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KNOWLEDGE TRANSFER AND COMPETENCE DEVELOPMENT IN COMPLEX PAPER PRODUCTION ENVIRONMENTS

Doctoral Dissertation

Ismo Laukkanen

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Department of Biotechnology and Chemical Technology

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Supervisor	Prof. Sirkka-Liisa Jämsä-Jounela
Instructor	

Abstract

Global business transformation, increased technological complexity and knowledge intensive work have increased the importance of knowledge and competence as a competitive edge in paper industry.

The goal of the study was to develop a new concept for knowledge transfer and competence development and to use the new concept in industrial paper production unit start-up projects. The outcomes of the concept are evaluated at the personnel, strategic business unit and corporate levels. The operational concept includes modelling of organizational competences and production processes at different levels, and the subsequent development of the knowledge transfer and simulation tools. The development of the simulator was based on hybrid process modelling in a web-based JAVA environment. The development of knowledge and performance support systems was based on strategic competence management and a web-based XHTML environment. The theoretical framework of the concept was based on the knowledge management, organizational learning and strategic competence management in complex manufacturing environments.

Longitudinal multiple case studies carried out in the three industrial business start-up projects, where the concept has been constructed and used, are described, including planning, concept development and evaluation of the outcomes. A corporate level knowledge support and learning system called KnowPap was also evaluated. The focus in the evaluation was on the assessment of the competences, evaluation of the participant experiences collected by questionnaires, and analysis of the business benefits at the strategic business unit and corporate levels.

The new concept was found to improve knowledge transfer and competence development during the start-up of a new paper production unit. It was possible to localize and transfer the knowledge and tools originally developed in the European business unit, to the Chinese production unit. The participants perceived the new concept and tools to be very useful compared to traditional methods. At the production unit level, new world records were achieved in business start-ups, e.g. in China just eight months after start-up. At the corporate level, the benefits were improved management of knowledge- and systematic development of strategy-based new knowledge and competences. The concept and the tools developed in this study, optimally, follow the life cycle of paper production units.

Keywords knowledge management, competence development, paper industry, process simulation

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Työn ohjaaja	

Tiivistelmä

Globaalin liiketoiminnan transformaatio, teknologisen kompleksisuus ja työn tietointensiivisyys ovat kasvattaneet osaamisen hallinnan ja kompetenssien kehittämisen merkitystä paperiteollisuudessa.

Tutkimuksen tavoitteena oli kehittää uusi konsepti osaamisen siirtämiseen sekä kompetenssien kehittämiseen ja käyttää sitä uusien paperikone tuotantolinjojen käyttöönottoprojekteissa. Konseptilla saavutettuja tuloksia evaluoidaan henkilöstön, strategisen tuotantoyksikön sekä konsernin näkökulmista. Operationaalisessa konseptissa mallinnetaan tuotantoprosessi ja sen vaatimat kriittiset kompetenssit eri tasoilla ja kehitetään tietokonepohjaiset simulointityökalut sekä työn tietotukijärjestelmät tämän pohjalta. Simulointityökalujen kehitys pohjautuu prosessien hybridimallintamiseen verkkopohjaisessa JAVA kehitysympäristössä. Kehitetyt työn tietotukijärjestelmät pohjautuvat kriittisen osaamisen ja strategisten kompetenssien mallintamiseen, verkkopohjaisessa XHTML kehitysympäristössä. Konseptin teoreettinen viitekehys pohjautuu informaation hallinnan ja tiedon johtamiseen, organisaation oppimiseen sekä strategisten kompetenssien kehittämiseen monimutkaisissa tuotantoympäristöissä.

Konseptia ja kehitettyjä työkaluja käytettiin monitapaustutkimuksessa kolmen eri paperikonelinjan käyttöönoton yhteydessä, mistä saadut tulokset konseptin suunnitteluun, käyttöön sekä kehittämiseen liittyen on evaluoitu. Oma tapaustutkimuksensa on KnowPap oppimisympäristön kehitys ja käyttö globaalissa paperiyhtiössä. Tulosten arviointi pohjautui strukturoituun kyselyyn, haastatteluihin sekä liiketoiminnalle saatujen hyötyjen analysointiin yksikkö- ja konsernitasolla.

Uuden konseptin avulla voitiin konsernin yksiköissä kehitettyä osaamista mobilisoida ja ottaa se tehokkaasti käyttöön uusien tuotantolinjojen käynnistyksen yhteydessä. Euroopassa kehitettyjä parhaita toimintamalleja voitiin käyttää paikallisen kiinalaisen organisaation osaamisen kehittämiseen. Saadut tulokset paikallisen henkilöstön osaamistasossa ovat verrattavissa Suomen parhaiden tehtaiden osaamistasoon. Liiketoimintahyötynä tuotantoyksikkö Kiinassa teki tuotantonopeuden maailmanennätyksen vain kahdeksan kuukautta käynnistyksen jälkeen. Konsernin hyötyjä kehitetystä konseptista ovat systemaattinen kriittisen tiedon ja osaamisen hallinta sekä sen strateginen kehittäminen. Optimitilanteessa kehitetty konsepti ja työkalut kehittyvät tuotantolaitoksen elinkaaren mukana.

