BEYOND IT AND PRODUCTIVITY

- EFFECTS OF DIGITIZED INFORMATION FLOWS IN THE LOGGING INDUSTRY

by

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ABSTRACT

The IT and productivity paradox has been the subject of considerable research in recent decades. Many previous studies, based mainly on macroeconomic statistics or on aggregated company data, have reached disparate conclusions. Consequently, the question whether IT investments contribute to productivity growth is still heavily debated. More recent research, however, has indicated that IT contributes positively to economic development but that this contribution is not fully revealed when only productivity is measured.

To explore the issue of IT and productivity further, the ITOP (Impact of IT On Productivity) research program was launched in 2003. An alternative research approach is developed with the emphasis on the microeconomic level and information flows in processes in specific industry segments. In the empirical study, the development of information flows is tracked over several decades. Effects of digitized information flows are hereby identified and quantified in order to determine their importance in terms of productivity.

The purpose of this study is to explore effects of information technology by studying digitized information flows in key processes in the logging industry. The research shows that several information flows in the logging process have been digitized leading to new ways to capture, use, spread, process, refine and access information throughout the logging process. A large variety of effects have also been identified from this development.

The results show that only a minor part of the effects identified have a direct impact on productivity and thus that a large number of significant effects do not. Effects with a major direct impact on productivity include increased efficiency in timber measurement registration, lower costs of timber accounting and increased utilization of harvesters and forest resources. Other significant effects with no direct impact on productivity are related to a more open timber market, increased timber customization, control, decision-making and access to information, as well as skill levels and innovation. The results thus demonstrate that it is questionable whether conventional productivity measures are sufficient for measuring the impact of IT.

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The field of Economic Information Systems (EIS) includes the communication and transmission of information to, from and between people, as well as the development and evaluation of appropriate information systems for those purposes. The field also covers information structures; in other words, the interaction among modern information technology, organizational solutions and people.

Doctoral candidates in this field are associated with various research programs. Some candidates conduct their research at IMIE (International Graduate School of Management and Industrial Engineering). Doctoral candidates at EIS may also participate in "Management and IT" (MIT), a co-operative research program involving ten universities. Other doctoral candidates are enrolled in the Industry Research School in Applied IT and Software Engineering, which is partially funded by the Swedish Foundation for Knowledge and Competence Development. There is also a three-year licentiate Research Program for Auditors and Consultants (RAC). RAC is being carried out in partnership with leading audit firms in Sweden. EIS also co-operates closely with Gotland University College and Skövde University College. EIS graduate study programs are open to some of their doctoral students.

EIS research is currently conducted under a number of principal headings:

- e-Business
- Combating Economic Crime
- Financial Accounting and Auditing
- Organization and Communication with New Information Technology
- Strategy and Management Control
- Simulation, Decision Support, and Control of Manufacturing Flows
- Applications of Principal-Agent Theory
- IT and Productivity
Maria Kollberg, Master of Science in Engineering wrote *Beyond IT and Productivity – Effects of Digitized Information Flows in the Logging Industry*, as her Licentiate thesis in the field of Economic Information Systems, Department of Computer and Information Science, Institute of Technology, Linköping University. She was enrolled in the Swedish research school MIT.

Linköping, August 2005

Birger Rapp Professor
Economic Information Systems
THE ITOP RESEARCH PROGRAM

Is information technology contributing to productivity growth? Until recently, studies based on aggregate data have failed to show any clear connection between IT investment and productivity in the US economy. The apparent absence of such a relationship has become known as the “productivity paradox”. Today, positive effects of IT investments on productivity have been reported, but to an appreciable extent the overall value of IT is still under debate.

Earlier research has focused largely on IT capital spending and has generally ignored how the technology is actually used. In contrast, the ITOP research program (Impact of IT On Productivity) has adopted a micro-level approach based on systems analysis for studying computer applications and embedded technology in several industries. The research is centered on the use of information in key industrial processes before and after the introduction of IT. In addition to effects on productivity as traditionally measured, numerous other benefits of IT, some of them intangible, are identified. The following books are published in 2005:

Cöster, M., (2005), *Beyond IT and Productivity - How Digitization Transformed the Graphic Industry*.


Linköping August 2005

Thomas Falk Professor

Birger Rapp Professor
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Trondheim, August 2005

Maria Kollberg
Economic Information Systems
3.3  **RESEARCH ON EFFECTS OF IT** ................................................................. 47
3.3.1  **Drivers for investing in IT** ................................................................. 47
3.3.2  **Different types of effects** ................................................................. 49
3.3.3  **Measures for IT evaluation** ............................................................... 52

4. **BACKGROUND ON THE LOGGING INDUSTRY** ............................... 55
4.1  **THE EVOLUTION OF THE SWEDISH FOREST INDUSTRY** ............... 55
4.1.1  **Specific characteristics** ................................................................. 56
4.1.2  **Economic development and role of the industry** ............................ 56
4.1.3  **Development in markets** ............................................................... 60
4.1.4  **Environmental issues** ................................................................. 62
4.1.5  **Organizational development** .......................................................... 63

4.2  **LOGGING OF SAW TIMBER** .............................................................. 64
4.2.1  **Planning and preparation** ............................................................... 65
4.2.2  **Harvesting** ..................................................................................... 67
4.2.3  **Forwarding and transportation** ...................................................... 68
4.2.4  **Measurement and follow-up** ........................................................ 69
4.2.5  **Brief overview of the sawmill process** ............................................ 70

4.3  **MILESTONES IN IT DEVELOPMENT** ................................................. 71
4.3.1  **An overview** ..................................................................................... 72
4.3.2  **A few words about production of sawn timber** ............................... 80

5. **EFFECTS OF DIGITIZED INFORMATION IN THE LOGGING PROCESS** .. 83
5.1  **INTRODUCTION** ................................................................................ 83
5.1.1  **Stakeholders involved** ..................................................................... 84
5.1.2  **Comments on the milestones in IT development** ........................... 86
5.1.3  **Overview of information flows** ...................................................... 87

5.2  **DIGITIZED INFORMATION IN PLANNING AND PREPARATION** ..... 89
5.2.1  **Digitized contract information** ....................................................... 91
5.2.2  **Digitized price information** ........................................................... 92
5.2.3  **Digitized bucking instructions** ...................................................... 94
5.2.4  **Comments on effects in planning and preparation** ....................... 95

5.3  **DIGITIZED INFORMATION IN HARVESTING** ................................ 96
5.3.1  **Digitized bucking support** ............................................................ 99
5.3.2  **Digitized harvester reporting** ....................................................... 102
5.3.3  **Comments on effects in harvesting** .............................................. 104

5.4  **DIGITIZED INFORMATION IN FORWARDING AND TRANSPORTATION** 105
5.4.1  **Digitized wood orders** ................................................................. 107
5.4.2  **Digitized transportation orders** .................................................... 108
5.4.3  **Comments on effects in forwarding and transportation** ............... 109
5.5 DIGITIZED INFORMATION IN MEASUREMENT AND FOLLOW-UP .............................. 110
5.5.1 Digitized timber accounting ............................................................................. 112
5.5.2 Digitized decision support .................................................................................. 116
5.5.3 Comments on effects in measurement and follow-up ............................................. 119
5.6 EFFECTS IDENTIFIED IN THE LOGGING PROCESS ........................................ 120
5.6.1 Summary of effects .............................................................................................. 120
5.6.2 Effects and affected stakeholders ......................................................................... 122

6. ANALYSIS OF EFFECTS OF DIGITIZATION ......................................................... 125
6.1 THE NATURE OF IDENTIFIED EFFECTS .............................................................. 125
6.2 EFFECTS WITH A DIRECT IMPACT ON PRODUCTIVITY ....................................... 129
6.2.1 Labor savings ....................................................................................................... 129
6.2.2 Other cost savings ............................................................................................... 131
6.2.3 Use of resources ................................................................................................. 131
6.3 EFFECTS WITH NO DIRECT IMPACT ON PRODUCTIVITY ...................................... 132
6.3.1 Market structure .................................................................................................. 132
6.3.2 Product value and customer relations ................................................................. 134
6.3.3 Control, decision support and access to information ............................................ 135
6.3.4 Skill levels .......................................................................................................... 137
6.3.5 Innovation ........................................................................................................... 138
6.4 EFFECTS AND THEIR IMPACT ............................................................................. 138

7. CONCLUSIONS ...................................................................................................... 143
7.1 EFFECTS OF IT ..................................................................................................... 143
7.2 THE ROLE OF IT IN THE LOGGING PROCESS ..................................................... 144
7.3 QUALITY OF RESULTS ....................................................................................... 146
7.4 SUGGESTIONS FOR FURTHER RESEARCH .......................................................... 149

REFERENCES ........................................................................................................... 151

APPENDICES ............................................................................................................ 163
APPENDIX A - KEY TERMINOLOGY AND ABBREVIATIONS ........................................... 163
APPENDIX B - INTERVIEW GUIDELINES ....................................................................... 165
APPENDIX C - INTERVIEWEES .................................................................................... 167
LIST OF FIGURES AND TABLES

Figure 1-1 An example of the development in the logging process ................................. 7
Figure 2-1 The research model ...................................................................................... 16
Figure 4-1 The number of employees in the Swedish forest industry by industry segment between 1970-2003 (Source: NBF, 2004) ........................................................................ 59
Figure 4-2 Value added to producer price, million SEK in constant prices (1991). (Source: based on SkogsSverige, 2005) ................................................................. 60
Figure 4-3 A general overview of the process of saw timber logging ................................ 65
Figure 4-4 Overview of milestones in the development of IT in logging ......................... 73
Figure 5-1 Scope and structure of the empirical description .......................................... 84
Figure 5-2 Information flows in the studied logging process, current situation ............... 88
Figure 5-3 Overview of the current situation: the planning and preparation phase .......... 89
Figure 5-4 Information flows in planning and preparation, 1960s-2000s ......................... 90
Figure 5-5 Overview of today’s situation: the harvesting phase .................................... 97
Figure 5-6 Information flows in the harvesting phase, 1960s-2000s ................................. 98
Figure 5-7 Overview of today’s situation: the forwarding and transportation phase ....... 105
Figure 5-8 Information flows in forwarding and transportation, 1960s-2000s ................. 106
Figure 5-9 Overview of today’s situation: the measurement and follow-up phase ........... 110
Figure 5-10 Information flows in the measurement and follow-up phase, 1960s-2000s .... 111
Figure 5-11 Example of a punch card for timber measurement at the SDC .......... 113
Figure 5-12 Summary of identified effects and affected stakeholders ............................. 123

Table 5-1 Effects of digitization in planning and preparations ..................................... 95
Table 5-2 Effects of digitization in harvesting ................................................................. 104
Table 5-3 Effects of digitization in forwarding and transportation .................................. 109
Table 5-4 Effects of digitization in measurement and follow-up ..................................... 119
Table 6-1 Overview of automational, informational and transformational effects identified in the studied logging process .................................................. 128
Table 6-2 Effects with direct impact on productivity ....................................................... 139
Table 6-3 Effects with no direct impact on productivity .................................................. 140
1. INTRODUCTION

The information technology and productivity paradox has been the subject of considerable research in recent decades. Using an alternative research approach, this study explores various effects of IT and discusses how these could be evaluated. Of particular interest are effects that are not likely to show up in conventional measures of productivity. The study is based on empirical data collected from the logging industry.

1.1 BACKGROUND

Estimating the economic impact of the information revolution is a complex task. In this study, various effects of digitized information flows in a process are investigated. A complex picture of a variety of effects emerges. This picture is discussed, and effects are quantified in order to determine their importance in terms of productivity.

Researchers have studied the impact of information technology (IT)\(^1\) on productivity growth for several decades (see literature reviews, for instance by Brynjolfsson and Yang, 1996; Dedrick, Gurbaxani and Kraemer, 2003). Productivity\(^2\), which is commonly defined as a ratio of a volume measure of output to a volume measure of input used (OECD,

\(^{1}\) Here, IT and ICT include “technology for collecting, storing, processing, recalling and communicating data, text, images and speech” (SIKA, 2001, p. 8). The term IT is used throughout this study.

\(^{2}\) Here, productivity is defined as a ratio of a volume measure of output to a volume measure of input used (OECD, 2001).
(2001), is often expressed in measures such as labor productivity, total factor productivity (TFP) or multi-factor productivity (MFP) (Schreyer and Pilat, 2001). Even though productivity is an important measure for evaluating financial performance of individual firms and economic growth on an industry or national level, it is questionable whether conventional productivity measures are appropriate for evaluating the role of IT in financial and economic development (Brynjolfsson, 1993; Statistics Sweden, SCB, 2004).

Of course, information technology could be expected to have some positive impact in this regard, but there are also benefits that are difficult to express in financial terms. For example, Brynjolfsson (1993) cites increased variety, improved timeliness of delivery and personalized customer service as additional benefits that are poorly represented in productivity statistics.

Besides effects that may be considered to have a direct impact in terms of productivity, this study seeks to assess also other effects that have no direct impact on productivity but may still be of major importance.

1.1.1 Previous research on IT and productivity

Previous studies on IT and productivity have reached disparate conclusions regarding the contribution of IT investments to productivity (see literature reviews, for instance by Dedrick et al., 2003). Consequently, the question whether IT investments contribute to productivity growth is still heavily debated.

An important milestone in this debate was the following statement by Robert Solow (1987, p.36): “You can see the computer age everywhere but in the productivity statistics”. Research on the so-called “productivity paradox” or “IT and productivity paradox” constitutes a starting point for this study and is further dealt with in Chapter 3.
Early studies in the late 1980s, which were mainly based on aggregated data from macroeconomic statistics and company databases, indicated that IT investments did not show up in aggregate productivity statistics and contributed to the development of a critical view on the impact of IT (see for instance Strassmann, 1990).

However, according to more recent studies on an aggregate level based on official statistics, both the use and the production of IT have made a positive contribution to productivity (see for instance Jorgensen and Stiroh 2000; Oliner and Sichel 2000; Whelan 2000; Council of Economic Advisers, 2001; Jorgenson, 2001; Stiroh, 2001).

In addition, studies with a firm-level focus (see for instance Brynjolfsson and Hitt, 1996), demonstrate that IT has had a significant positive impact on productivity growth on average, but also that the relationship between IT investments and financial performance varies considerably among companies and industries (reviewed in Dedrick et al., 2003). The issue of returns on IT investments therefore seems more complex than the original formulation of the productivity paradox (Brynjolfsson and Yang, 1996; Brynjolfsson, 2003; Dedrick et al., 2003).

The paradox can be explained in several different ways. For example, Triplett (1999) discusses seven explanations. According to Brynjolfsson (1993), measurement problems regarding inputs and outputs of firms and industries, as well as statistical issues, are recognized as the most common explanations. Others include time lags or delays due to learning and adjustment, and redistribution and dissipation of profits (Brynjolfsson, 1993).

One specific issue, which is related to measurement problems, concerns definitions of IT and IT investments and how these are dealt with in statistics. Technology that could be considered as IT, such as embedded systems, is seldom included in aggregate data on IT investments and is therefore not captured in the statistics (see Kviselius 2003; Falk and Persson, 2004). As long as statistics are based on narrow definitions of IT,
there is a risk that the financial and economic effects of IT in will be underestimated.

Even though the impact of IT on productivity statistics has not been solely positive, organizations in many countries have still shown a strong willingness to invest in IT over the last decades (OECD, 2004). This may indicate that there are several other potential forces driving organizations to invest in IT, besides increased productivity.

For example, Lucas (1999) identifies a number of ways in which IT generates value; one is that investments could create vital infrastructure or required systems while also serving strategic purposes or transforming organizations. The wide spectrum of possible uses and potential benefits of IT implies that managers also struggle to find adequate ways of measuring the business value of IT investments (see for instance Mahmood, Kohli and Devaraj, 2004).

1.1.2 The approach of the ITOP research program

To further explore the issue of IT and productivity, the ITOP (Impact of IT On Productivity) research program was launched in 2003. The present thesis is conducted within the framework of this research program. The research approach is further explained in Chapter 2.

Many of the studies aiming at understanding the role of IT are based on aggregated data and narrow definitions of IT, and have a strong focus on productivity statistics. In view of the deficiencies of this perspective on the benefits of IT, an alternative approach has been adopted in the ITOP program. In order to capture an extensive picture of the impact of IT, the emphasis is on the microeconomic level and information flows related to processes in specific industry segments. In the empirical study, the development of information flows is tracked over several decades. Effects of this development are further identified and evaluated in terms of their impact on productivity.
To provide a broad view of IT, there is a focus on digitization of information. In this study, that concept refers to the conversion of information to digital form, which can be processed by computers (Collin, 2001; Online Dictionary, 2005). The concept of digitization should be considered as a complement to IT, as it highlights the use of information and ensures, for example, that embedded systems are included in the study.

1.1.3 About the empirical study

In this study, information flows within key processes in the logging industry are examined. The logging industry provides raw materials to the wood and the pulp and paper industries (Hailu and Veeman, 2003). Here, the logging process covers activities related to logging operations such as planning of logging activities and preparations of the logging stand, harvesting or felling and reprocessing of logs, forwarding or transportation of logs in forest terrain, transportation of timber from the forest to the sawmill, timber measurement and follow-up on timber production.

During the last few decades, technological advancements and mechanization in logging operations have led to a rapid increase in productivity (SkogForsk, 1997; Södergren and Thor, 2003). Rationalization has been important for remaining competitive in the face of intensified global competition.

Logging operations are not traditionally considered as being in the forefront of IT development. Yet, digitization of information flows in logging operations started back in the 1960s, and today numerous IT applications can be found in a wide range of logging-related activities (see for instance Höglund, 2000). However, aggregate-level statistics from SkogForsk (1997) and Södra Skog do not show that IT investments have contributed to decreased costs or increased productivity in logging
operations in recent decades. There is still a strong belief in the industry that investments in IT would contribute to further productivity growth. This indicates that in the case of logging operations “computers can be seen almost everywhere but in the statistics on logging costs”.

So, why is it so difficult to estimate the financial impact of IT on firms and especially its economic impact on an aggregate level? An example is used below to illustrate the complexity of the IT and productivity issue. It also shows that contextual aspects are important when evaluating the role of IT.

To obtain an overview of the impact of IT in the logging industry, one could compare today’s situation in the process of logging timber and pulpwood to the situation in the 1950s, before information was digitized. However, there are some difficulties related to the comparison of “now and then”, as the process has undergone some significant changes. A simplified example of the development of the logging process is shown in Figure 1-1.

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4 Based on interviews with representatives of SkogForsk, September 2004.
Productivity can be estimated by comparing outputs per input. At first sight, both input and outputs seem to be similar in the figure. Trees enter the process, and products mainly include saw timber and pulpwood. The resource inputs have not changed over the years, and the products seem to be roughly similar. However, one cannot neglect the significant changes since the 1950s affecting the process, regarding technology and methods as well as products and market.

Within the process, activities have changed as new technology and methods have been adopted. In the 1950s, timber was felled with chain saws. No consideration was given to timber-market demand prior to logging; sellers just tried to sell what had been logged.

Today, modern logging machines called harvesters are used for felling and reprocessing logs. The requirements of sawmills are stated in detailed price lists where price varies according to such parameters as tree species, length, diameter and quality of logs. This information constitutes the foundation of the logging process and is used for bucking, the sectioning of a log into assortments so as to achieve the highest possible financial return on the tree. A bucking computer is used to calculate the optimal lengths of logs and serves as a bucking support for the harvester operator.
There have also been changes regarding products. As these have become more diversified, they have developed from standard to more customized timber or wood. Sawmills demand both specific assortments of saw timber and timber for specific purposes. Specific fiber characteristics of pulpwood are also required for pulp and paper production. In addition, further areas of application for timber have developed. Wood chips, for instance, can be used to provide energy in industrial processes. Even though resource inputs have not changed, it seems difficult to estimate how productivity has developed over time, as there have been significant changes in product outputs. The example also shows that there are significant drawbacks to using aggregate input and output data in productivity statistics to estimate the impact of IT over longer periods.

In order to overcome these weaknesses when seeking an increased understanding of the benefits of IT, it is necessary to consider the context surrounding the process studied. In addition, breaking up a single long period of development into shorter periods would permit continuous tracking of events over time instead of comparing two distinct situations: the one today and the one before IT was introduced.

1.2 Purposes and Research Questions

The overall purpose of the ITOP research program provides a basis for the study:

The purpose of the program is to provide additional knowledge concerning the contribution of IT to the development of productivity on an aggregate level in society, and on the contribution and role of IT in businesses and industries. A further purpose of the research is to generate theories about the role of information and IT in the financial development of firms and in economic development at the industry and national levels.

This overall purpose has been further adapted to this specific study, purpose of which is to:
…explore effects of information technology by studying digitized information flows in key processes in the logging industry.

This latter purpose is further divided into two research questions. The first question aims at identifying different types of effects from digitized information flows. The second research question aims at evaluating the impact of these effects on productivity.

• How have information flows changed over time because of digitized information in the logging process?

• How can the effects of this development be evaluated in terms of conventional measures of productivity?

1.3 Expected Contributions

The expected contribution of this research is to explore effects of IT and evaluate their impact on productivity. The principal product of the research will be an inventory of effects from digitized information; some of these may have a direct impact in terms of productivity while others have no direct impact. The results in this study are expected to demonstrate that the contribution of IT is larger and covers a wider range of benefits than can be estimated in terms of productivity. In a theoretical perspective, this finding challenges the relevance of conventional measures of productivity for estimating the payoffs of IT investments.

The primary target group is academics in the field of productivity research and with a particular interest in the role of IT in productivity growth. The thesis is further intended for academics interested in the role of IT in the logging industry.

The results also have a practical relevance in the discussion on the benefits of IT in individual organizations. Therefore, practitioners concerned with the impact of IT on a firm level, especially within the
logging industry, might also find the thesis interesting. In addition, the thesis is relevant for professionals dealing with official statistics.

1.4 **SCOPE AND LIMITATIONS**

In contrast with previous research on IT and productivity, which uses aggregate data and productivity statistics to investigate whether there is a positive impact of IT on productivity, the purpose of this study is to explore effects of IT based on empirical evidence collected from key processes in the logging industry. The productivity paradox is an important starting point of this study.

Productivity should be considered as one of several measures used to evaluate the impact of IT. This study is not intended, however, to specify productivity benefits in exact figures, but to quantify effects in order to discuss their importance in measuring productivity. In this study, the scope of analysis includes evaluating identified effects to obtain a rough quantitative indication of the importance of effects in terms of productivity. Consequently, an extensive financial and economic evaluation is outside the scope of the study.

As mentioned above, information flows in the logging industry are considered in this study. Since the focus of the empirical study is on logging of saw timber, the logging of pulpwood for further pulp and paper production is left aside. Some parts of the production of sawn timber are nevertheless included in Chapter 4 in order to provide background information on key activities at sawmills.

There are several differences between the Swedish logging tradition and international practices. For example, the traditional logging procedure in Sweden is the short-wood method, where the tree is cut into lengths at the stand. The full-tree method, where the tree is extracted from the forest and further processed at another location, is followed in a number of other countries, including Canada (MacDonald and Clow, 1999). The Swedish perspective was selected primarily to facilitate the collection of
empirical data. Therefore, the international context is not further considered in the study.

1.5 OUTLINE OF THE REPORT

This thesis is organized in seven chapters.

Chapter 1: In the Introduction, the background to the study is provided, including a presentation of the research field and a discussion of the problems addressed. Purposes and research questions are defined. Expected contributions to the research field are also described, as are the scope and limitations of the study.

Chapter 2: In Research Design and Methodology, the selected research approach, including the overall design of the study and the applied research model, is described. Also discussed are the research strategies and methods adopted, including techniques for data collection, presentation of findings and data analysis. Furthermore, some steps to ensure quality of the study are described.

Chapter 3: In Theoretical Discussion, a selection of relevant literature regarding the productivity paradox and effects of IT is reviewed. Also included are definitions of important concepts.

