining old infrastructure and in delivering new ones. Further, complex product business companies focusing on long term and knowledge based legacy building in emerging economies will develop, not only more robust global business platform for themselves, but they will also contribute to the sustainable development of the global economy.

In *Chapter 3* we focus on the complexity of globally distributed system support of a vertically integrated industrial automation application which has delivers uninterrupted real-time operations. The case system consist of more than thirty million lines of code, developed in different locations in different times over the last decades companies later acquired and merged to the case company. These subsystems have now been integrated to the case company’s vertically integrated industrial automation system which is expected to operate flawlessly for at least next twenty years with minimal corrections or functionality upgrades.

The essay addresses the improvement of customer satisfaction by increasing visibility and throughput time of those customer issues which are escalated to development for a probable source code change. The main novelty and direct implication of our findings is that the case company still has much potential to simultaneously increase customer satisfaction and profitability by focusing on reducing lead time of their end-to-end global software support process. Our results reveal that through process re-engineering and setting new KPIs the case company was able to reduce their average customer issue ticket throughput time by 50% in one year.

Chapter 4 focuses into the future of industrial automation. As all markets will eventually face technological disruption, we set out to study the next in Industrial automation. By using the research on technology evolution, paradigm shifts and related business models and management behaviors, we conduct a Delphi research and a survey among the customers, technology suppliers and experts of industrial automation.

Based on the collected case materials we foresee a possibility that SoC technologies can have a major impact on industrial automation. However the recognized early signals and surveys indicate that the change will eventually take place, yet a major disruption will not occur in the near future due to the slow clockspeed of industrial automation and the strength of the incumbents’ market position based on their proprietary hardware and software technologies and the engineering resources they control. The newcomers are faced with challenges that their offerings are currently proven only in a very limited number of installations with simple applications and they lack the recurring revenues for installed base maintenance services.

2 Captive outsourcing – the way to outsource complex products in globalized economy (Hameri & Tunkelo, 2009)

2.1 Introduction

Off-shoring and outsourcing of business and manufacturing processes have been vivid during the past 10 years. The volumes have been staggering with annual growth being continuously at double digit level (Corbett, 2004). The key driving force behind this trend has usually been focus on core competencies (Prahalad & Hamel, 1994) and access to low-cost labor (Farrell, 2004). Relocation of relatively trivial and simple business activities and operations has taken place throughout the history of manufacturing, but lately also knowledge-intensive and highly skilled operations have been off-shored to lower labor cost countries (Lacity et al., 2008; Ernst, 2002). The risks associated to outsourcing more complex tasks are not only related to the traditional cost overruns (Shi, 2007), but also to the possibility of losing vital core competencies, even innovations (Hoecht & Trott, 2006). And these risks have been materializing, as 20% of large companies that have outsources skilled operations have taken back off-shored work in the past years (Hayes, 2007).

Outsourcing takes place through a contractual agreement between the customer and one or several suppliers providing services or products the customer is currently producing internally (Elfring & Baven, 1994). Outsourcing is concerned with the logic behind make-or-buy decisions, which could be motivated by lower costs, or access to new processes and technologies, all of which affect time to market performance (Ülkü et al., 2005). Off-shoring, under the context of this paper, differs from this definition of outsourcing only in the fact that the suppliers are located in a significantly lower labor cost region than the customer. Reasons behind the outsourcing decision may be many, yet from the strategic point of view the dimensions for assessing outsourcing of a component or business process include the potential for competitive advantage and exposure to strategic vulnerability (Quinn & Hilmer, 1994). The higher the potential for competitive advantage with high degree of strategic vulnerability the more reasons there are to produce internally, and in the reverse case with low competitive advantage and vulnerability, the less control is needed and the more justified it is to outsource.

Despite the detailed tools to assess outsourcing alternatives, numerous, up to half of the organizations that have off-shored business processes have failed to meet the expected financial benefits (Aron & Singh, 2005). Problems are not only related to financial outcomes, but to employee dissatisfaction, customer complaints through defected products and bad service, and lost competencies and intellectual property. Insinga & Werle (2000) warn also that, outsourcing may be attractive at the strategic management level, but serious pitfalls are often encountered when the strategy is pushed downward into operations. In practice this means that outsourcing decisions once executed at the operational level can easily lead to dependencies that may create unforeseeable strategic vulnerabilities for the company. Also economic fluctuations affect the motivations for outsourcing and off-shoring, as Edgell et al. (2008) indicate that economic slowdown will direct companies towards cost-driven outsourcing, despite the fact that, over the long term, service-driven or value-driven deals tend to deliver more stable, successful relationships.

Despite the perils, at best, strategic outsourcing can lower costs, risks, and fixed investments while expanding flexibility, innovative capabilities, and opportunities for producing higher value-added and shareholder returns (Quinn, 1999). As mentioned, this becomes more challenging when the company is off-shoring non-trivial business processes closer to its core competencies. This challenge leads to the central research question of this paper: How companies should off-shore complex product related tasks to low-cost countries, without jeopardizing their competitive advantage and intellectual property, while building solid and sustainable business in the sourcing country? Further on, it is claimed that traditional outsourcing in global context is no longer valid, and that one should focus on long term and knowledge based legacy building in emerging economies, which will develop, not only more robust global business platform for themselves, but they will also contribute to the sustainable development of the global economy. In order to take this approach we claim that the company has to be prepared to move part of the core operations and competences outside their original high cost market to low cost country, i.e. going beyond just off-shoring of simple and laborious operations.

The rest of the paper is organized in the following way. First, the research questions are further refined, the applied case method is explained and the case characteristics are described. This is followed by a two-step case review, which starts with descriptive case information, which leads to in-depth case analysis based on the interviews. Then the results from the case analysis are presented and discussed. Finally, conclusions are drawn and the limitations of the research are discussed together with some guidelines for future research.

2.2 Research questions, scope, methodology and sample

The starting point for this research stems from the problems and challenges related to off-shoring complex product related tasks to low-cost countries. The underlying case concerns a multinational, globally operating engineering company delivering complex system products used as part of industrial and social infrastructure. This sets the research scope to complex products and off-shoring to low-cost and low-skilled countries, and questions how managers should tackle the cultural divide in skills and technological capabilities. Further on, and following Aron and Singh's (2005) urge for companies planning to off-shore that they should also evaluate different organizational forms, such as captive centers and joint ventures, we also question the business setting and proprietary implications of the ownership structure of the off-shored entity. Putting all this together the three detailed research questions for our case study are:

1. How low-skilled off-shoring differ from the traditional local and high skilled outsourcing, i.e. what are the managerial challenges related to off-shoring?
2. How to develop organizational capabilities in the off-shoring entity and to be able to educate and train low-skilled workers to maintain, develop and deliver complex system products, while at the same time protect the intellectual rights?
3. How to ensure that the outsourced operations support long product life cycles and customer service for years to come?

The first research question concerns the evolution of traditional outsourcing to off-shoring. The case company has been operating the past four decades in the field of complex infrastructure deliveries, thus it provides a unique source to document the various steps towards globalized industrial networking. The case company has been present several years in the main low-cost off-shoring countries, namely India and China. In this case we limit ourselves to India, which seems to have been longer involved with off-shoring of complex products and systems than China where lower skilled and more laborious tasks have been off-shored. Over the years the company has gained practical, very much hands-on, experience on the difficulties to develop organizational capabilities to manage people in these countries. Tackling the challenge of rooting company values and working disciplines in the off-shored unit has required major efforts and new approaches. As the scope of the paper concerns complex system products and their maintenance and development the aspect of managing new technologies and innovations becomes vital. Therefore we want to also question the methods to manage intellectual property rights when off-shoring engineering or manufacturing operations.

Methodologically this study combines both action research and traditional case study approach. Action research dates back several decades to the development of social theories and group dynamics (e.g., Argyris et al., 1985; Coghlan and Brannick, 2001). In its simple form action research is an approach to take an action, or to document and observe a phenomenon caused by an action, and to create knowledge or develop or refine theory from that action and its consequences. Action research tests the capacity of a theory to resolve problems in real life and in practical situations. This approach suits well for our purposes as one of the researchers has been involved with the setting-up of an off-shore business unit at the case company, and since its inception he has been responsible for it. According to Yin (1994), a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident and where multiple sources of evidence are used. Especially when how-questions are asked, the case method seems to provide vital insight in management studies. Eisenhardt (1989) has particularly focused on describing the process of building theory using a case study method. In her approach, the main strengths of the method are its novelty, testability and empirical validity.

To comply with these methodologies the researchers have been professionally involved with the concerned case, and they have had unique access to various business documents, including financial information. In addition, all the management level persons in the off-shored unit have been interviewed over the period of two years. The people were either general managers or directly responsible for the off-shored operations. The off-shored unit was studied through quantitative data, number of workers and expats, production volumes, output in R&D and how these have evolved over the time, and qualitative data, i.e. how management had perceived the evolution in the unit. Each session was documented and verified with the interviewees. Both quantitative and qualitative data were used to compile the main findings and these were checked to ensure they did not contradict each other.

2.3 The case: descriptive information

In general terms the case company with its well over 100'000 employees is one of the top three companies in its key market segments, namely industrial and utility automation systems. When viewing the demand side around 40% stems from the emerging markets, while about quarter of the supply originates from there. When compared with the key competitors the case company is among the players that are most advanced both in supplying from and delivering to emerging markets. The trend towards this direction has been gaining momentum during the past years, and most of the competitors have also become aggressive in gaining a stance in the emerging markets. The race is on, the investments are significant and the risks are great. And some of these risks have been realized, as indicated in the introductory literature review, over 50% of the major companies that have been off-shoring operations have to some extent retreated.

When viewed from the corporate level, the case company and its overall outsourcing from emerging markets vary strongly between internal business units. At the production plants of the case company the level of outsourcing to low-cost countries is around 3% of the total volume of outsourcing. This makes sense as these companies are producing hardware in industrialized countries and mainly do near-shoring. Units that are responsible for the testing and development of the software related products off-shore around 25% of their activities to low-cost countries, while the off-shore units themselves near-shore, i.e. outsource over 90% of their external activities to their low-cost partners. Some special cases exist within the case company, a business unit based in Scandinavia off-shore over 60% of their total outsourcing volume. In this unit and at the product cost level outsourcing to low-cost countries have resulted in sizeable cost savings ranging from 45% for a complex part requiring laborious machining to 30% in electronic components with programmable logic.

The complex product underlying the case is a general purpose control system to operate industrial facilities. It involves software and hardware components, multiple skills on control theory, management of multiple information flows and practical know-how on system integration. The product exists in many versions and its inception dates back several decades. The global installed base is significant and includes numerous product generations that are all in operation. Product development is distributed globally to U.S., Scandinavia, Germany and since 2002 to India. In all, India accounts about 5% of all outsourcing of the case company. The off-shored unit has been growing rapidly from a small unit to a medium sized operation of around 300 people, who are well integrated to the global value network maintaining and developing earlier generations of the product. Figure 1 summarizes the growth in sales, headcount and their ratio since the inception of the unit.

The average annual growth in sales and headcount has been around 80%, yet, as Figure 3 shows out that headcount has been increasing faster and the sales has been catching up later on. This is typical to any spin-off unit or company, where upfront investments and risk taking are needed before more stable operational mode is established. Actually, setting up an off-shore unit is one form of intrapreneurship, i.e. entrepreneurship within a large organization, and carries along similar risks as any entrepreneurial activity (Antoncic & Hisrich, 2001). At the very beginning, in 2002 the company allocated full workload to the newly founded unit, and the years to follow included establishing organizational structure, governance routines and improving skills to master more challenging tasks, thus making the ratio between sales and headcount go down. After 5 years of operation this ratio starts to reach the initial level of fully loaded unit.

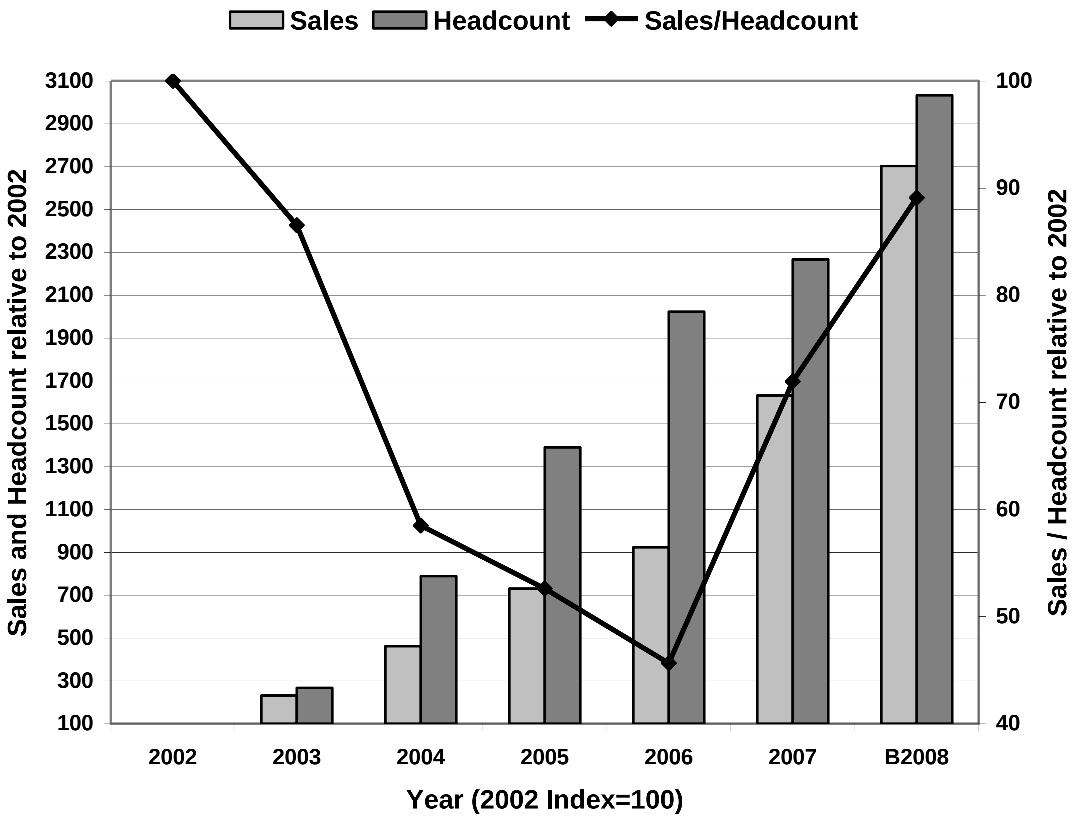


Figure 3. Annual growth in sales, headcount and their ratio at the off-shore unit in India (index = 100 for year 2002).

On the global level the product sales, including support, have been increasing all the time. At the same time product development resources have been cut in Europe and north-America, while the unit emerged to India. This transformation has not affected sales volumes, or product support. This transition has taken place during the past 6 years in gradual steps. The key is in the building of the right corporate culture right from the beginning, i.e. have the workers to respect the corporate values, assure them that top management is behind the effort and that they are not only exploiting cheap labor but to build permanent business presence with skill-based value creation. It is utmost important to show the new employees a sustainable long term career development as part of a core global team, not just an individual work against a pre-defined isolated work package.

The maturity model for IT outsourcing presented by Gottschalk & Solli-Saether (2006) outline three major stages along which most relationships evolve. The starting point is cost stage, which is based on economic benefits, low transaction costs and efficient division of labor. The resource stage concerns access to vendor resources, including innovation and strategic resources, and development of skills and capabilities. The third stage is final partnership in which work takes place in an alliance, with mutual relational norms, social exchanges and balancing stakeholder interests. These stages are partially visible in the case at hand, yet they take place in parallel and partially right from the beginning when the unit was founded. Clearly, the cost stage is prevailing all the time, but the resource and partnership stages have started early as the responsibilities and know-how increase.

As said, growth in manpower and sales has been facing double, even three digit growth since the inception of the off-shored unit. At the very beginning, in 2002, the off-shored tasks concerned simple system testing, which have since developed to include also software development and documentation tasks. After few years of operation the more demanding development tasks have occupied majority of the workforce. At the same time responsibilities for complete work packages have been assigned and gradually local people have been reaching higher management positions. The organizational structure is relatively flat (see Figure 4), which still reflects that tasks associated to the unit are related to well-defined and repetitive operations.

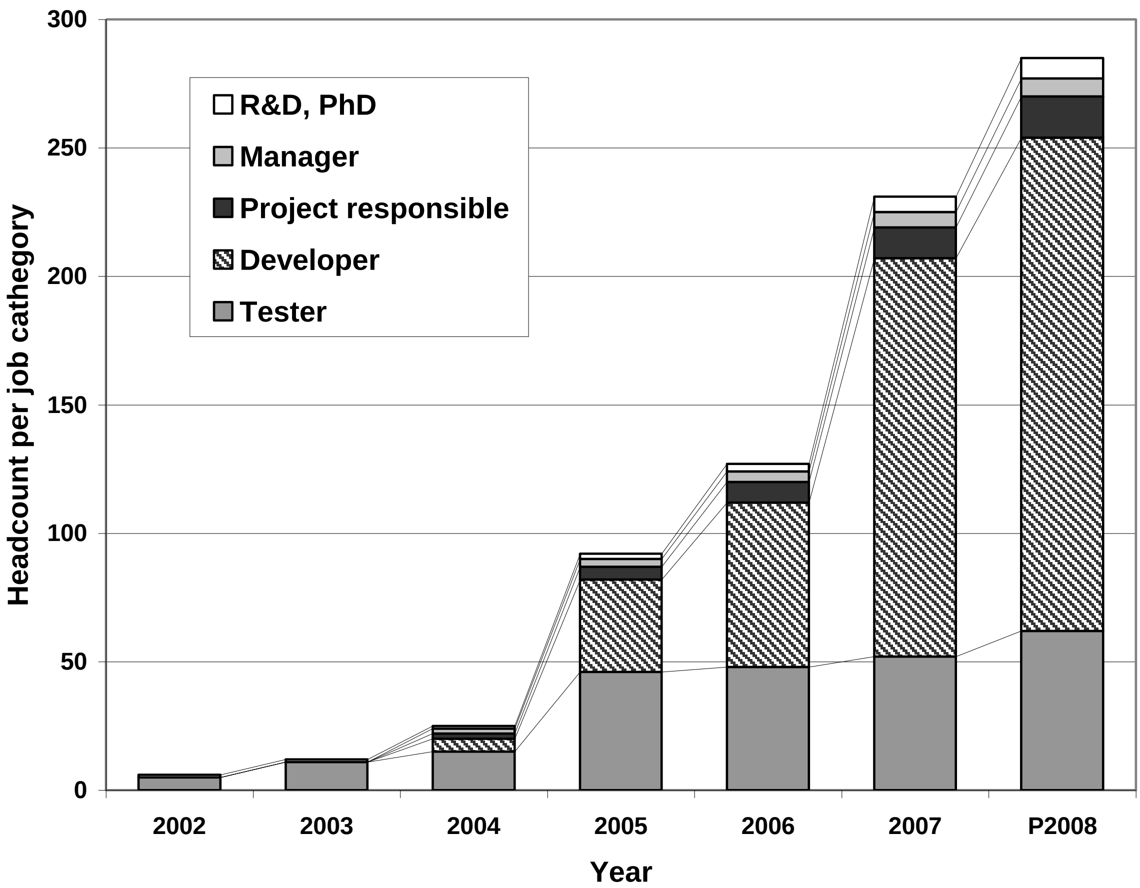


Figure 4. Development in manpower competences.

But when looking in detail the competence base at the off-shored unit, it has been changing continuously, in the beginning the focus was in easily defined and controlled testing tasks, and later on work related to product development has become the most prevailing occupation. In terms of numbers, in 2003 about 60% of the workforce was linked with testing and 24% with development, and in 2008 these are foreseen to be reversed. Also the number of people having direct project or work package responsibilities has increased. In practice this means that the working hour based reporting and compensation have gradually been changed into the purchasing of larger and more complex project entities. Along this evolution the performance measures have been evolving well beyond cost minimization towards traditional efficiency and productivity measures. Lately, the company has included also innovation related metrics in place. Since the off-shoring country is close to key growth markets, the unit has started to be involved in managing product processes in order to satisfy the local market requirements.

2.4 The case: practical insights

The risk related to loosing vital product development know-how at the off-shoring unit has been managed by assigning the unit to be responsible for product modules that are parts of a complex and systemic whole. This deliberate decision was made to prevent the hollowing out phenomenon, i.e. the peril that company loses vital skills to suppliers that turn into competitors with an upper hand to their former pier (Aron et. all, 2005, for a model see Anderson & Parker, 2002). This finding is not directly supporting Marion et al. (2007), who studied suppliers to automotive industry and concluded that there appears to be little financial or functional benefit to develop product platforms that share common components or subsystems when these products are being manufactured offshore. They do acknowledge, though, when considering outsourcing, platform-based product development principles can still yield tangible improvements in production costs over the life of the product. The case company with its robust multi-generation product platform and modular structure enables them to keep strict control on the overall product delivery process, thus using the off-shoring unit as complementary asset to the complex value chain they are mastering.

With complex system products outsourcing in carefully planned subsystems is possible while keeping the rights within the company. The case company has had bitter experiences in the past, as one supplier became a rival in a certain product category through the hollowing out effect. To avoid this to happen again, the case company has been very careful in defining what to outsource and off-shore. Maintaining direct management control of the off-shored organization is vital to keep the key operational processes to stay under own management, this way single employees leaving the company have practically no possibility to become a competitor on their own against their original employer.

In the Indian unit of the case company, to recruit one worker, one needs to hire 1.5 people on average. Influx of people is high and loyalty is low, as people change working place without notice and sometimes people who have even signed the contract never start in the job. Turnaround of workers at the off-shored unit has remained high at lower organizational levels. During the 6 years of operation loyalty has been gradually building up, people learn to take responsibilities and the local management is highly aware that they must deliver. Some of the local managers have already managed to reach higher levels in the corporate hierarchy. This development is vital to build sustainable presence in the off-shoring countries, as it shows that people are treated equally and rewarded, when they deliver.

Also in other aspects than recruiting the human resources department faces new challenges when operating in emerging markets. Building leadership skills in a culture that has birth given social hierarchies has proven to be hard and time consuming work. To tackle this, the case company has been investing in building leadership skills among the locals through intensive training, coaching and gradual introduction of responsibilities. The number of permanent expats at the off-shoring units has been low, roughly one against every one hundred local employees. In the beginning their relative portion was higher, but after 6 years the number of expats is going down in relative terms. Low presence of permanent expats has been compensated with tighter controls than normally used at near-shored units. These controls include shorter cycles in steering committee meetings and regular headquarter visits combined with monthly written reports on utilization, sales and other issues related to operations.