Chapter 4: In the Background on the Logging Industry, a general description of the empirical setting is given together with an overview of principal events in the history of logging operations. Major milestones in the development of IT in the industry are also identified.

Chapter 5: The empirical findings are presented in the Effects of Digitized Information in the Logging Process. Here, the studied case is presented in detail with the help of process charts to
illustrate the development of information flows over time. Effects of digitized information flows are also identified. The findings are further analyzed in Chapter 6.

Chapter 6: The analysis of the findings is presented in *Analysis of Effects of Digitization*. Effects are further discussed and evaluated in terms of productivity. Mathematical examples are used to illustrate the importance of various effects.

Chapter 7: The final *Conclusions* provide a summary of the results. Some implications of results are discussed followed by a discussion on the quality of results. Some suggestions for further research are also presented.

In *Appendices*, key terminology and abbreviations are presented together with some interview guidelines and an overview of interviewees.
2. RESEARCH DESIGN AND METHODOLOGY

As stated in the introduction (Chapter 1), since the results of previous research on the productivity paradox are ambiguous, an alternative research approach is adopted in this study for exploring effects of IT. This approach is further described in this chapter, which concerns research strategies and methods for data collection, data analysis and reporting of findings.

2.1 RESEARCH APPROACH

As stated in Chapter 1, much of previous research within the IT and productivity field has sought to determine whether IT contributes to productivity growth or not. Previous research is also dominated by a statistical approach with an emphasis on aggregate data.

In this research the aim is to understand the effects of IT. An explorative case study strategy is selected, with the study based on qualitative techniques for data collection such as interviews, documents, and presentations. The techniques applied are further described below. Collected data are both qualitative and quantitative. Quantitative data is used in mathematical examples (in Chapter 6) and background statistics on the logging industry (in Chapter 4). In the analysis (Chapter 6), identified effects are evaluated quantitatively. The approach is further described in this chapter.

2.1.1 Case study design

This study is influenced by case study design. Yin (2003) presents useful guidelines for case study research. Besides Yin (2003), case study research
strategies are dealt with in Benbasat, Goldstein and Mead (1987) and Eisenhardt (1989), for example.

The case is presented as a general empirical description of a series of events in the logging industry. The case description is based primarily on data collected from interviews and documents. It describes the development of information flows regarding digitization in the logging process over several decades. Digitized information flows constitute the unit of analysis.

The decision to use a case study strategy derives from the purpose of exploring effects of IT by studying digitized information flows in key processes in the logging industry. This strategy involves examining an extensive picture of information flows and effects of digitized information in a specific context, the logging industry.

The purpose and research questions are of an exploratory nature. Hence, the situation studied has no clear set of outcomes (see for instance Benbasat, et al., 1987; Yin, 2003). This study also has descriptive characteristics as it seeks to describe the development of information flows in a specific context.

The design adopted is influenced by the single-case design, as proposed for instance by Yin (2003). Here, the case represents a situation that is believed to be typical for other situations as well and is used to capture conditions of a common situation. Yin (2003) classifies this type of situation as a representative or typical case (p. 41).

Considering only a single case may limit generalization of results. However, as this study is part of the ITOP research program and is conducted in parallel with two similar case studies, the results from this study will be further compared to the results of the two others later on.
2.1.2 The role of theory
In this study, theory has primarily been used to obtain a pre-understanding of the research field.

The overall purpose of the research was originally set by the ITOP research program. Some of the important literature in the field was reviewed early in the research process to provide an overview of the research topic, to gain familiarity with literature within the area and to develop a knowledge base.

This review of previous research in the field of IT and productivity later led to the formulation of the purpose and the two research questions of this study. The review includes the major studies within the field and literature surveys. In the conclusions (Chapter 7), the findings of the study are discussed in light of some general results of previous research.

The review of previous research also served as a basis for selection of a suitable research design and for initially setting the scope the study. However, the definition of the final scope has also been influenced by the empirical setting.

2.1.3 The research model
In parallel with the initial phase of collecting empirical data, a research model was developed. The scope of the model was determined in collaboration with other members of the ITOP research program. The scope is influenced by the literature on previous research and other literature relevant to the approach of the ITOP program.

The simple research model presented in Figure 2-1 is intended to play a guiding role, describing how the study is conducted. It has been used primarily to set the scope of the empirical description as well as the analysis and evaluation of effects. The purpose of the model is also to show the overall structure of the study.
2.2 SELECTING THE EMPRICAL SETTING

The selection of the logging industry is influenced by a number of criteria. Some of these were defined in the ITOP research program to permit comparison of results from parallel studies. Some criteria were also used to select the empirical setting.

2.2.1 The logging industry

This study is conducted in parallel with two other similar studies within the ITOP research program that deal with information flows in different contexts. In this study the specific context is the logging industry. Grocery distribution (Horzella, 2005) and the graphic industry (Cöster, 2005) are dealt with in the two other studies. Certain criteria were used for the selection of the logging industry.
The three studies are intended to explore different types of processes in different industry segments. This is to permit comparison of findings across industries later on. The three studies should be considered complementary in terms of types of processes and products. This study covers information flows in the production process of saw timber. The study of grocery distribution explores information flows in processes based on information. The study of the graphic industry concerns information flows in processes where the end product is based on information.

The process in itself should also represent a flow “from basic resources to final product”. This is to assure coverage of multiple stakeholder perspectives in the process studied and to capture effects of digitized information as these are perceived from the perspectives of different stakeholders.

In order to obtain a pre-understanding of the empirical field, initial interviews with stakeholders involved in the logging industry were carried out in parallel with a review of literature describing the logging industry. Data from these interviews have been used to lay the foundation for an overview of milestones in IT development related to the logging industry. The IT milestones mapped out (in Chapter 4) have served as rough guidelines for further identification of events related to digitization of information in the logging process.

An important feature of this study is its retrospective nature. As defined by the ITOP research program, one objective of this study was that it should track the development of information flows several decades back in time. Therefore, the study includes both historical and longitudinal aspects in the sense that past events are examined over time. According to Bannister (2002), there is no clear distinction between longitudinal and historical research, but in an historical perspective, the researcher has not been present when events occurred and will have to reconstruct and interpret events using a variety of sources.
The 1960s have been chosen as the starting point for the empirical description. The first IT initiatives can be traced back to this decade. Furthermore, it has been important to obtain an overview of the series of events from before IT was introduced to today’s situation, in order to identify not only short-term but also long-term effects of digitized information.

2.2.2 Logging of saw timber at Södra

For the selection of a specific empirical setting within the logging industry, a number of criteria were applied.

- The logging process should be large-scale. This is to assure coverage of events that are representative for the major part of total saw timber production in Sweden.

- Different types of IT should be in use in the process. This is to assure variety in the types of IT applied and hopefully make it possible to identify various effects of digitized information.

- It was preferable if operations were located in southern Sweden. This would facilitate site visits and face-to-face interviews. Therefore, the results of the study may mainly reflect logging methods and traditions in the south of Sweden, which differ somewhat from those in the northern part of the country.

In the initial interviews, Södra Skog (hereafter referred to as Södra), a large forest owner association in Sweden, was recommended for my study. Other organizations considered during the selection process included large forest companies, such as SCA, Svea Skog and Stora Enso, for example. The decision to concentrate on Södra was based mainly on recommendations and convenience (see further below). One significant difference between this organization and other major stakeholders in the industry, such as many large forest companies, is that Södra represents a large number of private forest owners.
However, the study reflects not only the Södra perspective but also perspectives of other stakeholders. Logging operations at Södra involve several other stakeholders, among them contractors for logging operations and transportation services, the Forestry Computing Center (SDC) and sawmills. The Södra organization has a central position in this study, and the focus is on its relations to these other stakeholders. The study considers the roles that these organizations play in the process of saw timber logging at Södra. The selection of these organizations was based on their interaction with Södra in this process, implying that effects of digitized information could be identified throughout the entire logging process.

As the study includes the perspectives of the Forestry Computing Center (SDC) and of independent contractors, which may represent a general picture of the industry, the focus is not limited to the specific characteristics of a single organization. Instead, the events examined at Södra should be considered typical of a company in the logging industry, where services are provided at every stage in the logging process.

In order to obtain further general understanding of the logging process, visits were made to a logging site and a sawmill belonging to another organization, Callans Trä AB (Callans). Callans is a Swedish mid-size, family-owned forest and sawmill company. In the study, it has served mainly as a point of reference for the researcher’s understanding of basic principles of the logging process.

The empirical study resulted in a generic description of a logging process. This description is based primarily on the empirical data related to the Södra setting, including the stakeholders interacting with Södra. Data related to Callans has only been used to a limited extent in designing the case description.
2.3 COLLECTING EMPIRICAL MATERIAL

This section describes how empirical material has been collected in this study. In data collection, the techniques used have been mainly qualitative, while the data are both qualitative and quantitative. Qualitative techniques for data collection were found in a variety of literature on research methodology, for instance in Benbasat, et al. (1987), Eisenhardt (1989), Denzin and Lincoln (1994), Morse (in Denzin and Lincoln, 1994), Bryman (2001) and Yin (2003).

A key characteristic of case study research is that data are often collected from a variety of empirical sources to assure high reliability of results and often multiple techniques for data collection are also used (Yin, 2003). The goal is to obtain a rich set of data surrounding the specific research object, as well as to capture the contextual complexity. This study is therefore based on combinations of methods for collecting data from multiple sources. Using a variety of sources is also especially important in view of the historical elements and the long-term retrospective perspective of the study (see for instance Bannister, 2002).

Finding interviewees with long experience of logging activities has been crucial for this study. Interviewees within the same type of areas and representing similar views of the process studied were selected in order to obtain overlapping data. Through this procedure, data from one interview regarding a specific area could be verified with data from another source within the same area. Interviews were conducted with researchers, industry experts and practitioners, also to ensure data overlap for verification. In addition, there has been overlapping of data from interviews and documents.

A distinction is made here between primary and secondary sources of data (see for instance Myers, 1997). Primary sources refer to those from which data have been collected directly, mainly through interviews and distributed materials. Secondary sources refer to published materials, principally books and articles. Empirical materials from both primary and
secondary sources have been used to construct the generic empirical description of the case. Interviews with individuals constitute the main source of evidence. Data from secondary sources have been used primarily to verify and clarify data collected during interviews.

2.3.1 Primary sources

Regarding primary sources, data have been collected mainly through interviews with individuals, thereby making it possible to get direct answers from interviewees. Some evidence has also been taken from unpublished materials distributed during interviews. Written materials have been used primarily to verify answers from interviewees.

Regarding selection of interviewees, it has been critical to find some key individuals with long experience and enough insight into information flows in the production process to describe the development from the 1960s until today. Most interviewees have thus had a long experience in the logging industry, as much as 30-40 years in several cases. Some have recently retired.

Interviewees representing organizations involved in the Södra logging process were initially selected with assistance of Södra. During several interviews, other respondents were recommended. Interviews with researchers and practitioners also resulted in such recommendations. This may imply that the data are influenced by a specific group of interviewees. However, to reduce the potential risk of bias, contact was also established with interviewees that had not been recommended by others beforehand.

The empirical description (in Chapter 5) is primarily based on interviews with representatives of Södra and of organizations involved in the process studied (see Appendix C). In initial interviews with stakeholder representatives, researchers and practitioners, some questions were related to the general use of IT in the process. The answers provided a background description of milestones in the development of IT (in Chapter 4). In order to obtain a thorough understanding of the empirical
setting, site visits arrangements were also made at Södra and Callans. In addition, a conference for practitioners on the Swedish timber market organized by the Forestry Computing Center (SDC) was visited.

Interviews were focused on the individuals' own descriptions of the development of information flows and the effects of IT. Open-ended questions were used at the start, permitting interviewees to answer in their own words. More focused questions were asked as data collection proceeded.

Most interviews were conducted face-to-face, in smaller groups or individually. A few initial interviews were held by telephone. The interviews focused on how activities are carried out today, how they used to be carried out and what effects could be traced to the digitization of information in the process.

As support for the interviews, guidelines with specific questions were used (see Appendix B). The length of the interviews varied from about a half-hour to 3 hours. Some of the interviews were conducted in parallel with site visits.

Besides interviews with individuals, data have also been collected from written materials distributed during meetings. These materials consist mainly of unpublished documents and materials such as presentations, punch cards, timber-measurement receipts, printouts of information from internal systems and copies of internal reports.

### 2.3.2 Secondary sources

Secondary sources of evidence have been used primarily to verify the findings from interviews and distributed materials.

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5 Telephone interviews were conducted with three interviewees in June 2004.
In order to develop a pre-understanding of the empirical field, insight into processes and developments in the logging industry was gained through review of a variety of literature. This material included textbooks on logging and sawmill activities, research reports, articles about developments in logging and studies of specific terminology in logging and closely related areas such as forestry and sawmilling. These literature studies formed the basis for the background description of the logging industry (in Chapter 4).

In forestry and sawmill operations, a specific terminology is used. Some of the concepts are specific to the Swedish context, and it was sometimes difficult to find equivalent terms in English. For example, there are several terms in English for the Swedish word “aptering”. The division of a tree into assortments (product categories) could be expressed as “marking for cross-cutting”, “marking for cutting into lengths” or “marking for bucking”, or just “crosscutting”, “cut-to-length” or “bucking” (the term used in this study). In order to ensure consistent terminology throughout the study, central concepts in the logging industry as they are used here are summarized in Appendix A.6

Published materials, including brochures, company magazines and annual reports, were distributed during interviews. These have been used for the empirical description (in Chapter 5), mainly to verify the evidence collected from primary sources.

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6 Sources used for clarification of definitions include dictionaries, Skogsordlista (1994), Trä- och skogssordbok (Kassman, 1998) and the Encyclopedia of wood (1989); online databases, Agrovoc database (2004) and Forestry Dictionary (2004); the Swedish Statistical Yearbook of Forestry (2004) and Tracks in the forest (Drushka and Konttinen, 1997). Additional sources include articles in the logging area written in English such as Gellerstedt and Dahlin (1999) and MacDonald and Clow (1999). Use has also been made of textbooks describing the various activities in the process, for instance Sillerström (1985) and Eriksson and Johansson (1997). Overviews of the technological development are presented in SkogForsk (1997), for example.
A selection of annual reports from 1961 to 2003 was obtained from Södra and the SDC. Data from these reports are used in the mathematical examples (in Chapter 6).

2.4 DATA ANALYSIS AND REPORTING

In this study, the analysis of empirical findings has been carried out in parallel with the collection of data. Empirical findings are presented in a generic description of the logging process for saw timber. In the analysis (in Chapter 6), effects of digitized information are discussed and evaluated.

The empirical study has resulted in a detailed description of information flows in the process studied and their development over time, and of the effects of digital information. Information from interviews constitutes the primary source for this description, and the findings represent the interviewees’ perceptions of the development of information flows and the effects of digitized information. The aim of this description is to provide a general overview of developments in the logging process. An aggregate picture is presented where no specific distinction is made between different responses of particular individuals.

In order to create this description, a number of steps have been taken. Transcripts of interviews with involved stakeholders have been gathered together with additional documents and other materials. These have been further organized and analyzed to form a general description of the digitized information in the logging process and its effects. Detailed process illustrations have been developed to support the description in the text. These pictures are also based on interviews and documents.

Some quotations are presented throughout the description. These have been selected from interview materials and reconstructed from detailed transcripts based on notes taken during interviews. Since the interviews have not been recorded, the quotations are approximative and do not always correspond word by word to interviewees’ statements. However, it
has been possible to reconstruct statements from the detailed notes that were taken during all interviews.

The further analysis of empirical findings focuses on a discussion of identified effects. The research model has determined the scope of this analysis. Effects are discussed according to their characteristics and their impact on measurements of productivity. In order to demonstrate the importance of various effects, some mathematical examples are used for roughly quantifying effects.

### 2.5 Steps to Ensure Quality

There are several different sets of criteria for evaluating the quality of research (see for instance Guba and Lincoln, 1994; Bryman, 2001). The selection of the criteria to use depends on the typology of the study, but some frequent criteria are include trustworthiness, internal validity, external validity, generalizability, dependability, credibility, transferability, confirmability, reliability and objectivity. Yin (2003) presents a number of tactics for ensuring the validity of case study research. Those that are relevant for this study are considered here.

In order to increase the construct validity of the study, multiple sources of evidence have been used. It has been a challenge to interpret answers from interviewees regarding the historical development of logging. Empirical materials collected from interviews have therefore been combined with documents, reports, articles and other materials. Several site visits have also been conducted. Initial interviews were broad in scope, whereas subsequent interviews were more focused on obtaining targeted information, filling gaps and confirming previously collected data.

Interviews were conducted with interviewees in various roles including researchers, practitioners and experts, to ensure overlap of information. Overlapping data were also collected through several interviews with representatives of similar fields as well as representatives of different perspectives on the process.
A second measure taken to increase construct validity is that two informants in the case have reviewed a nearly complete draft of the case study description. In addition, continuous contact has been maintained with a key informant at Södra for clarification and verification of the description in the writing process. Moreover, early findings have been verified through discussions with other interviewees during the later phase of data collection.

In order to increase external validity (or generalizability), the findings of this study are compared with some general results of previous research on IT and productivity, as well as results of the two other studies in the ITOP research program. Furthermore, throughout the present study, regular meetings have been held within the ITOP research team. These meetings have been helpful in comparing the findings and results of this study with those of the two parallel studies.

In order to enhance the reliability of the study, the data collected have been carefully organized and documented. For each interview, the interview transcript, interview guidelines, original notes, documents and other empirical evidence have been systematically filed to facilitate review and replication of the study.

2.6 The Researcher’s Previous Knowledge

The author’s initial interest in studying the impact of IT on productivity in practice arises from previous studies within the field of IT and strategy and on using IT to increase business value in companies. For instance, during work on a master’s thesis about e-business, the author studied companies that use the Internet for selling goods and services and analyzed internet-based business models from a transaction-cost perspective (see Nyström, Kollberg and Eliason, 1998; Kollberg, 1999). The studies provided valuable insight into the underlying mechanisms for using IT in company businesses.
Besides this academic experience, the author has acquired deeper knowledge of the subject through previous practical experience. This experience involved working with IT-based business and concept development for a variety of businesses such as financial services, and with manufacturing- and technology-focused start-ups in Sweden and elsewhere in Europe.
3. THEORETICAL DISCUSSION

In this chapter, previous research on the productivity paradox that constitutes a starting point of the study is presented as background on the research field. Key concepts used in the study are also defined. Furthermore, relevant research dealing with different types of effects of IT and evaluation of such effects is reviewed.

3.1 PREVIOUS RESEARCH ON THE PRODUCTIVITY PARADOX

The so-called productivity paradox constitutes an important starting point for this study. Briefly, the productivity paradox concerns the discrepancy between measures of IT investments and measures of output at the national level (Turban, Leidner, McLean and Wetherbe, 2005).

3.1.1 The emergence of the paradox – is there a payoff?

Research dealing with payoffs of IT has been conducted for several decades. An important line of research emerged during the 1980s, when researchers began to study the contribution of IT to productivity based on macroeconomic statistics.

An important standpoint in the discussion on IT and productivity was represented by Solow (1987) who in a book review wrote, “...what everyone feels to have been a technological revolution, a drastic change in our productive lives, has been accompanied everywhere [...] by a slowing-down of productivity growth, not by a

7 The paradox is also often referred to as “the IT and productivity paradox”. The two concepts are treated synonymously in this study.
step up. You can see the computer age everywhere but in the productivity statistics” (p. 36).

A significant amount of subsequent research has tried to clarify and explain the issue of IT and productivity (see for instance the literature reviews of Brynjolfsson and Yang, 1996; Dehning and Richardson, 2002; Dedrick, Gurbaxani and Kraemer, 2003). According to a recent literature review (Dedrick, et al., 2003), less than a dozen studies were conducted within the research area in the 1980s, but more than 50 in the 1990s. These studies have focused on finding statistical correlations between IT investments and productivity growth on an aggregate level or between IT investments of firms and industries and different measures of firm profitability and productivity.

The paradox derives from the ambiguity in the results of several studies. For example, in a major survey based on business data, Strassmann (1990) found little or no correlation between IT investments and different measures of business performance. However, in a number of studies also based on firm-level analyses, Brynjolfsson and Hitt reached the opposite conclusion (Brynjolfsson and Hitt, 1996; Hitt and Brynjolfsson, 1996).

Focusing on the increasing productivity in the US during the late 1990s, several studies based on official statistics of aggregated data showed that both the use of IT and manufacturing of IT equipment have made a positive contribution to productivity (see for instance Jorgensen and Stiroh 2000; Oliner and Sichel 2000; Whelan 2000; Council of Economic Advisers, 2001; Jorgenson, 2001; Stiroh, 2001).

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Other researchers have reached different conclusions. For example, Gordon (1999; 2000) attributes the US productivity growth during the late 1990s to normal cyclical changes, changes in statistics and enhanced productivity in the IT sector. According to McKinsey (2001), the US productivity growth between 1995 and 2000 is explained primarily by the development of the IT sector, together with the growth in the grocery/wholesale and financial services sector. Kiley (1999), for instance, claims that increased costs associated with adopting IT in different industries have actually had a negative impact on economic growth.

Other research results demonstrate that the IT sector, including the production of computers, has had strong productivity growth (see for instance Pilat and Lee, 2001). Research based on aggregate official statistics for Swedish conditions also emphasizes the importance of the increasing productivity in the IT sector (especially the telecommunications sector) as a significant contributor to the recent growth of productivity in Sweden (Edquist and Henreksson 2001; 2002; Lind 2002a). One principal conclusion of this research is that the distributional effects in sectors of manufacturing where IT is being used have been limited.

From a Swedish perspective, several researchers have investigated the impact of IT on productivity growth. For example, Lundgren and Wiberg (2000) have shown that the productivity paradox is also valid for the Swedish context, a finding supported by data from the US and Sweden. Other studies, based on official statistics on an aggregate level, have shown a positive correlation for the late 1990s (Lind, 2002b; Gunnarsson, Mellander and Savvidou, 2001). Furthermore, results of a recent study (Mellander, Savvidou and Gunnarsson, 2005) show that IT has had an important effect on productivity growth in Swedish manufacturing industries, not only the IT-producing industries but also IT-using industries such as textiles and chemicals.

As a number of major studies have recently documented a significant impact of IT investments on productivity of firms, industries and
countries, it would appear that the productivity paradox has been explained (see for instance Brynjolfsson and Yang, 1996; Dedrick, et al., 2003).

According to recent research at the company level, however, returns on IT investments, though positive on average, vary considerably among companies. Thus, the issue of returns on IT investments seems far more complex than the original formulation of the Solow paradox (Brynjolfsson and Yang, 1996; Brynjolfsson, 2003; Dedrick, et al., 2003).

3.1.2 Explanations for the paradox

This section presents some of the most common explanations for the paradox, according to the literature studied. Triplett (1999) reviews and assesses the most frequent explanations for the productivity paradox. Several of these explanations are further discussed in other literature (see for instance Lundgren and Wiberg, 2000).

**Measurement problems and statistical issues**

In order to explain the paradox, researchers have often pointed to measurement problems and statistical issues related to lack of reliable data and issues regarding measurement of outputs and inputs.

For example, Triplett (1999) claims that the effects of computers cannot be seen in productivity statistics since the computers account for only a small share of the stock of capital and the input of capital services. This statement is related to difficulties in distinguishing IT investments from traditional technology investment due to integration of IT components in traditional machinery, as well as problems of measuring other complementary inputs such as software and training.

Another explanation is that output is poorly measured and not well defined, especially in service sectors. In addition, the types of benefits assigned to IT such as increased quality, variety and customer service, are poorly accounted for in productivity statistics. These issues are discussed,

From a Swedish perspective, the lack of reliable data and statistics on IT investments is treated by Apel and Lindström (2003), for example. The authors call for longer time series of data and more disaggregated data, such as the amount of IT capital for an increased number of industries, as well as better quality assurance of data. Statistics Sweden (2004) has also investigated the need for improved data. An important challenge in this regard is to define the aggregate use of IT in society and thereby the total IT capital. In Sweden, there are several weaknesses in this regard and thus a need for improvements (see for instance SOU 2002:118; Statistics Sweden, 2004).

A review of the statistics on productivity and IT investments in Sweden has been conducted within the ITOP research program (Falk and Persson, 2004). It shows several severe weaknesses in the current statistics: lack of consistency between data collected from different sources, collection of data from different periods, use of different definitions of IT, etc. Another aspect of this problem is that IT is not always clearly defined or is defined in different ways in the statistics.

Difficulties in dealing with this weakness in statistics become evident in studies based on the relative proportion of visible IT capital, a priori considering some sectors as using IT more than others, i.e. more IT-intensive (see for instance Stiroh, 2001; Lind, 2002b). Lind (2002b) shows that 25 percent of productivity growth in the Swedish industry between 1998 and 2001 is explained by the fact that IT-using industries as defined had higher productivity growth than the industry on average. Stiroh (2001) also shows that IT-intensive sectors had higher productivity growth than other industries in the U.S. during the late 1990s.
Complementary investments

Another explanation for the paradox is that IT investments must be accompanied by complementary organizational investments in order to contribute to economic performance (see for instance Brynjolfsson and Hitt, 1998; 2000; Brynjolfsson, 2003). Thus, even though IT constitutes an essential component of an IT investment, complementary organizational investments are necessary for generating increased productivity from IT. The greatest benefits are realized when IT investments are combined with specific sets of complementary investments in work practices, human capital, new strategies, new business processes and new organizations. The reason is that technology constitutes only one, albeit essential, component of an IT investment in a broader system of organizational changes, where there are usually large expenditures on training, process redesign and other organizational changes accompanying the IT investment.

Time lags

An additional explanation for the paradox involves the long-term perspective of payoffs from IT investments. This aspect is related to the concept of general-purpose technology (GPT) and organizational investments.

For example, Triplett (1999) claims that parallels can be drawn between the development of computers and IT and other major technological breakthroughs. Historically, the greatest increase in productivity has been associated with particular types of technologies such as the steam engine and electricity (see for instance David, 1990). The introduction of a major general-purpose technology (GPT), like computers, requires an expensive and time-consuming period of restructuring.

Historically, whole eras of technical progress and growth appear to have been driven by a few GPTs characterized by “the potential for pervasive use in a wide range of sectors and by their technological dynamism”
As a GPT evolves and advances, it diffuses throughout the economy, leading to generalized productivity gains. Most GPTs also play the role of enabling technologies, offering new opportunities rather than final solutions. A GPT has the following characteristics: initially it leaves considerable scope for improvement; eventually it is widely used for a number of different purposes, and it has strong complementarities with existing or potential new technologies (Lipsey, Bekar and Carlaw, 1998).

David (1990) draws a historical analogy between the computer and the electric dynamo, which had its breakthrough at the end of the 19th century. It would take several decades before effects of electricity could be detected in productivity or in new products, new companies and new positions. David’s primary conclusion is that IT influences business processes and that reorganizations are needed for achieving productivity gains. The great gains in productivity came when engineers adapted the factory layout to the electric motor. Further analogies and contrasts between the IT revolution and the historical case of the electric dynamo are discussed in David and Wright (1999).

Romer (1997) argues that the progress of the transistor does not sufficiently explain the growth in computing power and that many supporting technologies had to be developed before a working computer could be made. There is a need for coordination and synergies between different technologies, both old and new. It is not one single innovation that determines the development, but the coordination between several innovations.

Also relevant is the concept of development blocks, introduced by Dahmén (1950), which focus on the physical dimension of industrial development (see also Johansson and Karlson, 2002). A development block can be considered a kind of cluster or network of integrated physical production and distribution creating strong synergies. In order to
fully exploit industrial opportunities, it is often necessary to make complementary investments in other industries and product areas, and when this has happened, a development block has been created. Economic growth requires expansive development blocks built from innovations accompanied by physical investments and investments in closely related technology.

In addition, there is the concept of path dependence, which implies that historical aspects must be taken into consideration when technological development is studied (see for instance Rosenberg, 1994; David, 2000). In order to demonstrate the path in the growth of technological knowledge, it is necessary to consider historical aspects. A high degree of path dependence implies that the initial conditions and the particular sequence of subsequent events which constitute the history of a system are essential to explaining its impact on economic growth. The concept is used to include history in economics; in the context of technological change and economic growth, “history matters.”

Time lags can also be related to the time required for organizations to learn and adjust to new technologies (see for instance Lundgren and Wiberg, 2000). There is a learning effect in companies regarding the implementation of IT investments, which includes training of personnel and changes of the work organization to adapt to the requirements of the new technology.

In addition, the organizational changes necessary for realizing the value of IT are often costly, time-consuming and risky. This indicates that long-term benefits should not be considered as returns on IT only, but on a system of combined technological and organizational changes (see Brynjolfsson and Hitt, 1998; Brynjolfsson, 2003).

**Intangibles**

The productivity paradox is further explained by the fact that much of the contribution of IT is not captured by conventional productivity measures.
The reason is that these intangible effects are sometimes difficult to estimate in economic terms (Brynjolfsson, 1993).

A wide range of benefits that are poorly represented in productivity statistics have been recognized in previous research on the productivity paradox (see Brynjolfsson, 1993; Brynjolfsson and Hitt, 1998; Triplett, 1999; Brynjolfsson and Hitt, 2000; Dedrick, et al., 2003). Benefits of IT investment are often intangible and difficult to measure. Some of the effects include better responsiveness to customers, more extensive coordination with suppliers, increased variety, improved timeliness of delivery, personalized customer service, product quality, timeliness, spillover effects, excess returns, consumer welfare, customization, better user interface and convenience.

Complementary organizational investments also enable firms to enhance output quality in the form of new products or improvements in intangible aspects of existing products (Brynjolfsson and Hitt, 2000).

Another type of value that is not normally included in productivity statistics stems from network effects or network externalities (see for instance Katz and Shapiro, 1985; Shapiro and Varian, 1999). Briefly, network externalities arise when the value of a product to one user depends on the number of other users, or when the utility that a given user derives from the good depends upon the number of other users in the same network. Basically, this phenomenon occurs when the value of a product to a user increases with the total number who use the product.

Examples of IT that gives rise to network externalities include telephones, fax machines, e-mail accounts, Internet and peer-to-peer networks. Each

9 A peer-to-peer network is a local area network (normally using network adapter cards in each computer) where there is no central dedicated network server, but instead each computer in the network shares the jobs (Collin, 2001, p. 285).
time a person buys such equipment, the equipment of other people becomes more useful.

In economic theory, the increasing utility derived by a subscriber from a communications service as others join the system could be considered to reflect a kind of interdependent demand (see for instance Rohlfs, 1974; Katz and Shapiro, 1985). This interdependent demand depends on the features and scope of the network shared between users. Although the scope of the network may vary across markets, the central feature of the market determining the scope of the relevant network is related to linkages and compatibility, i.e. whether products of different firms may be used together.

Related to network externalities is the concept of increasing returns (see Arthur 1989; 1996). With the change of focus from resources to information in Western economies, the underlying mechanisms that determine economic behavior have shifted from those of diminishing returns to those of increasing returns. While diminishing returns tend toward equilibrium, increasing returns imply instability. For example, if a technology gains a lead, increasing returns can magnify this advantage, and the technology can obtain a lock on the market.

In the research on IT and the productivity paradox, customer surplus has also been found difficult to capture in productivity statistics (see for instance Brynjolfsson and Hitt, 1998; Dedrick, et al., 2003). Consumer surplus, or consumer welfare, has also been the subject of several studies such as Brynjolfsson (1996), Hitt and Brynjolfsson (1996) and Brynjolfsson, Hu and Smith (2003).

Consumer surplus reflects the amount by which consumers benefit from purchasing a product at a price less than they would be willing to pay. Basically, it represents a surplus value, implying an additional gain for the customer. Consumers who attach a value to a good or service higher than the market price retain the surplus.
For example, Hitt and Brynjolfsson (1996) investigated three different measures of IT value: productivity, business profitability and consumer surplus. Their results show that IT has increased productivity and created substantial value for consumers but that the benefits have not resulted in supernormal business profitability. IT investment does not necessarily improve profitability since productivity benefits associated with IT may be passed on to consumers through lower prices and not lead to greater profitability. Competition may be a reason why value from IT investments by firms can be passed on to consumers.

Another example of IT value passed on to consumers is found in a study of online booksellers conducted by Brynjolfsson, et al. (2003). They claim that important benefits lie in new products and services made available through electronic networks, but that much of the attention in research has been on the relative operational efficiency of the online channel versus traditional channels. The value of new products and services made available through electronic networks has remained unquantified. Value related to convenience and selection of products and services has been largely ignored. The study shows that the increased online availability of previously hard-to-find products represents a significant positive impact on consumer welfare, 7-10 times larger than the benefits of lower prices due to increased market efficiency in Internet book markets.

3.1.3 Summary

In general, much of previous research within the field has investigated whether IT contributes to productivity growth. Studies have been based mainly on macroeconomic statistics or on aggregated company data. These early studies have raised concerns among academics, as they showed that the contribution of IT investments was not evident in productivity statistics.
However, recent research indicates that IT contributes positively to economic development but that this contribution is not fully revealed when only productivity is measured.

The above-mentioned aspects of measurement and statistical issues, time lags, complementary organizational investments and intangible effects, have led to scholarly criticism of using traditional productivity measures for evaluating the role of IT in economic development (Brynjolfsson, 1993; Brynjolfsson and Hitt, 1998; 2000).

3.2 DEFINITIONS OF CENTRAL CONCEPTS

In this section, some central concepts used in this study are presented.

3.2.1 Information technology

Information technology, or IT, can be defined in various ways. There is no general definition of IT, and many different definitions of IT are used in research. A common view is to consider IT as computers. However, IT can be more than just computers; for instance, it may include telecommunications equipment and be used for a wide range of purposes. IT can also be regarded as a new technology base or a general-purpose technology (GPT) which permeates society as more and more IT components are embedded in products of various kinds. A selection of definitions and aspects of IT are discussed here. The definition of IT used in this study is also presented.

A common view in previous research based on IT investment statistics is to consider IT capital as hardware in terms of computers or other equipment (see for instance Brynjolfsson and Yang, 1996; Triplett, 1999). One of the most common definitions of IT used in research is that of the US Bureau of Economics Analysis (BEA) category “Office, Computing and Accounting Machinery (OCAM),” in which IT consists primarily of computers. Some researchers also consider the broader category of “Information Processing Equipment (IPE),” which includes
communications equipment, scientific and engineering instruments, photocopiers and related equipment.

Even though a broad definition of IT may include both computers and telecommunications and related hardware, software and even services, in nearly all of the research covered by the review of Dedrick, et al. (2003), IT investments were limited mainly to computer hardware.

In the Swedish context, the concept of IT often corresponds to the definition of the Swedish Institute for Transport and Communications Analysis (SIKA). According to SIKA (2001), the concepts of Information and Communications Technology (ICT) and Information Technology (IT) are often used synonymously. Both IT and ICT include “technology for collecting, storing, processing, recalling and communicating data, text, images and speech” (SIKA, 2001, p. 8). As IT and ICT could be considered synonymous and IT is more commonly used than ICT, the term IT is used throughout this study, and no specific distinction is made between IT and ICT.

Another aspect of IT is that it can be regarded as an enabling technology. For example, Davenport (1993) considers IT as an enabler of process innovation. Hammer and Champy (1993) claim that modern IT has an enabling role for companies in the re-engineering of business processes. This view emphasizes that the benefits of IT are not achieved through IT in itself, but only after organizations and processes have been adapted to the new conditions offered by the use of IT.

As mentioned above, IT can also be viewed as a general-purpose technology (GPT) (see for instance David, 1990; Lipsey, et al., 1998). In this respect, IT is an integral part of businesses, organizations, industries and economies and a source of further development in a range of different areas. IT can be embedded in other technology systems, where it is not always clear how to isolate the IT component from other technologies. Context-specific variables such as organization and infrastructure need to be considered when the effects of IT are explored.
On the basis of this discussion, it is not appropriate in this study to limit the definition of IT to hardware and software. Instead, a broad definition is applied here, though with a focus on digital information.

Information technology, or information and communications technology (in this study referred to as IT), covers technology for collecting, storing, processing, recalling and communicating data, text, images and speech (based on SIKA, 2001).

It is assumed that the enabling properties of IT itself and of IT embedded in other technology are both captured in this definition.

Given the role of IT in previous research on the productivity paradox, the concept of IT has initially played an important part in this study. However, since the purpose here is to examine the effects of digitization of information flows, the primary focus will be on information and use of information. These concepts are further defined below.

### 3.2.2 Digitization of information

**The concept of information**

Several definitions of information are found in the literature. From an information-theory perspective, Shannon and Weaver (1963) apply a fundamental definition of information; a message or sequence of messages that are communicated to a receiver.

Other definitions of information include anything that can be digitized or encoded as a stream of bits (Shapiro and Varian, 1999, p. 3); different types of information may include numbers, text, video, music, speech and programs (Brynjolfsson and Hitt, 2000). Information can also represent data and knowledge and include words, numbers, images and voices that communicate meaning and inform the information consumer (see for instance Davenport, 1993).

According to Collin (2001, p. 194), information is either 1) knowledge presented to a person in an understandable form or 2) data that has been
processed or arranged to provide facts which have meaning. Another formulation is “data which has been recorded, classified, organized, related, or interpreted within a framework so that meaning emerges” (AccessScience, 2003).

Langefors (1980) distinguishes between data, information and knowledge in the “infological” approach, where information is produced from data and the recipient’s prior knowledge through interpretation for a certain period of time. In this perspective, information can be regarded as knowledge and as a personal possession, whereas data are a set of symbols or signals. In this study, data are considered a type of information, and no specific distinction is made between data and information.

This study seeks to cover all kinds of effects from digitized information flows by investigating information that is communicated in the process (information flows). In order to capture all information flows in the study, a wide definition of information is required. However, many of the current definitions are considered to be too narrow or not relevant. Hence, in order not to limit the study and the results, the concept of information has not been strictly defined in this study.

The concept of digitization
The concept of digitization may also have many different interpretations. A simple definition of digitization is conversion of analog information into digital information, as for use in a computer (Online Dictionary, 2005).

Another definition of the term “digitize” implies a change from analog movement or signals into a digital form, which can be processed by

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10 Digitization often refers to the process of converting cultural collections of materials into digital format, involving museums and libraries with special collections containing text, images, audio, video, and other formats.
computers (Collin, 2001, p. 117). The word “digital” represents data or physical quantities in numerical form, in particular the binary system used in computer-related devices (Collin, 2001, p. 115).

A further definition, focusing on business activities, is “the transition from conducting business activities in a traditional manner to conducting them in a digital form” (BarNir, Gallaugher and Auger, 2003).

The definition of digitization of information adopted in this study is:

*Digitization of information means conversion of information to digital form, which can be processed by computers (Collin, 200; Online Dictionary, 2005). Digitized information refers to information that has been transformed to digital format from another format.*

### 3.2.3 The logging process

The logging process is in focus in this research. In previous research, a wide variety of process views have been considered (see for instance Lind, 2001). Some process flows are briefly presented here. A definition of the process of saw timber logging is presented in the background (in Chapter 4).

The value chain is a common tool for analyzing all activities performed by a firm and how they interact as sources of competitive advantage (see Porter, 1985). In this perspective, every firm is a collection of activities performed to design, produce, market, deliver and support its product or service. The relevant level for constructing a value chain is that of a firm’s activities in a particular industry, and value is the amount that buyers are willing to pay for what a firm offers them. Since IT affects production processes that reshape products, the value chain approach is also suggested for evaluation of the role of IT in competition (Porter and Millar, 1985).
Another line of research concerns process re-engineering and innovation (see for instance Davenport, 1993; Hammer and Champy, 1993). This research is devoted to re-engineering of business processes, or the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical contemporary measures of performance, such as cost, quality, service and speed. Processes here refer to a structured measured set of activities with a beginning, an end and clearly identified inputs and outputs. These activities are designed to produce a specific output that is of value to the customer.

The concept of value system refers to a larger flow of activities within which a firm’s value chain is embedded (see Porter, 1985; Porter and Millar, 1985). The value system includes value chains of suppliers providing inputs to the company’s value chain, and of channels performing additional activities that affect the buyer as well as influence the firm’s own activities. The linkages in these chains not only connect value activities inside a company, but also create interdependencies between the value chain of the company and those of its suppliers and channels.

As concepts, both the value chain and the value system have influenced the scope of the study regarding the process (logging of saw timber) and the industry (logging industry).

3.2.4 Measures of productivity
According to Bain (1982), productivity, which is the ratio of some output to some input, is used to measure how well resources are combined and utilized to accomplish specific, desirable results. Briefly expressed, productivity is an indicator describing the relationship between output and the inputs that are required to generate that output (OECD, 2001; Schreyer and Pilat, 2001).

The productivity measure is discussed in the OECD Manual on productivity (OECD, 2001). In this manual, it is shown that there are
several different measures of productivity and that the choice between them depends on the purpose of productivity measurement and on the availability of data.

For example, labor productivity takes account of inputs of employee hours worked, capital productivity takes account of inputs of machines or land, multi-factor productivity (MFP) implies that several factors are included as inputs, and total factor productivity (TFP) suggests that all possible factors are included (OECD, 2001).

Productivity measures can be classified as single-factor measures (relating a measure of output to a single measure of input) or multifactor measures (relating a measure of output to a bundle of inputs) (OECD, 2001). Another distinction is between productivity measures that relate some measure of gross output to one or several inputs and those which use a value-added concept of changes in output (OECD, 2001). The five most widely used productivity concepts are reviewed in the OECD manual (2001). Some of their main properties are briefly presented below.

Labor productivity, based on gross output, shows how productively labor is used to generate gross output over time. It is used to trace labor requirements per unit of output and for analyzing labor requirements by industry. Labor productivity, based on value added, shows how productively labor is used to generate value added over time. This measure is used for analyzing micro-macro links such as the industry contribution to economy-wide labor productivity and economic growth. However, measures of labor productivity reflect more the combined effects of changes in capital inputs, intermediate inputs and overall productivity than direct effects of technical change. Furthermore, they only partially reflect the personal capacities of workers or the intensity of efforts.

Capital productivity, based on value added, shows how productively capital is used to generate value added. It reflects the joint influence of for instance labor intermediate inputs, technical change, efficiency change,
economies of scale and capacity utilization. Changes in capital productivity indicate the extent to which output growth can be achieved with lower welfare costs.

Capital-labor MFP, based on value added, shows how productively combined labor and capital inputs are used to generate value added. In general, this is not an accurate measure of technical change but an indicator of an industry’s capacity to contribute to economy-wide growth of income per unit of primary input. It is used for analyzing micro-macro links such as the industry contribution to economy-wide MFP growth and living standards and analyzing structural change.

KLEMS Multifactor productivity shows how productively combined inputs are used to generate gross output. This is the most appropriate tool to measure technical change by industry as the role of intermediate inputs in production is fully acknowledged.

3.3 RESEARCH ON EFFECTS OF IT
This section deals with research on effects of IT, including drivers for investing in IT, different types of effects and a short overview of some common measures used for evaluating effects of IT.

3.3.1 Drivers for investing in IT
There are different drivers for organizations that consider investing in IT. In the general definition of the investment concept presented by Massé (1962), the act of investing constitutes the sacrifice of an immediate and certain satisfaction in exchange for a future expectation whose security lies in the capital invested. The term expectation shows the two-fold aspect of the decision to invest, that it is both arbitrage in time, since the expectation lies in the future and a gamble, separating between expectation and possession.
This implies that some kind of future effect can be expected from IT investments. An effect is here considered a condition or occurrence traceable to a cause (Encyclopædia Britannica Online, 2005). Effect and consequence are treated synonymously. The term effect is used throughout this study.

Regarding evaluation of IT investments, Lucas (1999), for example, suggests that the value of IT has many different dimensions and identifies a number of ways in which IT generates value. Value means a fair return or equivalent in goods, services, or money for something exchanged, or the monetary worth of something (Encyclopædia Britannica Online, 2005). Lucas (1999) presents a subjective evaluation of the probability of obtaining a return for the eight categories of IT investment described below:

- A firm may invest in IT in the form of computer communications networks or database management systems to build an underlying infrastructure. The probability of a payoff from this type of investment is about 50 percent.

- Investments in IT in the form of management control systems and applications like budgeting and accounting, which are essential for running a company, may be required. It is hard to glean much value from investing in these systems.

- Investments in IT applications for work that would not be feasible to perform manually, such as computerized reservation systems, stock exchange systems, navigation systems, and electronic road toll collection, can be considered “no-other-way” investments. A “first mover” has a high probability of obtaining a return on these investments.

- IT investments can lead to a direct return when it is possible to measure an expected return and evaluate the costs. There is a high
probability of obtaining a return from this type of investment if the benefits can be identified from the start.

- IT investments can also yield indirect returns such as increased customer loyalty and other benefits that are difficult to measure. As such indirect returns may be difficult to detect, identify or even imagine, there is little probability of achieving payoffs from this kind of investment.

- An IT investment may be a competitive necessity. Such is the case with the automatic bank teller machine (ATM), whose value increases as the technology matures. It is hard to obtain substantial value from investing in this type of IT.

- IT investments may also be made for strategic purposes. There is about a 50 percent chance of a return on a strategic IT investment if the system has been identified as strategic prior to the investment.

- With transformational IT, a combination of management and technology is used to change the organizational structure. The chance of a payoff from these types of investments is about 50 percent.

Important conclusions by Lucas (1999) are that not all investments in IT should be expected to show a measurable return and investments can be of value to an organization even without a demonstrable financial return.

### 3.3.2 Different types of effects

There is considerable literature on the effects of IT investments. It shows that IT contributes in several different ways and that its effects can be identified in a range of dimensions.

Mooney, Gurbaxani and Kraemer (1995) propose that IT affects business processes and creates business value in three different ways. They
categorize the three types of effects as automational, informational and transformational, respectively.

Davenport (1993) describes nine categories of ways in which IT can support process innovation: automational, informational, sequential, tracking, analytical, geographical, integrative, intellectual and disintermediating. These categories, which reflect the specific means by which business objectives are achieved, could also be included in the three dimensions of Mooney, et al. (1995).

**Automational effects**
According to Mooney, et al. (1995) automational effects refer to the efficiency perspective on IT value, where IT is a capital asset substituted for labor and value derives from effects such as productivity improvements, labor savings and cost reductions. This category would also include the automational category of Davenport (1993), which is based on elimination of human labor and production in more structured processes.

**Informational effects**
Informational effects are related to the capacity of IT to collect, store, process, and disseminate information; their value derives from improved decision quality, employee empowerment, decreased use of resources, enhanced organizational effectiveness and better quality of the product or service delivered (Mooney, et al., 1995).

This category of effects is also related to capture of information about process performance for purposes of understanding, close monitoring of process status and objects, improved analysis of information and decision-making and realization and distribution of intellectual assets (Davenport, 1993).

The informational perspective is related to the actual use of information. For example, Zuboff (1991) claims that IT can be used not only to
automate processes and minimize human intervention, but also to develop new intellectual skills and to “informate” as processes, objects, behaviors and events are translated into and made visible as explicit information. Therefore, the utilization of IT requires development of the organization.

Another example is Hopper (1990), who argues that the value derived from IT investments depends on how they are used in companies. Therefore, IT could be considered an “information utility,” implying that the focus should be on the way in which the technology is used and on information instead of systems and organizational aspects.

**Transformational effects**

Transformational effects refer to the value derived from IT as a facilitator and support for process innovation and transformation. The business value may include, for instance, reduced cycle times, improved responsiveness, downsizing and service and product enhancement as a result of re-engineered processes and redesigned organizational structures (Mooney et al., 1995).