Since the opening of the unit in India the case company has been applying similar approach to other countries. Figure 5 sums schematically how the restructuring of global manufacturing operations has been taking place. As one of the managers said: “We aim to have a global footprint, and in manufacturing it means that we have value adding units at each continent serving both local and global growth.” The restructuring has been taking place during the past decade and the emerging markets have been speeding this transformation even more during the past years. What is important is to note that as relocation to lower cost countries have been taken place, sales have started to increase, which is explained mainly by the sales to the emerging markets, while growth rates in already industrialized nations have remain modest when compared to emerging markets.

While units have been closed and new ones have been founded, the company has naturally learned on how to transform production from one place to another. Cultural differences and location make things different, yet the approach adopted with the case unit in India has been applied to numerous units in other countries since 2002. Restructuring of the manufacturing base has naturally reduced production work in industrialized countries, yet the overall number of employees in the company has remained almost the same. During the past years growth in the emerging markets has been significant, while industrialized countries have also been growing but with moderate speed. This applies to the case company also, i.e. the decision to have permanent global presence has made the company capable to keep up with the growth, wherever it has taken place.

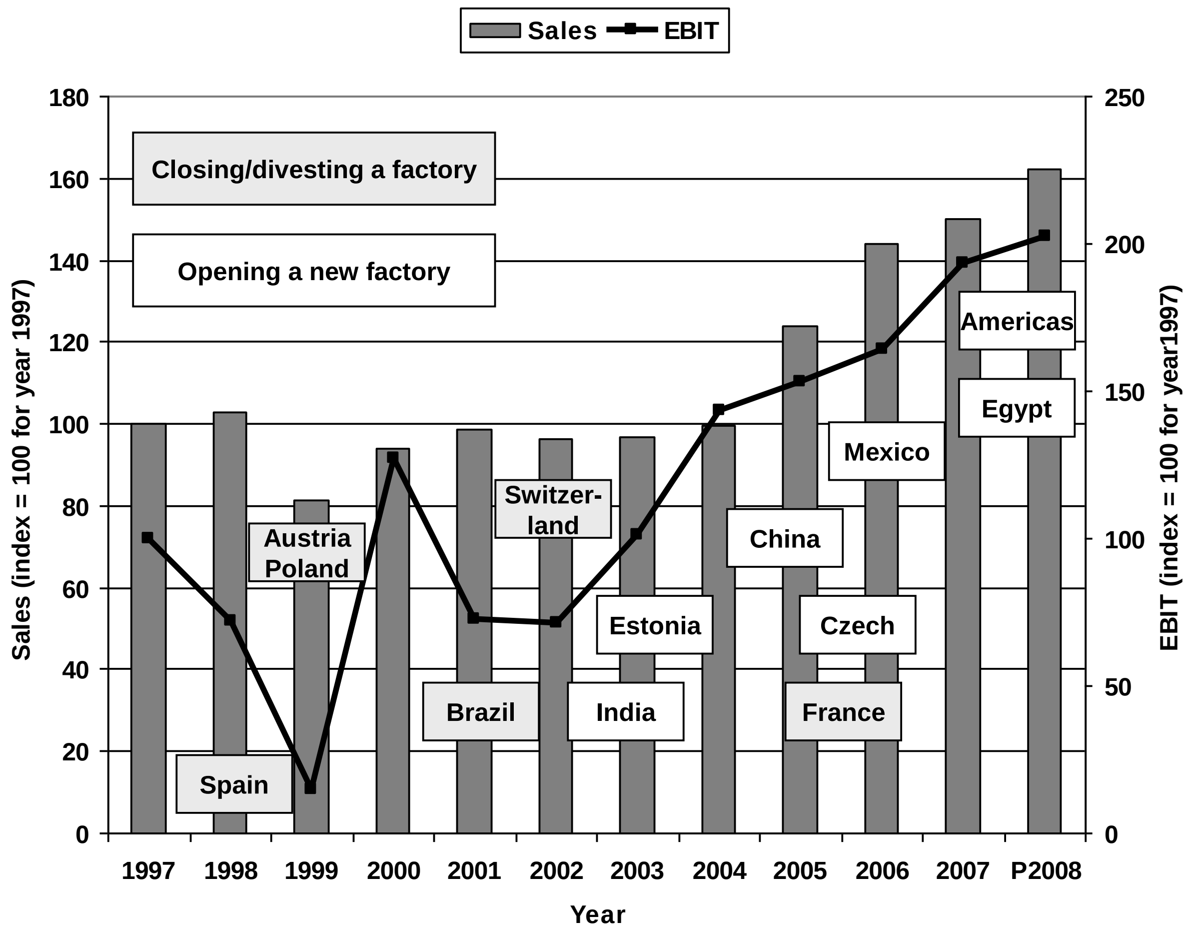


Figure 5. The global manufacturing restructuring program, the impact of off-shoring to the corporate unit with global footprint (both for sales of the unit and EBIT the 1997 is Indexed to 100).

"Managing change, what does it mean – all I know is that, if you think of it, you are already late", proclaimed one of the managers implementing the global footprint approach. Maybe this statement highlights the common banality that change is more of a norm than an exception in the management of global operations. And it sure is, as it should be emphasized that the transformation process described in Figure 5 concerns one business unit within our case company, should one put all the units and their own restructuring programs, then company could be viewed as a continuous stream of major changes and restructurings.

2.5 The rationale of captive outsourcing

Based on the case analysis it is time to detail what is meant with captive outsourcing and what are the managerial implications of it. The aim of captive outsourcing and off-shoring is to leverage the total purchasing volume of the corporate both internally and externally in a global scale. This requires strong local presence in all major emerging markets in order to reduce unnecessary general administration costs and to build long term relationships with the local employees and suppliers to ensure that the company values are secured and the operations become sustainable. Based on the case this can be achieved through tight ownership securing the corporation from the risk of slipping proprietary knowledge to external organizations that potentially could end up competing with them.

Off-shored units require also tighter controls and careful administration through centralization and standardization. This does not mean that the off-shored unit needs to be treated differently from the other corporate business units, but like in any start-up building a very competent core team is vital for solid foundation on which fast growth targeted operation can be built on. Like with any other unit the off-shored one is to be integrated with the corporate-wide IT platform for documentation and project management purposes. This complies with the tighter control requirements and is an efficient way to achieve the control. Further, in order to accumulate experience one should establish centers of excellence that are managed by the corporate, i.e. bring training and remote support services also to the off-shored unit.

The off-shored unit need to be secured with enough demand, so that the learning processes can be established. This means that seldom the off-shored unit sells to other customers than its parent company. This may change over the years as usually the first external customers are in the emerging markets, otherwise the captive outsourcing entails that their customers are units of the parent corporation. These units buy services at predefined fixed hourly rates or lump sums for complete work/project entities. This means that off-shored unit, through improved operations and efficiency, can make profit and further invest in its expansion. From the corporate point of view units that use the off-shored services may mark up as much as they can while holding the P&L responsibility of the total project.

Off-shoring decisions should be part of the long term strategy of a truly global corporation. Numerous companies seeking for short-sighted benefits from lower labor costs have reportedly got cold feet through higher than expected logistics costs and non-compliant quality. In the case company off-shoring is seen as part of its global presence in which benefits from emerging markets and rapid economic growth become intertwined with lowered labor costs, but in the longer run and with increased living standards becomes a solid international business unit serving global markets wherever they might at that time be.

The case company and many others with similar restructuring projects have been facing public criticism for their overly capitalistic pursuit to exploit emerging markets by cutting manufacturing jobs in the western countries. Clearly individual suffering has been taking place due to the restructuring, and also companies themselves have been facing bad publicity affecting their image. Let us see what this transformation really means from the point of view of our case company, in Figure 6 we have summed inbound and outbound transactions between and from the suppliers and units residing in lower and higher labor cost markets in the case business unit at corporate level.

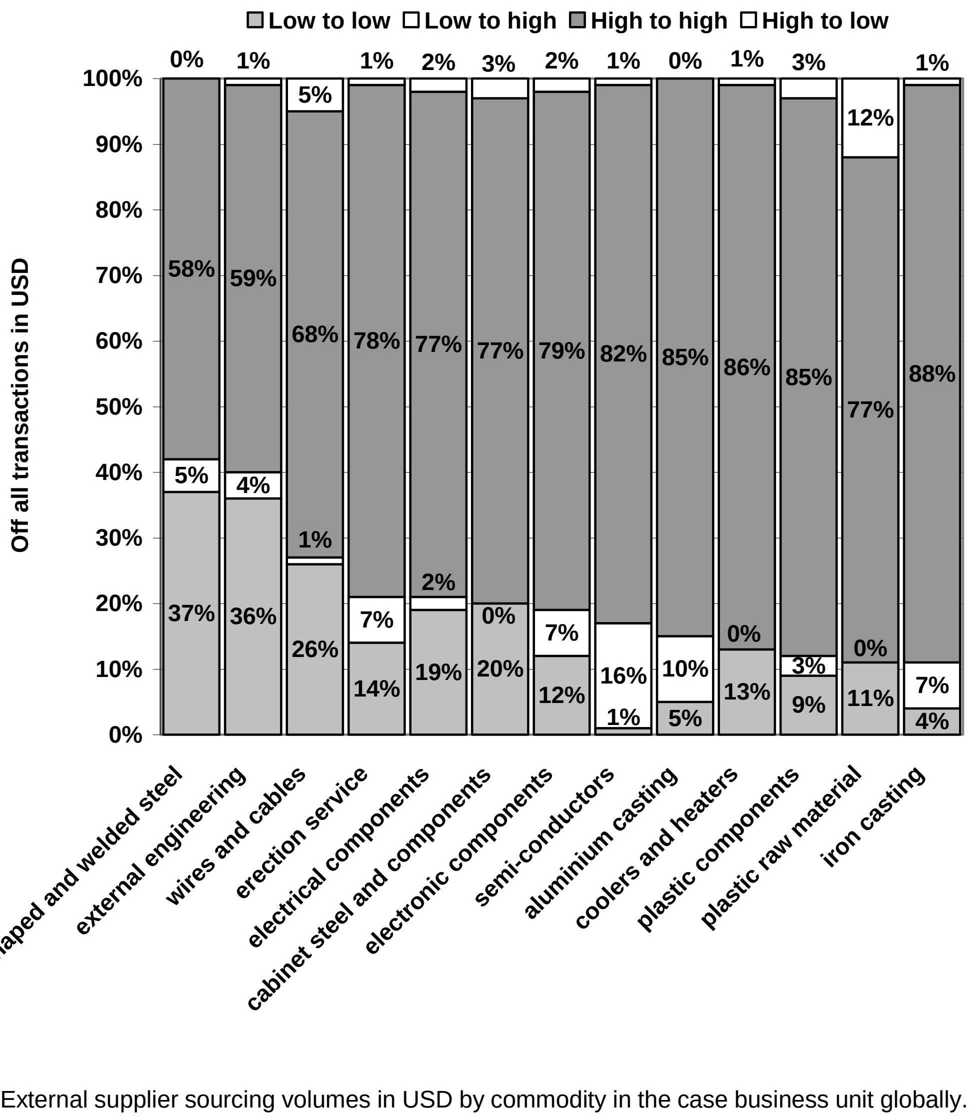


Figure 6. External supplier sourcing volumes in USD by commodity in the case business unit globally. Legend from top down: factory in low-cost country with high-cost (US or Western European) external suppliers; factory in high-

cost country with a local, high-cost supplier; successful export from low-cost supplier product to factories owned by the corporate in the US or Western Europe; corporate factories in low-cost countries with local, low-cost suppliers.

If we start examining Figure 6 from the top of the graph towards the bottom, the first class concerns supplier transactions from high cost countries to low cost ones. The first observation is that the volumes are small throughout the commodity categories, being in some of them non-existent. This means that few are the high cost suppliers and their deliveries to the units of the case company in the low cost countries. This can be explained partially by the logistics costs and by what tasks have been off-shored, i.e. in our case testing and software development, in which external supplies are limited. In practice, complete subassemblies are being delivered by high costs suppliers, which encapsulate proprietary technologies. The case company has intentionally limited sourcing from high cost countries to low cost countries, in order to boost local sourcing at the low cost country.

The next category concerns sourcing between high cost suppliers and producers, and it clearly holds the largest transaction volumes. The managers clearly see that these transactions will form the majority of sourcing in the future also, as the product factories with their know-how will remain in high-cost countries. As one manager said that “the know-how and experience of the demanding systems is within the walls of the factories located in high cost countries”. Moving these product centers and their supplier networks to low cost countries is simply unfeasible. But the engineering operations related to the installation of these systems, where ever it may take place are forced to be close to the end-user and these are globally scattered to high and low cost countries. One has to remember that the corporation is selling infrastructural solutions through complex project deliveries. They have to be able to deliver and serve their clientele despite potential social unrest and other hindrances in low cost countries. It is part of the contingency planning of the case company to maintain full delivery and service capabilities in high cost countries.

The third category consists of supplies from low to high cost country. Ironically, in high cost countries, this is seen as the major cause killing factory work at high cost countries, and at the same time it forms such a small fraction of the overall sourcing volume. From the corporate point of view the logic is solid, sourcing from low cost country will increase margins, and, yes, it works, when one is sourcing toys, apparel and other lower skill content operations, but in our case with complex systems this is not so straightforward. End customers of infrastructural products do not like the idea that their huge overall investment could be jeopardized by components that might be defected due to poor control and unknown components. This may be the situation now, which could change gradually with captive outsourcing, as one of the managers proclaimed: “it will take long, very long before whole systems will be delivered from low cost countries, first there is the peril of losing know-how and then there is the quality problem, but captive outsourcing is taking us in that direction in mutually sustainable way."

The last category counts transactions between suppliers residing in low cost countries. As already mentioned, the case corporation aims to increase local activity by giving the complete sourcing responsibility to the unit based in low cost country. This approach shows out as an activity that is increasing in volume along the overall growth of the economy in the low cost country. This development is also boosted by the increased end-demand for the infrastructural systems in the emerging countries. This evolution of supplier networks around the off-shored unit demonstrates nicely the healthy impact of captive outsourcing on the emerging and industrializing economy.

2.6 Discussion

The General Secretary of the Communist Party of China Mr. Deng Xiao Ping has summarized the main message of this essay by proclaiming: "We do have trained people, but the problem is how to organize them, arouse their enthusiasm and give full play to their special skills." This is exactly what the globalization is all about and what each and every company should keep in mind when off-shoring their operations. It is not trivial to achieve the challenge stated by the General Secretary, but the case documented in this paper shows, in a humble way and with the weak power of one case evidence, that there are means to achieve this. In the following each research question is reviewed and discussed.

The first research question focused on the differences between low-skilled off-shoring and traditional local and high skilled outsourcing, and especially what are the managerial challenges related to off-shoring. Already the simple fact of time zone differences makes it more difficult to keep real time contact and control on the off-shored units. The often heard claim that off-shore units work when we sleep can only be achieved after common working experience with clearly defined assignments. The shear physical distance makes face-to-face meetings time consuming, thus local presence is needed by relocating key people at off-shore location. The use of teleconferencing tools eases the daily collaboration to a certain extent, yet the lack of experience among the off-shored teams, which often have young age profiles, require more frequent progress monitoring meetings than with traditional outsourcing.

The primary motivation for off-shoring is cost efficiency, but estimating the total costs is significantly more difficult than the per diem or per hour basis of the service being bought. To avoid misunderstandings the assignments and work packages must be defined in more thorough manner than normally. Despite the increased control of the actual work and more extensive testing and inspection, quality problems tend to be common the company may be surprised when the initially anticipated gains form the off-shoring are not materialized. Off-shoring is a long term decision that should be part of larger strategic decision to enter the low-cost country, and shortsighted cost cutting decisions should be avoided.

The second research question focus on the potential risks related to intellectual property rights when the organizational capabilities of the off-shoring entity accrue over the time. This risk seems to be present especially when components and modules of complex system products are being off-shored. To control this risk the company should re-locate right mix of skills at the expert and management levels of the organization and pair them with local management candidates to initiate the training and knowledge transfer process. In order to facilitate fast and controlled handover the organizational structure has to be preplanned with efficient control structure. Implanting the right organizational values from the beginning is also vital and selected off-shoring people should be trained at other units of the company located in high-cost countries. This “train the trainee” approach has proven to boost loyalty, thus lowering the risk for the hollowing out phenomenon. Organizational job rotation, with clear career paths, of technical and managerial people is welcomed, especially when good performance is rewarded with advancements in the local, and when possible in international units of the company.

The applied off-shoring strategy should extend beyond the role of customer and employer to an active social contributor. Active stakeholder communication and interaction with local community, authorities, schools and universities are part of the valuable investment to build positive brand recognition and long term presence in the area. This kind of image of the off-shoring entity as a safe and long term employer is the best way to tackle the risk of knowledge spill-over. The legal foundation of the off-shoring unit sends a signal to the local market on the company’s intentions. The case company owns majority of the unit and the rest of the ownership is floated at the local stock exchange with certain reserves for employees’ incentive program.

The third research question concerns ways to ensure long term and global product and customer support jointly with the off-shore unit. This question highlights the long term partnership in which the off-shore unit plays significant role in the global operations of the company. In addition to the building of sustainable image and key people loyalty with correct compensation schemas, it is vital to treat the off-shore unit as an equal business unit. This would mean things like no layoffs due to economic cycles without proper reasons and the gradual assignment of sizeable responsibilities to the off-shored unit. With complex system products this means that gradually the off-shored unit should take full sub-system responsibilities including product development, maintenance and service.

To succeed in off-shoring requires an integrated vision from the management, which integrates product life-cycle understanding, cultural implications and organizational requirements. All this should be combined into a long term view, which is not limited to short sighted low labor cost exploitation. The case clearly shows, that starting small with full management backing and strategic vision for the coming 10 years a company can build a professional organization with innovative capabilities that is able to serve global markets with high customer satisfaction.

The underlying case limits most of the conclusions to companies with complex system products. But it is with these infrastructural products that companies may best benefit from off-shoring in longer term. These products have typically huge installed base with numerous different versions or generations of the same product. Managing the product life-cycles, versions and up-grades is laborious, but provides an excellent way for an off-shoring unit to tuck on to overall product management process. The case company started with older generation products with their support operations and have since moved towards more modern product generations. This way the skills have been gradually developed and the off-shored unit has gained vital experience by dealing with real customers and their needs.

At best off-shoring leads also to genuine wealth creation for the company with long term vision to develop truly global R&D, product delivery and support center in all emerging markets. As one of the mangers said, “A company is truly global only when it has global presence in high value adding operations in every continent”. The fact that work places have been lost in Europe is unfortunate but inevitable development following the logic of Ricardo’s comparative advantage according to which the job lost to lower-cost nation will eventually be replaced by a job producing higher value. This has taken place also in the case company, while in the short term jobs have been transferred to the lower cost companies, different kinds of work opportunities have been created within the company concerning disruptive technologies and specialized expert services.

This study leaves many issues open for future research. Detailed studies are needed on how complex product development and maintenance should be managed when off-shored units are contributing to these globally distributed processes. Human resource related issues, especially incentive schemas, remain weakly explored area when off-shoring is concerned. Cultural setting has potentially strong impact on how off-shoring strategies should be implemented, what works in India may not be the case in China. Cross-cultural studies on traditional outsourcing do exist, but similar studies on low-cost off-shoring are few and this study contributes to this research tradition.

3 Improving quality and customer experience of a globally distributed software development and support process – A case study (Tunkelo et al. 2013)

3.1 Introduction

Software process improvement projects are recurrent management initiatives in most companies developing, maintaining and supporting software products. These projects seldom have long lasting impact on the organizational performance as the changes are not sustained (Napier, 2008). Heavy duty approaches like the implementation of the capability maturity model (CMM) are laborious and also suffer from long term support from the management (Jalote, 2000). In a similar fashion, the implementation of various recommended software standards is seen as the first step, yet far from the conclusive step towards consistent software quality and processes (Yang, 2001). As process development is concerned, the Total Quality Management (TQM) legacy is vast and has been broadly implemented in software processes, yet even there critical improvements have not been lasting, especially when projects and processes are changed (Ravichandran & Rai, 2000). The increased outsourcing of software development tasks has not improved the situation as these tasks generate changes in the processes and cost reduction targets are not met (Caldwell, 2002). Maintaining and improving software quality remains to be a challenge both for in-house and geographically distributed networked operations.

To address this challenge we document a longitudinal and in-depth case study on how a globally operating engineering company delivering complex and tailored hard- and software systems improved its development and customer support processes. The problems prevailing in distributed software development are known to many companies and several approaches have been applied to improve these processes. They have also been extensively studied by academic scholars (for a summary see Da Silva et al., 2012). Issues related to quality are a major concern in these studies. After studying 189 globally distributed software projects Cataldo and Nambiar (2012) show that distribution of developers across locations along with architectural and technical linkages between these development teams affect significantly software quality. Taxén (2006) documents how complex telecommunication system delivery processes were improved by establishing a central control on different subproject interfaces and through the operationalization of the engineering processes and their coordination; the latter meaning the division of the process into elements in which they can be measured and observed as an independent entity. Despite the challenges related to the management of distributed and knowledge intensive operations, they make it possible to harness diverse expertise and ease access and improve the service provided to globally scattered clients. According to Boutellier et al. (1998) the challenges could be managed with modern IT tools and centralized project management. However, it is, in reality, more complex than that, especially when operations are performed in a geographically distributed manner by interconnected units in different continents.

Relationships between organizational context and management information system (MIS) structures are significantly correlated with organizational structures which, in turn, are closely associated with organizational size (Ein-Dor and Segev, 1982). Most global companies are the result of numerous mergers and acquisitions and therefore their structure by default is decentralized, heterogeneous with a mosaic of different cultures, information systems and leadership traditions. In their thorough case study Sambamurthy and Zmud (1999) show that companies with a past filled with mergers and acquisitions seem to result in a federal and decentralized governance mode, meaning that IT responsibilities vary from one business unit to another and that centralized control is hard to accomplish and information system related decision-making is located at divisional or even lower organizational levels. This type of corporate environment, which has emerged through numerous large scale mergers with its problems to manage complex software development and support processes, sets the scene for our case study. Therefore, we simply reflect on how a company in this kind of heterogeneous and global environment can initiate and maintain company-wide software development and support process improvements. We also assume that applying the operations and production management domain knowledge to lead time reduction can be used to the workflows related to the globally distributed software development and support processes.

This paper addresses operational efficiency issues related to global companies with cross-continental workflows in complex system development and support processes. Improving these processes continues to be challenging as the business environment is changing continuously through increased outsourcing and off-shoring of operations. Edgell et al. (2008) indicate that economic slowdown and fluctuations in general direct companies towards cost-driven outsourcing, despite the fact that, over the long term, service-driven or value-driven deals tend to deliver more stable, successful relationships. This entails that the value network in which the development and support processes are managed is continuously changing, thus making process improvement even more difficult. But managing remote sites, be they own or outsourced, may generate all kinds of friction to the development work through distrust and fear (Piri et al., 2012).