This category of effects is also related to elimination of intermediaries from a process, co-ordination of processes across distances and between tasks and processes, and enabling changes in the sequence of processes or transformation of a process from sequential to parallel (Davenport, 1993).

For example, Hammer (1990) argues that IT investments have delivered disappointing results because companies have used IT to mechanize old ways of doing business, leaving existing processes intact and using computers to increase efficiency. He therefore claims, “it is time to stop paving the cow paths” and instead obliterate outdated processes and start over (“Don’t Automate, Obliterate”). It is suggested that businesses should be re-engineered by using IT to radically redesign business processes in order to achieve dramatic improvements in performance.

In parallel with the view of IT as an integral element of an organization, IT could also be considered as part of its surrounding context. Melville,
Kraemer and Gurbaxani (2004) emphasize that at the core of the business value created by IT is the organization that invests in and deploys IT resources; they add, however, that external factors also play a role in shaping the extent to which IT business value can be generated and captured. In particular, the competitive environment, including industry characteristics and trading partners as well as the macro environment, are relevant factors in the generation of business value through IT.

The framework of Dedrick, et al. (2003), reflecting components of IT and economic performance, is also based on complementary factors. These include organization and management practices, industry organization and regulation, economic structure, government policy and investment in human capital.

3.3.3 Measures for IT evaluation

There is a significant amount of literature on ways to measure the impact of IT in terms of economic performance (see for instance Turban, et al., 2005). Several frameworks and models have been created for assessing the value and other benefits of IT (see for instance Melville, et al., 2004).

Productivity has been identified as an important measure for evaluating the impact of IT. Some other views of measures for IT evaluation are briefly described here.

**NPV and ROI**

Turban, et al. (2005), for example, classify net present value (NPV) and return on investment (ROI) into traditional tools used to evaluate capital investment decisions. NPV calculations are often used in cost-benefit analyses where the total value of benefits is compared with the associated costs. In NPV analysis, future values of benefits are converted to their present-value equivalent by discounting them at the cost of funds. Costs and benefits are hence converted into monetary values. ROI measures the effectiveness in generating profits with available assets and is normally
calculated by dividing net annual income attributable to a project by the cost of the assets invested in the project.

However, these kinds of monetary evaluation tools are less suitable for estimating intangible benefits that are often generated from IT investments such as faster time to market, employee and customer satisfaction, easier distribution, greater organizational agility and improved control (Turban, et al., 2005).

**Strategic importance**

Besides monetary evaluation of IT investments, a large amount of research has sought to evaluate the strategic importance of IT and information (see for instance McFarlan, 1984; Porter and Millar, 1985; Hopper, 1990; Evans and Wurster, 1997). Many studies show that competitive advantages could be achieved through investments in IT. However, critical views have come to question the strategic value of IT. For example, Carr (2003) claims that IT should be considered a common good and could therefore not be used for achieving competitive advantages.

As a reaction to research with a strong focus on a firm’s external environment in strategic analysis represented by for instance Porter (1985), a view that stresses an internal analysis of the organization has emerged. This so-called resource-based view is based on a that there is a strong correlation between a company’s internal characteristics and its performance (Barney, 1991).

According to Barney (1991), an organization’s performance is dependant on its ability to build sustained competitive advantages based on resources that are valuable, rare, imperfectly imitable and non-substituteable. From a resource-based perspective, several studies have discussed the role of IT as a resource for achieving sustained competitive advantages (Bharadwaj, 2000; Clemons and Row, 1991; Mata, Fuerst and Barney, 1995; Powell and Dent-Micalef, 1997).
4. BACKGROUND ON THE LOGGING INDUSTRY

In this chapter, a background description of the logging industry is presented, with a specific focus on the production process of saw timber. The first section provides a short introduction to the industry. The next section presents an overview of the production process and describes the development of these activities over time. The final section reviews the milestones in the development of IT in logging operations.

4.1 THE EVOLUTION OF THE SWEDISH FOREST INDUSTRY

In this study, the logging industry is in focus. As a background, some major trends in the evolution of the Swedish forest industry during the last few decades are presented in this section. This presentation describes the context of the production process of saw timber and includes economic, market, organizational and environmental aspects.

According to the Swedish Forest Industries Federation (SFIF, 2005a), the forest industry includes the pulp and paper industry, the sawn timber industry, the board industry, the industry producing packaging based on wood, paper and paperboard, and the joinery industry. The paper industry is the largest sub-sector.

This study is based on empirical data concentrated on the logging industry. The logging industry provides raw materials to the wood and pulp and paper industries (Hailu and Veeman, 2003). The industries concerned by the process studied, include parts of different industry sectors related to logging operations, such as forestry, sawmilling and transportation.
4.1.1 Specific characteristics

The Swedish forest industry has a range of specific characteristics that distinguish it from other producing industries (see for instance Adolfson, Melin and Markgren, 2000; Höglund, 2000; Björklund, 2003).

• Since the forest resources are biological and individual trees are unique, the forest can be considered a resource that is heterogeneous and fragmented. This implies a high degree of uncertainty, which affects for instance the relationship between the resource and the final product.

• Forest resources are utilized to produce different product assortments. As shown in the illustrative example in Chapter 1, a tree can be used as a raw material for several diversified product groups such as pulp wood, saw timber, full-tree lengths, sawmill chips and bio fuel, supplied to various industries such as construction and packaging.

• Geographical aspects are important in the forest industry. Employees and forest workers are often spread over large and sparsely populated areas, and the landings where timber is gathered for road transportation are at various locations. Regarding the material flow, most sawmills need a reliable source of supply nearby to assure balance in available resources, customers and supply of products.

• Environmental aspects are also important since forestry operations often have a direct impact on the environment.

4.1.2 Economic development and role of the industry

Sweden has a long tradition of forestry and production based on forest resources (see for instance Drushka and Konttinen, 1997). Today forests cover more than 56 percent of the country’s land area (SFIF, 2005b), and the stock of standing forest is growing. In 2003, the total timber stock reached 3 billion m³sk (forest cubic meters); the annual increment is 101
An industry with great economic importance

The Swedish forest industry occupies an important position on both a national and an international level. Recently published figures from the Swedish Forest Industries Federation (SFIF, 2005a) are used here unless otherwise stated.

The forest industry and forestry provide almost 4 percent of the country’s GDP. The forest industry accounts for 10 percent and 14 percent, respectively, of employment and value added in Swedish industry and roughly 12 percent of the country’s exports of goods. In addition, the Swedish forest industry ranks fourth among the world’s exporters of pulp; it is the third largest exporter of paper and the second largest exporter of sawn timber. Sweden’s pulp and paper industry is the third largest in Europe, after Germany’s and Finland’s. Deliveries from Swedish sawmills also provide about 12 percent of the total saw timber consumed in the EU.

Both production and export of sawn timber have increased in recent decades. The production of sawn timber has constantly risen during the 1990s and thereafter, reaching 16.9 million m$^3$ in 2004 compared to 11.7 million m$^3$ in 1990. Exports of sawn timber also grew steadily during the 1990s and reached 11.3 million m$^3$ in 2004 compared to 6.5 million m$^3$ in 1990. Exports represented almost 70 percent of production in 2004.

The principal export markets for sawn timber in 2004 were Great Britain, Denmark, Germany, the Netherlands, Norway, Japan, Spain, France and

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11 The Swedish Forest Industries Federation (Skogsindustrierna) is the trade and employers’ association for the pulp, paper and wood industries.
the USA. Exports to countries outside Europe have increased from about 13 percent of total exports in 1990 to around 23 percent in 2004.

*Increasing productivity*

Productivity in the forest industry has strongly increased during the last few decades (see for instance SkogForsk, 1997; Södergren and Thor, 2003). Rationalization has been important for remaining competitive in the face of intensified global competition.

The results of an analysis of the development in forestry between 1950 and 1992 show that productivity in 1992 was eleven times higher than in 1950 (SkogForsk, 1997). In the past ten years (1993-2003), productivity in the forest industry has increased by about 60 percent (Södergren and Thor, 2003).

A condition for this development has been technological enhancement, mainly regarding forest machines. Besides mechanization, rationalization in forestry can also be related to other factors such as changes in workload, better training, improved daily routines, increased use of IT and better planning.

Rationalization has led to a decrease in the number of employees over the past few decades, as shown in Figure 4-1 below.
According to official statistics of the National Board of Forestry (NBF, 2004), the total number of employees in the industry has decreased by almost 60 percent over the last 30 years (from 224 400 to 89 800 between 1970 and 2003). In 2003, 16 000 persons were employed in forestry while the wood products industry employed about 38 000 and the pulp, paper and paper products industry about 36 000 persons. In 2003, the forest industry employed some 2 percent of the total labor force in Sweden compared to almost 6 percent in 1970.

According to statistics (based on data from Statistics Sweden) published on a web portal for the Swedish forest industry (SkogsSverige, 2005), value added has increased in forestry and the pulp, paper and paper products industry during the 1980s and 1990s. In the wood and wood products industry, value added increased between 1980 and 1990 but then decreased between 1990 and 1996; see Figure 4-2.

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Figure 4-2 Value added to producer price, million SEK in constant prices (1991). (Source: based on SkogsSverige, 2005)

4.1.3 Development in markets

Unless otherwise stated, the following general description of the market development in the forest industry is based on SkogForsk (1997) and Södergren and Thor (2003).

The main stakeholders on the market for wood products include: the industrial forest enterprises with their large forest assets as well as their own pulp and paper industries and sawmills; forest-owners associations, which represent the private entities and have their own pulp- and sawmills; purchasing sawmills, without any substantial forest assets; the remaining forest owners and landowners that are not connected to any industries.

13 http://www.skogssverige.se/skog/skogen/swe/statistik/statistikomr/forald.cfm
The industrial forest enterprises sector is a large net buyer of pulpwood and net seller of timber. Members of forest owner associations own more forest than processing capacity and are therefore net sellers of both pulpwood and timber, whereas purchasing sawmills often do not own much forest and are therefore large net purchasers of sawn timber. The remaining forest owners lack processing capacity and are exclusively sellers.

Regarding the ownership structure of Swedish forests, private individuals own more than 50 percent of productive forest land, private companies about 25 percent and the state about 20 percent (see SFIF, 2005a).

The forest industry has been exposed to increased competition in recent decades. From the mid-1950s until the beginning of the 1980s, forestry benefited from quite favorable and stable external conditions. However, during the 1980s and 1990s, conditions changed radically when price pressure and increased competition from abroad forced forest companies to focus on cost reduction and rationalization. At this time, many forest workers lost their jobs, and forest companies started to focus on reducing stocks in forests in order to decrease capital costs.

Growing customer requirements have been compelling the industry to adapt production as well as products to market demands, and many forest companies to focus more on production of customer-oriented products to industries (see for instance Eriksson and Johansson, 1997; Andersson, 2004).

Within the sawmill industry, extensive structural changes have taken place in the last few decades. Today, the ten largest companies account for close to 60 percent of production, and production per sawmill has increased from 40 000 m³ in 1980 to 91 000 m³ in 2004 (SFIF, 2005a). However, many sawmills are still small, with limited production, and most sawmills are privately owned and are operated as family enterprises (Eriksson and Johansson, 1997).
4.1.4 Environmental issues

A general overview of environmental issues and developments in the forestry and the forest industry is presented here. The description is based on NBF (1983), SkogForsk (1997) and Södergren and Thor (2003) unless another source is stated.

In response to increasing mismanagement of forest resources, organized efforts to protect the forest environment were undertaken in the first half of the 20th century. The Regional Boards of Forestry started their activities in 1905; the Forest Management Association (Skogsvårdsföreningen) was founded in 1902; the Foundation of the Forest Association (Stiftelsen Skogssällskapet) was created in 1912; forest owner associations were established during the 1930s, and the National Board of Forestry (Skogsstyrelsen) began functioning in 1941.

The first Forestry Act (Skogsvårdslagen), which was passed in 1903, regulated re-planting after logging. Legal regulation has developed since then regarding protection of younger forest, clear-cutting of large areas, old forests, forest management to provide a satisfactory financial yield, specific interests of conservation, and requirements of forestry plans and minimum levels of logging. In the revised law of 1993, production and the environment are given equal priority, implying that the need for conservation and the impact of various forestry practices on the environment must be considered in the daily operations and practices of forestry.

In 1999, the Swedish parliament adopted 15 national environmental quality goals, one of which was Sustainable Forests. This goal is expressed as follows: “the natural productive capacity of forests and forest land must be protected and biological diversity and cultural heritage and recreational assets preserved” (Proposition 1997/98:145, p. 5).

As an effect of regulation and increased awareness, environment-friendly management practices and ecological awareness in forestry emerged in the
1980s and advanced during the 1990s. Environmental awareness has spread rapidly to the machine operators and has improved working conditions for forest workers (see Södergren and Thor, 2003). Many companies have made significant investments in environmental measures and have sought certification such as ISO 14001. Swedish forestry is expected to continue its transformation through increasingly environment-friendly management practices in the future.

4.1.5 Organizational development

The following description of the organizational development in the forest industry is based on SkogForsk (1997) and Södergren and Thor (2003).

In forestry, there have been major changes regarding employment during the last few decades. Earlier, large forest companies and forest owner associations used employed forest workers to carry out logging operations. However, between 1990 and 1995, the number of forest workers employed by forest companies decreased from about 11 000 to 3 000 (SkogForsk, 1997).

During the 1990s, forestry saw an extensive increase in contract work as machine operators that were previously employed by forest companies became contractors; about 70-80 percent (6 800 persons in 1995) of forest machine operators are contractors or employed by contractors, while the remaining 20-30 percent are employed by forest companies (SkogForsk, 1997).

Through high volume and continuity in operations, large corporate owners and owner associations are able to employ heavy and more specialized logging machinery compared to small-scale operations often carried out by private owners for whom it is not economically feasible to invest in expensive, specialized equipment (SkogForsk, 1997).

Regarding the transformation in the forest industry 1990-2000, Södergren and Thor (2003) discuss some of major organizational aspects.
During the late 1990s, there was an increasing focus on flows and processes in logging operations as companies began to be more customer-oriented and contractor teams were substituted for in-house forest workers. Forest-machine teams (often including harvesters and forwarders with four to six machine operators) were given more responsibility in operations. The introduction of IT has also contributed to a more decentralized approach, permitting forest workers to access and analyze important information while in the forest. The increased responsibility of the teams for areas like planning, conservation, follow-up, inventories, planting and silvicultural tasks have reduced the workload of forest-company administrative personnel. At the same time, organizational structures have changed in many forest companies. Many functional structures were replaced by more geographically oriented ones. The number of administrative units was reduced, and geographical units became fewer and larger.

4.2 LOGGING OF SAW TIMBER

In this section, a general overview of the logging process is presented. This overview is intended to convey an overall understanding of the activities in the process and includes a brief survey of the development of technology and methods.

In this study, the production process of saw timber refers to a range of activities starting with planning and preparations prior to harvesting of a stand and ending with measurement of saw timber at the sawmill. The description is focused mainly on logging operations. In order to give the reader an idea of what happens to the timber after it has been measured at the sawmill, it also includes some key activities in the reprocessing of timber in the sawmill.

The description should be considered as one example of the production process. Many of the activities described are similar across organizations, but substantial variations within different parts of the process can also be
expected. This general overview of the process provides a conceptual model that outlines the process of saw timber logging.

Figure 4-3 presents an overview of the phases in the logging process. The process is divided into four phases: planning and preparation, harvesting, forwarding and transport, and measurement and follow-up.

![Figure 4-3 A general overview of the process of saw timber logging](image)

The requirements of the timber market are the starting point for the process, and the output is the saw timber delivered to the sawmill. Planning and preparation take place before logging operations begin. The trees are harvested, and the logs are forwarded to a landing by the roadside, where they are piled for transportation to the sawmill. At the measurement station by the sawmill, the timber is measured; the information provided is used for invoicing and production follow-up. The subsequent phase of sawmill processing for production of sawn timber is also shown in the figure.

The description of the four phases is based on SkogForsk (1997), Eriksson and Johansson (1997), NBF (1983) and Sillerström (1985), unless otherwise stated.

### 4.2.1 Planning and preparation

Prior to the logging activities, the buyer and seller agree on a contract. The seller contacts potential buyers and typically receives a number of proposals before a deal is closed. The buyer makes an assessment of the stand taking several aspects into consideration, such as timber quality, price, location, environment, silviculture and specific customer requirements.
The forest owner can choose to sell the timber in different ways: as standing forest timber (rotpost), as a delivery stumpage purchase (leveransrotköp) or on cutting commission (avverkningsuppdrag). The type of contract chosen depends on the best prices proposed by the buyer and determines how the stand is to be evaluated.

In contracts based on standing forest timber, the forest owner receives a fixed price based on a close examination of the stand by the buyer. Prior to logging, each tree is marked and registered, and after logging each log is measured for valuation.

In contracts based on delivery stumpage purchase or cutting commission, where the volume does not have to be exactly specified, sample measurement and marking at some sample areas can provide a sufficient basis for calculating logging costs and the value of the stand. Forest owners also use their own personnel and equipment to carry out the logging operations.

When the contract is based on a cutting commission, the seller receives a preliminary proposal from a buyer based on the logging yield and a preliminary estimate of logging costs. The measurement to determine the value of the timber is performed at a measurement station at the sawmill.

Forest data is normally collected from logging sites prior to logging. The selection of stands to be harvested is often based on the particular requirements of the forest industries; mills express their timber requirements in terms of species and desired proportions of log lengths and diameters in different grades of quality. With current data on the inventory of stands, the potential yield of different assortments in individual stands can be estimated. Based on this knowledge, the order in which the stands are to be logged is determined, mainly with regard to optimizing log tally distribution and minimizing costs of transferring machinery between logging sites and costs of transportation to the sawmill.
The logging site also needs to be prepared. Tags are put either on each tree to be felled or on the trees at the border of the felling area (marking). Underbrush is also cut in the area to facilitate accessibility and paths and roads for transportation and forwarding are identified and marked by tags.

### 4.2.2 Harvesting

When the logging area has been prepared and the necessary planning done, harvesting can begin. The tree is felled and the limbs removed (limbing). Then the trunk is measured and divided into assortments for optimal utilization of the tree (bucking\(^{14}\)), before it is cut into desired lengths. The timber is sorted and piled for forwarding.

The traditional logging method in Sweden is the short-wood (cut-to-length) method, a system where trees are cut into logs in the forest rather than at industrial facilities. Tree-length (full-tree) methods were introduced in the early days of mechanization but are only practiced to a very limited extent today. The short-wood method is suitable when operations are small and scattered; and logs are bucked according to prior specifications and delivered to local sawmills. It causes fewer disturbances at the logging site and in the remaining stand. This method is still prevalent in Sweden, in contrast with Eastern Canada, for instance, where there was a general shift from the short-wood to the full-tree harvesting system between 1950 and 1991 (MacDonald and Clow, 1999).

In the early 20th century, the axe was the dominant tool in logging. Chainsaws were introduced in the 1940s, initially for felling and cut-to-length, and later for limbing. In the 1950s, use of the chain saw was widespread.

When the forwarder was first used for extraction work in the mid-1950s, it served as a base machine on which units could be mounted for

\(^{14}\) Bucking means “the division of a tree trunk into assortments” (Sillerström, 1985); the purpose is to make the division that will provide the maximum financial yield.
processing work in the forest. At the end of the 1960s, machines for limbing and bucking were introduced and soon became widespread. Heavy machinery began to be utilized in forestry during the 1960s, and there was a rapid increase in mechanization during the 1970s.

Basically, a harvester is a logging machine for felling and reprocessing of logs, including limbing and crosscutting (cut in lengths). Among modern mechanized methods, the predominant one is to use a harvester machine for felling, limbing and bucking.

There are both single-grip harvesters with one unit for both felling and reprocessing of logs, and two-grip harvesters with separate units for felling and reprocessing of logs. The single-grip harvester is clearly more common today although two-grip harvesters remain an option in large-diameter stands. The two-grip harvester was introduced in the early 1980s and was further developed in combination with the forwarder into an efficient system for logging operations. Mechanization of large-scale logging operations continued during the 1990s. In 1993, for example, harvesters accounted for 95 percent of final felling.

4.2.3 Forwarding and transportation

This phase involves forwarding of timber from forest to roadside landing and further transportation to the sawmill, where measurement for determining the value of timber normally takes place.

In the early 20th century, the timber was transported by horse to the nearest road, railway or practicable watercourse for log driving. In the 1940s, the forest tractor replaced the horse for work in the forest. From the mid 1950s on, adapted skidders and forwarders started to replace the tractors. Today, modern forwarders account for about 90 percent of all extraction work.

In the early days, river driving was the only way of getting logs to the mill. During the 1940s, road networks were developed close to forests to
permit truck transportation. Nowadays, all secondary transportation is carried out by road or rail.

4.2.4 Measurement and follow-up

This phase covers activities related to measurement and follow-up of measurement results. The logs that enter this phase have been transported on a truck from the landing site. The output is logs that have been assorted according to customer requirements.

Timber measurement has been regulated in the Timber Measurement Law since 1935 (SDC, 1986). The concept used has been developed jointly by buyers and sellers of timber, and measurement is carried out by an independent body, normally from the Timber Measurement Associations (VMF), which is contracted by the buyer. The VMF has an important role as there is a need for a third party to check the quality and dimensions of the logs, and to evaluate how well the logging technology has worked so that the customer receives what has been stated in the contract. The main purpose of the measurement is to establish supporting documentation for invoicing and payment.

The timber may be measured at the roadside landing or on arrival at the industrial facility or at terminals, but most saw timber is measured at the sawmills.

The timber enters the measurement station, where its dimensions are gauged in a measuring frame. Important parameters include timber volume and quality. The measurement report contains information about the value of the delivery. Measurement results can be used for follow-up and evaluation of timber transactions and logging operations.

After being measured, logs are assorted according to customer requirements with regard to saw class, tree species, lengths and qualities,
and placed in piles for storage in the timber yard before entering the sawmill.

4.2.5 Brief overview of the sawmill process

The description in this section is based on Eriksson and Johansson (1997) unless otherwise stated.

The decision on what should be sawn is based on qualities and quantities of sold units and the type of timber that is available. The contract between the sawmill and the buyer of sawn timber is based on specific information about quality, tree species, dimension, sawing method, moisture quota, planing method, use and packaging.

The logs are moved from the timber yard to the timber feed of the sawing hall, where an operator assesses the tree species, buttress, thickness, quality and damage, and assures that all logs are placed in the right direction when entering the saw line. The buttress and bark are then removed from the logs before sawing. The bark is kept on the logs as long as possible in order to protect them from dryness and damage. Mechanization in debarking began during the 1940s, and today almost all debarking is carried out at the sawmill (SkogForsk, 1997).

Before the logs enter the saw line, they pass a measuring frame where the length and diameter of each log are measured. The form of the log is also assessed to define the sawing yield. In the sawing procedure the log is sawn according to a specific pattern in order to optimize utilization of the log.

In edging sawing, two sides of the log are sawn and a block of two treated sides and two untreated sides is generated. Subsequently, the edge boards pass an edger, and the edged block is sawn into planks and boards. In resawing, the sideboards and main yield are generated. After resawing, the boards from the side yield are edged, and the wane is cut and made into wood chips.
The unseasoned sawn timber is assorted and stacked with blocks of wood between the planks or boards to permit air to circulate around them during drying. Most sawn timber needs to be dried to reduce the moisture content.

In the drying kilns, the climate, temperature and humidity can be adapted to the drying need, which depends on the purpose and conditions of utilization. Since timber adapts to the surrounding humidity, it should be dried until the moisture content corresponds to the environment where the timber is to be used as a finished product. The purpose is to avoid shrinkage and damages, to facilitate handling and to increase the strength of the timber. The dry timber is then placed in storage for adjustment to climate and external conditions.