The challenges related to global software process improvement are numerous; cross-border and intercontinental workflows, different computer systems and protocols inherited over time, collaboration with off-shored units and, naturally, increasingly demanding customers with their unique requests (Šmite and Wohlin, 2012). To address these challenges we document a case of a global company and its efforts to speed up the workflows related to software development process and customer request response times, in order to improve the overall software quality and customer experience.

To achieve this, the rest of the paper is structured following the action design research approach (Sein et al., 2011) in the following way. First, a literature review of software quality, process improvement and distributed operations is presented to detail the main drivers for the case study. Then the case company is described by reviewing its history and evolution to a global, yet heterogeneous and cross-cultural organizational structure and the particular challenges faced by their software processes. This is followed by a chapter detailing the key research questions from the literature review and the case characteristics, including a discussion of the justification for the single case study and for the action research methodology together with the scope of the study. Details of the software development and support process are then discussed and the improvement project is documented, mentioning how it was initiated, what goals were set and which metrics were implemented. Finally, the results and lessons learned are documented with implications for managers and for future research.

3.2 Literature review on software process improvement

Several high-profile software failures in the 1980s and 1990s, like the Airbus 320 and Ariane 5 together with the seminal Standish Group study (1995) on software projects rarely meeting their objectives triggered a software quality improvement effort in the industry (Niazi et al., 2005). Numerous studies indicate that the root cause for software quality problems lies in the management and/or in the lack of the software process and its continuous improvement. Vitharana and Mone (2008) study software process improvement (SPI) models like CMM and ISO 9000, and identify six critical factors of software quality management (SQM) to develop an instrument that can be used to measure critical factors of SQM. These six critical factors are top IS management commitment, education and training, customer focus, process management, quality metrics, and employee responsibility. These factors are very broad and describe the whole software process environment with all the key dimensions, which serve well for the structure of the literature review.

Human factors, be they commitment or competence, seem to play a crucial role in software quality. McDermid and Bennet (1999) have argued that human factors in SPI have been ignored and this has damaged the effectiveness of SPI programs. Hall and Wilson (1998) also suggest that the experiences, opinions and perceptions of software engineers have an indirect impact on the quality of the software produced. Further in this line of research, Baddoo and Hall (2002) show that there are different motivational clusters among the software developers which should be understood to better manage the software development process. Following this trend Prikladnicki (2012) applies psychological and physical distance to analyse the collaborative workings of the remote teams, proving that things unknown to project managers are happening irrelevantly to physical distance. Naturally, training and concerted actions are important when managing distributed software processes, thus actions like continuous training and education of those involved in the software process along with disciplined reviews and respect on design standards are important (e.g. Rainer and Hall, 2002; Subramanian et al., 2007). Different skills and working traditions in globalized software processes call for unified procedures in order to keep the software process under control, therefore most of the SPI training aims to establish common working procedures (Pettersson et al., 2008).

Software process maturity is directly linked with the expertise and discipline of the people involved in the SPI, which, in turn, affects the productivity of the process (Chapin et al., 2001). Harter at al. (2000) studied the relationship between process maturity, quality, cycle time, and effort for the development of 30 software products by a major IT firm. They found that higher levels of process maturity as assessed by the CMMI are associated with higher product quality, but also with increases in development effort. Findings indicate that the reductions in cycle time and effort due to improved quality outweigh the increases from achieving higher levels of process maturity. This means that the net effect of process maturity shows in reduced cycle time and development effort. Thus, process maturity correlates not only with product quality but also with operational efficiency.

Ultimately software quality is determined by user satisfaction. After a thorough literature review and a follow up survey, Issac et al. (2006) conclude that employee competence is a crucial factor affecting software quality. They also found that product attributes i.e. reliability, integrity, portability, extensibility, flexibility, reusability, functionality, and maintainability, are vital for customer satisfaction. Customers see that the characteristics of software are highly influenced by process quality management and competence of the employees. Quality is judged indirectly by focusing on the effectiveness and usefulness of the delivered system in performing the task for which it was designed. In other words, quality refers to whether the system is constructed and performs as it should have been built and as it should perform. Moses (2009) argues that direct measurement of quality attributes should be encouraged and that such measurement can be quantified to establish consistency and continuous improvement. Sousa and Voss (2009) show that services failures, once happened, can be successfully worked out when correcting things swiftly.

Service and support activities are directly linked with customer satisfaction and company success. Watson et al. (1998) show evidence suggesting that management's attention to service quality has not been consistent and that ignoring it is harmful for the company. Information system management needs to recognize that service quality is not a fad but an on-going commitment and the CIO must continually pay attention to IS service quality. Continuous process performance measurement and information visibility at all levels of the process are vital for software companies as Bharadwaj (2000) documents results indicating that firms with high IT capability and process maturity tend to outperform a control sample of firms on a variety of profit and cost-based performance measures. Better control reduces process variability, thereby improving operational efficiency and software product quality. After studying 37 CMM level 5 projects in four organizations, Agrawal and Chari (2007) find that high levels of process maturity, as indicated by CMM level 5 rating, reduce the effects of most factors that were previously believed to impact software development effort, quality, and cycle time. They also show that the biggest rewards from high levels of process maturity come from the reduction in variance of software development outcomes that were caused by factors other than software size.

Lead time based metrics can be applied to any business process and workflow (Bartezzaghi et al., 1994), yet the metrics for software development projects and processes are numerous and seldom based on time-based measures. Project related metrics follow traditional earned value and effort versus outcome metrics (Raffo, 2005). Process related metrics are traditionally based on various lead time, work-in-progress, throughput and punctuality versions depending on whether testing, in-process activities, architectural design or software engineering are concerned (Kan, 2002). Traditionally, seven tools of quality have also been applied to software development and support processes and total quality management is a well-established part of the software process improvement (Vitharana & Mone, 2008). The total quality management approach is widely used in any process development (Kueng, 2000), not only in software, but also in manufacturing, services and governmental process. SPI does not differ from other process improvement projects. They all fundamentally aim to reduce variation and lead times, while increasing output and improving punctuality. Challenges to improve software related processes remain and become more significant when the work is done in an emergent network of different cultures and technologies, as the case company will show.

The above literature review shows a glimpse of the vast research tradition in software quality improvement and measurement. We aim to follow this research suit by extending the software quality management and customer service to a global environment of a major company in industrial information technology. This aim is backed also by the profound literature study by

Šmite et al. (2010), who show that global software engineering research lacks in-depth case studies. To meet this challenge we document the key findings of a three year long change management project aiming to improve software quality and request response times in a global setting, where work is done on different continents. Issues concerning how the improvement project should be managed, what metrics to be used and how to institutionalize the changes are reviewed. These are all critical issues for most of companies developing, delivering and maintaining complex software systems, where the systems are often the result of an amalgamation of different sub-systems through various acquisitions and partnerships. Initiating and maintaining process improvement in this type of heterogeneous software development and support environment has seldom been discussed in the academic literature.

3.3 The case company and its challenges

3.3.1 Building a global player through acquisitions

The case company was created through a major merger between two large engineering companies in the end of the 1980s. The merged companies were specialized in the engineering and production of electrical equipment, turbines, motors, generators and transformers. Both companies had an industrial history stemming well over a century of pioneering work in building electrical infrastructures. By joining forces, the idea was to build a global industrial giant that would be capable of competing against the two major global rivals in the industry. The rationale behind the new competitive advantage was based on an unsurpassed in-house technology portfolio behind one single corporate brand to be sold directly to utilities and industry conglomerates in large infrastructure businesses.

Radical organizational change was implemented to globally manage local businesses, also known through the slogan “local everywhere”. This was to be the key differentiation against the targeted rivals to challenge the fact that the merged company did not have large home markets unlike its key competitors. To pursue its new strategy the company started to acquire domestically operating European companies in power generation, transmission and distribution. The operations of the acquired companies were mostly kept untouched as local governments wanted to secure the local capability to serve their electrical infrastructure in case of crisis. This was an even more understandable request as most of the countries had used different standards when setting up their electrical infrastructure. Most of the acquired companies were made to serve as the main supplier for their home country’s infrastructure. The new global products were to follow these markets as soon as the new strategic product and technology development would be completed.

The acquired companies were old-fashioned mainly locally operating engineering and technology companies and therefore their balance sheets included undervalued fixed assets (especially land and buildings). By liquidating these assets the company had the opportunity to fund further growth. It was time to shift the focus outside of saturated Europe, and with its experienced engineering workforce the aim was set on the electric infrastructure in Asia and Middle East. The strategy used in Europe was also applied to the Asian markets, and the approach was well received by Asian and Middle East governments since it provided them with an approach where they could be self-sufficient for their electrical infrastructure in case of economic and social instability. At the same time the company acquired a foothold in the North-American market. This wave of acquisitions took place in the 1980s, and more were to follow toward the end of the century and finally the company achieved its world leading position in automation and instrumentation. In some industries the company practically ruled the market.

Through the acquisitions and growth of local, yet global operations the company had to face the issue of underutilization of its engineering resources which were spread over tens of countries operating in an autonomous manner. Restructuring was costly and barriers imposed by national standards, different languages and cultures hindered the efforts. The different information systems also constituted a significant problem for process integrators. In addition to the "local everywhere" concept, that provided all units with the production capacity to address the global markets, it created strong internal competition. The strong position of local management made it very difficult for the global management to address the internal competition through market allocations and operation closures.

3.3.2 Building competences

The company started a massive investment in R&D to address two difficult problems: overcapacity in engineering and globalization of product and technology portfolios. The existing engineering capability was leveraged to build leading edge technological products since downsizing of these resources would have been costly and politically too risky. The Internet boom fuelled the company to focus on industrial information technology as a vital part of their product offering. Simultaneously the company continued to develop new breakthrough technologies to replace local products with new and improved global products. One fundamental issue remained; the company had a lot of software capable engineers, but no history in running a successful software business.

Due to the numerous acquisitions the company was like a patchwork quilt and was faced with serious challenges in engaging in R&D with such a distributed organization. The responsibility for development initiatives was given to different countries based on political needs rather than the true competence of the respective operations. At the same time major efforts were made to integrate IT systems so that some visibility was achieved to global support and development processes. Common to all of these activities was that the development programs resulted in cost and time overruns and had severe quality problems. Products were delivered late with inadequate quality, the company needed more IT skills instead of control systems skills and the system was lacking functionality required by the market, and which the competing systems had.

To tackle these problems the company made a radical organizational change. The company was to run three different business models simultaneously. First, there would be a product division responsible for creating technologically leading products and strong indirect sales. The customer division with an ultimate customer intimacy approach was to sell the total range of the products through a customer segmented sales force. Finally, the information technology and support division was planned to interconnect the products seamlessly and simultaneously with the customer's value adding process. The main idea was that the customer is locked-in with the company for a long term relationship. The aim was to get scalable business with global proprietary products and software, and a common global sales and engineering force for all products.

Focus was also put on life cycle services as the customer base included users of practically all system versions ranging over 20 years of development work. This meant that customer specific application engineering and commissioning as well as life cycle services represented a significant source of the total revenue generated. Being an advanced and innovative company the software products were based on object oriented software architecture long before object oriented programming had become common in software industry. This approach enabled the company to liberate itself form dealing with multiple applications, operating systems and platforms. The new platform allowed any application to see and manipulate data in real time giving the company a significant advantage over the rivals.

3.3.3 Challenges of distributed operations

The way the company had evolved generated several challenges for the management. Focusing on the software process improvement we detail here the following software process improvements to shape the research questions for the rest of the essay. The software engineering platform that is used to develop customer solutions from different hardware and software components is developed in different locations or on-site at external suppliers.

Customer solutions are designed at an engineering center and then finally commissioned to the end-customer site. Coordination is vital. For example, a typical delivery in which platforms and modules are developed in four different countries on three different continents, can be required to be operational in another country on another continent. Special challenges are related to the metrics that must be implemented to improve product quality, operational performance and delivery efficiency in the development and support processes. From the value chain point of view, it is necessary to determine how the company can better integrate its distributed R&D and support operations in a more efficient manner.

The current product offering is monolithic and hybrid, a combination of MS Windows and other platforms, with several in-house built processing units handling I/O streams from tens of thousands of control points in one typical installation. In all, the system consists of tens of millions lines of code. 80% of the customer base runs older versions of the systems than the company is currently offering for new installations. Industrial companies operating their factories are reluctant to upgrade as long as the existing system runs well. The customers expect that the system lifetime is well over ten years without major upgrades. 20% of the customers use the latest version of the system, and sales offers one solution. New product development and related support teams of the latest software version are overloaded with the older system versions, and their work gets hampered with multiple requests. The underlying heterogeneous software platform does not make things any easier, especially when part of the development and testing activities have been off-shored.

The challenges the company faces on its current technology base are linked with challenges listed in the literature review:

- How to organize workflows at different levels of the multi-tier support processes to manage multiple software versions in a distributed environment?
- How to measure and improve the multi-tier support processes to reduce response times and variation in the process?
- How to collect vital user experiences to improve overall product quality of the system versions to come?

Today the case company is the result of numerous mergers and acquisitions resulting in numerous independent units and several different technologies. It is not surprising that the company has sometimes been labelled a “loose federation of independent nations”. The challenges they face in their customer support are to some extent known to any company delivering, developing and supporting complex software in a distributed manner.

3.4 Research methodology, questions, scope and sample

3.4.1 Research methodology

This research is based on a single company case, and it includes change actions with controlled observations and deductions based on individuals, groups, organizational setting, hardware and software configurations (Lee, 1989; see also Cavaye, 1997). To achieve this we apply action design research (ADR) methodology (Sein et al., 2011), which assumes that the information technology artefacts are ensembles shaped by the organizational context during development and use. Following Sein et al. (2011) ADR shares two key challenges, the first being the definition of the problem situation encountered by the specific organizational setting through interviews and other objective evaluations. The second issue concerns the construction of research problems encountered in the situation in which the artefact or company is found. These two challenges have been defined and documented in the previous chapter on the case company and its evolution in the current operational environment.

We also follow the traditional action research tradition dating back several decades to the development of social theories and group dynamics (e.g., Argyris et al., 1985; Coghlan and Brannick, 2001). In its simple form, action research is an approach to take an action, or to document and observe a phenomenon caused by an action, and to create knowledge or develop or refine theory from that action and its consequences. Action research tests the capacity of a theory to resolve problems in real life and in practical situations. With its various paradigms, action research has a strong position in social sciences, and for the present research the focus is on learning through interaction, which results in an increase in the ability for practitioners to solve problems. In our case study the action involves the implementation of a new performance monitoring system for the software development and support process and the related coaching to manage the processes accordingly. This action is based on the operations management principles stemming from efficient manufacturing processes. This means that in order to follow the action research tradition the researchers have been professionally involved in the case for several years and the work has been documented over the past two years through active participation in the change process.

This means that our research action is in line with the design science approach (Holmström et al., 2009, see also Kuechler & Vaishnavi, 2008) as we use the well-established domain knowledge from operations and production research on the efficient management of distributed software development and support processes. According to the design science approach the work is broadly divided into four progressive steps, the first being the development of an initial solution design, and secondly applying the solution to a real problem and documenting the outcomes. The third step is dedicated to explaining and developing a substantive theory and establishing theoretical relevance. To achieve the fourth level of contribution and development to a formal theory, i.e. strengthen theoretical and statistical generalizability, further explanation is needed. This approach follows the Stuart et al. (2002) conclusion that general research as well as case research can be broken down into five critical stages: definition of the research question, instrument development (including site selection), data gathering, data analysis and dissemination.

We cannot avoid touching the case research tradition as Yin (1994) defines it. For him a case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context when the boundaries between phenomenon and context are not clearly evident and where multiple sources of evidence are used. We also apply the case study guidelines for software engineering (Runeson & Höst, 2009). According to Eisenhardt (1989) the main strengths of active case research method are its novelty, testability and empirical validity. Gummesson (1991) considers that this is also one significant reason why the action research approach is seen to be the most far-reaching method of case studies.

3.4.2 Research questions

Based on the ADR approach, literature review and the case description the work sets out to study the following research propositions:

- What are the key workflow performance indicators for a process improvement project in a distributed, heterogeneous and multi-tier software development and support organization?
- How to initiate change in such an environment towards more efficient processes and to sustain the transformation with continuous improvement?

The approach, or action, applied to improve the processes followed the key theoretical dimensions stemming from the very core of operations management (Schmenner, 2001). These basically concern four main themes. The first is value-adding and value-creation at task, process and whole operational level, i.e. the work must somehow produce quantified value for the company. Operations not producing value should be eradicated and focus should be directed on increasing value in such a manner that customers are best satisfied and company stakeholders receive a decent return on their investments. The second theme highlights operational speed and its improvement by removing hindrances to improve performance. This simply means that operations should take place swiftly and predictably and that operational lead times should be under continuous control with the aim to relentlessly reduce them. The third dimension states that variability is inherent in every process and generates delays and disturbances. Usually the more players in a process the more prone it is to the negative impacts of variability. Efficient operations management aims to reduce man-made variability and the vulnerability in external and natural variability. The last and fourth dimension promotes service level and customer satisfaction, which should form one of the key measures for operational performance. These include punctuality, fast response and right quality level delivered to fully meet customer requirements. These key operations and production management principles are the basis for the applied process improvement approach.

3.5 Sample and scope

A total of 32 people on three different continents and at different support levels were interviewed numerous times over a period of three years (Table 3 & 4). The people were either general managers (8) or directly responsible for development and support activities (24). The support process was studied through quantitative data on support requests with their workflow lead times and variations during the whole project period. These requests include all possible requests and their escalation to different levels of the support process. They also concern different versions of the supported system and its different sub systems. Using longitudinal data analysis covering a period of three years, the various trends of the workflow performance in the development and support process could be depicted and indicate how the various changes affected the outcomes. Throughout the data analysis, records were kept on each session and interview, all of which were approved by the concerned people and the interviewees. This means that both quantitative and qualitative data were used to compile the main findings and these were checked to ensure they did not contradict each other. We follow Myers (1997) who writes that as the focus of information systems research shifts from technological to managerial and organizational issues, qualitative research methods become increasingly useful.

	Trained support personnel			Installed Systems per Employee		
Region	**L1/L2**	**L3**	**L4**	**L1/L2**	**L3**	**L4**
1	80	25	20	12	37	46
2	100	21	10	18	85	178
3	108	17	10	10	65	111
4	160	5	0	5	146	N/A
	448	**68**	**40**	**11**	**83**	**112**
	Total			Average		

Table 3. Multitier support organization scattered in 4 global regions and their responsibilities.

Support level	***Description***
L1	Local language and English call logging and simple (e.g. password) problem resolution
L2	Primarily English problem resolution by trained personnel needing no configuration changes
L3	English only problem resolution by experienced experts needing no source code changes
L4	English only problem resolution requiring source code change leading possibly to a customer specific or general patch or even a new release

Table 4. Support level definitions.

Fundamentally, we document a business process reengineering project (BPR). Following Kettinger and Teng (1997), the BPR techniques and tools form a knowledge base to improve business process change practice and provide a basis for future BPR research. We also contribute to this research tradition, and therefore issues that are beyond the scope of this paper include actual software product configuration and technological solutions and decisions made. With the workflow view we focus on the software development and support processes of the complex system in a distributed organization by using the action design research approach.

3.6 The change project

3.6.1 Motivation for the project

The justification for the change project originated from the customer feedback clearly indicating that less software updates were needed, even though most of the updates included new useful functionality. The company performed an internal and external study to find out how they could improve their customers' performance when they use the system. To establish this outside-in view, i.e. how customers appreciate using the system, was vital to set the benchmark to improve the quality perception of the system both internally and externally. The internal questionnaire was conducted by people covering the whole value chain from sales through delivery to support, while the external questionnaire covered customers working with the system every day. The results showed two main concerns: 1) certain limitations of the system remain even though they were escalated several times, and 2) there was a steady flow of various new quality issues after every update.

To move on along the operations management path, the first objective was to reveal the end-to-end lead times and service levels of the problem reporting and correction process (see

Figure 7 for an overall view of the process, and Figure 8 for a typical process for one request). All this was based on real process data on how customer complaints are handled. The data used was retrieved from three different request/incident management systems that basically are enhanced workflow management systems. The data set covers a time period of four years (2005-8, actual change project started in 2006) and the total number of customer requests and their workflows analysed was around 16'000 originating from over 1'000 customers using various versions of the software. Figure 9 sums the overall data set with the number of software versions in use by a customer and how requests originate from these customer groups. The figure shows that the more versions are used by the customer the more requests it generates per customer. It also shows that about 90% of the customers use less than 3 versions of the system.