After drying, the timber stacks are fed into the trimmer where the final length of the units is adjusted and the units are assorted in different sections. The quality is assessed, and the butt end and length of the unit are adjusted to optimize the value per unit. Adjustment and sorting depend on sorting standards for different grades of quality and customer requirements and is based either on strength or on appearance.

The units are finally marked at the ends with a firm and quality label and are either moved to a facility for further reprocessing, such as planning, adjacent to the sawmill, or packaged for transportation to the buyer.

4.3 MILESTONES IN IT DEVELOPMENT

Information technology was introduced in Swedish logging activities during the 1960s. Since then, various IT applications have spread throughout the process.

This section deals with the principal milestones in the development of IT in the logging process. The different types of IT solutions used in the logging process are explained, and the time when they were introduced is
noted. Since variations across organizations regarding this development are expected, the overview should be seen as a general indication only.

4.3.1 An overview

In an overall perspective, IT has been used for several decades in the forest industry (see for instance Höglund, 2000). In the early days, the focus was mainly on administrative work, but today IT can be seen in both administrative and production processes. Some examples are the foundation of the Forestry Computing Center (SDC) in the 1960s, the use of mobile phones for forest workers in the field, the introduction of computers in harvesters during the late 1980s for bucking support, digital maps for updating of borders between different districts and register databases.

Some general milestones in the IT development in logging operations are summarized in Figure 4-4 (M1-M8). The figure shows roughly at what time (during the period 1960-2000) the type of IT was introduced and in which phase of the process the type of IT has been primarily used.
Figure 4-4 Overview of milestones in the development of IT in logging

Briefly, the introduction of IT began primarily in the phase of measurement and follow-up, where it was used to facilitate administration in timber accounting and registration of timber measurement results. Radio communication in forest machines were followed by mobile phones. Harvester computers were introduced in the late 1980s. These have primarily been used for advanced bucking support. More recent development concerns vehicle computers in forwarders and trucks, geographical and positioning systems (GIS and GPS), online internet applications and information transfer over mobile phones (GSM).

The following description is mainly based on information collected in interviews. An overview of interviewees is presented in Appendix C. All other sources are referred to in the text.
Milestone 1 – Computer-based timber accounting
The Forestry Computing Center (SDC) was founded in 1961. It serves as “the IT company of the forest industry,” and its original purpose was to coordinate and rationalize timber measurement reporting through computerization to benefit SDC members. Members represent most buyers and sellers of timber in Sweden.

Different tools have been used for timber accounting over the years. For example, during the 1960s, a buyer and seller who had made an agreement measured the logs by the main road together with an independent party, often a representative of one of the Timber Measurement Associations (VMF). Punch cards were used to transfer measurement information from the landing to the central system at the SDC. In 1963, the pen-punching board developed by the SDC was introduced for timber measurement registration (SDC, 1986).

In the late 1960s, two different systems for timber measurement and customer contracts management were created for members, one for the north and one for the south of Sweden (the AVS system). These were based on mainframe computer systems and were further developed at the SDC during the 1970s.

Milestone 2 – Automatic timber measurement stations
In the 1970s, digital management of measurement data based on optical registration of measurement results at the SDC was introduced. SCA, MoDO and Holmens Bruk established collaboration for automatic data transmission to the SDC (SDC, 1986).

During 1985, automatic measurement stations for saw timber were installed in sawmills, enabling data transmission over the telephone network (SDC, 1986).
Milestone 3 – Development of VIOL
In 1981, the two systems for timber measurement and customer contracts management were merged into the nationwide system for timber measurement, the VIOL (Virkesmätning Online) system. Since 1983, all timber accounting has been managed through VIOL (SDC, 1986). The system enables buyers and sellers to access information about their timber transactions that has been registered in VIOL.

A new version of VIOL was developed in 1994. In the early 2000, it was possible to transfer data digitally from the harvester computers to the SDC.

Today, VIOL serves as an information center and has enabled centralized reporting for measurement at the sawmill and harvesters. Members also have their own interfaces with the SDC database, from which they transfer important information to their internal systems.

Milestone 4 – Harvester computers
The main focus of IT development in forest machines has been on computers in harvesters beginning in the mid 1980s. In the 20 years since that time, their application has become widespread. Today, computers are used primarily for support in bucking and to provide production data.

For example, at SCA, a large forest company, computers were installed in all forest machines in 1989-1990. Since then, bucking computers have been installed in harvesters integrated in the data and communication system, enabling information to be sent via the Mobitex network (Höglund, 2000).

Basically, with a bucking computer the harvester is used to divide each tree into different assortments, cutting the tree into various lengths depending on tree species, quality and diameter. Today, given the complexity of the calculations, it would be impossible for a harvester operator to manage this bucking manually.
The computer capacity was quite limited at the start. Not until the early 1990s could the computers perform advanced bucking calculations based on price lists. Bucking to order, for instance, was introduced in the mid 1990s.

The example of the Dasa (short in Swedish for Datorbönder aptering, or computer-based bucking) system developed by ESE Technique\(^\text{15}\) is used here as an example to illustrate the development of bucking computers.

The first generation of Dasa was introduced in 1985 and mounted into two-grip harvesters that were already in use. In 1990, the Dasa 380 was first used in bucking to taper in single-grip and two-grip harvesters. At first, the Dasa system was sold directly to contractors, but in 1989 a large Swedish forest company became an important partner. Soon ESE Technique signed its first machine-manufacturing customer.

In the early 1990s, bucking calculations became more advanced. In 1993, bucking to order was introduced in Dasa 380. Bucking to order was the most customer-oriented bucking method; calculations are based on the percentages of timber in different assortments that best fit the orders of the sawmills.

Between 1994 and 1996, ESE Technique contracted several new machines and new machine-manufacturing customers. There was also a large market for updating old machines. However, in 1996, the market for mounting the system into harvesters already in use had diminished, and there was increasing competition, primarily from machine manufacturers.

\(^{15}\) ESE Technique AB is a company that develops and manufactures bucking systems i.e. computer-based systems for bucking, including both hardware and software. ESE Technique is an independent system manufacturer that has been at the forefront in the use of systems in harvesters.
Between 1996 and 2000, there was a change of focus in logging operations to flows of material and information, and the forest machines became part of an information system. This led to a more flow-oriented cost focus.

In 2000, Dasa 4 was launched. This solution was adapted to the growing demand for increased functionality and integration of information flows by the use of e-mail, digital maps and control systems. Recently, the Dasa 5 development project was started for the purpose of developing a new system including the next generation of control systems for mobile applications.

SkogForsk is involved in a program to develop a standard for harvester reporting and bucking instructions, StanForD (Standard for Forestry Data and Communication). Together with the forest companies, SkogForsk identified the need for a standard to facilitate the management of on-board computers. A standard was agreed on in 1987 and was further developed during the 1990s.

**Milestone 5 – Harvester measurement for compensation**

Today, the SDC is involved in discussions about using the harvester measurement as a basis for payment (compensation) to the forest owner. Most payments are now based on the timber measurement carried out at the sawmill, but the SDC has developed a specific service for harvester measurement. There is still only limited support for harvester-measured compensation. Some reasons include lack of quality assurance and unwillingness of forest companies to change routines. However, it is possible both in theory and in practice to base the compensation on the measurement by the harvester and to supplement this procedure with some kind of acceptance test performed by an independent party at the sawmill.
**Milestone 6 – Computers in forwarders and trucks**

In contrast with the rapid development of the harvester computer, the introduction of computers in forwarders did not begin until the 2000s.

Computer systems in trucks are still used mainly for test operations. Today, there are a number of different systems for route planning, and several different systems for transfer of transport information. These include: Åkarweb, which is managed by Holmen Skog; Skogsåkarna, which has another system on test; KOLA, developed by Södra and Sydved, and Tromb, which is managed by VSV Frakt. Some of the principal actors within the industry recently agreed to develop a common standard for vehicle (truck) computers as well.

The need for further increasing efficiency in transportation seems to be driving the future development of IT. Some examples include WAP technology, map systems based on GIS, communication systems and navigation systems based on GPS, and Internet-based systems for contractors and transportation managers, with information about timber in stock, position, volumes and destination (Höglund, 2000).

**Milestone 7 - Mobile communication over GSM**

Because of the geographical aspects of forestry, where machine teams relocate often and there are gaps between harvester operations, forwarder operations and transportation at logging sites, there is an increasing need for communication in logging operations.

Radio communication has been used in forest machines since the 1970s. At the end of the 1980s, telephones based on Mobitex and NMT 450\(^{16}\) (Nordic Mobile Telephony) were introduced.

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\(^{16}\) Mobitex is a mobile system for text, speech and data communication, and transmission of data over radio that was launched in 1986. Even though NMT has almost totally been
In the early 2000s, data could be transferred digitally from harvesters to the SDC by mobile phones over the GSM (Global System for Mobile communication). Today, however, the GSM is not considered a reliable technology for communication in forestry operations in Sweden, as coverage is lacking in many sparsely populated areas.

Since computers have not yet been implemented on a large scale in forwarders, most communication involving the forwarder is still provided by mobile phones. This is particularly true of the communication between the truck driver and the forwarder operator.

**Milestone 8 – GIS and GPS in planning and navigation**

In view of the geographical aspects, there is also a need for geographical information support in logging operations. Since machine operators and truck drivers often work in conditions of limited visibility -- in nighttime and early-morning darkness, in rain and fog, and when snow covers the logging site -- there is a need for navigation support.

IT applications for geographical information seem to be useful in several phases of the logging process, including planning, harvesting, forwarding and transportation. For example, GIS (Geographic Information Systems) is a computer-based information system with functions for collection, treatment, storing, searching, analysis and presentation of geographical data. GPS (Global Positioning System) is a satellite-based positioning system that can be used in forestry for defining coordinates of test areas and for updating digital forest maps. These technologies can also be used for several different purposes related to logging.

According to Höglund (2000), the need for geographical information has led to growing demands for accuracy in positioning, and has in turn replaced by GSM, NMT-450 still has outstanding coverage compared to other mobile telephone systems.
driven the increasing use of GPS. Real-time updated positions facilitate navigation and information collection, and they enhance the quality of geographical information, thus helping to improve planning of logging operations. In planning, GPS can be used in combination with digital maps of the logging site stored on a PC. This application enables the planner of logging operations to know the exact position of boundaries and facilitates setting limits for logging areas and marking specific natural features.

GPS technology has considerable potential in logging operations (see for instance Höglund, 2000). For example, with a GPS on the harvester, the position of each tree could be related to the measurements collected and processed by the bucking computer. GPS could also be used for positioning timber piled in the forest. With a GPS on the forwarder, the position of timber piled in the forest and at the landing could be defined. Geographical information gathered in the forest could also be used for transportation and transportation planning.

4.3.2 A few words about production of sawn timber

At the sawmill, it is important to assess a number of variables describing the timber characteristics such as length, diameter, crook, quality, limbs, species, strength, etc. This permits optimal sorting of timber and assures correct deliveries to buyers.

Regarding major milestones in the digitization of information at the sawmill, a lot of information is currently collected through different sensors and is used for planning and forecasting of sawmill activities. However, sawmills have generally made limited use of IT. There is a large potential in visual systems for use along the saw line. An important technology in this regard is Fin Scan, used for scanning timber prior to sorting.

There is increasing use of 3D measuring frames, and the point laser has been replaced by the line laser and image analysis (see for instance
Björklund, 2003). The 3D measuring frames, which were introduced during the second half of the 1990s, improve the definition of surface-form variables. Where there is no need for a complete 3D image of the log, matrix cameras and image analysis could be used instead of laser-based measuring frames. The development of cameras and software is rapidly progressing. During the 1980s, X-ray technology was introduced for assessment of logs, but because of the high costs of purchase and maintenance, this technology is not yet widespread.
5. EFFECTS OF DIGITIZED INFORMATION IN THE LOGGING PROCESS

In this chapter, the findings of the empirical study are presented. The stakeholders involved in the logging process are identified, and an overview of today’s situation is given. This is followed by a description of the development over the last decades. The presentation is structured according to the four phases of the logging process.

In each phase, the focus is on describing the information flows in the logging process and how these have changed over the last four decades. Illustrations are used to clarify the description and to provide an overview of developments. Also presented are findings regarding effects of digitization of information flows.

5.1 INTRODUCTION

In this chapter, findings are presented as a case description showing the digitization of information flows in the logging process and its effects. This description is based upon data collected from various sources, primarily interviews with representatives of stakeholders involved in the process studied (see Appendix C) and documents describing the studied logging process.

As mentioned in Chapter 2, some quotations are presented throughout the description that have been selected from interview materials and reconstructed from detailed transcripts based on notes taken during interviews. Since the interviews have not been recorded, the quotations are approximative and do not always correspond word by word to interviewees’ statements. However, it has been possible to reconstruct statements from the detailed notes that were taken during all interviews.
The description includes overview charts showing how information flows in the logging process have changed over the last four decades. It follows the structure of the logging process, which is shown in Figure 5-1.

![Diagram of logging process]

**Figure 5-1 Scope and structure of the empirical description**

### 5.1.1 Stakeholders involved

There are several stakeholders involved in the studied process. These are briefly presented here.

**Södra and Contractors**

Södra Skog (hereafter referred to as Södra), which is part of the Södra Group, is a forest owner association representing 35,000 forest owners. Södra provides for the acquisition of timber and offers a range of forestry services to its members, for instance logging services, and has about 450 employees.

The association has its principal operations in the south of Sweden, where Södra covers 50 percent of the market. Timber production volumes account for about 13 percent of the total production in Sweden in 2003.

Södra buys timber from its members as well as from other suppliers. Most of these purchases are made as cutting commissions to contractors engaged by Södra to carry out logging operations. These forest machine contractors are often small companies that perform mechanized forest work on commission. Also, transportation contractors are engaged for transportation of timber. Södra serves as an intermediary between the forest owner and the sawmill. The timber volume measured at the sawmill determines the final revenues and costs of the timber transaction.
TITAN is an information system used for planning of logging operations, including contracting. Since the end of 2004, all information systems for the timber flow at Södra are integrated into one single system, VIL (VirkesInformationsLager, Timber Information Storage). This system, which is intended to provide support in all phases and activities of the timber flow, replaces a number of separate systems.

Södra Skog is referred to as Södra in the empirical description. Both TITAN and VIL are referred to as internal information systems at Södra.

The Sawmill

Within the Södra Group, Södra Wood Products operates nine sawmills in southern Sweden producing 1.4 million m$^3$ of sawn and planed wood products in 2003. Södra Timber Mönsterås, with 112 employees, is one of these sawmills, producing 275 000 m$^3$ of sawn timber in 2003. Södra Timber sawmills, which buy 75-80 percent of the saw timber logged by Södra Skog, started operations in 1998. Its primary markets are in Great Britain, Japan, the USA and Sweden. The competition on the sawn timber market has increased, leading to price pressure and greater specialization.

The Mönsterås sawmill is considered here as a general example of a sawmill.

The Timber Measurement Association

At the sawmill, representatives of a Timber Measurement Association (VMF) are responsible for the measurement of incoming logs. The final price paid by the buyer is determined by this measurement.

The first VMF was established at the end of the 19th century. Ever since, it has played an important role in timber measurement procedures that assure an objective (neutral) determination of timber value.

In the south of Sweden, the association VMF Syd takes care of measurement operations.
The Forestry Computing Center

Information flows in the logging process are developed and supported by the SDC, which is the Forestry Computing Center. This organization has 110 employees and is owned by about 50 member companies in the Swedish forest industry. In addition, some 130 sawmill companies are indirectly members of the SDC via the sawmill associations that are full members. Most buyers and sellers of timber in Sweden are members of the SDC. Södra is one of those members.

The SDC was founded in 1961 to facilitate and support timber accounting. The SDC provides the infrastructure for management and exchange of information on timber transactions and develops services based on information collected at different measurement points in the timber flow.

Within the SDC, a number of information solutions that have been developed are managed. For example, VIOL is the wood measurement system at SDC, PRINS is a production information system at SDC for harvester and forwarder reporting and VIS is a service provided by SDC for members to access information about timber transactions in VIOL.

5.1.2 Comments on the milestones in IT development

The general development of IT in logging operations presented in Chapter 4 is used to compare the case studied with the more general situation. Comparing the specific case to the general overview provides an indication of the stage reached in the empirical case regarding IT implementation.

The development of the timber accounting information system (VIOL) involving the Forestry Computing Center (SDC) could be considered general since most buyers and sellers of timber are members of the SDC. In the process studied, Södra joined an early version of the timber accounting system (the predecessor to VIOL, the AVS system) at the SDC in 1968 and has been a member of the SDC ever since.
Among forest machine contractors in the process studied, the development of radio and mobile communication seems to be in line with the general trend. This is also the case with the introduction of harvester and forwarder computers.

In view of the slow diffusion of computers in forwarders, Södra has promoted some initial initiatives at contractors regarding the use of computers and handheld devices (PDA’s) in these machines. The computerized support (KOLA system) installed in some trucks is also a specific initiative promoted by Södra, among others.

Regarding the development of geographical information systems and positioning systems (GIS and GPS), there seem to be variations among contractors and individual machines. New machines are more likely than older ones to have these types of technologies installed. Moreover, if the machine operator is familiar with the logging area, there is less need for navigation support.

5.1.3 Overview of information flows
There are several information flows in the logging process studied. The current situation regarding these flows is described below. An overview is shown in Figure 5-2.

In the following sections, findings on the development of these flows over the last few decades are presented. The description of the process is divided into the four phases and includes the major steps in the digitization of information that began in the early 1960s.
Figure 5.2 Information flows in the studied logging process, current situation.
5.2 **Digitized Information in Planning and Preparation**

The first part of the process consists of planning and preparation. The overview of the current situation is presented once again in Figure 5-3, where this part of the process is shaded.

Figure 5-3 Overview of the current situation: the planning and preparation phase

An overview of information flows in the planning and preparation phase is presented in Figure 5-4. The figure shows the development during three periods, 1960s-1980s, 1980s-1990s and 1990s-2000s, which roughly indicate when changes have occurred.
Figure 5.4: Information flows in planning and preparation, 1960s-2000s

1960s-1980s
- Acquisition
- Planning
- Harvesting
- Contracts
- Sawmill prices
- Site directive
- Logging plan
- Internal systems
- Södra
- Forest owner
- Södra

1980s-1990s
- Acquisition
- Planning
- Preparation
- Harvesting
- Site directive
- Contract
- Contract and Plan
- Internal systems
- Södra
- Contractor
- Södra

1990s-2000s
- Acquisition
- Planning
- Preparation
- Harvesting
- Site directive
- Contract
- Internal systems
- Södra
- Contractor
- Södra

Stakeholder
- Type of interface
- Information flow
- Information carrier
- Digital format
- Process step
- Information system

VMF – the Timber Measurement Association
SDC – the Forestry Computing Center
VIOL – Timber Measurement IS at SDC
AVS – Predecessor of VIOL at SDC
PRINS – Production IS at SDC
APT-file – Computer file with bucking instructions
GSM – Global System for Mobile communication
5.2.1 Digitized contract information

The agreement between Södra and the forest owner (seller) is established in a contract. Most of the activities in negotiations between Södra and the forest owner are carried out in a traditional manner. Information about the stand is gathered in a site directive and is stored in the internal information system of Södra. Maps are used for acquisition and planning activities, but only recently did digital maps start to replace paper copies of maps.

Södra also enters into a contract with the sawmill (buyer). Contracts constitute the basis for the wood order. The contract must be registered in VIOL before the wood order can be registered there. The wood order constitutes a basic part of the timber transaction and could be considered a type of account where information is added during the process. Contracts are stored in the internal information systems of Södra.

Back in the 1960s, some members decided to register contract information at the SDC, but doing so was optional, and most only registered this information in internal systems. At this time, it was also voluntary to register the measurement notification (a predecessor of the wood order). The larger companies had individual routines for handling this information and did not need all services offered by the SDC.

In 1968, Södra joined the system for timber accounting and measurement registration (the AVS). The AVS was a mainframe environment, and information was punched in manually at the SDC. The first timber accounting system developed for the south of Sweden at the SDC, the AVS was later replaced by VIOL.

In the latest version of VIOL, which was developed during 1994-1999, registration of both wood orders and contracts has been required for a timber transaction to be accepted. It was not common to store contracts in VIOL before that time.
Södra also reaches an agreement with a forest machinery contractor to carry out the logging operation. The contract includes information about time, volume, quality and price. A contract is established for each contractor and mission. A document template is used for the contract, of which Södra sends a paper copy to the contractor.

Södra uses information systems in planning and contracting. Early versions of systems for managing digital information were implemented during the late 1980s at Södra. A logging plan for each assignment is registered in internal information systems. Earlier, planning tables were used, and paper cards with information on assignments and orders were handled manually.

In the site directive, Södra provides all instructions that the contractor needs in order to carry out the logging operations. For the past few years, the site directive has been stored in internal information systems at Södra. The logging area needs to be planned and prepared with due regard for conservation and the environment. Today, contractors prepare the logging area prior to logging, whereas before 1960 preparations at the site were often carried out by the forest owner.

**Effects of digitization**

The digitized information flows in the valuation of stands in planning has led to increased control in forestry planning. With greater and more detailed information on stand characteristics, the probability of optimally utilizing the stand increases.

The storage of contracts and wood orders in VIOL and in the internal systems at Södra has enhanced the availability and rapid accessibility of updated information.

**5.2.2 Digitized price information**

The contracts are based on current price lists for saw timber; these prices are set by the sawmills, which adjust prices according to their needs for
timber suitable for specific purposes. Price levels for saw timber are based on parameters such as tree species, timber quality and dimensions (diameter and length). Sawmills continuously update the price lists and send price information by e-mail to Södra. Södra then registers the price list together with the contracts in VIOL.

General price levels are established once a year, but the specific prices applied change according to market fluctuations. The prices applied in actual agreements reflect current market demands. Market demands from sawmills have been taken into consideration in the logging process for about ten years.

Today, market demands influence the logging process from the start. Before 1960s, logging took place with no specific knowledge of what sawmills demanded. Södra tried to sell the logged timber to sawmills that would pay a high price. For example, one manager at Södra stated:

“Earlier, the timber was logged and then you tried to sell it to any buyer you could get, but now logging is done according to sawmill orders...Today, the customer enters the picture early in the process. There used to be a clear distinction between “us” and “them” but today you have to adjust to the customer who is paying at the other end... Timber flow control begins right in the forest...You already know out in the field what should be delivered to the market.”

At this time there was no customer focus, and the logs were not even separated according to tree species. The harvester operator then kept memorized prices over the year for cutting the trees into optimal lengths. Sawmills were not as specialized as today and supplied all markets with timber. The focus was on volume, not specific timber characteristics. For example, one manager at Södra stated:

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17 This manager has been working with logging operations at Södra for 34 years.

18 This manager has been working with logging operations at Södra for 34 years.
“Södra buys and sells timber to customers based on the price lists. You already know before logging who has bought the timber…Bucking support has changed conditions in logging…Now there is no longer any such thing as general timber. Today all timber is logged for a specific purpose…and all logging decisions are based on that purpose.”

**Effects of digitization**

Digitization of information on sawmill prices used in negotiations between Södra and the forest owners has increased flexibility in price management at the sawmill. Timber prices are continuously updated by sawmills and then distributed to Södra. Every activity in the logging process is adapted to current timber prices.

Timber transactions are also better optimized since timber is adapted to the requirements of the sawmill that pays the highest price. There has been increased integration between activities in the forests and at the sawmills.

**5.2.3 Digitized bucking instructions**

Today, contractors perform most of the logging operations in the forest. Until the end of the 1980s, employees of Södra carried out these activities. Information flows were then more concentrated within the Södra organization.

Before bucking computers were installed in harvesters in the mid 1980s, information regarding bucking was managed on paper. General sawmill price lists were used as bucking support. These were later replaced by bucking instructions adapted to each specific logging agreement. Today bucking instructions are based on prices set by the sawmills (buyers).