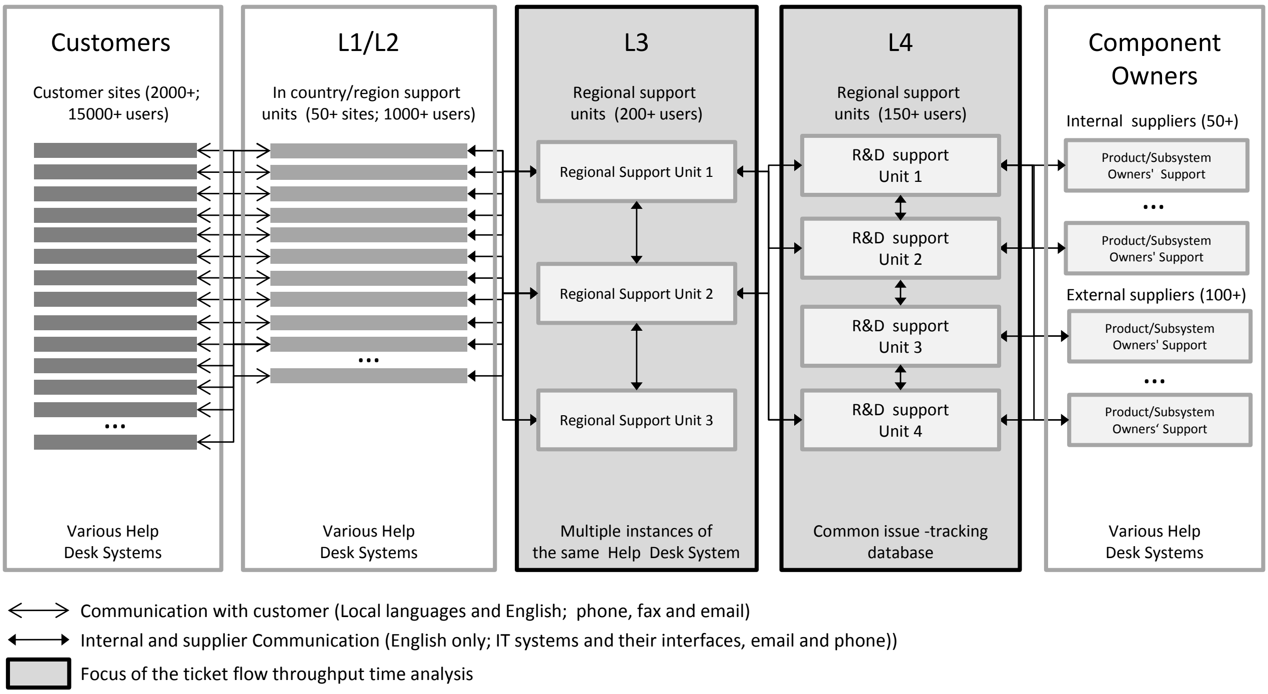
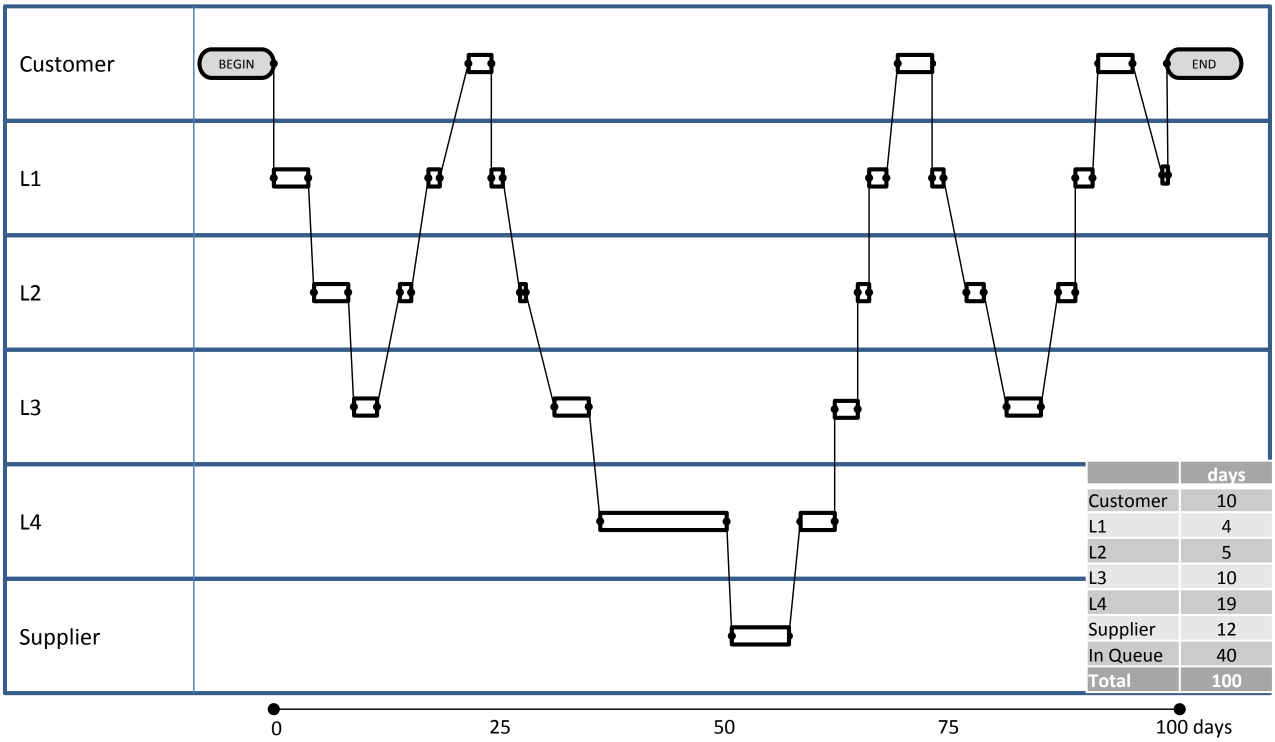


Figure 7. End-to-end overview of the customer request resolution process. The highlighted levels L3 and L4 form the focus of the analysis.



	days
Customer	10
L1	4
L2	5
L3	10
L4	19
Supplier	12
In Queue	40
Total	100

Figure 8. Example of a low performance (multi-hop) issue resolution flow requiring a source code change. Overall lead time is the sum of all lead times at each support level.

From the analysis point of view focus was on back office support levels L3 (system and module level, handled regionally) and L4 (product and source code under the R&D department), which make most of the long lead time experience by customers and are mostly concerned with possible real problems with the software. Requests that are solved at customer unit form levels L1 (plant) and L2 (application at the plant level) are handled by customer service units. The three year time window helps to reveal the dynamics in the whole support process, including how customer complaints originate (in batches, after upgrades etc.), how complaints are batched and work is routed to different support units. The long term view also supports the research aim to enhance and complement the existing key performance indicators (KPIs) and related performance dashboards for the support processes. Thus, in short, the aim of the change project was to improve end-customer satisfaction and software quality.

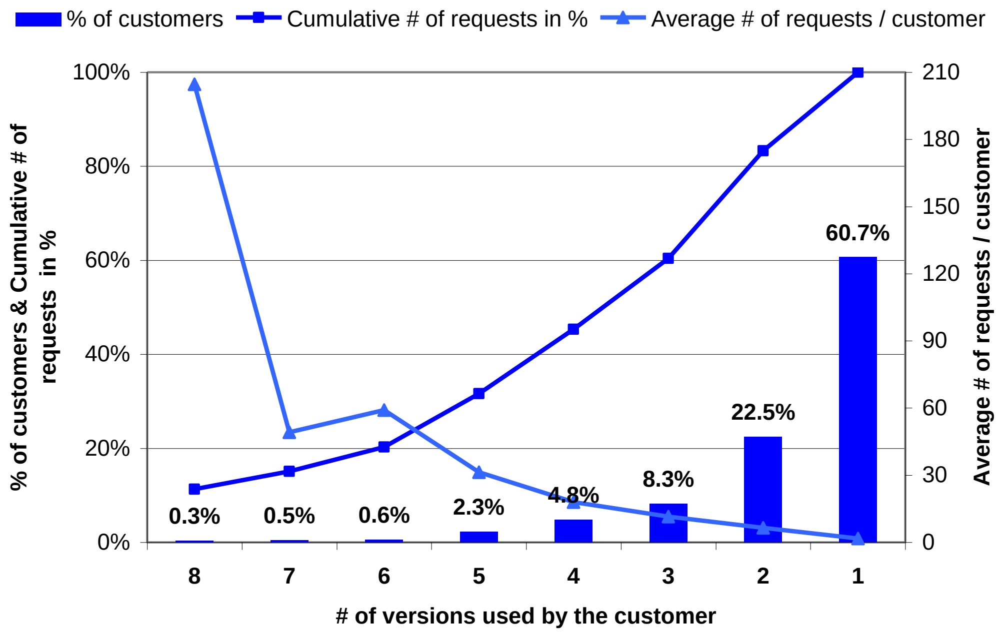


Figure 9. Number of different versions used by the customer with their average and cumulative service requests.

3.6.2 Workflow process analysis

Process data was retrieved from different systems. The first analyses concerned support requests and their average lead times with their development trends and distributions. This general information was then reviewed at the sub-system and product version level. Other attributes for the analysis of the support requests concerned their severity and criticality. Further analyses also included the origin of the supplier request, for example which customer and from which geographical location or business unit the request came. To illustrate the initial analyses, Figure 10 shows how the overall service requests get distributed longitudinally along the sample period. The versions also include the releases of different service packages, which shows that gradually the versions mature and the number of requests decrease. The work load varies not only in terms of number of requests being treated but also by their criticality. Figure 11 shows the quarterly average of request handling times in days and their count. Clearly, L3 support feeds L4 in slight delay and the number of requests shows an increase in handling times. This follows the central operations management principle stating that, while work-in-progress increases and the throughput rate of the system remains more or less the same, the lead times will increase. But measuring the lead times speeds things even at L4, like one software engineer stated that “lead time measurement is very important for a customer, but it is not emphasized in our often quite internal focused KPIs.”

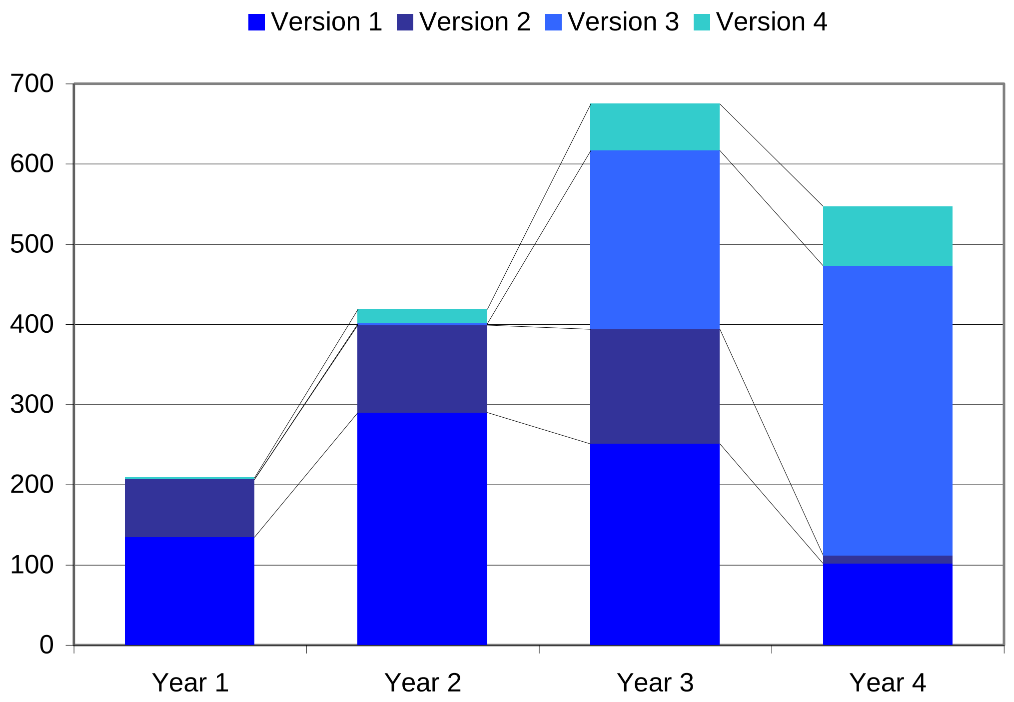


Figure 10. Number of requests per software version during the sample period

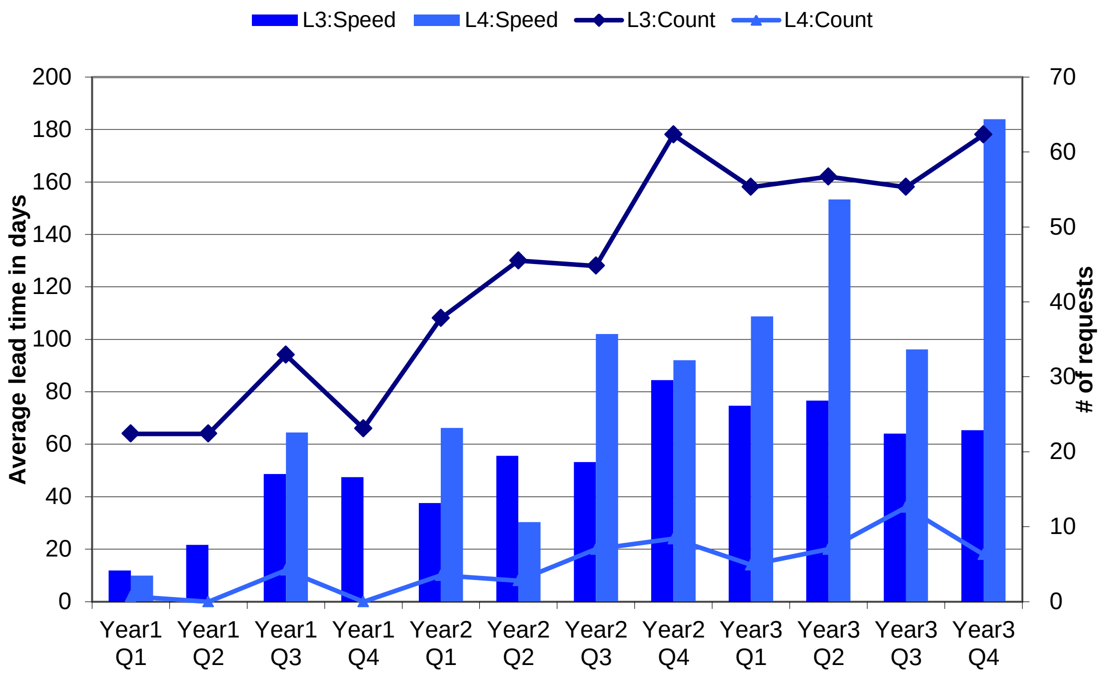


Figure 11. Quarterly average request handling lead times in days and request count at levels 3 and 4.

The immediate outcomes of the analysis indicated that the lead times in the handling were very long and their variation was significant. This means that the work-in-process is large due to the queues and parallel processing of the requests (the same problem can create a request from several customers on different continents leading to repeated support work). This also means that the predictability of the finishing of the task was difficult, thus contributing to low customer satisfaction. Also allocating capacity to these situations is difficult as work load fluctuates making the planning of human resources also more difficult. What could have been the reason for this? The data points indicate that there is a problem with matching the plans with the reality.

Requests are released as they are independent of the capacity situation, no planning is made based on the load situation and all requests are queued as they arrive. Some of them are classified based on their urgency. Open requests prolong their processing lead times eventually affecting the software quality and delaying the testing and releasing of the new versions. Several open requests may also generate a collateral effect due to their interrelated impact when they get handled, thus generating more unforeseen problems in the software that may not be caught in routine tests. Once requests are received their proper and thorough processing is vital to have a proper diagnosis and related decisions made at the first step of the support process. Too lax or even incompetent and over cautious releasing of requests to other support levels often generates unnecessary work and overall loads that further make situations at lower support levels more difficult. It was clearly seen from the data that proper gatekeepers, who are not numerous in the total population taking part in the process, are essential.

To facilitate change and better manage the project centralized reporting database was established to collect actual ticket flow data from multiple systems. This data was used to create a set of standard reports to relevant stakeholders. The global business management took a visible lead in making sure everybody knew about these reports and each KPI was to be understood and monitored. The improvement of customer request resolution time was made to be an essential part of every business review. This generated initiatives at all levels to improve the situation as a regional manager said: “When people became aware that the top management had become very interested in the improvements achieved in the ‘Outside-In’ KPIs, they themselves analysed what these KPIs meant to them and started their own improvement. This made the improvements come through much faster than the central project team could ever have managed to control.”

3.6.3 Organizational aspects

A cross functional virtual project team with members from all geographic regions was established. The team was supported by external experts on process analysis and data mining. The team was mandated to visit customer support and development centers to perform interviews and to access databases to collect actual process data to capture the true state of the customer service quality. Additional targets for the project were to improve trust and co-operation between various support levels and to provide even L4 teams with a fact based view on how end-customers perceived the service provided by the whole support organization. The project was assigned to report to a steering committee of various stakeholders (business management, sales, service and finance representatives) on regular intervals. The steering committee had a central budget which it could assign to targeted improvement initiatives presented by the project. The project would oversee the implementation of the improvement actions, but the actual responsibility was at the target unit. Impacts and results of these actions were monitored through a centralized reporting system.

Gatekeepers, who share installation specific information, are vital for the overall quality of the process. One of them sincerely suggested, “Why not spend more time on the request evaluation in order to avoid unnecessary non-value adding work in the upstream of the process”. Another one had a KPI implemented that prevented his team from “overloading the next support levels with critical requests”. These gatekeepers are mostly very knowledgeable people who have worked for a long time in the corporation and its various locations. They have accumulated a massive amount of tacit knowledge that should be documented properly. It became apparent that their decisions were documented in the workflow management system, but neither the reasons nor the inference logic behind the decisions made were documented. These people hold profound product know-how extending even to the knowledge of different customer installations and their past history of problems. Several things came up in the interviews. The database holding information on the installed base should hold detailed information on the history of updates and problems they have experienced earlier. This accumulated tacit product know-how was largely unexploited and not documented in the support database.

One support engineer at L3 summed the situation “The regional support centers have a complex role of prioritizing the customer requests and escalating them accordingly. Using the physical world logistic analogy has been helping us in our realm of information logistics. Understanding the ABC-classification in regard to issue tickets has been helpful in my co-operation with my colleagues who are facing the customer. Not all issues are equally important, but for every ticket the lead time matters most to the end customer. And of course that the resolution has to be first time right." This highlights that the measuring the request workflow across support levels helps to bring the end-customer closer to lower support levels. The end-to-end visibility and its analogy to physical material flows was nailed down by another support engineer at L2: "I have always wondered why our ticket tracking system could not have the same feature as DHL has with physical packages. Why is it not possible for us or even the end customer to go to web and see where is an open ticket now, who is working on it or is it only waiting and when should the resolution arrive".

The source of the requests varied also, making their prioritization difficult in a system with single window processing. They could originate from daily use of the system, customers experiencing problems after an update, or projects being managed by the software vendor. Their source could also be traced back to brand new installations, new version development and testing. Yet, the main finding of the analysis was that independently from where the request originates it is treated the same way as all other requests. This means that their urgency was defined not by their source but their assessment at L1 and L2 levels. This also means that the same major support team was used to treat any problems that may occur from any possible source. The importance of the gatekeepers and their correct assessment of the request and consequent decisions in analyzing the requests play a vital role. The only dedicated resources assigned to handle project specific requests were related to major upgrades in major industrial facilities, although even they were organized into specific regions at the level L3, thus bypassing the main support channel serving all the other requests.

The data shows that new installation and version update projects along the normal request flow should be separated and managed differently. These different sources of requests have their own time lines and urgency. Why should a critical request related to an upgrade jeopardizing the whole operation of the factory wait for a request related to maintenance with no immediate impact on the operation of the facility? Each request is related to a normal operation, special upgrade project or new installation. In addition, the request is related to a particular customer installation and version used in the facility. Prioritization of the processing of the request should be evaluated against the particular case, i.e. customer, software version, module and the corresponding schedule. The analysis shows that the work is not prioritized and the support system treats requests as they arrive. This is also shown in the analysis related to severity level of requests and their processing lead times.

More detailed analyses were made on the specific performance of support process at the different levels, i.e. cases that do not cross from one level to another. Furthermore, the case company started to match implementation projects and version release timetables with the lead time performance. There was a special focus on how project milestones affect lead times and performance and how disciplined the processes are, e.g., features are accepted/added after a design freeze. Dedicated performance dashboards were developed to visualize the workflow and its performance. In addition, target lead times were set for different support levels, request types and modules. It was also noted that the data used for the analyses were incoherent due to different ways of coding and documenting the requests. Serious efforts were made to build up awareness of the importance of disciplined use of the support system. Special training events were developed to show bad and good cases. It became clear that the way the requests are coded in the database directly affects the software and service quality. Special attention was paid to gate keeping i.e. on the decisions to pass a request on to another support level. More discipline was introduced when documenting the request, including customer specific data on their installation and past support history. This information provides the gate keepers with the much needed tacit knowledge on the special customer installations.

3.7 The results and managerial implications

From the management viewpoint, the case study highlights the "outside in" process view, meaning that process metrics should be based on customer experience. The way the customer perceives company performance is more important than how the company perceives its performance. Ideally the process of improving software quality should be seen as the process of an express carrier with full traceability and procedures to react in case the shipment is delayed. In our case the throughput measurement was based on input and output flows of the requests and resolution with detailed analysis on process slack times and actual value adding, i.e. hands-on times. These were measured for different software versions, sites and levels of the process. These measures, which point out delays and general improvement trends, initiate a continuous improvement process mimicking the logic of Deming's Plan-Do-Check-Act cycle with a focus on internal communication and achieve the buy-in from the key stakeholders in the line organization.

The case company implemented an independent team to constantly analyze the throughput data and to convert it to actionable information by customer, subsystem and geography. To catalyze prioritization, a special weight was put on each request based on its origin. The priorities were signed accordingly according to whether it came from the customer, service manager of the company or consultant. Progress in speeding the process was reviewed periodically and reports were distributed to all those involved, including top management, which also monitored the process on a monthly basis. To promote management involvement an escalation routine parallel to a technical routine was established based primarily on the time the case was opened and second on the maturity of the product and the customer affected.

When new product introductions take place the management has clear benchmarks (time to resolve, case criticality, number of cases per month) which take into account number of systems in installation, ramp up and steady operation correlated to the number of cases from the field to different support levels. These indicators are part of the R&D team's compensation schema. In addition to these measures and incentives the continuous improvement – kaizen – mind set was promoted to drive towards zero R&D cases and fixed throughput and response times for each support and criticality level, which are measured, reported and used as part of the team's compensation plan.

As for the quantitative results and implications, the collection, classification and analysis of the request flow took 3 months. The newly defined customer experience metrics were added to the standard global management team agenda in 2 months. Every unit in support and R&D were required to report monthly progress according to a separate dashboard. The main result achieved was the reduction in the overall throughput time from the opening to the closing of the request. In one year the reduction was about 50% in all severity classes (Figure 12). The overall reduction in request handling lead times was 19 days, i.e. from the initial 38 to 19 days. The number of open requests was also reduced proportionally to lead time. What does this mean in reality? This means that support people may focus on fewer requests at the same time, and in all they have released capacity to take on more requests and development tasks, and perhaps even to improve their competences through additional training. It is difficult to assess the cost reduction implications of this improvement due to skill and location mix in the global business, yet it is obvious that all employees involved now have more time for more value adding duties. The idea of classifying and prioritizing requests by value for the customer and the effort needed to provide the support proved to be difficult. More analysis is needed to define simple enough rules for the call desk to correctly classify the incoming requests.

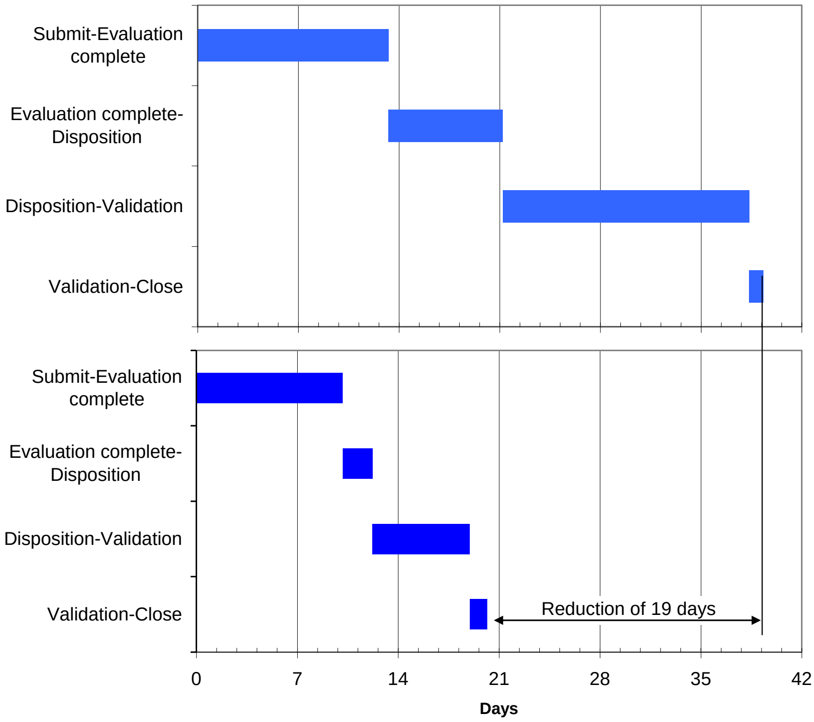


Figure 12. Overall lead time reduction in the processing of the customer requests.

Due to the complexity of the system with its different versions running on different hardware and operating systems, customers have started more and more to push the system management responsibility to suppliers due to the complexity and expertise required to operate the system efficiently. One of the latest trends in customer relationships has led the case company to take over the operational responsibilities of the customer's plant, i.e. the company not only develops, supports, delivers and maintains the process control system, but actually runs the plants on a daily basis for the customer according to predefined performance guarantees. This makes ease of operation and maintenance of the system directly business critical for the company since the inefficiencies directly impact the company's bottom line.

When adding new measurements the organization always reacts nervously due to the increased oversight and control. Therefore it was important to motivate people working in different support and R&D organizations - both in developed and emerging countries – to understand that the new measurements are a good tool to increase customer satisfaction not a tool for increased finger pointing. Yet, the relatively significant effort and top management involvement in the project showed that when adequate resources on a specific topic are placed the organization shows its capability to change. This means that numerous improvement efforts die in vain over time as their momentum runs out due to inadequate top management support and investment.

Following the theoretical framework set by Meijboom and Houtepen (2002) for international service operations along with their case in IT-sector, our results support their findings and underlying model. The more diverse and global is the service offering, the more important is the need to distinguish between services and related operations that have to take place either locally in close proximity of the end-customer, or in centralized manner in strategic global locations. Our case amends to this by showing that the service offering evolves through acquisitions, outsourcing and product development, and that this process of allocating operations and improving their productivity has to be under constant scrutiny. Theory of production and operations management with its lead time based principles complements well the existing performance metrics used in distributed development and support operations, thus helping management to maintain and improve continuously competitiveness in their operations.

3.8 Conclusions

Essentially the above described change project is very similar to any productivity improvement effort normally seen in manufacturing industries, where focus often is on reducing inventories through better flow and faster and less variable lead times. Similar time based performance metrics that are used in manufacturing can also be used for any workflow management system. Time is a critical component of any value adding process and therefore it should form one of the key metrics used to control and improve its performance. The present case and its follow-up customer questionnaire showed that customers not only appreciated faster response times, but also that they were predictable, i.e. variation was reduced. The request throughput of the whole support organization increased while resources remained the same, thus the capacity of the existing organization increased without investments.

In the complex distributed support and development environment described in this case, the full end-to-end visibility on the source of the requests and full resolution lead times as experienced by the client are needed to provide a comprehensive view of the true performance of the organization. The initial analysis set the benchmark for the management responsible for improving quality and customer experience. As such, uniform, easily understandable and well communicated lead time measurement on a global scale seems to lead positive change when this is followed regularly by upper management. An additional benefit provided by uniform measurement is that it not only makes comparison and improvement tracking easier, but it also requires a uniform application of common tools and processes to be implemented. This helps to institutionalize the change and makes adaptation to other parts of the organization easier.

This case study shows that reducing request handling times improves productivity and customer satisfaction, but the link to actual software quality remains to be studied in more detail. The assumption that, if an organization is able to treat software requests faster, it would also improve the software quality, cannot be established directly from this case study. However, operations management studies in manufacturing industries have been able to establish the positive link between operational speed and quality, which should also be valid in any value adding process including software development and support processes.

There are also other issues that emerged during the project that could make interesting research topics for the future. The general issue related to the support of multiple versions at the same time and how the outsourcing part of the support tasks should be organized remains to be studied in more detail. Another future research topic is related to the management and archiving of the tacit customer support knowledge that accumulates gradually on various systems. This special know-how on individual customers, system versions and their interrelations seems to be critical when decisions are made at each support level.

4 Technology disruption in industrial automation: A study on a major proprietary industry (Submitted (Tunkelo & Hameri, 2013))

4.1 Introduction

Technological innovations will eventually alter the status quo of any industry. Successful new technologies create disruptions leading to changes in profit pools and thus new corporations will emerge and historically successful ones will fade away or disappear through mergers and acquisitions. How and when an industry is affected by a disruption depends on the underlying technological cycles and the inherent clockspeed of the concerned industry. This process of creative destruction has received significant research focus ever since Schumpeter (1942) introduced his dynamic model of technological evolution. This was developed by Rogers (1962) in his technology adaptation lifecycle, further in Moore’s (1991) crossing the chasm and Christensen’s (2006) innovators dilemma, that is when new technologies fault well established ones. According to Christensen (1992), technological innovations are either incremental or disruptive. Disruptive technology change occurs when an application market incrementally develops new products that reach the performance requirements of a different more valuable application market. These new products are often developed by new players causing a threat to the incumbents of the disrupted higher end application market.

We deploy the concepts and models developed by the research on technological evolution and disruption in an industry that has remained immune to major technological change for more than ten years. Industrial automation (IA) a over $50 billion industry consisting of products, systems and services, mostly captive, used to run industrial processes and facilities. A handful of global corporations like Honeywell, Emerson, Siemens, Yokogawa, ABB, Schneider and Rockwell control this market with their proprietary integrated systems based on in-house developed closed computer hardware and software systems. This industry is characterized by long investment cycles, requirements for safety, reliability, uninterrupted operations and real-time control capability of physical events.

The use of computers in IA started about fifty years ago, when real time requirements of IA could only be achieved through the development of specific real-time systems forming its own niche computing market separate from the mainstream information and communication technology (ICT) market. Today the IA market consisting of proprietary tightly integrated hardware and software systems and limited interoperability significantly resembles the minicomputer market in the 1980s prior to the rise of PCs, LANs and Internet. Based on well accepted theories, we assume that the IA market will eventually also change. Industrial automation had its latest minor disruption when moving from Unix to PC based operator stations, which took place about ten years after the PC disruption in the mainstream ICT markets. Our fundamental research question is: When and how will the next disruption in IA take place? To explore this we assess and define the technological cycle of this industry and review how new computing and control technologies and software platforms developed for the smartphone and tablet industries, specifically the system on chip (SoC) paradigm, could impact IA. These new embedded systems with open software platforms have already disrupted TV, PC and laptop industries, all of which are known to have fast clockspeed. Recent examples abound: Kodak was hit by digital photography, and Nokia is suffering from touch screen smartphones, while at the same time Apple has lost its volume lead to Google due to a different business model.

To address the research problem we deploy the Delphi-method and multifaceted surveys among the customers, incumbents and newcomers of IA. Two surveys, one with In-depth interviews and the other with a structured web-questionnaire involved 78 executives and senior experts. The surveys were initially performed in 2011 and selectively rechecked for validity in 2013 to achieve a longitudinal view of the current speed of change in the industry. The customers are expecting the disruption to happen as it happened when PCs replaced minicomputers in 1990. However, the study shows that none of the interviewed customers have yet initiated activities to test the new technologies. They would prefer that the current incumbents introduce the new technologies. The incumbents are not concerned about the threat of new technologies. They are confident that entry barriers are adequately high and that the focus on competition between current players will resolve the situation. Only limited efforts were found to investigate possibilities of using disruptive technologies inside their own portfolio. Finally, the newcomers leveraging novel technologies in IA believe in entering the market through selling their products to current incumbents or through offering specialized solutions to pioneer-spirited customers. The newcomers also see a business opportunity by becoming acquisition targets for incumbents.

We conclude by proposing an experimental measure to assess foreseeable technological change called the Disruption Ratio. This variable predicts the closeness of the next technological disruption an industry will face. Industries or industry segments operate at largely varying industry clockspeed (Mendelson & Pillai, 1999) which are however hard to define precisely. Fine (1998) suggests that an industry clockspeed can be measured by the rate at which capital equipment becomes obsolete, the pace of organizational restructuring, and the rate at which brand names are established. A key strategic decision for a corporation to make is to decide whether to deploy a new technology for its products and related processes. Extensive research has proven that corporate management strategic decision making and leadership is crucial for the success of strategic initiatives. Corporate managers are human which means that their assessment and decision making may have a personal bias (March, 1994). With regard to our study, we have tried to avoid this bias by using eclectic samples for the interviews and by verifying the survey data after a couple years have gone by.

The mainstream ICT markets of today, namely computers, tablets and smartphones are converging. In the midst of this disruption, technology-based ecosystems have emerged with three main platforms. These platform architectures vary: 1) closed hardware and software (e.g. Apple), 2) closed hardware agnostic software (e.g. Microsoft) and 3) open hardware and software (e.g. Google and Texas Instruments). The size of the available profit pool and earning models of the platforms differ and different actors in their respective ecosystems have different opportunities to achieve their respective volumes and margins. For example, recently Samsung and other hardware vendors betting on Google’s Android platform have introduced their own application stores to capture at least some share of the application revenue market currently received by the platform owner. It is these platforms, especially the open ones that will potentially play a key role in the future disruption in IA. When and how this will come about is the very objective of this paper.

To achieve this objective, the rest of the paper is structured in the following way. First, a literature review is provided on technology lifecycles, technological evolution industry clockspeed and management behaviors in strategic decision making. We also study the latest developments in technological platforms and ecosystems that seem to be currently leading ICT market developments. These trends are presented to define the main drivers for technological change to be used in the survey questions. Next we detail the key research questions based on the literature review and the target market characteristics, including a discussion on the justification for the structured interview and web questionnaire approach. The applied Delphi-method is also explained in detail, The results of the surveys are then presented and details of the automation market key actors and their drivers as well as their respective parameters are defined and assessed. Finally, the results are documented, including their theoretical and practical implications, and the validity of the research is reviewed before presenting avenues for future research.

4.2 Literature review

Schumpeter (1942) developed his theory on economic innovation and creative destruction in the 1940s to reveal the dynamic nature of the capitalist system strongly driven by technological development (Pol & Carroll, 2006 and Backhaus, 2003). The technology adoption lifecycle model (Bohlen & Beal, 1956) explains Schumpeter's theory in the context of technological change and evolution. Rogers (1962) extended this model to include five phases for the diffusion of innovations (innovators, early adopters, early majority, late majority and laggards). This model explains how new technologies enter the marketplace and gradually evolve into mature businesses. Rogers (ibid.) suggested that the same product can be sold to customers of different characteristics using different argumentation depending on the particular phase of the cycle. This model was further refined by Moore (1991) by adding the 'Chasm' between the early adopters and beginning of the mainstream markets, which he defined as the critical crossroads t for new technologies to evolve into success or not.

Christensen (2006) introduces his principles of technological disruption by describing why great companies fail due to a lack of recognition and management in circumstances of technological change and paradigm shifts. Leading incumbents tend to focus on their main customers by fulfilling their expectations for too long. Lacking adequate precautions, other less demanding markets develop cheaper and more performing products and services which eventually become applicable to their markets. This gives the newcomers a competitive advantage and, in response, the incumbents should develop new technologies disconnected from their mainstream business in a non-adjacent market. This may also be an opportunity for the incumbents. Enkel and Gassman (2010) indicate that using cross-industry innovation existing solutions from other industries can be creatively imitated and translated to meet the needs of the company's current market.

Defining is the nature of disruptive technology is not trivial. Danneels (2004) points out that the Christensen's (2006) chasm-model does not establish clear-cut criteria on how to determine whether a particular technology is to be considered disruptive. Be it disruptive or not, companies should keep several different technological avenues open. Bergek et al. (2013) argue in favor of a creative accumulation approach that requires firms to simultaneously manage a triple challenge: (a) fine-tuning and evolving existing technologies at a rapid pace, (b) acquiring and developing new technologies and resources and (c) integrating novel and existing knowledge into superior products and solutions. This comes back to the opportunity that is embedded in the technological evolution. Knecht (2014) describes industry dynamism as a strong force in the market that can present an opportunity or a threat to a corporation. He defines the concepts for dynamism and some measurement methods to quantify it in multiple dimensions.

The history and theory on technological change indicates that companies should always remain prepared for a possible technological disruption. Rohrbeck (2011) claims that many firms lack effective processes to spot, interpret, and react to external change. Foresight capabilities are required to maintain competitive advantage in times of disruption according to Seabright et al. (1992). Rohrbeck (ibid.) also raises serious concerns about the ability of corporations to sustain their competitive advantages when a disruption occurs. To either mitigate or leverage the impact of a technological disruption is even more crucial in industries with fast clockspeed. Mendelson and Pillai (1999) argue that industries are characterized by a dedicated clockspeed that measures the speed of change in the external business environment and sets the pace for internal operations of the companies. Guimaraes (2011) suggests that industry clockspeed is a result of measuring relationships between strategic leadership, competitive intelligence, and management of technology, innovation process and success in business model innovation. This means that companies operating in fast clockspeed industries should be agile and vigilant in their strategic management and ready to maintain multiple technological trajectories open.

Establishing innovative business models becomes critical, especially in high clockspeed industries. Therefore strategic discontinuities and disruptions call for changes in business models as argued by Doz and Kosonen (2010). Business models of efficient firms constantly evolve towards stability which leads to increasing inflexibility. This may pose a threat when a company operates in a high clockspeed industry. Osterwalder and Piqneur (2010) suggest that when assessing business model changes, nine elements need to be well defined, planned and appropriately interconnected to accurately manage the relation between cost implications and revenue impacts: 1) customer segments, 2) value propositions, 3) channels to market, 5) customer relationships, 6) revenue streams, 6) key resources, 7) key activities, 8) key partnerships and 9) cost structures. All these elements fit well when developing or probing disruptive technologies, but whether this really takes place in companies in IA remains to be studied.

This leads to Porter's (2008) theory of competitive forces where the rivalry is surrounded by entry and exit barriers. Entry barriers are advantages that incumbents have relative to new entrants. Exit barriers force existing players to remain in the business which can arise due to highly specialized assets that cannot be redirected or due to management's devotion to a particular business. In the case of disruption, the management may easily overestimate the strength of the entry barriers and end up facing the exit barriers. This theory has been challenged by Harney (2012), who points out that far too often once lauded companies like Nokia and Kodak succumbed to complacency and inertia apparently by surprise. Garrison (2009) studied large corporations and their technological-sensing capabilities on the early adoption of disruptive technologies to determine whether this technological myopic view is dependent on company size and market position. The size of a corporation was shown to be a hindrance to its capability to respond to technological change despite its superior technological awareness and capabilities relative to smaller companies. This may also be valid for the companies ruling the IA industry, as they all are large multinational corporations.

Managing technological change and preparing for disruption requires decision making from management. As indicated earlier, management may become complacent through a strong market position and decisions may be made purely on a cost and revenue basis. According to Simon (1959), decisions are affected by cognitive facts and forecasts, but fundamentally they are based on individual experience, beliefs, emotions and an intuitive assessment of the company's needs. More importantly decisions are based on personal risk and reward assessment both short and long term. Personal perspective and emotions are important behavioral drivers which may prevent management from making the decisions needed to prepare for the technological disruption (Pinsonneault & Beaudry, 2010). This may partially explain some of the technological ignorance by management leading to major corporate phase outs. This also may be the case in IA as a low clockspeed industry with complacent market positions.

The past decades have shown that successful technologies emerge not only because of their superiority over the existing ones, but because of their overall offering to develop and build an ecosystem with significant business opportunities. Economides and Katsamakas (2006) claim that technology platforms like Microsoft Windows are the fundamental elements of technology industries. They conclude that when users have a strong preference for application variety, the total profits of the proprietary industry are larger than the total profits of an industry based on an open source platform. Nagy et al. (2010) assess business cases adopting open source software. Open source software is free but they claim that the related products and services such as hardware and consulting are not. This has motivated many proprietary technology vendors such as Hewlett-Packard, IBM and Sun Microsystems to embrace open source software to expand their market coverage in services. This type of development is now also starting to happen in IA. The mainstream ICT technology development is closing in on IA with the rise of the Internet of things (IoT) concept. Tu (2012) estimates an annual growth of 14% for SoC computers with ARM architecture based IA and points out that solutions for sensors, networking and software platforms are the key enablers for ARM based automation solution growth.

Open source and other hardware independent software platforms have been shaping the IT landscape radically. IA remains a major industry that has not yet opened up. Determining when this will happen is part of our research agenda and we expect that companies will show significant interest in studying this phenomenon as one of their technological trajectories in the future. Following Lianes and Elejaldeb (2013) this may be a source of future competitiveness for IA companies as they suggest that participation in open source is the optimal choice for profit-maximizing corporations. Open-source and proprietary solutions can coexist in specific markets. Similarly, Maltz and Chiappetta (2012) argue that strong enforcement of ownership rights eventually leads to enforcement challenges, which IA players may already be aware of. Finally, Nevo et al. (2010) analyze the business value of Free/Libre Open Source Software (FLOSS) technologies as alternative to proprietary and commercial solutions. They suggest that realizing benefits from open source requires in-house expertise to use, manage and leverage communities of other users and developers.

The above literature review, whilst limited in comparison to the vast tradition of research on technological change, lays down the main fundamentals to be covered when assessing potential technological disruption in IA. Current industry specific research on technological disruption does not cover IA; there is no research available on the potential significance, timing and speed of the next disruption in IA. Specifically we seek to study the following research topics highlighted by the literature on technological change:

- IA is no different from other technologies, notably ICT related technologies, and it is bound to eventually face a technological disruption. To estimate when and how this disruption will take place, as so many ICT and computing related businesses have gone through several disruptions over the past decades, is the main underlying research objective.

- Industry clockspeed dictates the speed of change in an industry or a sector. Clockspeed is very low in IA because of its very long lifecycle products and intense customer lock-in mechanisms. This may make it harder to estimate timing and form of the disruption, yet major events have taken place in ICT demolishing traditional businesses and their models through the introduction of open hardware and software platforms and related ecosystems. How this evolution will affect and influence IA iss our second research topic.
- A new technological paradigm, namely the system on chip (SoC) with its related software platforms, has changed several proprietary industries and continues to change others. IA is fundamentally based on the very technologies that have been and are being transformed by this new paradigm. Therefore, our third research objective is to assess how the new technology could potentially transform IA and how the different IA stakeholders see this threat and/or opportunity.

4.3 Research hypotheses and methodology

Companies running factories and industrial processes know that once something works and the processes are under control and producing the specified output the system should not be altered. This has been proven in practice for example one major producer of an industrial control system has released eight major versions of their system during the past 50 years and their current customer base uses all the versions ever produced by the company (Hameri and Tunkelo, 2009). This means that the IA supplier has to support multiple versions of their products unlike other software based industries where companies one-sidedly declare that certain older versions of their products are no longer supported. These special features of customer high risk leverage, strong customer lock-up and potentially high switching costs make the underlying clockspeed of the IA industry very low. As the literature indicates no industry is immune to technological change. Taking into account the latest development in system on chip and other embedded systems and their related software platforms, we set to study whether IA is about to face a technological disruption. Therefore our first research hypothesis is:

H1: Technological disruption will eventually take place in industrial automation.

We specifically study the industrial atomation characteristics that delay this technological change and whether there are already signals of this change. These signals are increasing as new technologies and their open software platforms and related ecosystems for fast development and revenue sharing protocols are changing the overall ICT landscape. Therefore our second research question is dedicated to discovering whether the new technologies are about to change the competitive landscape in IA. Our second research hypothesis is:

H2: The new technologies based on SoC hardware and related software platforms are strong contenders to trigger the next technological change in industrial automation.

This hypothesis is especially interesting as IA is clearly a mature proprietary business while the new low cost, environmentally resilient, compact and energy efficient SoC based products in conjunction with their respective open and widely used software platforms have revolutionized and created the enormous and rapidly growing smartphone and tablet businesses. This new technology is entering new application and service areas while changing our everyday lives: Why should IA be unaffected by this major technological paradigm shift?

From a methodological point of view we study the current situation of IA and how it will potentially evolve in the future. In essence, we look forward in time by first reviewing the current state of the industry, identify the current drivers and how the other technological drivers external to IA might shape its future. To find concrete answers to these research questions we applied the Delphi method, which is often defined by referring to the seminal work by Linstone and Turoff (1975) as an approach for structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex issue. Despite the numerous interpretations of this versatile technique (Mullen, 2003), all members of the group share the diverse expertise to project future trends with partial anonymity, iteration, feedback and consensus. But in practical implementation, as Okoli et Pawlowski (2004) indicate, many studies have not adopted a systematic approach to conduct a Delphi study. Guidelines for the process of selecting appropriate experts are not necessarily respected.

The method has also evolved into different versions, as many Delphi studies focus on purely forecasting issues. One variant, called Argument Delphi (Kuusi, 1999; Kuusi et Meyer, 2002), focuses on the production of relevant arguments to obtain several well-founded opinions, and viewpoints that the expert panelists disagree upon. The approach applied here respects the common features of the Delphi method and extends to arguments that are later evaluated in detail. The study was executed in the following chronological order and rounds of Delphi by using different stages during the interview process according to Campion et al. (1994):

1. An extensive literature review was performed using the main electronic archives, including those searching through daily business journals in IA, process industries and

industrial engineering. Numerous key words were used to track technological advances and pilots that are being tested in IA which are not related to the proprietary technologies. Citation and referencing tools were also used to understand the publication networks around different topics attracting the attention of the researchers. In addition, numerous academic works and practical reports on IA and latest trends in computing hardware and software were reviewed. This literature review brought out the main change drivers for the technological disruption, which were used to establish the surveys of the following Delphi rounds.

2. The literature review covering the main issues led to the development of the semi-structured questionnaire for interviewing the 27 experts (Table 5). These experts had typically over ten years of IA experience either in management or expert positions at customers, incumbent suppliers or market entrants which we call newcomers. Each expert was contacted two or four times over a period of several months to verify the transcripts and their content, thus each expert had time to contemplate their point of view.
3. The results of the step 2 interviews and the transcripts were also used to create a broader and structured web-questionnaire among 51 IA professionals from customers, incumbents and newcomers (Table 6). These professionals did not overlap with the 27 experts of the previous step. This step was used to validate the results of phase two of the Delphi rounds. This survey used a five-point Likert scale to assess the validity of the various parameters of the chosen drivers that either prevent or accelerate a disruption in IA.

In-depth survey	**Average years of IA experience**	**Response Count**	**Response %**
Customer	17	11	22%
Incumbent Expert	11	9	18%
Incumbent Management	15	20	39%
Newcomer Expert	8	5	10%
Newcomer Management	14	6	12%
Total	13.9	51	100%

Table 5. In-depth survey respondent profile.

Web interview	Average years of IA experience	Response Count	Response %
Customer	17	5	19%
Incumbent Expert	11	7	26%
Incumbent Management	15	7	26%
Newcomer Expert	8	3	11%
Newcomer Management	14	5	19%
Total	13.4	27	100%

Table 6. Web survey respondent profile.