The bucking instruction and corresponding data file for the harvester computer (APT file) are created at Södra. The APT file contains identifying information such as supplier number and contractor, price matrices for the assortment to be logged, minimum and maximum lengths
and diameters, qualities, VIOL codes, and location of delivery. Södra sends the data file by e-mail to the contractor, who downloads it to the harvester computer. The contractor uses e-mail or a floppy disk to transfer the bucking instructions to the bucking computer.

The harvester operator reviews the bucking instruction and the data file before these are downloaded to the harvester computer. Because of the varying types of machines and computers, specific adaptations and adjustments of the information are common. The harvester operator makes these preparations at home or at the office before work starts in the forest.

**Effects of digitization**

The digitization of bucking instructions has led to increased flexibility in bucking support and the availability of updated support. Since changes can be made regularly, instructions are better adapted to market demands.

### 5.2.4 Comments on effects in planning and preparation

An overview of the effects of digitized information flows in the planning and preparation phase are presented in Table 5-1.

<table>
<thead>
<tr>
<th>Digitized information</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract information</td>
<td>Increased control in forestry planning</td>
</tr>
<tr>
<td></td>
<td>Increased optimization of stand utilization</td>
</tr>
<tr>
<td></td>
<td>Increased availability of updated information</td>
</tr>
<tr>
<td></td>
<td>Quicker access to updated information</td>
</tr>
<tr>
<td>Price information</td>
<td>Increased flexibility in price management</td>
</tr>
<tr>
<td></td>
<td>Increased optimization of timber transactions</td>
</tr>
<tr>
<td>Bucking instructions</td>
<td>Increased flexibility in, and availability of, updated bucking support</td>
</tr>
</tbody>
</table>

**Table 5-1 Effects of digitization in planning and preparations**
In this phase, the most significant changes from digitization include greater awareness of sawmill prices and market demands right from the beginning of the logging process. Digital bucking instructions also have an important role in the flow of this information. Management of digital price information is enhanced by continuous updating; prices have gone from being stable over time to reflecting current market demands. Today market demands are taken into consideration even before logging.

Other changes include the development of digital maps for stand evaluation, helping to increase control in forestry planning and to optimize stand utilization. In addition, storage of contracts and wood orders in VIOL has given stakeholders quicker and greater access to more updated information. The role of VIOL is further discussed below.

5.3 **Digitized Information in Harvesting**

The second part of the process includes harvesting activities. The overview of today’s situation is presented once again in Figure 5-5, where this part of the process is shaded.
Figure 5-5 Overview of today's situation: the harvesting phase

An overview of information flows in the harvesting phase is presented in Figure 5-6. The figure shows the development during three periods, 1960s-1980s, 1980s-1990s and 1990s-2000s. These periods roughly indicate when changes have occurred.
Figure 5-6 Information flows in the harvesting phase, 1960s-2000s
5.3.1 Digitized bucking support

In felling, the harvester operator cuts the trees according to the bucking instructions. The operator enters information on the quality and species of each tree into the computer. The computer program calculates and indicates in turn the category into which the cut logs should be sorted. The harvester fells the tree and measures the diameter. Limbing is also done. The computer calculates the optimal cutting based on current price lists and orders in order to achieve the highest timber value. The lengths are assorted in different piles according to quality.

Before the mid-1960s, a specific bucker was responsible for carrying out the bucking operation. Bucking decisions were important as they determined the final value of the timber. At this time, price levels remained quite stable from season to season, and bucking was not related to timber prices. However, forest owners were roughly aware of sawmill needs, and parameters such as quality, species and taper were taken into account in cutting decisions.

In bucking, simple calculators were used in harvesters to keep track of tree lengths in the late 1970s. The first computer system for harvesters was introduced in the 1980s, primarily as support for log measurement in bucking. The computer has been used for bucking calculations since the beginning of the 1990s.

Before computers were installed in harvesters, the harvester operator had to memorize information about sawmill prices. Today, the harvester operator can determine which tree should be delivered to which sawmill based on the bucking instruction. Each tree has a specific purpose and is evaluated individually in order to obtain the optimal value. Earlier, the operator did not know where the tree would end up or for what purpose it would be used. Today timber delivered to the sawmill is more adapted to the market demands than before.
Over the years, the capacity of computers has increased. This has led to the addition of computer applications such as harvester reporting, remote troubleshooting (service and maintenance) and positioning systems (GPS). The operator can also keep track of other administrative applications like logbooks for maintenance and fuel, salary calculations, and time and production management.

Effects of digitization
Digitization of bucking information has helped to increase timber value by enabling sawmills to differentiate timber prices today. Greater customer orientation has enhanced the value of timber; the sawmill receives exactly what is requested in the bucking instructions, and there is high precision in deliveries.

Digitization of bucking information has contributed to an increased customer focus in the logging process. Customized timber management now starts in the forest, and forest workers start thinking about customer adaptation right at the logging site. There is also closer collaboration and integration between sawmills and forests today.

Bucking instructions based on price lists are changed continuously as individual sawmills have become more specialized, with considerable variation in orders. For instance, there is additional value in delivering timber to the Japanese market, which is known for requiring specific customized timber. Sawmills prepare special deliveries for the Japanese market by beginning to track specific timber resources while these are still in the forest. Computer-based bucking support thus has a key role in production of customized timber.

With the increasing amount of information captured and used in the bucking computer, there has been a growing demand for additional information services among SDC members. The bucking computer has helped to collect information regarding quality and dimensions for cutting
trees into lengths. This information is also useful for process management and control.

The enhanced capacity of the bucking computer has led to an increasing demand for integration with other applications. A manager at ESE Technique stated:

“Harvester operators often want to install additional applications on the bucking computers, but it is sometimes tricky to integrate existing computers with other applications such as GPS…Systems become unstable and the computer more vulnerable…You don’t want the user to go into the systems and make a mess of things.”

Another example of an additional application integrated with the bucking computer is maintenance and support services for harvesters and computers. For instance, maintenance companies can remotely access the harvester computer for troubleshooting and updating software. Utilization of harvesters is increased with operators working in shifts.

The introduction of the bucking computer has also entailed some problems. With increased automation, there is a greater risk of severe failures like price-list errors. It has become more important for harvester operators to review the information to ensure that it is reasonable and to have the skill necessary to detect errors in software, data files and documents.

Another aspect is related to the fact that the forest is a very demanding environment for a computer. The system is sensitive to damage, and it is hard to continue logging if the bucking computer is not working properly. Even though the bucking computer is associated with greater vulnerability, there are fewer problems in harvester systems today than ten years ago.

The use of the bucking computer calls for highly skilled personnel in the logging process. For example, one harvester operator stated:
“The operator must not only run the harvester but must also be a computer expert, machinery expert and forest expert...consider environmental conservation, and so on...The operator also needs to do a lot of surveillance in order to make everything run smoothly.”

At the same time, digitization of bucking information has led to an improved work environment for the operator as the computer provides support and aid in bucking.

The harvester operator also needs to have control over more information. The advanced calculations required make it impossible to keep track of lengths and prices manually in bucking. For example, one manager at ESE Technique stated:

“The harvester operator has to have control over more information today than earlier...It would not have been possible to memorize lengths and prices with today's advanced calculations, but the operator still has to verify that the computer calculations seem reasonable.”

The increased amount of information also demands more of operators regarding efficiency in selection and management of information. In parallel with verification of bucking calculations, the operator needs to check trees for quality and possible damage when processing timber.

5.3.2 Digitized harvester reporting

After each shift, the operator sends information from the harvester computer via a mobile telephone (over GSM) to the SDC. The harvester report (production data file) contains information about the timber that has been measured and processed by the harvester, including number of logs and quality, length, diameter per log (stock list of saw timber).

Since the beginning of the 2000s, digital harvester reports are sent via e-mail over GSM from the harvester computer to the production information system at SDC (PRINS). Today, 80-85 percent of transfers to
SDC are made directly from bucking computers. Before GSM was used for data transmission, harvester reports were sent to the SDC as paper copies or stored on floppy discs. The SDC has registered information from harvesters since 1992.

Today, the forest worker operates alone in the forest. The digital production information helps in follow-up of harvesting results. Earlier, forest workers in the forest were under the control of administrative employees at Södra.

**Effects of digitization**

Digitization of harvester reporting has increased the opportunities for information exchange between stakeholders. The harvester report is generated in bucking and stored in the production information system at SDC (PRINS), where stakeholders can access it. This has improved opportunities for follow-up on production.

With information now captured at several points, more information is used by stakeholders to enhance process control. For example, the SDC facilitates an additional service, Timber Forecast, that is based on information captured in the harvester computer during bucking. This service gives sawmills access to harvester reports and thus early information about the timber that will arrive. For the sawmills, this leads to better planning, more reliable delivery to customers, reduced stocks and less spillage. For the timber supplier, the benefits are a better overview of activities, enhanced control based on market needs and improved relations with sawmills.

Digitization of harvester reports has improved decision making by providing access to updated information in VIOL through the follow-up register service. This service enables stakeholders to review reported information from harvesters and compare it with reported measurement results.
5.3.3 Comments on effects in harvesting

An overview of effects of digitized information flows in the harvesting phase is presented in Table 5-2.

<table>
<thead>
<tr>
<th>Digitized information</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bucking support</td>
<td>Increased utilization of harvester</td>
</tr>
<tr>
<td></td>
<td>Decreased stability in harvesting system</td>
</tr>
<tr>
<td></td>
<td>Increased need for review and surveillance of bucking support</td>
</tr>
<tr>
<td></td>
<td>Improved adaptation to customer needs</td>
</tr>
<tr>
<td></td>
<td>Increased value of customized timber</td>
</tr>
<tr>
<td></td>
<td>Increased market opportunities</td>
</tr>
<tr>
<td></td>
<td>Increased support in bucking</td>
</tr>
<tr>
<td></td>
<td>Increased opportunities for integration of computer applications</td>
</tr>
<tr>
<td></td>
<td>Greater employee skills required</td>
</tr>
<tr>
<td>Harvester reporting</td>
<td>Improved production follow-up and process control. Increased opportunities to utilize measurement results</td>
</tr>
<tr>
<td></td>
<td>Improved support for decision-making</td>
</tr>
</tbody>
</table>

Table 5-2 Effects of digitization in harvesting

This development marks a significant phase in the digitization of the logging process. The digitization of bucking support has led primarily to greater differentiation and customization of timber, thus facilitating the exploitation of new market opportunities. In addition, remote maintenance services have led to increased utilization of the harvester. The development in harvester reporting has enhanced production follow-up and process control.

Other changes include a need for more skilled operators, integration of additional computer-based applications, decreased stability in the harvesting system, and a greater need for review and surveillance of bucking support due to the risk of errors with severe consequences.
5.4 DIGITIZED INFORMATION IN FORWARDING AND TRANSPORTATION

The third part of the process consists of forwarding and transportation activities. The overview of today’s situation is presented once again in Figure 5-7, where this part of the process is shaded.

An overview of information flows in the forwarding and transportation phase is presented in Figure 5-8. The figure shows the development during three periods, 1960s-1980s, 1980s-1990s and 1990s-2000s, which roughly indicate when changes have occurred.
Figure 5-8 Information flows in forwarding and transportation, 1960s-2000s
5.4.1 Digitized wood orders

After the trees have been felled by the harvester operator, the forwarder arrives (normally within one hour to two days). The harvester operator and the forwarder operator communicate via mobile phone. Normally, machine teams representing the same contractor take care of both the harvesting and the forwarding of timber.

At the logging site, the forwarder operator moves the timber from the forest terrain to a landing by the main road, where it assorted according to purpose and destination. When the timber has been piled at the landing, the forwarder operator informs Södra via telephone about the volume and location of the timber that is ready for transportation.

Södra fills out a wood order in VIOL based on the harvester report. This report contains information about the amount of timber at the landing that should be transported to the sawmill and how it should be measured. The report is also sent by e-mail to a transportation management center at Södra, which handles the necessary transportation arrangements.

Before computers were introduced at the SDC, hand-written documents with wood order information were processed manually. In 1975, employees at the SDC still entered information from documents to digital format. In 1983, transmission of computerized data over the telephone network became possible, and today 99 percent of all data is transferred over the telephone or the SDC network.

Recently, the SDC has identified a growing interest among members in reducing lead times in logging operations between felling and timber measurement. Earlier, lead-time was often not considered a critical factor, and it could take up to two months from the time that timber was piled at the landing until it reached the sawmill. The growing interest in control is also explained by the increasing number of points of information capture and communication in the process.
Effects of digitization

Digitization of wood orders has increased the availability of information and provided quicker access to it through VIOL. Today this information is registered directly in VIOL, where it can be accessed by the stakeholders concerned. There is growing interest in using information to improve timber flow. However, there are still some weaknesses in the communication between harvesters, forwarders and transportation, and there is also a potential for improving information flows related to these activities.

5.4.2 Digitized transportation orders

At the landing, the piled timber is picked up by a truck and transported to the sawmill. Transportation of timber to sawmills is arranged by Södra through a network of transportation contractors. Earlier, Södra oversaw the entire chain of logistics, including harvesting, forwarding and transportation.

Wood order information is used for generation of the transportation order at Södra. The transportation order (including information about the position of the timber at the landing, forwarded volume, supplier, assortment, road standard, destination, etc.) is sent by e-mail to the transportation contractor.

When the truck is loaded, the driver prints a report and sends it by fax from the truck to the measurement station at the sawmill. The driver also telephones the measurer at the arrival location and obtains information about where to unload the timber. Planning at the measurement station can be facilitated if the necessary information is available earlier. The measurer prepares the registration and accounting when notified of the delivery by the truck driver. On arrival at the measurement station, the timber is measured and the driver is given a transportation receipt. Registration of transportation reporting has been done through the SDC since the early 1980s.
Effects of digitization

As with the development regarding wood orders, digitization of transportation orders has made more information available and permitted quicker access to it through VIOL.

In transportation, which is an important part of the logging process, there is considerable potential for cost reduction. An example is the National Forest Road Database (SNVDB), a service developed to improve optimization of logistics in planning and transportation in forest operations. This service will be used for transportation invoicing, route planning, navigation, logging planning, thereby helping to optimize timber flows, road investments and transportation schedules. Small savings per transportation could have a large effect on an industry scale, and generally there is considerable interest in optimization and cost-effectiveness in road transportation.

5.4.3 Comments on effects in forwarding and transportation

An overview of effects of digitized information flows in the forwarding and transportation phase is presented in Table 5-3.

<table>
<thead>
<tr>
<th>Digitized information</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood and transportation orders</td>
<td>Increased availability of updated information</td>
</tr>
<tr>
<td></td>
<td>Quicker access to updated information</td>
</tr>
</tbody>
</table>

Table 5-3 Effects of digitization in forwarding and transportation

The most significant development in information flows in forwarding and transportation is related to the registration of both wood orders and transportation orders in VIOL. This advance has helped stakeholders by providing quicker and enhanced access to more updated information.

There is great potential in further digitization of information flows related to forwarding and transportation. The implementation of computers in forwarders and trucks is fundamental for this development.
5.5 **Digitized Information in Measurement and Follow-up**

The fourth part of the process includes measurement and follow-up activities. The overview of today’s situation is presented in Figure 5-9, where this part of the process is shaded.

![Figure 5-9 Overview of today's situation: the measurement and follow-up phase](image)

An overview of information flows in the measurement and follow-up phase is presented in Figure 5-10. The figure shows the development during three periods, 1960s-1980s, 1980s-1990s and 1990s-2000s, roughly indicating the time when the changes have occurred.
Figure 5-10 Information flows in the measurement and follow-up phase, 1960s-2000s

1960s-1980s

- Timber measurement
  - Transportation
  - Södra
  - Measurement report
    - Punch cards
    - Follow-up
      - Mail

1980s-1990s

- Timber measurement
  - Transportation
  - Measurement Receipt
  - Follow-up
    - Telephone network
    - Mail

1990s-2000s

- Timber measurement
  - Manually registered report
  - Automatically generated report
  - Measurement Receipt
  - Mail

Stakeholder Types of interface

- VMF – the Timber Measurement Association
- SDC – the Forestry Computing Center
- VIOL – Timber Measurement IS at SDC
- AVS – Predecessor of VIOL at SDC
- PRINS – Production IS at SDC
- APT-file – Computer file with bucking instructions
- GSM - Global System for Mobile communication

Information flow

- Information carrier:
  - Document
- Process step
- Stakeholder

Type of interface

- Information system
5.5.1 Digitized timber accounting

Today, timber is measured on arrival at the sawmill at the measurement station run by independent representatives of the Timber Measurement Association (VMF). The payment to the forest owner is based on the measurement information generated here.

Prior to measurement, the measurer extracts information about how the timber should be measured (measurement order) from the wood order registered in VIOL. In the 1960s, a measurement notification (predecessor to the measurement order) was sent by ordinary mail to the SDC. In the 1980s, the measurement order replaced the measurement notification, and the information was entered in VIOL.

Before industry measurement was introduced in 1969, VMF representatives measured timber at the landing or at the supplier's location together with representatives of buyer and seller. Punch cards were introduced during the 1950s, and there were punching departments at forest companies. For example, Södra had a department for processing measurement information, with 15-20 punching operators.

In 1969 industry measurement stations were introduced. Measurers now began to work indoors, and timber was transferred through the measurement station. Optical reading based on electronic measurement frame and punch tapes was used.

With the foundation of the SDC, it became possible to register measurements centrally via punch cards. In 1968 Södra joined the AVS system (predecessor of VIOL) for measurement registration and price calculation. The information was sent by ordinary mail to the SDC. During the 1960s and 1970s, the SDC had a department of 30-35 persons for punching cards with information for registration in the AVS system. An example of the design of an SDC punch card for timber measurement is shown in Figure 5-11. Between 1963 and the early 1980s, punch card
equipment was used to register and handle punch cards with measurement information. In 1981, the AVS system was replaced by VIOL.

The physical handling of punch cards and tapes entailed a risk of failures due for instance to coffee stains. There was also a danger that cards could be mixed up, possibly with serious consequences for sellers and buyers of the measured timber. For example, one manager at the SDC stated:

“Bunches of punch cards used in the forest were sent to the SDC for registration.
The cards were often sticky and the registration often crashed, with the result that cards had to be re-punched.”

In the 1980s, measurement stations were connected to VIOL, and measurement results were automatically registered in VIOL without any intermediary or conversion.

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19 This manager has been working at the SDC since 1975.
Effects of digitization

The development in timber accounting has improved efficiency through harmonization of routines used in different parts of Sweden. With the mergers of forest companies with operations in different parts of Sweden, there was a growing need for a single system for timber accounting. Earlier, there were 13 different measurement societies, each using different systems. The common infrastructure enabled different stakeholders to communicate and exchange information. This has led to substantial economies of scale and other benefits for the stakeholders involved.

The development in timber accounting has also led to greater openness, a freer flow of information that has improved the functioning of the Swedish timber market despite its fragmentation and geographic spread, with many buyers and sellers of timber. The nation-wide infrastructure for timber accounting developed by the SDC has permitted greater diversity of the Swedish timber market by allowing a large number of sellers and buyers to share information. For example, one manager at the SDC stated:

“The SDC has an important function as an enabler so that many different stakeholders can communicate and share information with each other.”

The head of VMR stated:

“The timber market is more diversified and fragmented in Sweden than in many other countries... Since information on timber is a prerequisite for switching between different buyers and sellers, the SDC has contributed to a more open timber market in Sweden.”

The information flows based on VIOL have provided a platform for standardization and development of a common nomenclature in timber

20 This manager has been working at the SDC since 1975.
accounting in Sweden. This has reduced misunderstandings between stakeholders. As one manager\textsuperscript{21} at the SDC stated:

“The SDC has succeeded in uniting all of Sweden on one system and one common nomenclature…With everyone speaking the same language, the benefits are enormous.”

The digitized information stored in the VIOL timber accounting system has stimulated innovation and increased the opportunities for the SDC to develop new services based on stored information.

The development in measurement registration and reporting has improved efficiency and reduced the risk of error. Earlier, special stamping departments were responsible for conversion and registration of punch cards and tapes. There was a high risk of error in manual processing of punch cards, where sorting and order were important. Information registered in VIOL is automatically checked before it is accepted and stored. This verification assures a high quality of information.

The costs of timber accounting have decreased. During the 1970s, the cost was 0.78 SEK per m\textsuperscript{3}, whereas during the last ten years, the cost has been stable at about 0.50 SEK per m\textsuperscript{3}. In parallel, there has been a significant increase in the amount of information managed, timber volumes produced and information services offered by the SDC.

However, the development in timber accounting has also made it more complex to carry out tasks related to timber accounting. SDC member companies sometimes need extra help from experts and consultants at the SDC for training and the use of the SDC information systems. For

\textsuperscript{21} This manager has been working with timber accounting at the SDC since 1969.
example, one interviewee with long experience in timber accounting stated:

“Things have surely become more complicated. At least one computer expert is required at each member company to assure that systems are working. The systems can also be difficult to learn how to use. In some cases, the SDC systems might make it harder for sellers and buyers to close timber deals.... The SDC has provided capabilities that have been very important for the members.”

The development has also led to stricter requirements of operational reliability. If a central node such as VIOL goes down, it the whole logging process will be severely disrupted.

5.5.2 Digitized decision support

The SDC sends measurement receipts to suppliers (forest owners) and buyers (sawmills). At the start of SDC operations, receipts were in paper format and sent by ordinary mail. Since 1969, the SDC also offers additional follow-up services to members. Today, members obtain receipts as paper documents and/or access information in VIOL via the timber information system (VIS) at the SDC and transfer that information to internal information systems for further processing. Members can also select specific reports from the system and order aggregate measurement receipts on a regular basis, such as per week or per month.

Södra can continuously access information on measurements performed in harvesters and at sawmills through VIOL and PRINS respectively. Södra also extracts information from VIOL and transfers it to internal information systems for further processing and refining.

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22 The interviewee worked with timber measurement and accounting between 1964 and 2002 and was employed for most of this time at the SDC.
Södra uses information in VIOL to compare results with plans. For instance, the results from the measurement station are used to determine how well a final delivery corresponds to the contract with the forest owner and how well the stand has been evaluated. Contractors and forest owners do not normally have access to information in VIOL.

Another aspect is how well the contractor has fulfilled the obligation of providing timber that corresponds to the contract. Making such determination is possible as each harvester has a unique identification number, which can be used to track timber to specific harvesters and operators. The sawmills can also obtain feedback on how well the processed timber matches the original order. The VMF at the measurement station has access to wood order information stored in VIOL.

The increasing number of points for capturing information in the logging process provides further opportunities for information usage. For example, one manager at the SDC stated:

“Information describing the production flow is merging with information describing the timber deal; this could be utilized…Important points of measurement in the process include the harvester, the forwarder, the truck and the point of delivery.”

**Effects of digitization**

Storage of timber measurement results in VIOL has led to faster access to information and improved support for decision-making. Stakeholders can access updated information more quickly for use in negotiations, planning and invoicing. Processing, refining and extraction of information have also been improved through VIOL.

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23 This interviewee has been working with timber flow related to logging and sawmilling since the 1990s and joined the SDC in 2003.
Moreover, digitization of information has facilitated the use and spread of information, leading to a freer flow of information among stakeholders. With each stakeholder better able to see what the others are doing, their knowledge and understanding of different parts of the timber flow is enhanced. For example, one manager at the SDC\textsuperscript{24} stated:

\begin{quote}
With greater openness due to the increased spread of information, it is now possible for individuals to see what other people are doing in the process and thereby to understand more about the different parts of the timber flow…Now that information can be more easily extracted, distributed and processed, there is greater transparency and there are fewer difficult discussions and disagreements…It is also easier to involve several persons in the same problem."
\end{quote}

VIOL constitutes an important information node in timber accounting. Information stored in one single place provides benefits to all stakeholders through equal access to updated information. With this step, information analysis in VIOL has become functional.

The development in decision support has enhanced creativity and competence on an individual level among stakeholders. Positions have become more qualified and require a higher level of skill. There has been a transformation toward more skilled and creative employees than those who used to punch measurement cards at the SDC and at Södra.

There is significant potential for further digitization of information throughout the timber flow. In the beginning, digitization was introduced mainly for purposes of rationalization, whereas today the tendency is toward providing faster access to information at various stages in the process. In the last five years, new services have been added, and there has been further innovation. Information describing the flow of production is merging with information on timber transactions and can be

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\textsuperscript{24} This interviewee has been working with timber flow related to logging and sawmilling since the 1990s and joined the SDC in 2003.
utilized for different purposes. Important measurement points include the harvester, forwarder, truck and point of delivery at the measurement station. New possibilities for information utilization are being detected as new points of measurement are established.

5.5.3 Comments on effects in measurement and follow-up

An overview of the effects of digitized information flows in the measurement and follow-up phase is presented in Table 5-4.

<table>
<thead>
<tr>
<th>Digitized information</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timber accounting</td>
<td>More open Swedish timber market</td>
</tr>
<tr>
<td></td>
<td>Increased efficiency in measurement registration</td>
</tr>
<tr>
<td></td>
<td>Quicker access to updated information</td>
</tr>
<tr>
<td></td>
<td>Enhanced opportunities for services</td>
</tr>
<tr>
<td></td>
<td>Higher quality of information</td>
</tr>
<tr>
<td></td>
<td>Lower costs of timber accounting</td>
</tr>
<tr>
<td></td>
<td>Greater complexity in work routines</td>
</tr>
<tr>
<td>Decision support</td>
<td>Quicker access to updated information</td>
</tr>
<tr>
<td></td>
<td>Improved support for decision-making and evaluation</td>
</tr>
<tr>
<td></td>
<td>Enhanced opportunities to refine information</td>
</tr>
<tr>
<td></td>
<td>Greater transparency and understanding of timber flow</td>
</tr>
<tr>
<td></td>
<td>More and better opportunities for services</td>
</tr>
<tr>
<td></td>
<td>Increased spread and use of information</td>
</tr>
<tr>
<td></td>
<td>Increased employee creativity and higher level of skill</td>
</tr>
</tbody>
</table>

Table 5-4 Effects of digitization in measurement and follow-up

The development in timber accounting has played a crucial important role in developments in logging. The SDC and especially VIOL have been pivotal in this regard. Most importantly, the Swedish timber market has opened up, allowing a large number of sellers and buyers to communicate, share information and close transactions. The VIOL system has supported this process by enabling access to updated information.
Other principal effects are related to the development in measurement registration and reporting. Increased efficiency, reduced risk of error and enhanced quality of information have been achieved through elimination of manual conversion and increased automation through the VIOL system. Also important has been the reduction in costs of timber accounting for SDC members.

Regarding decision support, the use of VIOL has increased access to information and the opportunity to refine and process it. This has enhanced the transparency of the timber flow and made it easier to understand. It has also provided improved support in decision-making and evaluation, and increased creativity and raised skill levels among stakeholders. New opportunities for the SDC to develop information services based on VIOL have also been identified.

5.6 Effects Identified in the Logging Process

The findings show that the digitization of information flows in the logging process has entailed a revolution over the last 40 years. Numerous effects of this development have been identified. These are summarized in this section.

5.6.1 Summary of effects

In planning and preparation
With the use of digital information from digital maps in stand evaluation, increased accuracy is obtained. This helps to improve control in forestry planning and also to optimize utilization of a stand. Using digital bucking instructions enhances flexibility and makes it easier to update information to reflect market demands. The storage of contracts and wood orders in VIOL has helped to provide involved stakeholders with quicker and greater access to more updated information. Digitized price information gives sawmills more flexibility in pricing and facilitates optimization of
timber transactions, as prices are more likely to reflect current market demands.

**In harvesting**

Digitized bucking support has had a wide range of effects. The possibility of subscribing to a remote maintenance service has permitted greater use of the harvester, for instance. However, decreased stability of the harvesting system due to dependence on the computer may limit utilization. With the risk of mistakes that could have severe consequences, there is a greater need for review and surveillance of bucking support. Other effects are increased differentiation and customization of timber and improved market opportunities. A further consequence is that operators are required to have a higher level of skills. The bucking computer has also permitted integration of additional computer applications.

Harvester reporting has mainly improved production follow-up and process control. In addition, more opportunities to utilize measurement results have been identified, and support for decision-making has been improved.

**In forwarding and transportation**

The storage of wood orders and transportation orders in VIOL has helped to give involved stakeholders quicker and greater access to more updated information.

**In measurement and follow-up**

Digitization in timber accounting has led primarily to a more open timber market in Sweden, but also to increased efficiency in measurement registration, lower costs for the members of the SDC, quicker access to updated information and better-quality information, which is now registered directly in VIOL with no need for conversion. Furthermore, increased opportunities for the development of additional information
services, but also greater complexity in work routines, have been identified.

The use of VIOL has contributed to quicker access to information and has enhanced opportunities to refine, spread and use it. This has in turn increased transparency and understanding of the timber flow, improved support for decision-making and evaluation, and provided more opportunities for services and for the development of creativity and skills among involved stakeholders.

5.6.2 Effects and affected stakeholders

Effects are summarized in Figure 5-12. It shows an overview of identified effects of the digitized information flows, as well as the stakeholders concerned.

The majority of identified effects are related to bucking support, timber accounting and decision support. These effects have resulted primarily from the introduction of the bucking computer in harvesting and the development of information systems for timber accounting at the SDC. These systems constitute the cornerstones that have made digitization of information possible in logging. The national timber accounting system (VIOL) is compatible with most information flows and is used throughout the logging process. Bucking-related systems (the bucking computer and the production information system, PRINS) are appropriate primarily for information flows in harvesting and follow-up.

In addition, all stakeholders are affected by the development in timber accounting and decision support. Overall, Södra and the contractors are the most extensively impacted stakeholders. The identified effects are further analyzed in Chapter 6.
Figure 5-12 Summary of identified effects and affected stakeholders
6. ANALYSIS OF EFFECTS OF DIGITIZATION

In this chapter, effects identified in the logging process are further assessed, and their nature is discussed based on some of the categories of effects identified in the literature. Effects considered to have a more direct impact on productivity are then evaluated. It is assumed that these effects are likely to have a direct impact on outputs and inputs of the logging process. Other effects that are less likely to influence inputs and outputs are also reviewed. Central effects are quantified to determine their importance. The results of the analysis are then summarized.

6.1 THE NATURE OF IDENTIFIED EFFECTS

In this section, the effects identified in the logging process are further discussed in terms of some of the categories identified in the literature in order to provide further insight into their various properties.

The following discussion of different effects involves a simple tool for categorization of effects presented by Mooney, Gurbaxani and Kraemer (1995), previously described in Chapter 3. The tool is based on three categories reflecting effects of IT on business value. Briefly, automational effects refer to the efficiency perspective of IT as a capital asset substituted for labor. Informational effects concern the use of IT to collect, store, process and distribute information. Transformational effects refer to facilitating and supporting process innovation and transformation through IT.

The increased efficiency in measurement registration is considered an automational effect, as IT in this case is used for eliminating conversion work. Lowering costs of timber accounting are a closely related benefit that is also considered an automational effect.
Better optimization of stand utilization, optimization of timber transactions and greater utilization of the harvester are considered informational effects, as IT is employed in these cases to optimize the use of resources through improved quality of decisions. Decreased stability in the harvesting system is also considered an informational effect, but in this respect, utilization of resources is reduced.

Increased control in forestry planning and improved production follow-up and process control are considered informational effects, as IT improves decision quality. This also includes greater and more widespread use of information, enhanced opportunities to refine information, increased support in bucking, improved decision support through harvester reporting as well as improved support for decision-making and evaluation.

More flexible information and better availability of updated information are considered informational effects that help to improve decision quality. In this respect, higher quality of information is also considered an informational effect.

However, quicker access to information is considered an automational effect, as IT improves efficiency by substituting labor. The greater need for review and surveillance is also considered an automational effect, but in this case IT gives rise to more work.

Added complexity of work routines in timber accounting, greater employee skills required in bucking, increased employee creativity and higher level of skill as well as greater transparency and understanding of timber flow are considered informational effects. The reason is that all these effects are related to the use of IT to process and spread information and thereby to empower employees.

Better adaptation to customer requirements, higher value of customized timber and increased market opportunities are considered transformational effects. In this respect, IT facilitates and supports
innovation and thereby responsiveness to customer needs, as well as product and service enhancements.

Furthermore, the increased opportunities for integration of computer applications in bucking, and for utilizing measurement results, as well as the enhanced opportunities for new services and decision support, are also regarded as transformational effects of IT’s innovative capacity.

A more open Swedish timber market is considered an informational effect. In this respect, IT has contributed to increased optimization and flexibility in the use of timber resources in market transactions. This is also viewed as a transformational effect, since IT has helped in the redesign of organizational structures between buyers and sellers on the timber market.

This brief analysis, which is summarized in Table 6-1, further explores some typical aspects of identified effects.

<table>
<thead>
<tr>
<th>Effects</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased efficiency in measurement registration</td>
<td>Automational</td>
</tr>
<tr>
<td>Lower costs of timber accounting</td>
<td></td>
</tr>
<tr>
<td>Increased optimization of stand utilization</td>
<td>Informational</td>
</tr>
<tr>
<td>Increased optimization of timber transactions</td>
<td></td>
</tr>
<tr>
<td>Increased utilization of harvester</td>
<td></td>
</tr>
<tr>
<td>Decreased stability in harvesting system</td>
<td></td>
</tr>
<tr>
<td>Increased control in forestry planning</td>
<td>Informational</td>
</tr>
<tr>
<td>Increased support in bucking</td>
<td></td>
</tr>
<tr>
<td>Improved production follow-up and process control</td>
<td></td>
</tr>
<tr>
<td>Improved support for decision-making</td>
<td></td>
</tr>
<tr>
<td>Increased spread and use of information</td>
<td></td>
</tr>
<tr>
<td>Improved support for decision-making and evaluation</td>
<td></td>
</tr>
<tr>
<td>Enhanced opportunities to refine information</td>
<td></td>
</tr>
<tr>
<td>Effects</td>
<td>Category</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Increased flexibility in, and availability of, updated</td>
<td>Informational</td>
</tr>
<tr>
<td>bucking support</td>
<td></td>
</tr>
<tr>
<td>Increased flexibility in price management</td>
<td></td>
</tr>
<tr>
<td>Increased availability of updated information</td>
<td></td>
</tr>
<tr>
<td>Higher quality of information</td>
<td></td>
</tr>
<tr>
<td>Quicker access to updated information</td>
<td>Automational</td>
</tr>
<tr>
<td>Increased need for review and surveillance</td>
<td></td>
</tr>
<tr>
<td>Greater complexity in work routines</td>
<td>Informational</td>
</tr>
<tr>
<td>Greater employee skills required</td>
<td></td>
</tr>
<tr>
<td>Increased employee creativity and higher level of skill</td>
<td></td>
</tr>
<tr>
<td>Greater transparency and understanding of timber flow</td>
<td></td>
</tr>
<tr>
<td>Improved adaptation to customer needs</td>
<td>Transformational</td>
</tr>
<tr>
<td>Increased value of customized timber</td>
<td></td>
</tr>
<tr>
<td>Increased market opportunities</td>
<td></td>
</tr>
<tr>
<td>Increased opportunities for integration of computer applications</td>
<td>Transformational</td>
</tr>
<tr>
<td>Increased opportunities to utilize measurement results</td>
<td></td>
</tr>
<tr>
<td>More and better opportunities for services</td>
<td></td>
</tr>
<tr>
<td>More open Swedish timber market</td>
<td>Informational/</td>
</tr>
<tr>
<td>Transformational</td>
<td>Transformational</td>
</tr>
</tbody>
</table>

**Table 6-1 Overview of automational, informational and transformational effects identified in the studied logging process**

It shows that the majority of effects belong in the informational category, as defined by Mooney, et al. (1995). Effects in this category are mainly related to the use of information and to the information itself; they include increased flexibility and availability, optimized use of resources, follow-up and control, quality, adaptation to customer requirements, integration, skills and creativity and general understanding.

Only a few effects fall into the automational category, as defined by Mooney, et al. (1995). These include reduced costs and labor savings in timber accounting, especially in administrative work, and through quicker access to information.
Some effects are also considered transformational, as defined by Mooney, et al. (1995). These are related to IT as support for innovation and transformation and include for instance a more open timber market, increased adaptation to customer needs and development of new services.

This brief analysis demonstrates the multifaceted effects of IT identified in the logging process. Most effects have been classified into a single category. However, a more open timber market overlaps both the informational and transformational categories. Other effects such as increased availability of updated information, and quicker access to it, are closely related but separated into different categories.

6.2 Effects with a Direct Impact on Productivity

The following discussion concerns effects from a productivity perspective. The discussion concentrates on the extent to which effects have a direct impact in terms of productivity as traditionally measured, with a focus on inputs and outputs of the logging process.

Some simple mathematical examples are used to illustrate how effects can be quantified to determine their importance. These examples are based on indicators collected from interviews and documentation.

The emphasis in this section is on quantifying direct effects on inputs and/or outputs of the logging process that are likely to show up in conventional productivity measurements. Some of the other effects are quantified in the next section (6.3).

6.2.1 Labor savings

Increased efficiency in registration of measurements is considered to have a positive impact in terms of input if it results in labor savings. Hence, the number of employees at the SDC and Södra are used here to indicate the importance of this effect.
The number of SDC employees increased between 1989 and 2003 from 45 to 101. The SDC had more than 340 employees in 1981-1982, before the major reorganization where subsidiaries were phased out. This indicator is misleading, however, since no distinction is made between employees working daily with measurement registration and those involved in development of new services. In order to use the number of employees as an indicator, one must determine how many of the total number of employees worked with handling and conversion of information.

The number of employees handling measurement information at the SDC is considered to have been significantly reduced by digitization in timber accounting. Earlier, about 30-35 employees were converting written documents to digital format. Today, many employees are occupied with development of new services and systems operations and support.

The increased efficiency in measurement registration has also affected Södra. It can be assumed that the number of employees handling measurement information at Södra has been significantly reduced as an effect of the development at the SDC.

Another indicator is the number of measurement stations connected to the SDC, which has steadily grown during the years. For example, in 2003 there were 378 PC installations at the measurement stations compared to 170 in 1994.

In order for effects such as quicker access to updated information and increased need for review and surveillance to show up in productivity measurements, they need to have a substantial influence on labor input, for instance in terms of hours worked or number of employees. It is assumed, however, that they only have a limited impact on labor and therefore are of minor importance in terms of productivity.
6.2.2 Other cost savings

The lower costs of timber accounting are also considered to have a positive impact in terms of input as SDC members now pay less for timber accounting.

Regarding the price of timber accounting that each member of the SDC pays per registered cubic meter in VIOL, it has decreased slightly over the years. It remained largely unchanged after the end of 1980s, varying marginally between 0.48 and 0.56 SEK from 1988 to 2003. Today it is about 0.50 SEK.

However, while price levels have been more or less stable in recent years, there has been an increase in the amount of information collected and available. More importantly, the timber volumes registered in VIOL have steadily increased. From 1988 to 2003, they almost doubled, from 66 to 114 million m³.

The timber accounting cost per cubic meter is considered to be small, but since large volumes are handled through the VIOL system, even very small changes in price levels can have quite a substantial impact on the members.

6.2.3 Use of resources

Improved use of machinery is considered to have a direct positive impact on input as fewer resources are needed in production. However, with an increased need for review and surveillance, there is also a negative impact in terms of input.

Regarding harvesters, the bucking computer systems have made remote troubleshooting and failure repair possible. This in turn has raised the increased level of utilization. A typical indicator for evaluating harvester performance is operational time, which also measures how much time is lost in case of failure.
In general terms, modern harvesters can be used 24 hours a day, and harvesters are now used more than before the bucking computer was introduced. The increased utilization of harvesters is considered to have improved productivity significantly. However, compared to hydraulics and mechanics, the bucking computer is only considered to have had limited positive effect on harvester performance.

Improved optimization of stand utilization and timber transactions is considered to have a direct positive impact on output as the standing timber is better evaluated and utilized in timber production. This implies fewer miscalculations in stand evaluation and a better fit between delivered timber and customer expectations.

With greater support in site evaluation and a better fit of resources to market demands, it is assumed that overall efficiency in utilization of forest resources has improved. The increase in output is therefore considered to show up in productivity measurements.

6.3 **EFFECTS WITH NO DIRECT IMPACT ON PRODUCTIVITY**

The discussion below is devoted to analysis of identified effects that are considered not to have any direct influence on inputs and/or outputs of the logging process. Therefore, these effects are less likely to show up in conventional measurements of productivity.

Simple mathematical examples are used to illustrate how effects can be quantified in order to determine their importance. The examples are based on indicators obtained from interviews and documentation.

6.3.1 **Market structure**

The more open Swedish timber market achieved through digitization of timber accounting is considered not to have had any direct impact on the input or output of the logging process. But it is judged to have significantly affected market structure in terms of network synergies.
The network synergies are related to the standardization aspect of the timber accounting system developed at the SDC. The more buyers and sellers of timber that join the SDC, the more value derives from the system, and this increased value is assumed to be the primary benefit to members. The network synergies are quantified here by the number of SDC members and the timber volumes managed through the SDC systems.

During the initial period of the SDC, the number of members increased steadily from 16 in 1961-1962 to 52 in 1969-1970. Since then, the number of members has been roughly the same, varying from 48 to 54 between 1990 and 2003.

However, the markets have been significantly transformed during these decades; companies have merged, new companies have emerged, international competition has increased, for example. For instance, the number of sawmill companies indirectly members of the SDC decreased from some 330 sawmills in 1990-1998 to about 250 in 2000-2002. In 2003 the number of sawmill company members was only 130. This development is evidence of ongoing consolidation in the sawmill industry.

Another indicator is the timber volumes reported through the SDC systems, where there has been a steady increase from 54.2 million m$^3$ in 1973 to 56.8 million m$^3$ in 1983, 73.3 million m$^3$ in 1993 and 114 million m$^3$ in 2003.

Since it can be assumed that most buyers and sellers of timber in Sweden are members of the SDC, in view of the timber measurement laws and regulations in Sweden, a more open timber market is considered to have been important for buyers and sellers of timber as well as society at large. Since this effect is widespread and does not directly influence inputs and outputs, it is considered not to show up in conventional productivity measurements.
6.3.2 Product value and customer relations

The increases in adaptation to customer needs, in the value of customized timber and in market opportunities achieved through digitized bucking support are considered not to have had any direct impact on input or output in the logging process. Primarily, these effects are judged to have been significant for product value and competitiveness related to product variety, customer service and customer surplus.

The development of more assortments and increased diversification of timber products can be regarded as consequences of a growing market for specific timber assortments and customized timber. Greater demand for specific fiber characteristics of pulpwood is also seen in pulp and paper production. In addition, further applications for timber have developed, such as biofuel.

Enhanced customer service and customization of timber have gone hand in hand with increasing competitiveness and the emergence of new markets with specific requirements such as the Japanese construction industry. For example, about 80 percent of the total output of the Södra Mösterås Sawmill is exported to the USA, Great Britain and Japan. In view of the growing international competition, it can be assumed that the international timber market will become increasingly important for many Swedish companies, especially in customized timber production. In addition, with widespread implementation of bucking computers, most large forest companies in Sweden will likely have an interest in further increasing their international competitiveness through customization.

Regarding value to customers, it is assumed that buyers of specialized timber initially pay a higher price compared to buyers of timber in general. Hence, producing companies such as forestry operators, sawmills and contractors benefit from customized timber at the start. However, with the growing importance of customization and increasing price pressure, the higher prices of customized products are likely to decrease, favoring
customers. It is thus assumed that the initial benefits to producing companies will be transferred to customers in the longer term.

Regarding the bucking computer, it is considered an embedded technology because it is integrated into a larger system of harvester technology. Since an investment in a harvester\(^{25}\) is likely to be classified as an investment in machinery rather than IT, investments in harvester technology are traditionally categorized in the same way, i.e. as machinery and not in IT, even though modern harvesters are equipped with advanced IT support. This indicates that the bucking computer is not accounted for as an IT investment in previous studies based on conventional productivity measurements.

With intensified competition and price pressure on the timber market, increased product variety and customization are likely to have a significant impact in terms of value to customers, or customer surplus. These customer-oriented effects, which do not directly extend to inputs and outputs of the process, are considered not to show up in conventional productivity measurements.

### 6.3.3 Control, decision support and access to information

Increased control in planning, support for decision-making and evaluation, improved production follow-up and process control, enhanced opportunities to refine, spread and use information, increased flexibility in and availability of updated information and higher quality of information through digitization of several information flows throughout the logging process – none of these effects is assumed to have any direct impact on the input or output of the process. Rather, they are considered to

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\(^{25}\) The cost of a new harvester is 3.5-4.5 million SEK. The bucking computer system, including training and adjustments, constitutes about 5 percent of this investment (175 000-225 000 SEK).
influence control, decision-making and access to information in the process.

With the increased control and decision support in many parts of the process, it is likely that a better decision quality has been achieved. This kind of impact seems difficult to quantify. One indication of the importance of bucking support may be a comparison between harvester measurement results and results from sawmill measurement stations. The importance of production follow-up in terms of improved decision support may be illustrated with indicators related to selection of contractors. Indicators showing mistakes, failures and misunderstandings in the process may also be used.

The importance of flexibility, quality, availability, access, refinement, spreading, etc. related to information also seems difficult to quantify. Given the widespread use of information throughout the logging process, access to information is assumed to be important in this process.

For example, lead-time indicators can demonstrate the importance of information. How long it takes to handle timber from the forest to the sawmill can be shown by the time required per timber transaction in VIOL, from registration of the wood order to reporting of measurement results. However, the inflow of timber from the forest is uneven, with large seasonal variations, and the capacity of measurement stations and sawmills is limited. So far, lead-times are of minor importance to involved stakeholders, but several SDC members have recently requested further services for follow-up on lead-time.

Since information is widely accessed throughout the logging process and used for different purposes, information itself is considered important to stakeholders involved in the process. But despite the widespread impact of these information-focused effects, they do not directly influence inputs and outputs; therefore, they are considered not to show up in conventional productivity measurements.
6.3.4 Skill levels

The greater complexity of work routines and required skills, increased employee creativity and higher levels of skill, as well as the greater transparency and understanding of timber flow achieved through digitization of several information flows throughout the logging process – none of these are considered to have any direct impact on the input or output of the process. Primarily, these effects are associated with the general level of skills among employees involved in the process.

The development of computer skills seems to have been especially important for involved stakeholders. The SDC has assumed the role of developing expert skills in digital timber accounting, thus stimulating members to develop internal computer skills. Contractors have also developed skills to manage the bucking computer. Thus, higher skill levels seem to have major importance for many involved stakeholders.

During bucking, for example, the harvester operator takes the final bucking decisions even though the computer suggests how to cut the logs into lengths. The reason is the risk of severe losses in timber value in case of mistakes in bucking support. With manual control of the support, mistakes can be detected. Indicators of increased operator skills can include education and training, perceived motivation and variation in tasks.

Another example is reduction of somewhat monotonous tasks involving manual information processing, such as registration of measurement results, which have been replaced by more qualified tasks. With digital information present in daily tasks, users may also start to consider new applications for information.

In view of the higher skill levels required in the logging process, employee skills are considered important to stakeholders involved in the process. However, these effects do not directly influence inputs and outputs and
are not considered to show up in conventional productivity measurements.

6.3.5 Innovation

The greater possibilities of integrating computer applications and utilizing measurement results, as well as the enhanced opportunities for services, are considered not to have any direct impact in terms of input or output of the process. These effects relate primarily to innovation in logging.