Respondents were guaranteed anonymity in relation to responses they provided at every stage. Each expert produced epistemic rational arguments and compared different future options from his or her personal point of view. The challenge for managing the Delphi process was mainly in the dissemination of the results and assignments in a neutral manner. There were four vital factors in the success of the Delphi process: the selection of the expert panel; the anonymous and discrete argumentation to and among the expert panel; the creation of meaningful questions and future statements; the structured and systematic evaluation of these statements. The broad scope of the study concerned IA and its technological evolution for the coming decades. This being a very broad scope for the study issues related to macroeconomics was left out and the focus was set solely on technological issues reshaping the IA business.

The interviewees were selected based on their industry experience representing a balance between customers, incumbents and newcomers. After the interviews had been transcribed, they were analyzed quantitatively and qualitatively. The research team worked together closely during the iterations to become intimately familiar (Eisenhardt, 1989) with the data. The analysis advanced from open coding to axial coding (Corbin et Strauss, 1990). After coding, the four major themes that emerged were growth impact, cost impact, risk impact and control impact. These themes were chosen as the parameters for the drivers to be examined in the context of Hypothesis H1. The initial interviews were performed in 2011 and a longitudinal re-check was performed in 2013 to estimate the possible change of view.

The Delphi-method is not without limitations. The common issue is in manipulated consensus, i.e. the results do not hold the best judgment, but a compromised position. This may be the result of non-objective monitoring of the research process and/or biased expert panel that does not sufficiently represent a broad spectrum of the population to assess the research questions. To tackle these common pitfalls of the method, the panel was carefully chosen to cover all aspects of the IA business. However, in some areas (newcomers), the representation was weaker than in others (customers). The researchers were aware of this, and this imbalance was taken into account while mediating proposals, comments and assessments. To maintain objectivity, strict documentation policies with full transparency and complete feed-back loops were applied throughout the research process. The overall process took around 6 months, which gave all participants time for in-depth reflection and contemplation.

4.4 Results

Following the steps outlined in the methodology we start by identifying the drivers for the disruption in IA. This is done by reviewing past disruptions in the mainstream ICT markets and then we summarize some of the key findings in the literature indicating that a disruption in IA is slowly under way. We then go through the various surveys and define the key characteristics and current trends of the IA market. Subsequently, we assess cause, timing, shape and speed of the next disruption based on the following drivers: benefits of the disrupting technologies and the acting powers and motivations of customer, incumbent and newcomer. We bear in mind H1 stating that disruption in IA will eventually take place.

4.4.1 Related disruptions, early signs of disruption and market forces

Christensen et al. (2001) claim that managers often allow cheaper, simpler and more convenient products and services to enter the markets they are controlling with existing more expensive offerings. The leading companies are so focused on sustaining innovations and addressing the most profitable customers that they ignore the threat imposed by disruptive technologies. Business failure due to disruption is caused by management's misplaced focus on: 1) their current customers' needs, 2) the size and growth rate of the current market, 3) the most profitable parts of the market and 4) the largest segments of the market. These four points explain why, for example, the main players in the minicomputer market failed during the disruption caused by Personal Computers with de facto industry standard operating system enabling hardware independent applications

Hernández-Ortega (2011) defines post-use-trust as the role of trust in the acceptance of a technology based on company's own experience of using it. . The elements of the post-use-trust are: 1) perceptions experienced by the company during the deployment of the technology, 2) influence of the company's business partners and 3) importance of the IT manager's attitude towards the technology. The acceptance of a technology requires that the company considers it easy to use and secure. The manager's personal attitude impacts the company's post-use-trust in a technology. Post-use trust is a key variable between the drivers and a company's technological behavior. The business performance of a company can be impacted by the post-use- trust practices used.

Sonmez and Moorhouse (2010) study the purchasing criteria for professional services and present the main criteria in supplier selection split into two distinct groups: pre-qualifiers and final stage differentiators. In IA one key pre-qualifier is that the offering is proven in use in a relevant context which creates a high entry barrier for new technologies.

Elaluf-Calderwood et al. (2010) investigate the role of control points in defining business models in mobile business. External triggers from different domains like technology, business cycle and customer preference, capital can lead to changes in the control that market actors hold. The product life cycles also play a role in new technology adoption. The shortening life cycles of products are especially characteristic for ICT. For example, in the early 1980s, hard disk drives would typically remain competitive in the market for four to six years before being replaced by less expensive and better products. By the late 1980s, the product life had decreased to 2-3 years and by the 1990s to just 6-9 months (Chesbrough, 2007).

Häfinger et al. (2010) suggest that a disruption can be created by the customers who learn to the use a technology and can develop new products, acquiring initial customers and become competitors to their suppliers. Schmidt and Cohen (2010) claim that in ICT, current technology companies are often surprised by their customers. Texas Instrument's image and video processors are used as an example by Cunnin et al. (2003). They point out the critical role of software and hardware in high performance computer platform designs based on SoC technologies. TI allowed their hardware design to be published in open source and supported the creation of open community development platforms. Qualcomm, initially TI's customer, moved from a mobile phone maker to a chip producer and seller of technology licenses (Chesbrough, ibid.). Qualcomm turned its previous competitors to its customers and has taken the leading market position ahead of Texas Instruments.

Rumelt (2011) describes how Nvdia is using the SoC technology to cause a "disruption from below" and upset the Intel-AMD-Windows hegemony in desktop game applications by creating a much simpler and more efficient platform with its SoC based Tegra product line.

Android is a Linux-based open source mobile phone operating system developed by Google. Google actively develops the platform, but gives it away for free to hardware manufacturers for use in their devices. This gives Android a competitive advantage since Google uses its other revenue streams (Gurley, 2009) to subsidize the software platform forcing its competitors who rely on technology based revenues into a disadvantageous position.

There are already early signs of mainstream ICT technology being applied to industrial automation both with proprietary and open source based solutions in research and business contexts. In their research, Kumar et al. (2012), Hou (2013), Nanajkar and Nagrale (2013), Liang and Wu (2012), Singh et al. (2013) Fang and Zhang (2012) and Gan et Al (2013) successfully implement IA applications using SoC technologies. In the business side several companies are entering the market using SoC technologies in IA applications. Texas Instruments is focusing on embedded systems with their open source hardware Sitara™, and its related Beagleboard and Pandaboard open source based hardware and software ecosystems support IA applications like the cost free industrial software development kit (Texas Instruments, 2013). Other low cost SoC based hardware and software platforms like Raspberry Pi, Arduino, and software platforms like mbed are also increasingly being used in industrial automation applications, for example in an OPC evaluation kit that costs only fifty dollars (Unified Automation, 2013).

NASA's PhoneSats program (Alexander and Marlare, 2013) leverages SoC technology benefits in satellite applications by exploiting fast processors, versatile operating systems, multiple miniature sensors, high-resolution cameras, GPS receivers and several radios. NASA considers their test a success with significant cost benefits. The total cost of the ICT components for the three prototype satellites is between $3,500 and $7,000 using primarily commercial hardware and keeping the design and mission objectives to a minimum. The hardware for this mission is the Google-HTC Nexus One smartphone with Android operating system.

New successful industrial automation product and system companies like Pro-face, BiemmeItalia, Armac, Atmel, Beckhoff Automation, Moxa, B&R, Kontron and Baumüller use ARM and PC hardware based open automation software systems developed specifically for industrial use. They either use open SoC based technologies or only focus on software offerings. They believe that industrial automation solutions remain to be sold as value adding applications where the industrial automation system provider takes overall responsibility for the automation system and its maintenance over its lifetime. They consider their new offerings having a technology benefit over the current main incumbents through newer design, based on new hardware and software leading to better hardware reliability, improved processing capacity, lower cost and more efficient engineering. According to Vyatkin et al. (2005), one key trend is the development of open reusable portable software modules for industrial automation and control systems. Based on the literature review, it is evident that technological disruption from the high volume cost sensitive mainstream ICT markets is becoming visible in industrial automation. Concluding from the above mentioned technological disruptions in the mainstream ICT and management decision making on technology choices we define four key drivers that impact a company's decision-making when choosing an underlying technology. These are 1) Growth of company revenues, 2) Reduction of company operating and purchasing costs, 3) Risk mitigation of company operations and 4) Capability for a company to control customers and suppliers and not to be controlled by them.

4.4.2 In-depth survey results

The in-depth survey was executed through semi structured interviews aiming to answer our two hypotheses: Is a technology disruption in industrial automation likely and could the SoC based hardware and related hardware independent software platforms form the basis for such a disruption. The literature research has revealed that strategic technology decisions are impacted not only by cognitive criteria, but also by personal bias, thus the impact of management behavior in strategic decision-making was also addressed. The interviewed 27 experienced industrial automation managers and experts were selected from three industrial automation actor groups: Customers (5), Incumbents (14) and Newcomers (8).

The interviewed executives and experts were asked to assess the industrial automation disruption threat from three angles: customers, incumbents and newcomers. Based on the initial interviews, hypothesis H1 was assigned 4 drivers (D1-D4) and H2 was assigned six drivers (D5-D10) that can have a propellant or repellent impact for the hypothesis. The drivers and their impacts are presented in Table 7. According to the interviewed industrial automation customers, incumbents and newcomers a possible technology disruption in industrial automation could be enabled by SoC hardware and related software platforms already widely used in other ICT markets. The disruption could tentatively offer significant concurrent improvements in prices for industrial automation products, spare parts and engineering and support services, computing power, energy consumption and heat generation, smaller size, large data storage without moving parts, better shock, vibration and dust resistance and wider operating temperature range, huge improvement in the performance of processing power, main memory size and availability of new low cost capabilities like camera, video, multiple parallel reliable wireless communication methods, GPS , wireless LAN based location services and remote data access.

Next we summarize the comments received during the interviews that inflict the rationale for choosing the drivers for the hypotheses. For Hypothesis H1 our in-depth interviewees insisted on the difference between consumer markets and industrial markets. The industrial automation market differs from consumer markets in three major dimensions: Firstly, the average purchase is larger, secondly the rationale for it and thirdly the duration of the usage time. According to the consensus among the interviewees there are only a few reasons for an industrial company to spend money: to increase their own revenue (D1), to reduce their own costs (D2), to reduce their business risks (D3) or a compulsory regulation and sometimes due to severe public pressure. When addressing their respective positions in the industrial automation ecosystem, companies try to gain control (D4) over their sales prices and purchases. To achieve this they aim to maximize their purchasing power and lock in the customer to limit the competitive pricing pressures. New features and technologies as such are not a justification for a purchase or new investments as strongly as in consumer markets.

The six key drivers for H2 were derived from the Delphi interviews. They address the customer's criteria for a purchase of an open industrial automation application instead of a traditional closed one. These drivers are: lower cost of the hardware (D5), significantly higher processing power (D6), lower power consumption and thus heat generation plus low environmental requirements (D7), hardware independent real-time capable software platform (D8), ease-of-use (D9) and new functionality (D10) presented in Table 7.

Furthermore, the in-depth interviewees were asked to estimate the relative weights of each driver for each hypothesis (H1: D1-D4, H2: D5-D10). This was done to obtain an estimate for the relative strength of each driver impacting its respective hypothesis (Table 7). For H1 the key drivers that impact a disruption in industrial automation are Cost and Risk. For H2 the most important drivers were price, open software platform and ease-of-use.

Hypothesis	**Driver**	**Disruption changes**	**Relative weight**
H1	D1: Growth	The possibilities for the actor to increase its own revenues	13 %
	D2: Cost	The possibilities for the actor to reduce its own costs	42 %
	D3: Risk	The actor company's and personal risk position	33 %
	D4: Control	Changes the actors' company's or personal possibilities to control the market	17 %
H2	D5: Price	Leveraging the larger ICT market for spreading the R&D costs on a larger base, reduction of initial hardware, software and training costs as well as on-going spare part, support and other lifecycle costs	23 %
	D6: Processing Power	Enables more distributed computing to increase the information value of the data that needs to be transmitted from the production process to the operator	12 %
	D7. Energy and Environment	SoC hardware has significantly low energy consumption i.e. can operate on low DC voltage (e.g. PoE), needs very limited cooling, has wide operating temperature range, is very vibration resistant and has no moving parts	11 %
	D8: Hardware independent software platform	Software platform is widely used in other ICT markets which offers access to capable application developer community, Software platform is hardware agnostic and can perform real-time applications	20%
	D9: Ease-of-use	With already over billion units shipped end users are already familiar with the user interface of the applications	24%
	D:10 New Functionality	Locations services, (GPS), camera and video, multiple parallel wireless and wired communication channels available, touch screen, large local persistent data storage (SSD)	10%

Table 7: Drivers impacting hypotheses H1 and H2

Industrial automation customers see their current key issues being far from Industrial automation technologies: increasing regulations in relation to product tracking and environmental impact of production units, increasing size of production units, ageing workforce in existing plants in the Western world is an increasing challenge, global demand remains in the west but production facility investments are mainly in the Far East, continuation of Industrial automation customer consolidation, that is, key customers become larger and thus gain more purchasing power. Their main concerns in relation to Industrial automation are focused on the reliability, safety and total cost of ownership of the Industrial automation systems, meaning both the capital expenditure and operating costs. An Industrial automation customer executive claims that while cost is always of importance, in Industrial automation the proven-in-use reliability is the most important Industrial automation system qualification criteria. The customers see only limited possibilities of improving production output and quality through the implementation of new Industrial automation systems based on more advanced technology.

Customers see inherent risks in choosing Industrial automation applications so significant that mistakes can seriously impact the decision maker's personal career development. One CTO of a major Industrial automation customer claimed: "We never entered into a long term single supplier situation in Industrial automation applications, but they validate three or four suppliers for each Industrial automation application and make sure that none of these suppliers gets too large a part of the installed base."

The incumbent's view of the Industrial automation is focused on maintaining good profitability and steady growth by using their proprietary Industrial automation hardware and software platforms. A senior executive from an incumbent vendor said: "From every Industrial automation installation we receive in service and support revenues during three to five years equal to the initial project cost. That is the fundament of our profitability". They see new changes not arising from the technology as such, but rather from increased integration with ERP systems, new more advanced manufacturing software solutions, implementation of the cloud concept in the Industrial automation space, developing algorithms for industrial big data especially in the context of condition monitoring and the integration of electricity and automation technologies through the increasing popularity of IEC 61850 standards. One Incumbent's head of engineering said: "The actual cost of Industrial automation hardware is not a relevant element for the customer price. Thus there is no need to seek less expensive hardware". They also see significant growth opportunities from increased service opportunities arising from the customers' increasing efforts to focus only on their core competencies and purchasing Industrial automation technology related work as a service from the Industrial automation suppliers. They perceive their core competitive edges in understanding the customer systems and the proven track record through their large installed base.

Newcomers believe that customers' seek open Industrial automation systems to reduce their dependence on closed system Industrial automation suppliers as the key driver for their opportunity to enter the market. One newcomer CEO pointed out: "It was the hardware independent MS-DOS operating system that created the competition that led to the creation of the highly cost competitive PC market." In his view the incumbents enjoy too high profitability with their closed systems that they will not compromise for the openness. This gives the opportunity to successfully enter the market. The second major advantage is the open software platform already used in mainstream ICT markets which ensure good availability of competent developers and ease of use because the application users are already familiar with the user interface.

4.4.3 Web Questionnaire results

The web questionnaire's 51 respondents are all experienced participants in Industrial automation. Based on the in-depth survey 22 questions were designed for the web interview: One for reach driver of the hypotheses, four questions related to the comparison between consumer and industrial electronics and seven general questions compiled based on the in-depth interview results (see Appendix 1 for full list of questions). The results from the web interviews suggest that (H1) key drivers slightly support the probability of a forthcoming technology disruption. But the growth and risk drivers strongly repel against the disruption. On the other hand (H2) the technical benefits are generally well recognized and the SoC technology and related software platforms are seen clearly as having a good potential to cause a technology disruption in Industrial automation.

The respondents' current role in the Industrial automation business shows a systematic bias in their responses (Figure 13). The customers see the Growth (D1) and Risk (D3) drivers being the biggest opponents towards the disruption, while incumbents do not see the benefits of the SoC technology (D4,D5,D8 and D9) advancing the transition. The newcomers are more positive in all drivers for disruption than the other actors. Looking at the results from the questionnaire we can also see that there is still a strong perception that "Industrial electronics" is more trusted and the risk avoidance factors postpone the readiness to expedite a technology disruption in Industrial automation (Figure 14).

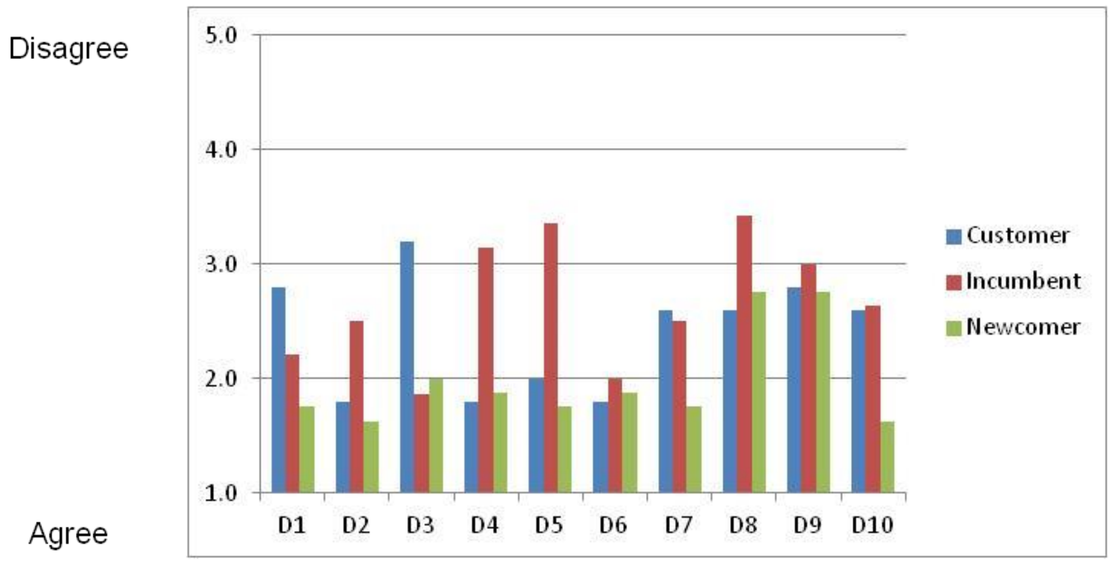


Figure 13. WEB survey results by actor group.

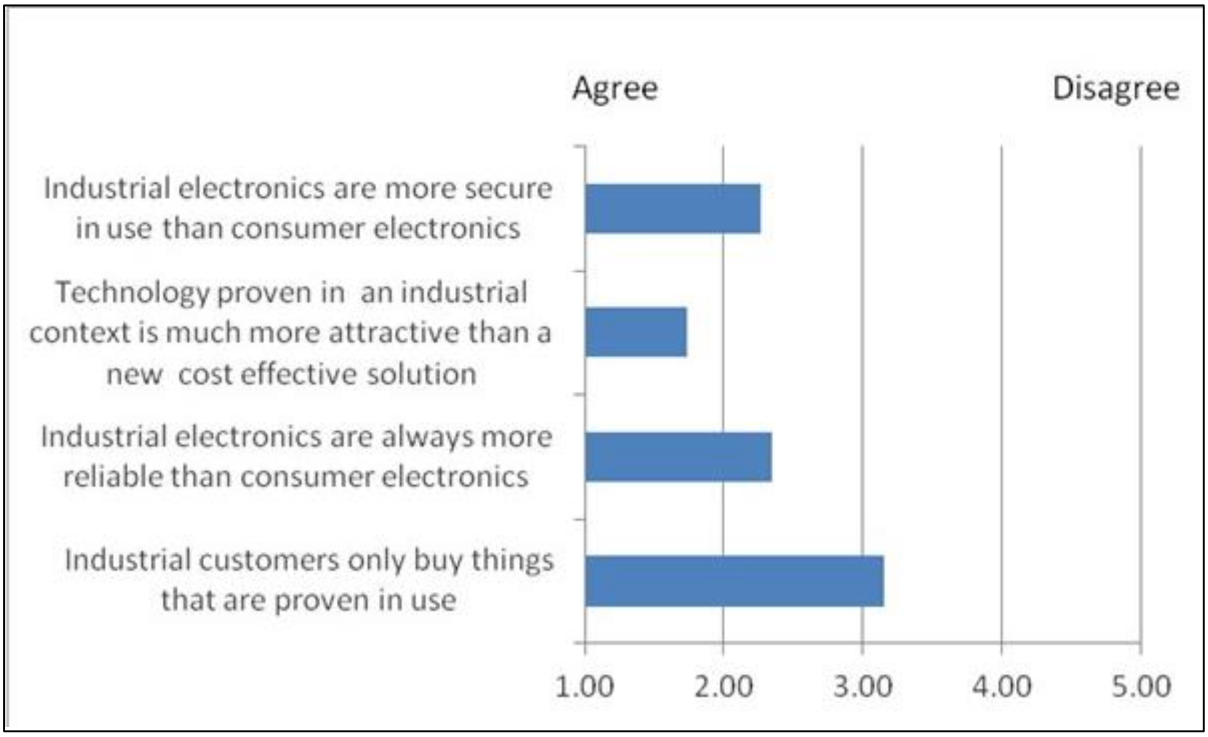


Figure 14. Web survey comparison consumer electronics vs. Industrial electronics.

We used five point Likert scales to assess the strength of the chosen drivers. Since these forward looking views cannot inherently be accurate, we considered the five point scale to be appropriate. We further performed statistical analysis on the data collected from the web questionnaire to test the homogeneity of the three actor groups (customer, incumbent and newcomer) for each of the ten disruption drivers. The heterogeneity of the three groups can be considered statistically significant if the calculated F-ratio is greater than a given critical value of 8.005. The critical value depends on the overall alpha level chosen. In the case we used overall alpha = 0.01. This alpha level is actually the probability to wrongly reject the homogeneity of the three groups for at least one of the drivers. This is also called type I error. We also applied ANOVA analysis for the ten disruption drivers. The conclusion was that there is a significant heterogeneity between the actor groups for the following drivers: D1, D2, D3, D4 and D8. This can be either caused by the bias in the selection of the interviewees or insufficiently articulated questions for these drivers. When reflecting back to the hypotheses it seems clear that Industrial automation is a slow clockspeed industry and therefore the disruption will start later and evolve slower than in faster ICT markets, which are closer to consumer business. By analyzing the results we find a strong correlation of the responses inside the actor groups. The customers expect the disruption to happen as it happened when PCs replaced minicomputers in the 1990s as operator stations. However, the study shows that none of the interviewed customers have yet initiated activities to test the new technologies.

They would prefer that the current incumbents introduce the new technologies. The incumbents are not concerned about the threat of new technologies. They trust that entry barriers are adequately high and focus on competition between current incumbents and maximizing the service opportunities inside their own installed base. Only limited efforts were located where incumbents investigate possibilities of using disruptive technologies inside their own portfolio. The newcomers leveraging novel technologies in Industrial automation believe in entering the market by selling their products to current incumbents or by offering targeted solutions to pioneer-spirited customers. Some of the newcomers aim to apply to both markets in parallel to accelerate their growth in order to be acquired by an incumbent or by private or venture capital.