In parallel with the development of core functionality in bucking computer systems and timber accounting, for instance, additional services have been developed. Two examples are the harvester and forwarder reporting functions. In 2001, about 150 harvesters had installations for production reporting. In 2002 the figure was 190, and by 2003 the number of installations in harvesters had skyrocketed to 559. In 2003, the number of installations for forwarder reporting reached 250 units, and a volume of 26 million m³ was registered from harvesters and forwarders (in addition to the reported volumes in 2003 of 114 million m³).

With the increasing integration of applications in bucking computers and a growing demand from SDC members for additional information services, innovation is likely to be even more important in the future. However, the innovative impact does not directly influence the input and output of the process and is not considered to show up in conventional productivity measures.

6.4 Effects and Their Impact

The analysis of effects is presented in Table 6-2 and Table 6-3 below.

In Table 6-2, effects that are considered to have a direct impact in terms of productivity, through either input or output, are shown. The area of impact describes the means by which the effect influences input or output. A negative input (−) or a positive output (+) means that the effect
on productivity is positive, while the effect is negative if input is positive (+) and output is negative (-).

<table>
<thead>
<tr>
<th>Effects with direct impact on productivity</th>
<th>Area of impact</th>
<th>Impact on I/O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased efficiency in measurement registration</td>
<td>Labor</td>
<td>-Input</td>
</tr>
<tr>
<td>Lower costs of timber accounting</td>
<td>Costs</td>
<td>-Input</td>
</tr>
<tr>
<td>Increased optimization of stand utilization</td>
<td>Resource use</td>
<td>+Output</td>
</tr>
<tr>
<td>Increased optimization of timber transactions</td>
<td>Resource use</td>
<td>+Output</td>
</tr>
<tr>
<td>Increased utilization of harvester</td>
<td>Resource use</td>
<td>-Input</td>
</tr>
<tr>
<td>Decreased stability in harvesting system</td>
<td>Resource use</td>
<td>+Input</td>
</tr>
<tr>
<td>Quicker access to updated information</td>
<td>Labor</td>
<td>-Input</td>
</tr>
<tr>
<td>Increased need for review and surveillance</td>
<td>Labor</td>
<td>+Input</td>
</tr>
</tbody>
</table>

**Table 6-2 Effects with direct impact on productivity**

In Table 6-3, effects that are considered to have no direct impact in terms of productivity are shown. The area of impact describes the primary means of influence of effects.

<table>
<thead>
<tr>
<th>Effects with no direct impact on productivity</th>
<th>Area of impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>More open Swedish timber market</td>
<td>Market structure</td>
</tr>
<tr>
<td>Improved adaptation to customer needs</td>
<td>Product value</td>
</tr>
<tr>
<td>Increased value of customized timber</td>
<td>Product value</td>
</tr>
<tr>
<td>Increased market opportunities</td>
<td>Competitiveness</td>
</tr>
<tr>
<td>Increased control in forestry planning</td>
<td>Control</td>
</tr>
<tr>
<td>Improved production follow-up and process control</td>
<td>Control</td>
</tr>
<tr>
<td>Increased support in bucking</td>
<td>Decision support</td>
</tr>
<tr>
<td>Improved support for decision-making and evaluation</td>
<td>Decision support</td>
</tr>
<tr>
<td>Increased spread and use of information</td>
<td>Information access</td>
</tr>
<tr>
<td>Enhanced opportunities to refine information</td>
<td>Information access</td>
</tr>
<tr>
<td>Increased flexibility in, and availability of, updated bucking support</td>
<td>Information access</td>
</tr>
<tr>
<td>Increased flexibility in price management</td>
<td>Information access</td>
</tr>
<tr>
<td>Increased availability of updated information</td>
<td>Information access</td>
</tr>
</tbody>
</table>

139
Table 6-3 Effects with no direct impact on productivity

<table>
<thead>
<tr>
<th>Effects with no direct impact on productivity</th>
<th>Area of impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher quality of information</td>
<td>Information access</td>
</tr>
<tr>
<td>Greater complexity in work routines</td>
<td>Skill levels</td>
</tr>
<tr>
<td>Greater employee skills required</td>
<td>Skill levels</td>
</tr>
<tr>
<td>Increased employee creativity and higher level of skill</td>
<td>Skill levels</td>
</tr>
<tr>
<td>Greater transparency and understanding of timber flow</td>
<td>Skill levels</td>
</tr>
<tr>
<td>Increased opportunities for integration of computer applications</td>
<td>Innovation</td>
</tr>
<tr>
<td>Increased opportunities to utilize measurement results</td>
<td>Innovation</td>
</tr>
<tr>
<td>More and better opportunities for services</td>
<td>Innovation</td>
</tr>
</tbody>
</table>

Despite difficulties in quantifying effects in detail based on the information collected during this study, the results of the analysis can give a rough indication of the impact of various effects.

Effects considered to have a major direct impact on productivity include increased efficiency in measurement registration and lower costs of timber accounting. The increased utilization of harvesters and forest resources is also considered to have a direct impact. On the other hand, quicker access to information and increased need for review and surveillance are likely to have only a minor direct impact on productivity.

Some effects are assumed not to have any direct impact on productivity but are still considered to be of major importance; these include a more open timber market and effects related to timber customization. These effects have influenced and are still influencing the structure of the whole Swedish timber market. Effects related to control, decision-making and access to information, as well as to skill levels, are also regarded as important to most stakeholders in the logging process. Furthermore, effects related to innovation are likely to have at least significant future potential for the logging industry.
The results of the analysis demonstrate that only a few effects directly impact productivity and thus that a large number of significant effects do not. Consequently, most identified effects are not expected to show up in conventional measurements of productivity. Some implications of these results are further discussed in the conclusions (Chapter 7).
7. CONCLUSIONS

7.1 EFFECTS OF IT

The IT and productivity paradox has been the subject of considerable research in recent decades. Many previous studies, based mainly on macroeconomic statistics or on aggregated company data, have reached disparate conclusions. Consequently, the question whether IT investments contribute to productivity growth is still heavily debated. An important milestone in this debate was the following statement by Solow in 1987: “You can see the computer age everywhere but in the productivity statistics.”

More recent research, however, has indicated that IT contributes positively to economic development but that this contribution is not fully revealed when only productivity is measured.

To explore the issue of IT and productivity further, the ITOP (Impact of IT On Productivity) research program was launched in 2003. Using an alternative research approach, this study examines various effects of IT and discusses how these could be evaluated in terms of productivity.

The purpose of this study has been to explore effects of information technology by studying digitized information flows in key processes in the logging industry. Two research questions have been addressed: 1) How have information flows in the logging process changed over time because of digitized information? 2) How can the effects of this development be evaluated in terms of conventional measures of productivity?

Results show that the development of digitized information in the logging process has entailed significant changes in information flows throughout the process over the period studied. New ways to capture, use, spread, process, refine and access information have emerged, and the introduction of different types of IT has contributed to this development.
The digitization of information has also generated a large variety of effects.

The developments in timber accounting and bucking are considered to have had the most important effects on the logging process. The SDC infrastructure has contributed to efficiency gains in the administration of timber transactions and to standardization in the timber accounting systems used by buyers and sellers on the Swedish timber market. The bucking computer has permitted increased customization of timber and a wider variety of assortments.

In terms of productivity, the results show that only a minor part of the effects identified have a direct impact on productivity and thus that a large number of significant effects do not. This both confirms the productivity paradox and explains why it exists.

Those effects with a major direct impact include increased efficiency in measurement registration, lower costs of timber accounting and increased utilization of harvesters and forest resources. Other significant effects with no direct impact are related to a more open timber market, increased timber customization, control, decision-making and access to information, as well as skill levels and innovation.

The results further indicate that conventional measures of productivity are not sufficient for demonstrating the various effects of IT. There is little doubt that IT has had a significant contribution to the development of the logging process, even though it does not show in conventional productivity measures. It is difficult to imagine how the logging process had developed if information flows had not been digitized and there had been no investments in IT.

### 7.2 The Role of IT in the Logging Process

Information has had an important role in the logging process since the very first timber transactions in Sweden. Information is necessary to
conduct timber transactions and to ensure reliability for buyers and sellers. While information has long played a central role in the process, IT (digitization) is a more recent phenomenon.

The development of digitized information in the logging process described in this study can illustrate the advance of IT as a general-purpose technology (GPT). Even though some steps still remain before IT is fully integrated into the logging process, the study indicates that IT is becoming more and more prevalent in procedures and daily routines. The development of IT in the logging process may also affect other processes and industries, with an impact on the entire economy and society.

Given the complex transformation made possible by a GPT, it will take time before benefits of IT are exploited and show up in economic statistics. With a large potential for exploitation of future benefits from the use of IT in the logging industry, it is expected that IT will have a powerful impact on the economy, at least in the long term.

Furthermore, there are synergies between different types of IT as well as interaction with other types of technologies. Since IT is integrated with its surroundings and also interacts with other technologies and organizational contexts, the development of IT is dependent on other technological and organizational advancements. In general, this development evolves primarily in small steps and at a varied pace in different areas where IT is applied. This interactive development may be said to have ratchet effects, implying that progress depends on consolidation of previous advances involving contextual factors.

Other phenomena that make it difficult to estimate effects of IT development are consumer surplus and network synergies. The contribution of IT in terms, for instance, of increased variety of products and a higher level of service, is primarily in the form of benefits to consumers. Since these benefits are often intangible, they are also difficult to estimate. In addition, the benefits of IT may increase with the number of users. The time factor is important for network effects, with the
principal benefits occurring primarily in the longer term. Another time-related aspect is that information captured for one purpose may be utilized for other purposes in the future. As new applications can arise over time, the benefits of information depend not only on its current use, but also on its possible future applications.

In view of the high degree of integration and interaction in IT, it seems difficult to isolate the IT component from its surrounding context when estimating the benefits of IT development. The more IT is integrated into our daily lives, the more difficult it will be to isolate and estimate its contribution alone. With further integration and interaction of IT with its context, trying to isolate its impact seems less and less important, despite its relevance today. In other words, it may well be of little interest to determine the impact of IT and digitization in the future. More likely, the future focus will be on estimating the influence of other new emerging technologies on economic development.

7.3 QUALITY OF RESULTS

High quality of results is ensured primarily through certain actions taken in data collection and analysis as well as through comparison with other research results.

As mentioned in Chapter 2, data have been collected from overlapping sources. Data from interviews have also been supplemented with documentation and interviews have been conducted with interviewees in various roles, including researchers, practitioners and experts, to ensure overlap of information. Overlapping data were also collected through several interviews with representatives of similar fields as well as representatives of different perspectives on the process. In addition, informants have reviewed the case study description, and data have been carefully organized and documented.

Moreover, useful discussions in the ITOP research program have been held during data collection and analysis. The collaboration in the ITOP
program has made it possible to compare the present results with those of the studies conducted by Cöster (2005) and Horzella (2005). With specific industry characteristics taken into consideration, the overall findings from the logging industry are similar to those from the graphic industry and grocery distribution. This implies that results are applicable in still other industries besides logging.

Even though the approach adopted in this study is different from that of many other previous studies, the results agree with several general conclusions of previous research.

With results showing that the majority of identified effects of digitization in the logging process have no direct impact on productivity, most benefits of IT are not expected to show up in conventional productivity measurements. Hence, it is assumed that these benefits are not included in many of the previous studies on the productivity paradox, which are based mainly on aggregate data (see for instance Strassmann, 1990; Jorgensen and Stiroh 2000; Oliner and Sichel 2000; Whelan 2000; Council of Economic Advisers, 2001; Jorgenson, 2001; Stiroh, 2001).

The results are largely consistent with the later current of research on the productivity paradox represented by Brynjolfsson and others (see for instance Brynjolfsson, 1993; Brynjolfsson and Yang, 1996; Brynjolfsson and Hitt, 1998). According to this view, the types of intangible benefits attributed to IT, such as increased quality, variety and customer service, are poorly accounted for in productivity statistics.

Since the findings also indicate that IT could be considered a GPT, this study supports the various views of scholars like Romer (1997), Lipsey, et al. (1998), David and Wright (1999) and David (2000). In addition, effects regarding both consumer surplus and network synergies have been identified, in consistency with research by Hitt and Brynjolfsson (1996), Shapiro and Varian (1999) and Brynjolfsson, Hu and Smith (2003) for instance.
Since the results indicate that only a few effects of IT show up in measurements of productivity alone, it is questionable whether conventional productivity measures are sufficient for measuring the impact of IT. This view agrees with the research of Brynjolfsson and others, who criticize the use of traditional productivity measures for evaluating the role of IT in economic development (see for instance Brynjolfsson, 1993; Brynjolfsson and Hitt, 1998; 2000).

The research approach adopted here has helped in studying effects of IT in detail in a specific context over a longer period. The context is important for understanding the specific properties of effects and their realization as benefits. As these aspects are often lacking in previous research, the detailed description in this study of many different effects of IT over a longer period in the logging industry may be considered a significant contribution.

Another contribution of this study is that it provides a rough indication of the importance of various effects that have no direct impact on productivity. Previous research has shown mainly that some effects are difficult to capture in productivity measurements, and certain intangible effects have been identified (see for instance Brynjolfsson, 1993; Lucas, 1999). However, since these are difficult to estimate in quantitative terms, few studies have been undertaken to quantify them (see for instance Brynjolfsson, 1996; Hitt and Brynjolfsson, 1996; Brynjolfsson, et al., 2003).

Empirically, the results are also consistent with the impression that IT has had a limited impact on productivity in the logging industry. For example, aggregate-level statistics from SkogForsk (1997) and Södra Skog do not show that IT investments have contributed to lower costs or higher
productivity in logging operations in recent decades. This indicates that in logging operations “computers can be seen almost everywhere but in the statistics on logging costs”. However, there is a strong belief in the industry that investments in IT would contribute to further productivity growth.

7.4 Suggestions for Further Research

This analysis gives an indication of the type of effects that may show up in conventional measurements of productivity. However, more research based on an approach similar to the one applied in this study is needed to provide further details on effects, including their impact on inputs and outputs and thus on productivity. A more detailed quantitative evaluation is also needed to furnish more exact figures on the importance of various effects.

If we are to understand more about the role of IT in various contexts, we need to compare results from different industries. This is essential for identifying which effects are industry-specific and which are more general to their character. Furthermore, comparison of results from the logging and graphic industries, and from grocery distribution, may be supplemented with empirical data from additional industries.

Determining the impact of IT appears to be a difficult task. Since this study shows that productivity is not likely to suffice as a measure for this purpose, research on alternative measures is suggested. For quantitative evaluation of effects, it would be valuable to conduct research on tools that could involve a set of existing measures, combinations of measures or altogether new types of measures.

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REFERENCES


154


### APPENDIX A - KEY TERMINOLOGY AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation/English term</th>
<th>Description (Swedish term)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVS system</td>
<td>The first timber accounting system for the south of Sweden at SDC (Avverkningsystem för södra Sverige). This was replaced by VIOL in the beginning of 1980s.</td>
</tr>
<tr>
<td>Bucking</td>
<td>Division of logs into different assortments (aptering)</td>
</tr>
<tr>
<td>DASA</td>
<td>ESE Technique’s computer system for bucking (Datorstödd Aptering)</td>
</tr>
<tr>
<td>Forwarder</td>
<td>A machine used for transport of logs or trees in forest terrain. Logs are carried completely off the ground (skotare)</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System for Mobile Communication</td>
</tr>
<tr>
<td>Harvester</td>
<td>A logging machine used for felling and reprocessing of logs (skördare)</td>
</tr>
<tr>
<td>KOLA</td>
<td>An internet based computer system for timber transports of Södra Skogsägarna and Sydved (Kommunikation Lastbil)</td>
</tr>
<tr>
<td>Landing</td>
<td>Location close to the logging area by the roadside where logs are piled for transport to the sawmill (avlägg)</td>
</tr>
<tr>
<td>Limbing</td>
<td>Removing of twigs and branches from the logs (kvistning)</td>
</tr>
<tr>
<td>Log</td>
<td>Part of tree trunk which is cut and limbed (stock)</td>
</tr>
<tr>
<td>Log tally</td>
<td>List of number of logs in different dimensions (stocknota)</td>
</tr>
<tr>
<td>Logging</td>
<td>Felling and extraction of timber (skogsavverkning)</td>
</tr>
<tr>
<td>PRINS</td>
<td>A production information system at SDC for harvester and forwarder reporting (Produktionsinformationssystem)</td>
</tr>
<tr>
<td>SDC</td>
<td>The Forestry Computing Centre (Skogsbruks Datacentral Ekonomisk Förening)</td>
</tr>
<tr>
<td>Abbreviation/English term</td>
<td>Description (Swedish term)</td>
</tr>
<tr>
<td>---------------------------</td>
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</tr>
<tr>
<td>Single grip harvester</td>
<td>A harvester with one unit for both felling and reprocessing of logs (engreppsskördare)</td>
</tr>
<tr>
<td>Skidder</td>
<td>A machine for dragging logs partially or entirely on the ground (lunnare)</td>
</tr>
<tr>
<td>SkogForsk</td>
<td>The Forest Research Institute in Sweden (Svenska skogsbrukets forskningsinstitut)</td>
</tr>
<tr>
<td>SNVDB</td>
<td>The national forest road database (Skoglig Nationell Vägdatabas)</td>
</tr>
<tr>
<td>Stand</td>
<td>A group of trees (bestånd)</td>
</tr>
<tr>
<td>Timber measurement</td>
<td>Specification of a consignment's quantity, dimensions, volume or mass and evaluation of the nature of the wood and the adequacy for its designated purpose (virkesmätning)</td>
</tr>
<tr>
<td>TITAN</td>
<td>The internal information system of Södra Skog for planning and contracting of logging operations</td>
</tr>
<tr>
<td>Two-grip harvester</td>
<td>A harvester with separate units for felling and reprocessing respectively of logs (tvågreppsskördare)</td>
</tr>
<tr>
<td>VIL</td>
<td>The new integrated information system of Södra (Virkesinformationslager)</td>
</tr>
<tr>
<td>VIOL</td>
<td>The wood measurement system at the SDC (Virkesmätning Online)</td>
</tr>
<tr>
<td>VIS</td>
<td>Service provided by the SDC for members to access information about timber deals (Virkesinformationssystem)</td>
</tr>
<tr>
<td>VMF</td>
<td>The Timber Measurement Associations (Virkesmätningsföreningarna)</td>
</tr>
<tr>
<td>VMR</td>
<td>The Swedish Timber Measurement Council (Rådet för virkesmätning och redovisning)</td>
</tr>
<tr>
<td>Wood order</td>
<td>Contains information about for instance timber identity, location and destination of timber, and measurement principles (virkesorder)</td>
</tr>
</tbody>
</table>
APPENDIX B - INTERVIEW GUIDELINES

Examples of questions for obtaining a general overview of important milestones in the IT development related to the logging process:

- What are the most important milestones regarding the IT development in logging?
- Which type of IT is used in logging today and when were different types of IT introduced?

Examples of questions for understanding the logging process as of today regarding timber and information flows:

- What activities are carried out and what parties are involved in the process?
- How are the timber flow and information flows?

Examples of questions for understanding how the logging process has developed over time regarding timber and information flows, due to digitization of information:

- How has the timber flow changed over time due to digitization?
- How have information flows changed due to digitization?

Examples of questions for understanding the effects of digitization in the logging process:

- Which are the major effects of digitization of information in the process?
- How could these effects be evaluated (in economic terms or other values)?
## Appendix C - Interviewees

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Interview focus</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andersson, Gert</td>
<td>Program Manager, Logistics department, SkogForsk</td>
<td>Development in logging and effects 2004-09-08</td>
</tr>
<tr>
<td>Andersson, Johan</td>
<td>Project Manager, Productivity, Södra Skogsägarna</td>
<td>Opportunities for evaluation of effects 2004-10-12 2005-01-11</td>
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<td>Andersson, Per</td>
<td>Sawmill Quality Manager, Callans Trä</td>
<td>Sawmill process 2004-10-22</td>
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<tr>
<td>Arborelius, Johan</td>
<td>Head of VIOL Development and Management, SDC</td>
<td>Development in timber accounting and effects 2005-01-14</td>
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<td>Arlanger, John</td>
<td>Researcher, Wood utilization department, SkogForsk</td>
<td>Development in logging and effects 2004-09-08</td>
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<td>Bergman, Björn</td>
<td>Head of Business Development and Logistics, SDC</td>
<td>Development in logging and effects Opportunities for evaluation of effects 2005-01-14</td>
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<td>Davidsson, Göran</td>
<td>Manager (retired), Timber accounting, Södra Skogsägarna</td>
<td>Development in logging 2004-06-04</td>
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<tr>
<td>Eriksson, Jörgen</td>
<td>Software architect and designer, ESE Technique AB</td>
<td>Development in harvesting and effects 2004-09-06</td>
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<td>Gransvik, Kjell</td>
<td>CEO, ESE Technique AB</td>
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<td>Gustafsson, Thomas</td>
<td>Sawmill Manager, Södra Timber Mönsterås</td>
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<td>Hagblom, Jan</td>
<td>Manager, Timber measurement and accounting (retired), SDC</td>
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<td>Hedin, Magnus</td>
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<td>2005-01-14</td>
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<td>Manager, Business development and logistics, SDC</td>
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<td>Magnusson, Ulf</td>
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<td>Head of VMR, SDC</td>
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<td>Olovsson, Pär-Anders</td>
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<td>Harvester operator, Bröderna</td>
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<td>Director, Forestry technology, Södra Skogsägarna</td>
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<td>Manager in Timber processing, Forestry technology, Södra Skogsägarna</td>
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<tr>
<td>Sjöberg, Lars</td>
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<td>2004-10-12</td>
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<td>Product Manager, Södra Timber Mönsterås</td>
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<td>Thor, Magnus</td>
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<td>Program Manager, Technology department, SkogForsk</td>
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</tbody>
</table>
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42. **Christina Keller** (2005), *Virtual Learning Environments in higher education. A study of students' acceptance of educational technology*, lic.-avh. No. 1167 IDA-EIS, Universitetet och Tekniska Högskolan i Linköping.


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Licentiate theses (2004- )


5. **Stoltz, Charlotte (2004).** *Calling for Call Centres - A Study of Call Centre Locations in a Swedish Rural Region,* lic-avh. No. 1084, IDA-EIS, Universitetet och Tekniska Högskolan i Linköping.


**Licentiate theses (2005- )**


13. **Dahlin, Peter (2005).** *Structural Change of Business Networks – Developing a Structuration Technique,* Mälardalen University, Licentiate thesis No.49.


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Beyond IT and Productivity – Effects of Digitized Information Flows in the Logging Industry

Maria Kollberg

The IT and productivity paradox has been the subject of considerable research in recent decades. Many previous studies, based mainly on macroeconomic statistics or on aggregated company data, have reached disparate conclusions. Consequently, the question whether IT investments contribute to productivity growth is still heavily debated. More recent research, however, has indicated that IT contributes positively to economic development but that this contribution is not fully revealed when only productivity is measured.

To explore the issue of IT and productivity further, the ITOP (Impact of IT On Productivity) research program was launched in 2003. An alternative research approach is developed with the emphasis on the microeconomic level and information flows in processes in specific industry segments. In the empirical study, the development of information flows is tracked over several decades. Effects of digitized information flows are hereby identified and quantified in order to determine their importance in terms of productivity.

The purpose of this study is to explore effects of information technology by studying digitized information flows in key processes in the logging industry. The research shows that several information flows in the logging process have been digitized leading to new ways to capture, use, spread, process, refine and access information throughout the logging process. A large variety of effects have also been identified from this development.

The results show that only a minor part of the effects identified have a direct impact on productivity and thus that a large number of significant effects do not. Effects with a major direct impact on productivity include increased efficiency in timber measurement registration, lower costs of timber accounting and increased utilization of harvesters and forest resources. Other significant effects with no direct impact on productivity are related to a more open timber market, increased timber customization, control, decision-making and access to information, as well as skill levels and innovation. The results thus demonstrate that it is questionable whether conventional productivity measures are sufficient for measuring the impact of IT.

Information technology, productivity paradox, digitization, logging industry