Based on the above results technology disruption in Industrial automation caused by SoC based hardware and software technologies is not viable in the near future, but will most likely happen in the midterm future. The new technologies based on SoC hardware and related software platforms will trigger a technological disruption in Industrial automation. Compared to mainstream ICT markets where SoC technologies are already causing a significant disruption Industrial automation seems to be non-existent especially when special pilot projects and experiments are not considered. This is mainly caused by customers' high risk leverage since their own revenues are fully dependent on the flawless operation of Industrial automation systems. However, their strong focus on costs will lead them to try the SoC based automation systems initially in simple and low risk applications. The Industrial automation incumbents' responses seem to confirm Christiansen's assessments that they are dismissing the weak signs of the forthcoming disruption since they rely on their customers' high dependence on their proprietary technologies and engineering resources. Incumbents remain confident that the entry barriers are adequately high to stop the SoC based disruption for a long time. The newcomers seem to underestimate the disruption resistant market forces and assume that the benefits offered by the SoC technology enable a relatively rapid disruption.

4.5 Discussion and conclusions

Although our research improves the insight on the technology disruption process in slow clockspeed industries, questions still remain open regarding the shape, speed and timing of the next period of technological disruption in Industrial automation. We were able to collect a relatively large amount of qualitative data and to some extent were able to classify it into categories that can have a guiding quantitative significance. Error margins are however large, due to the data and sample sizes, the representativeness of the samples, and individual answering style on a five-point Likert-scale. Certainly our survey results are to some extent biased since our target group was chosen mainly from individuals mostly familiar with Industrial automation.

The original interviews were conducted between November 2011 and April 2012. To internally validate the results a selected group of in-depth interviewees was contacted in September 2013 and questioned about possible changes in their views regarding the potentially forthcoming technological disruption in Industrial automation. No major changes in their views were found, other than the awareness that the disruption had been increasing, perhaps due to the initial questionnaire. For the internal validity the use of the different groups of people helps to avoid one sided and biased answering. As for the external validation of the analysis, the researchers have been continuously scanning the professional Industrial automation literature and clearly the weak signals have become slightly stronger. More complete and complex pilots are being studied and introduced to demonstrate the benefits and advances the SoC based technologies have over traditional proprietary solutions.

In defining the actors and disruption drivers perhaps too many simplifications were made. Due to the complexity of the Industrial automation value network, additional actor groups like consultants, system integrators, production experts should perhaps have been included more in the surveys. Possibly more drivers could also be defined to better understand the forces affecting the progress for the disruption. Quantification of disruption probability, shape, direction, and timing is hardly trivial. The research using a cross section of industry experts however proved that the 'Zeitgeist' is different in Industrial automation than in mainstream computers. PC and Laptop sales are in decline whereas tablets and smartphones have reached unbelievable shipment numbers. This is clearly a signal of the slow clockspeed of Industrial automation.

To further develop the disruption model more research is required. This can be achieved through analyzing past disruptions. As more data becomes available, the number of actors needed, the parameters for their respective drivers preventing and accelerating the disruption can be better defined. This data can also be used to better define the weighting of the drivers and the weighting of the forces prohibiting and accelerating the researched disruption. Based on the literature review and our surveys we used our knowledge base to attempt to simplify the assessment of the probability of a technology disruption occurring in an industry by defining a model for the forces affecting a technological disruption. The disruption model consists of three elements: Actors, Drivers and Disruption ratio. Actor groups were defined to be Customer, Incumbent, Newcomer and Technology. Drivers are variables that the actors use to influence the progress of the disruption by trying to accelerate or decelerate its development.

The drivers were defined to be: Growth, Cost, Risk and Control. We can now define a disruption ratio as an equation which is calculated for each driver by combining each actor's positive and negative driver forces adjusted by the weight of each actor. The equation for the calculation of the disruption ratio for drivers is presented here in the form of an Ishikawa diagram in Figure 15.

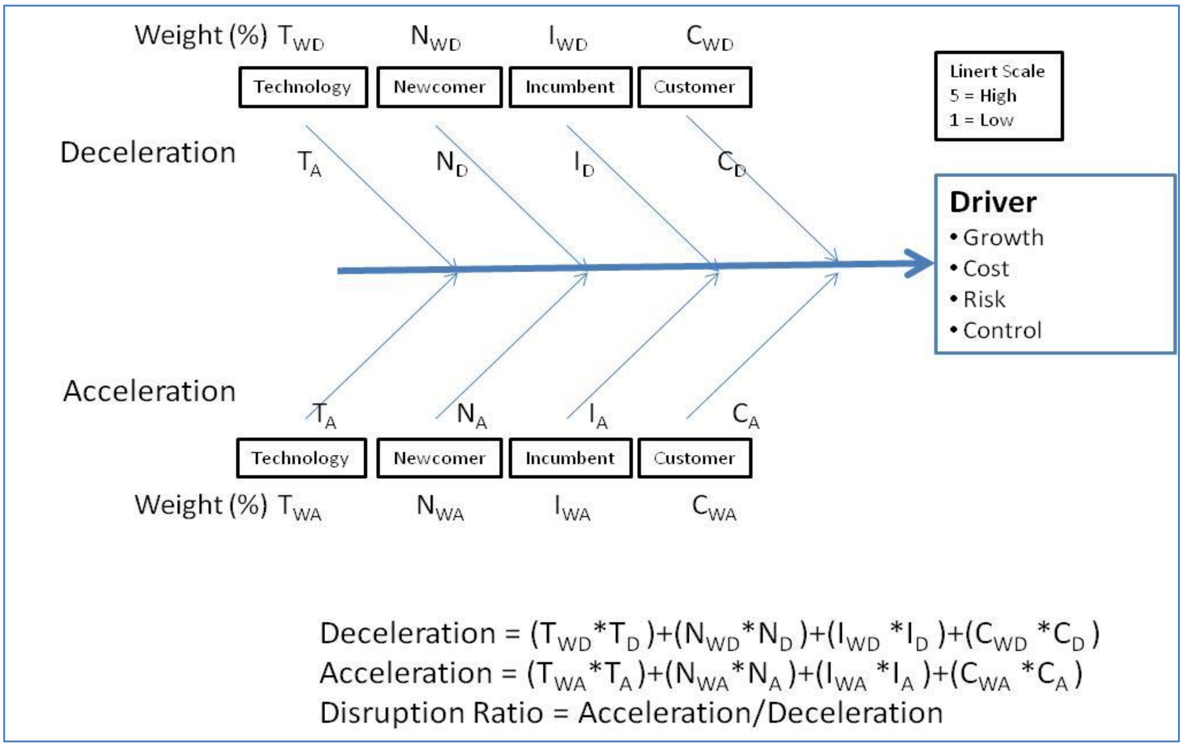


Figure 15. Disruption ratio definition

Disruption ratio is calculated for each driver by dividing the forces resisting and supporting the disruption. When the disruption ratio has a value of one the drivers for and against the disruption are equal. When the value is above one the drivers favour the disruption to occur and when below one they are against the disruption. Using the data from this research the disruption ratio has the value of 0.76.

Disruption ratio could be leveraged to define the guidelines for a corporation's technology watch function: Customers could use it to analyze when it is beneficial to require the suppliers to offer solutions based on new technologies, protecting incumbents from disruption or enabling newcomers to choose those disruptions where timely success is more probable. It can also be used as a simulation model when assessing changes in technology markets.

Customers expect the disruption to happen as it happened before when PCs replaced minicomputers in the 1990s. However none of the interviewed customers have initiated activities to test the new technologies in Industrial automation. Should they do so, they would prefer the current incumbents to introduce the new technology to them. The Industrial automation incumbents are not concerned about the threat of new technologies and believe that entry barriers are adequately high and focus on the issues around competitive inertia with other incumbents and maximizing their life cycle business opportunities inside their installed base. Only limited efforts are engaged to investigate possibilities of using new disruptive automation technologies in the incumbents own product portfolio.

The new technology leveraging automation suppliers currently remain limited in size and geographical coverage. Most of the researched companies focus on developing new technology hardware products and software rather than providing full Industrial automation applications. Entering the market through selling their new hardware and software components and solutions to current incumbents or through offering a new small high value add point solution directly to end customers. Many of these companies also aim at a strategy to grow just to be acquired by an incumbent or by venture capital.

Further research is required to improve and validate the accuracy and usefulness of the disruption ratio. Possible future research could also study an industry clockspeed ratio similar to the disruption ratio. Combining the clockspeed of the industry and the impact of the forces in the industry acting for and against disruption might be of interest to possibly develop a quantitative method to assess the timing of a technology disruption in a certain industry. Predicting the disruption in Industrial automation can also be seen from recent market movements: Schneider Electric of France acquired Invensys PLC of UK for $5.2 Billion in 2013, the first major acquisition in Industrial automation for a long time. Perhaps this and other future incidents will be the cause of the next technological disruption in Industrial automation sooner than we estimate based on this research.

5 Theoretical and practical contributions

This thesis focuses on technological lifecycles in industrial automation, a slow clockspeed industry, in its current mature phase focusing on the competition between the incumbents and on the possibility of a disruption by SoC technologies and related software platforms. In three distinct journal essays we address topics that are central both to information technology and operations management research, using empirical and qualitative approaches leveraging one company case study, action research, Delphi and survey research practices.

5.1 Contributions to the body of knowledge

This thesis applies existing competition, technology lifecycle, disruption and behavioral decision theories in the context of major trends in industrial automation. The research examines the current paradigms for customers, incumbents and newcomers and their respective actions and views in this slow clockspeed market. The thesis studies the current paradigm in industrial automation and possible new paradigm alternatives when industrial automation is affected by SoC technologies and related software platforms.

The theoretical implications of this thesis propose to leverage emerging countries with captive outsourcing rather than traditional outsourcing in *Chapter 2*. *Chapter 3* deals with the improvement of customer satisfaction in complex systems support by using throughput time based practices which are well established in logistics. *Chapter 4* presents a new way of quantifying the prediction of a disruption occurrence based on key actors and their respective drivers that cause actors to drive changes in an industry. We then explain these contributions in detail.

Chapter 2, published in *Strategic Outsourcing: An International Journal* (2008), documents the case company's experiences in offshoring a slow clockspeed industry's detailed engineering, research and development work. Our results highlight the complexity of process related issues as well as time zone, cultural and emotional topics impacting the organizations capability to offshore activities to emerging markets both from the point of view of the people transferring the work and people receiving it. Our findings point out direct and important implications for offshoring. The case provides support to the fact that companies which understand that building permanent, knowledge-based and proprietary presence with full product management responsibility in lower labor cost countries will be more responsive in serving customers, cost efficient in maintaining old infrastructure products and in delivering new ones in the future. Further, complex product business companies focusing on long term and knowledge based legacy building in emerging economies will develop, not only more robust global business platforms for themselves, but will also contribute to the sustainable development of the global economy.

A new way of outsourcing is proposed, namely captive outsourcing, which should be used with complex systems that have long lifecycles. This is fundamentally different from traditional outsourcing which focuses on leveraging the lower hourly rate to gain short term financial benefits. If a company is capable of having its own permanent, knowledge based and proprietary presence with full product management responsibility, it will reap long-term benefits from offshoring complex systems development and supporting it.

In *Chapter 3* published in *Journal of Software: Evolution and Process* (2013) we expand the scope of our study to explore how operational improvements can be achieved in a global context of software support. New KPIs proven in physical logistics were implemented in information logistics via controllability analysis. We focused on the lead time and work in progress (WIP) reduction in the context of information flow in customer issue management of industrial automation system support problems. As the main result is that there is significant improvement in issue resolution throughput time when it is properly measured.

Traditionally in the case company the primary KPI for software support is the number of open cases by criticality and the average time to solve them. We propose an approach based on an 'outside-in view' instead of an internal view which provides more benefits for the customer and thus indirectly the case company. A process defined and measured from the view of a customer is an effective way to drive customer satisfaction improvement.

Chapter 4 submitted to Technovation (2013) is based on an extensive literature review and Delphi and online surveys. We gathered a wide knowledge base assessing the probability of a technology disruption occurring in an industry by defining a model for actors who use their levers to accelerate or decelerate the progress of a technological disruption. This was analyzed using Delphi method and a survey. We also developed the Disruption Ratio, a quantitative model for estimating the occurrence of a disruption in a long lifecycle business in the context of industrial automation. We defined equations for the Disruption Ratio based on Actors each with their respective Drivers for and against the disruption. Actor groups were defined to be Customer, Incumbent, Newcomer and Technology. Drivers are variables that the actors use to influence the progress of the disruption by trying to accelerate or decelerate its development. The drivers were defined to be: Growth, Cost, Risk and Control. We define the Disruption Ratio as an equation which is calculated for each driver by combining each actor's positive and negative driver forces adjusted by the weight of each actor. The drivers were weighted based on their relative strength and the disruption ratio was calculated. Our approach differs from other related studies in that it takes into account the management bias in strategic decision making based on the role of each actor in the industry.

5.2 Practical contributions and recommended management actions

The practical contributions of this thesis are focused to offer advice to the management operating in a slow clockspeed industry. Generally speaking to remain successful a company needs to constantly focus on operational excellence improvements of its operations and at the same time look out for technology disruptions and test out relevant new technologies in a timely manner. Management attention also needs to be given to competence development in recognized new superior technologies which may threaten the competitiveness of company's current products.

In *Chapter 2* we suggest that it is beneficial to make the outsource services unit an integral part of the company's global core operations, not an external supplier. It should be granted full product lifecycle responsibility for complete modules and subsystems rather than using its resources as a low cost engineering pool. Since the analysed systems serve in operations for decades it is important to maintain a strong focus on employee satisfaction to reduce the attrition rate. We found that the local reputation of the company and its actions as a responsible member and integral part of the local society help to reach this goal.

Based on the theoretical and practical contributions presented above we recommend several detailed actions that can be taken when implementing a captive outsourcing entity in an emerging country:

- Establish legal entity within company's direct management control. If needed, have local minority shareholders.
- Use outsourcing to improve overall value chain efficiency not superficial gains from leveraging the lower hourly rates.
- Have operation KPIs streamlined across the global value chain, not by operating unit silos.
- Measure and target management on global common KPIs. Communicate progress against these KPIs homogeneously in all countries.
- Make offshore unit to offer not only component level engineering services against narrow specifications but make it responsible for the full subsystem responsibility for all product lifecycle elements.
- Offer possibility to have assignments or permanent employment in company's units abroad
- Create long term career prospects for emerging country employees.
- Create possibilities to earn salaries which enable equal purchasing power parity as company's engineers in the developed economies.
- Create possibilities to move to management roles.
- Have a combination of local and ex-patriot management.
- Respect intellectual property rights when moving operations overseas.
- Have local board members in offshore unit's management board.
- Pay fair company taxes at offshore location.

Chapter 3 proposes that to improve customer satisfaction of complex software systems the support organization needs to be primarily measured based on throughput time of a customer issue instead of number of open issues. Clear global support process definition with full end-to-end visibility and control point with related KPIs ensure transparency and measurability.

New software releases have more errors than mature ones. Management of new release introductions with specific KPIs tied into R&D targets and compensation is a good way to improve end user satisfaction and the reputation of a company's systems. To achieve this it is necessary to continuously benchmark performance by customer, release, support unit, R&D unit and customer's and support unit's physical location.

Based on the teoretical and practical contributions presented above we recommend several detailed actions that should be considered when improving complex systems global support:

- Implement an independent team to constantly analyze the throughput data and to convert it to actionable information by customer, subsystem and geography.
- Base the KPI metrics for customer complaints resolution process on customer experience not on internal workload and utilization level.
- Integrate the support process performance in the management review agenda as a standard item.
- Implement management escalation routine parallel to the technical escalation based primarily on the case lap time and secondarily on the maturity of the product and the kind of customer affected.
- Ensure and communicate the global and local management aligned keen interest in the performance of the customer support process.
- Invest more time in case evaluation instead of fast escalation.
- Globally align the KPIs and related targets and compensation schemes along the customer support process.
- Measure new release related customer cases separately comparing with earlier releases.
- Include in the R&D team's compensation plan new release and continuous improvement elements based on the global KPIs.
- Attempt to analyze customers defect issue ratio normalized by the size of the installed base.
- Use ABC analysis to classify customers by their importance to the company.
- Some issues and certain customers consume more support resources than others. Aim to classify and prioritize requests by value for the customer and the effort needed by the company to provide the support.

Chapter 4 investigates the rationale various actors have when they assess a technology disruption. Customers are driven primarily by their high risk leverage and secondarily by cost. They avoid taking risks on new technologies and prefer current suppliers and aim to increase competition when related risks are manageable. The incumbents are likely to protect their vertically integrated lock-in model and will attempt to delay the acceptance of new technologies making it difficult for newcomers to enter the market. Newcomers attempt to enter the market with simple point solutions targeted at non-critical customer applications or they attempt to sell new technology based components to current incumbents.

Similar to ensuring quality through formal ISO-9000 certifications and corporate compliance through the SoX compliance review process, companies should establish a disruption management process. This empowers the company to leverage disruptions or become disruption resistant depending on their strategic choice. We develop an assessment model for industrial automation to measure the importance of each driver at subcomponent level (Appendix 4) and to facilitate the formalized process of periodical measurement of the disruption ratio on a more detailed level for better accuracy.

Based on the theoretical and practical contributions presented above we recommended several detailed actions that should be considered when ensuring that the company is prepared to face a disruption:

- Customers and Incumbents should establish a Disruption management function to proactively scan and assess relevant upcoming technologies using the Disruption Ratio in regular intervals to recognize early signs of a disruption. Based on the assessment they should start to develop the organization’s capabilities to master the disruptive technologies in a timely manner.
- Newcomers should use the disruption ratio as a model to assess the timing and target of the disruption.
- Customers should focus more on total lifetime cost of the system than the initial capital investment cost.
- Customers should actively participate in standardization efforts to implement well defined standard interfaces between industrial automation system modules.
- Customers should maintain adequate technical competence in house to avoid being dependent on incumbents’ engineering services.
- Develop the capabilities to master new technologies with a small separate organization.
- Actively participate in standardization efforts to understand the impact of upcoming standards on their business model.

- Newcomers should segment the market and identify point solutions whiuch are only loosely connected to the core automation system.
- The point solutions should preferably be of medium complexity and production process independent allowing cross industry leverage.
- Locate customers with their own technology research organization or a track record of regularly testing new technologies and suppliers.
- Company should perform regular reviews of the drivers at subcomponent level and adjust the relative weight of the drivers for them.

5.3 Validations and generalizability

Internal validity qualifies the causal conclusion of the research. It minimizes the bias of research and reflects the extent to which a causal conclusion based on the research is warranted. To ensure internal validity of *Chapter 2* the interviews were performed in different countries and in different departments of the company both with managers and experts. Internal validation of *Chapter 3* was based on collecting the system data, design documentation and relevant business documents from different countries and departments with a longitudinal approach. The KPIs were collected from different systems and compared when assessing the impact of the change actions of the company. In *Chapter 4* the interviewees were selected in a balanced way from all actor groups, several different countries, in different roles and in different segments of industrial automation. This was further validated through different individuals in the Delphi and web survey interviews. Finally a selective longitudinal follow-up was performed.

External validity measures the results of a research from a generalization point of view that is it can be applied to other contexts. External validation in the case of *Chapter 2* shows that our results seem to be well aligned to other relevant scientific literature. Nevertheless as a single company case study it is not generalizable. In regard to *Chapter 3* it is evident from the operations management literary that reduction of throughput times and variances improves efficiency and thus the results can be generalized. External validation for *Chapter 4* is more demanding due to the focus on future events. To address this challenge we conducted a multifaceted external validation process that included systematic identification of suitable and reliable data sources by comparing, simulation and sensitivity analysis of the disruption ratio.

6 Future research

In addition to a wide base of empirical data collected and the presented managerial insights and theoretical implications, this thesis raises a number of interesting topics for future studies. For the operational excellence topics more research should be focused mainly with quantitative methods like analyzing the development of defined KPIs, Analyzing the number of continuous improvement projects executed and the type of business process improvements they recommended. A longitudinal study would be interesting to execute now building upon the fieldtrips from 2008 and analyzing the perceived and measured success of the offshoring activities both from the sending and receiving country point of view.

Deeper studies could be used in the industrial automation market to enrich the understanding of the evolution of this business from the mature phase towards the inevitable technology disruption. The most promising methodology to use would be quantitative experiments where the actual performance of an open industrial automation platform based on SoC technologies. A pilot candidate considered for process re-engineering is analytical control and reporting for a rare sugar producing plant including both elements of defining the production process and related KPIs and using an open SoC technology based industrial automation platform for production control.

The empirical findings in *Chapter 2* related to the clarification of roles and responsibilities in outsourcing, and *Chapter 3* focusing on throughput time instead of number of open cases in software support form a basis for future research. Another appealing extension would be to conduct a longitudinal extension of the current research to estimate the speed of progress of industrial automation from the proprietary technology based vertical systems towards commoditized and more networked application ecosystems with different control points and success factors based on open hardware and software platforms from the mainstream ICT industries.

Looking at further possible future research avenues related to *Chapter 4*, the topic of technology lifecycles in slow clockspeed industries may begin to fascinate scholars more when the technology and cost advances in SoC technologies and related software platforms that enable almost any equipment from a thermometer to a toaster to be more intelligent in a cost and energy efficient manner. Due to the low cost and energy efficiency of the powerful SoC computers they are capable of running demanding applications at the place where the data is created and controlled by an intelligent device like smartphone or tablet. The theme already arising in this context is the Internet of Things (IoT), which is receiving more attention than its predecessor Machine-to-Machine (M2M) theme. Additionally, the weightless network standard which leverages frequency channels originally intended for TV broadcasting will add a low cost low bandwidth solution for transmitting for example condition monitoring data from intelligent sensors and actuators.

Reflecting on the disruption ratio (Figure 15) seems attractive to develop a new tool for companies to help them quantify the timing of future disruptions relevant to their business. First one needs to model the industry clockspeed frequency and its current phase. Then using Disruption Ratio with the help of the theory of system dynamics and Causal Loop Diagram - modelling (CLD) one could provide quantified time estimates of a specific technology disruption impacting a certain industry. This kind of tool when accurate could become a strategic competitive edge as long as the model is kept proprietary. Otherwise it needs to be regularly recalibrated due to the improved transparency it provides and induces change on the industry's clockspeed and Disruption Ratio.

Further research could be commenced to define a better way to set management's long term incentives based on the technology lifecycle phase of their businesses. In Roger's model of technological lifecycles a product with certain characteristics is sold to different customers with different arguments depending on which phase the market resides. Managers managing a mature business tend to have tilted their focus towards the exploitation rather than exploration. This is correct only for short and medium term performance of the business. Let us think about an oil company having two distinct part of their operation: 1) existing wells delivering oil (exploitation) and 2) exploration activities looking for new wells. In this context it is easy to understand that stopping the exploration activities would increase the short term financial performance but this would be detrimental for company's long term survival. In industrial automation as in many other businesses it is not equally easy to comprehend the need for different approach, organizational structure, resources and investment needed for exploitation and exploration.

Amodel rising from this research looks at each impendent business the company operates and classifies their respective strategic intention to either 1) high per cent growth in the two first phases, 2) absolute monetary growth (instead of % growth) in maturity phases or 3) cash from operations in the laggards phase. In this matter the management is motivated to focus their actions in each on every business they operate to better balance their focus on the exploration - exploitation axis.

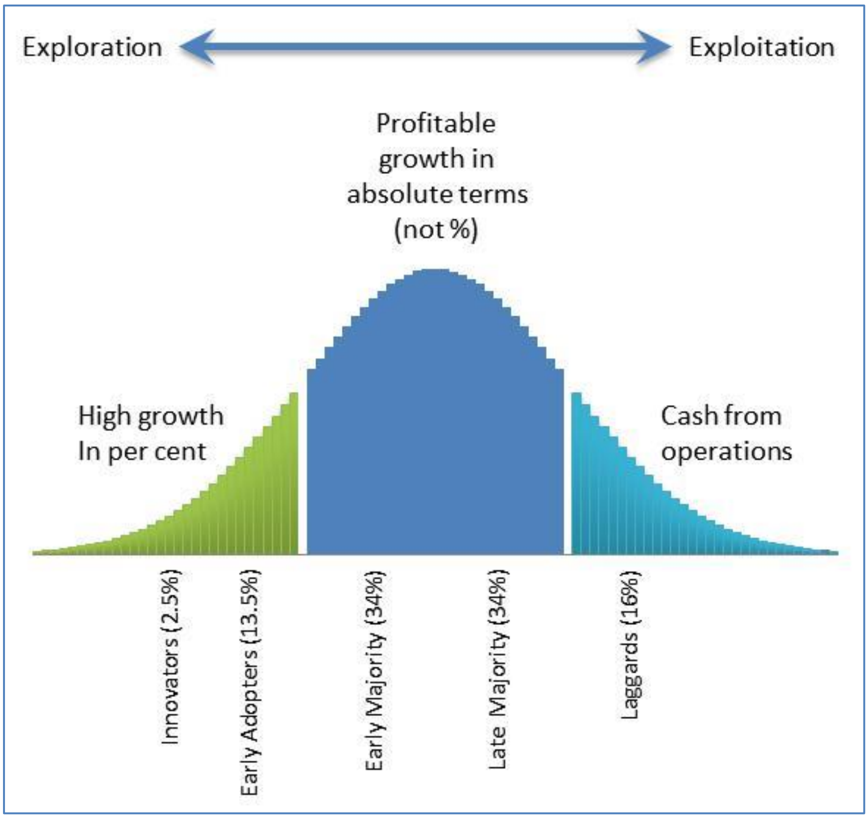


Figure 16. Long term management incentive model based on technology lifecycle phase

Further research is required to better estimate the next disruption rationale and timing in computer technology. Let me take the opportunity to explain the context of this future research in more detail. Comparing the Information technology (IT), information and communication technology (ICT) and industrial automation (IA) technology lifecycles in Figure 16 and taking into account the findings from *Chapter 4* we claim that the key to the initiation of the fundamental technology disruption is based on the following eleven elements: a new technology offering that is 1) inexpensive, 2) high performance, 3) low energy consumption, 4) environmentally resilient and 5) based on an open architecture SoC systems with related software platforms which in turn are 6) open source based 7) hardware independent 8) real time capable software platforms and have well established 9) development and 10) user communities as well as 11) an immense and fast growing installed base in smartphones and tablets to cover the further technology development costs.

However as we discovered in *Chapter 4* the customers' high risk leverage and incumbents strong vertical business model together with their adequate profitability are strong forces that are capable of postponing the starting date of the disruption. Early signals from research and hobbyist communities give reason to believe that the disruptive technology is already available but the major incumbents are actively delaying the creation of firm standards that would allow the industrial horizontal markets to develop. IoT will perhaps have the necessary inertia to drive the SoC disruption into industrial automation thus creating the Information, Communication and Automation Technology industry (ICAT).

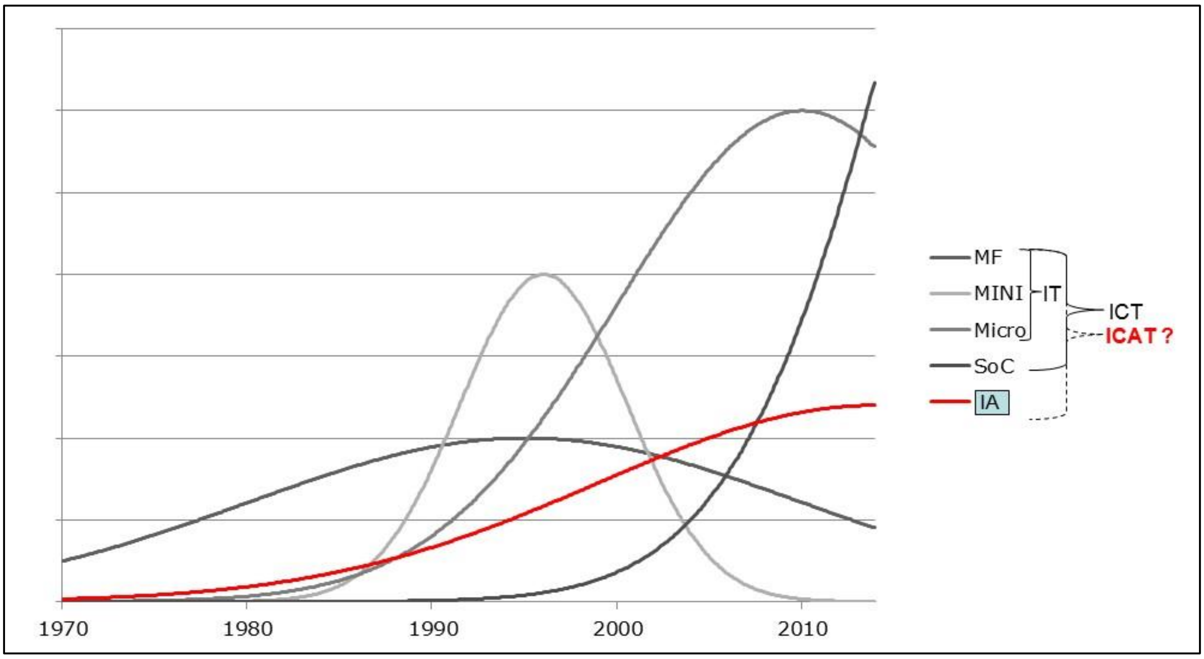


Figure 17: Industrial automation and related technology lifecycles

The key driving factor of the commoditization of computer based applications is hardware independent software. Mainframes still operate today in thousands of sites tightly coupled with the original system architecture. Minicomputers also operate in tens of thousands of sites equally tightly coupled with their original design. The personal computer revolution created a standard interface separating hardware and software and formed the IT industry. For industrial automation it did not fulfil the real-time and harsh environment requirements anywhere else but in control rooms. Smartphones and tablets created the ICT industry and as a by-product have also fulfilled the real-time and harsh environment requirements (Table 8). A more detailed longitudinal analysis of major technology lifecycles is presented in Appendix 5.

	1970	1980	1990	2000	2010	2013
Mainframe						
Application	Hardware Dependent				Mostly IBM Hardware (90%) and emulation	
Minicomputer						
Application	Hardware Dependent		Operating System dependent		Ported to PC or Emulation	
Microprosessor based						
Application		Operating System and partially CPU dependent				
SoC technologies and related platforms						
App stores, web services and cloulds					Software platform dependent	
SoC systems					RISC architechture dependent	
Industrial Automation						
External communication				OPC		
Application and internal communication				Hardware dependent		
Field communication				HART, Foundation Fieldbus, Profibus, Canbus, Modbus		
Internet of things						
External communication, application and field communication based on standards						?

Table 8: Technology lifecycles possibly forming the ICAT industry

This thesis studies industrial automation, a slow clockspeed industry based on well-established economic theories. In a recent discussion with my business associates we concluded that a market assessment on industrial automation written fifteen years ago is still valid today. Industrial automation is controlled by incumbents with strong technology based lock-in strategy and enabled by the customers' high risk leverage. This leaves the newcomers in a very challenging position to find a bridgehead where new technologies could be applied successfully. However if we look back twenty years, PCs entered industrial automation markets in operator stations replacing Unix workstations. The technology was not ready and proven at that time but customers demanded standard PCs and shrink-wrap software. Through a burdensome learning curve PCs are now used in critical industrial applications. The driving force for this change was customers' interest to control their automation system costs through increased transparency of the different cost elements of the system by using more standard components. This positive feedback mechanism that operates within markets, businesses, and industries generates instability: If a technology becomes popular by chance or clever strategy, it can rapidly cause business to work differently.

The customers of industrial automation are a very traditional part of the economy. However industrial automation systems are based on computers and software and thus are inherently knowledge-based industries which in other segments – like banking and telecom move at much higher clockspeed. Industrial automation will follow its ICT siblings at its own pace, much slower than I would have anticipated before starting this research. The key in technology disruptions is the formation of loosely interdependent horizontal technologies that can be used as commodities to build a technology stack which is not dependent on a single supplier or a very limited number of interconnected suppliers. In my mind the Internet of Things is likely to offer the necessary vertical standard interfaces that will eventually cause the next major disruption in industrial automation.

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Appendixes

APPENDIX 1: Web Interview questions

H1	W1: IA customers' key purchasing criteria is revenue growth
	W2: IA customers' key purchasing criteria is cost reduction
	W3: IA customers' key purchasing criteria is risk management
	W4: IA customers' do not want to be dependent on a single source vendor
H2	W5: SoC technology's price/performance ratio makes it attractive for IA applications
	W6: SoC technology's high performance adds value in IA applications
	W7: SoC technology's energy consumption and operating environment requirements are attractive for IA applications
	W8: SoC technology enabled open hardware agnostic Software platform which can perform real-time applications would be attractive for IA applications
	W9: User interface and development tools used in smartphone and tablet markets would be useful for IA applications
	W10: Features such as GPS, touch screen, large local SSD-storage, low cost cameras and various communication methods from smart phone and tablet markets would be useful in IA applications
Consumer and industrial electronics differences	W11: What is the clockspeed of industrial Automation?
	W12: Industrial customers only buy things that are proven in use
	W13: Industrial electronics are always more reliable than consumer electronics
	W14:Technology proven in an industrial context is much more attractive than a new cost effective solution
	W15: Industrial electronics are more secure in use than consumer electronics
General questions	W16: In which area if IA can the processing power of SoC based computers be best leveraged: (Visualization, Asset management, Open loop control, Closed loop control, Mission critical applications , Cannot be used at all):
	W17: Do the compensation schemes of managers in Industrial Automation drive their behavior in strategic decision making (annual salary, annual bonus, Long term incentives, pension scheme) ?
	W18: How important is risk avoidance vs. fast reward to different players in the Industrial Automation business?
	W19: Porter five forces impact on Industrial automation?
	W20: What is the clockspeed of industrial automation?
	W21: What is your role in your current job in relation to automation?

APPENDIX 2: List of abbreviations

IA	Industrial automation
IT	Information technology
ICT	Information and Communication technology
SoC	System on Chip
PoE	Power over Ethernet
ARM	Acorn RISC Machine, a set of instruction set architectures for SoC processors
TI	Texas Instruments

APPENDIX 3: Web references

Item	**Link**	**Accessed**
Texas Instruments (Sitara™)	http://www.ti.com/lsds/ti/apps/automation/end_equipment.page	8.11.2013
Raspberry Pi	http://www.unified-automation.com/news/news-details/article/1098-opc-ua-evaluation-kit-for-raspberry-pi.html	8.11.2013
Arduino,	http://forum.arduino.cc/index.php?topic=50780.0	8.11.2013
Beagleboard	http://www.ti.com/lsds/ti/apps/automation/end_equipment.page	8.11.2013
Pandaboard	http://pandaboard.org/	8.11.2013
mbed	https://mbed.org/explore/	8.11.2013
Pro-face	http://global.pro-face.com/product/index.html	8.11.2013
BiemmeItalia	http://www.biemmeitalia.net/ltouch/	8.11.2013
Armac	http://www.armac.nl/en/software_engineering	8.11.2013
Atmel	http://www.atmel.com/applications/industrialautomation/default.aspx	8.11.2013
Beckhoff Automation	http://www.beckhoff.com/	8.11.2013
Moxa	http://www.moxa.com/	8.11.2013
B&R	http://www.br-automation.com/en/	8.11.2013
Kontron	http://us.kontron.com/	10.11.2013
Nasa	http://www.nasa.gov/home/hqnews/2013/apr/HQ_13-107_Phonesat.html	8.11.2013

APPENDIX 4

ALL ACTORS				
RATIONALE	**REAL OPTIONS**	**POSSIBLE ACTIONS**	**Example**	**Relevance for IA actors**
GROWTH	Price reduction	Production standardation and volume	T Model Ford	XXX
		Production quality and risk management	Toyota, Motorola	XXX
		Production efficiency improvement	Volkswagen	XX
		Supply chain optimisation	Dell, Coca-cola	X
	Increase services	Proprietary spare parts and service personnel	Kone, Siemens, ABB	XXX
	Related offering extensions	Trading platforms and ecosystems	iTunes	
	Take over customer activities	Pay per demand	RollsRoyce	XX
	Change pricing models	Leverage internet	iTunes	
	Gain market control, increase entry barriers	Take over customer activities (e.g. outsourcing)	EDS, IBM, HP, Monsanto	X
		Acquire competitors	Cisco, Schneider, Swatch	XX
	Increase marketshare	Portfolio extension and economies of scale, go to market coverage	Toshiba	XX
	Value chain change	Forward Integration	Kone	XX
		Market redifinition	Apple (iPod, iPhone, iPad)	
		Indirect channels for better market coverage	Cisco	X
	Business model choice	Direct sales	Dell, EDS, IBM	XXX
		Change product offering	ARM	
		Indirect go to market	Compaq	XX
		Leverage open source software	Google, Apple	
		Indirect revenue earning model	Google	
		Trading platform	iTunes	
	Branding	Value proposition and related marketing	Apple, ABB drives, Siemens PLC	XX
COST	Better production process	Production volume	T Model Ford	XXX
		Production quality	Toyota, Motorola	XXX
		Net working capital optimization	Dell	
		Supply chain optimization & sourcing policies	Dell, Coca-cola	XXX
	Employee competence management	Employ the best	McKinsey, Accenture	
		Retain the talent	HP, Apple, Microsoft, Porsche	X
	Material choices	Use new materials	IKEA	
	Use of consumer commodities	Use of standard components	WANG	
	Reduce production variety	Software controlled performance	ABB	XXX
	Reduce components with software	Use modeling instead of sensing or feedback	ABB (DTC-control in drives)	
	Control point choice	Outsourcing	Nokia, Apple	
	Total cost of ownership	Improved remote or software based diagnostics	RollsRoyce jet engines	
	Ease-of-use from consumers	User interface redesign	GE medical	
	New service models	Optimize service offering	Ryanair	
	Value chain improment	Contract management or outsourcing	Nokia	XXX
		Backward Integration		
		Production efficiency and agility	Foxconn, Toyota, Porsche	XXX
		Logistics	Dell	
		Channel management	Subway, McDonald's	XXX
RISK	Channel management	Channel partner qualification	Nokia, BMW	X
	IP right management	Litigation over IP rights	Apple, Samsung, Nokia	
	Supplier management	Supplier control		
		supplier qualification	Samsung	XXX
	Internal process control	compliance management	Siemens, Avionics industry	XXX
		Internal controls	GE, Siemens	XXX
	Disruption management	Technology cost change	Personal computer, TCP/IP and open source routers	XXX
		Technology functionality change	Disappearance of cameras due to smartphones	XX
		Customer requirements or opinion change	Nuclear, Compliance	X
			Minicomputer and microcomputer disruptions	
		Supplier, customer, competitor and nowcomer moves	Qualcomm	XX
		Government regulations and regulation change	Kyoto protocol,reach, rochs, material declaration, (plumbum, silicony)	XXX
		Public opinion change	Corporate branding for customers	
			Environment	XX
	Mitigation of competitive moves	Customer watch	Apple, Google, Ericsson	XXX
		Incumbent watch		XXX
		Newcomer watch		XX
		Technology watch		XXX
CONTROL	Customer Lock-in	Vertical solution	IBM mainframe	XXX
		After sales service and maintenance outsourcing	RollsRoyce, Andritz, Metso, EMC, GE, Siemens	XXX
		BPO, outsourcing	EDS, IBM	
		Proprietary solution on a perceived open platform	SAP, Mixrosoft	XXX
		Branding	Apple	
		Customer behaviour information	Google	
	Efficient market coverage	Direct sales in attractive segments	HP, Emerson	XXX
		Market specific pricing	Winchester	XX
		Leverage competence in the channel	VMware, EMC	
		Indirect sales to cover the less attractive geographies or application segments	Emerson, Compaq	X
		Indirect only for cost efficiency	Compaq, Dell, Cisco	
	Supplier management	Multisource supply	ABB	XXX
		Purchasing volume benefits	Apple, Samsung, Nokia	XXX

INCUMBENTS DEFENDING AT THE CHASM

RATIONALE	REAL OPTIONS	POSSIBLE ACTIONS	Example	Competitiv e advantage	Primary mover	Relevance for IA supplier
EXTEND	Strengthe n current position	Grow in current business through price, offering differentiation or customer coverage improvements	ALL	Cost, product or customer intimacy leadership	Incumbe nt	XXX
		Grow in current business through mergers and acquisitions	Spery, Univac, Burroughs = UNISYS, DEC,Compaq, Tamdem, HP; Westinghous, Toshiba, Ladis+Gyr	economies of scale, customer intimacy	Incumbe nt	XXX
		Extend functionality on the vertically integrated offering	IBM mainframe	Customer loyalty due risk profile	Incumbe nt	XXX
		Work together with a customer partnership	IBM, EDS, McKinsey, SAP	Customer loyalty	Incumbe nt	
		Internal Restructure by 1) Products, Systems and Services, 2) Geographies or 3) Customer segments 4) Functions to gain desired focus or a combination of them	IBM, Siemens	Economies by focus	Incumbe nt internal	X
		Develop new technology for vertical use	IBM	Differentiat ion	Incumbe nt	XX
		Focus on services	IBM Global Services	Cost leadership	Incumbe nt	XX
		Increase exit barriers	SAP	Customer dependenc y	Incumbe nt	XXX
		Acquire new technology for vertical use	Siemens S7	time to market, cost	Incumbe nt	XX
		Create an in-house common technology platform across markets	Siemens S7, Siemens PN+ÖN, Nokia, ABB, GE Intelligent Platforms	Cost, market presence	Incumbe nt internal	
	Defend current position via cost	Improve operational excellence through process streamlining and re-engineering	Siemens, IKEA, Airbus, Chrysler	Relative cost position	Incumbe nt	XXX
		Leverage Emerging Markets with BPO offshoring	IBM, EDS, HP, Honeywell, ABB	Cost	Newcom er	XX
		White-label core technology	Fuji+ Siemens, outboard motors, Bosch, Korean LCD TV screens	time to market, cost	Incumbe nt	X
REPOSITION	Join forces with	Strategic partnerships	NSN, SonyEricsson, japanese companies	Economies of scale but keep	Incumbe nt	XXX

	other incumbents			option to re-enter		
	Position change in value chain forwards	Move to services based on an internal or external platform	Unisys, IBM Global Services, Wang, Current SAP integrators; Schneidewr, Telvent+ Invensys, Xerox	Economies of scope	Incumbent	
		Focus on outsourcing services	IBM, Fujitsu, HP	Customer intimacy	Incumbent	**X**
		Create an application based on a platform	Wonderware, MS Office, WordPerfect, Supercalc, Lotus 123	Customer value	Newcomer, incumbent	**X**
	Position change in value chain backwards	Position change in value chain backwards	Qualcomm	technology leadership	Customer, Incumbent	**X**
	Move from vertical to horizontal	Focus on a horizontal component product	SAP, IBM global services	Cross the Chasm	Newcomer	**X**
EXIT	Spin off	MBO, Trade sale, IPO	EDS, Compaq, Infineon			**XX**
	Sell when still value		IBM Levono, Nokia Microsoft, Siemens BenQ	face the exit barrier	Incumbent	**XX**
	Fade away	Close down	Philips (CRT), StoraEnso, ABB Power Systems, Sony Walkman	Supply to market and internal cost reduction	Incumbent	**X**

NEWCOMERS ATTEMPTING TO CROSS THE CHASM

RATIONALE	REAL OPTIONS	POSSIBLE ACTIONS	Example	Competitive advantage	Primary mover	Relevance for IA supplier
ENTER	Create a dominating platform; first mover advantage is not first mover advantage	Cost benefit, first mover advantage	Microsoft, Google, Apple	The one who gets ahead, gets ahead (Arthur)	First mover w	x
	Capture a Blue Ocean, i.e. fulfil an unrecognized need	Fulfil customer need with new technology	Apple, Cisco	Blind competition	Newcomer	
	Offer cost, quality and time benefit	Establish emerging market engineering center	TCS, Infosys, Wipro, HCL, Cognizant	Cost	Newcomer	x
	No risk from market erosion	No need to maintain old platforms				
		Keverage new technologies	Cisco	Agility, no need to protect existing business	Newcomer	
	Marketing	Create new needs	Angrabird, Supercell	Attractineness	Newcomer	
		Ease of purchase	Zalando	Visibility	Newcomer	
	Customer purchasing behaviour change	Leverage NWC reduction initiatives	BYOD	Cost reduction	Newcomer	x
	Geographical expansion	Start local	Halaus	Nokia and NMT	Newcomer	x
		Segment the countries	Ammutaan haulikolla ja focusoi	Nestle, ABB	Newcomer	x
		Country ny country	Ammutaan kiväärillä	Compaq, Dell	Newcomer	x
	Implement a new business architechture	Offer tangible customer benefits	iPod	Blind competition	Newcomer	x
	Introduce a better commodity product for standard	Lower cost, more fuctionality, easier to use	Cisco	New customer value	Newcomer	xxx
EXPAND	Branding, Acquistions, Technology leadership; Business model change	Acquire new technology to maintain lead	Cisco	Maintain first mover advantage	Incumbent, n	x
		Acquire more customer access	Kone	Customer intimacy	Incumbent	x
		Leverage Open Source	IBM, HP	Cost	All	xx
		New business model	Google, Microsoft, Apple	Change the game	Newcomer	
		Stealth marketing	Google	Brand	Newcomer	

APPENDIX 5: Major IT technology lifecycles