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Helsinki, January 24th 2008

Ismo Laukkanen

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List of Abbreviations

AI	Artificial Intelligence
CAI	Computer Assisted Instruction
CBT	Computer Based Training
DCS	Distributed Control System
DKD	Digital Knowledge Development
ERP	Enterprise Resource Planning
GPSS	General Purpose Systems Simulator
EPSS	Electronic Performance Support System
HPT	Human Performance Technology
HTML	Hypertext Markup Language
IBT	Internet Based Training
ISD	Instructional System Development
KE	Knowledge Engineering
KM	Knowledge Management
LMS	Learning Management System
MES	Manufacturing Execution System
OJT	On-Job-Training
PCS	Process Control System
SECI	Socialization, Externalization, Combination, Internalization
VLE	Virtual Learning Environment
WBT	Web Based Training

List of Symbols

GREEK SYMBOLS

α	Slope of the curve K(X) as a function of X
β	Compressibility [dimensionless]
ε	Porosity [dimensioless]
ρ	Density [kg/m^3]
μ	Viscosity of the fluid [Pa s]
τ	Web dewatering constant [ms]
ϕ	The ratio of solids volume on the total volume [m^3/m^3]

ROMAN SYMBOLS

A	Flow area [m^2]
a_1	Material specific coefficient [m^{-1}]
b_1	Material specific coefficient [dimensionless]
b	Material specific compressibility parameter [dimensionless]
C'	Web apparent compressible modulus, [MPa]
C	Consistency [kg/m^3]
c	Consistency [kg/m^3]
c_0	Initial consistency [kg/m^3]
F	Acting force [N]
h	Enthalpy [kJ/kg]
i,j	Indexes of discretized grid [dimensionless]
J_{SSF}	Steady-state flow per cross sectional area [m/s]
L	Length [m]
K	Kozeny coefficient [dimensionless]
K_D	Permeability [m^2]
$K(X)$	Permeability constant [dimensionless]
K_1	The sum of the fiber and absorbed water volumes [m^3/kg]
k	Permeability of the medium[m^2]
M	Compressibility coefficient [(kg/m3)/PaN]

M_1	Compressibility coefficient [(kg/m^3)/Pa^{N1}]
MC	Moisture content of the web (water/fiber)
(MC/MC_{IN})	Fractional change in the moisture content [dimensionless]
m	Experimental compressibility coefficient [kg/m^3]
N	Compressibility constant [dimensionless]
n	Number of individual element
p	Average pressure [MPa]
P_h	Hydraulic pressure of the fluid [Pa]
P_m	Mechanical stress exerted on the medium [MPa]
Q	Flowrate through the fiber bed [m^3/s]
S_0	Spesific surface are of fibers [m^2/m^3 fibers]
S_{i1}	Source term for mass
S_{i2}	Source term for energy
S_{i3}	Source term for momentum
S_s	Specific surface area of the fibers [m^2/kg fibers]
S_w	Specific surface area [m^2/m^3]
t	Time [s]
u	Velocity [m/s]
V_i	Volume [m^3]
V	Total volume [m^3]
va	Volume of the absorbed water [m^3/kg]
V_{sa}	Volume of solids and absorbed water [m^3/kg]
v_s	Specific volume of fibers [m^3/kg]
V_V	Void volume
W	Basis weight of the web [g/m^2]
X	Void ratio in the web
y	Depth coordinate of the web
z	Displacement in the z direction [m]
t	Nip residence time [ms]

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1 Introduction

1.1 Business transformation in the manufacturing industry

1.1.1 Globalization and changes in the business environment

As a result of globalization, the business environment in multinational manufacturing companies like those in the paper industry has changed dramatically. The business environment is very demanding, because structural overcapacity and highly competitive global markets are causing continuous erosion in the price levels of products. The expectations of global customers are the same worldwide, thus the processes, competence and capability of the personnel should be at the same level in every unit. The ownership structure in companies is global and the requirements for the return of capital employed are the same for all companies. At the same time the estimated demand for paper products is growing very fast in emerging markets such as China, India, and Latin America, where the fast growing forest plantations are also located (Siitonen 2003; Balter 2006; Lamberg *et al.* 2006; Young and Lan 1997). The focus of business growth has shifted from the mature markets, e.g. in Western Europe and North America, to the emerging markets in Asia, Latin America and Eastern Europe. Paper production capacity has started to be transferred to the emerging markets in line with the trend in other manufacturing branches. Despite expectations, not all the business start-ups of multinational companies in China have been very successful. The fierce competition with local companies is threatening the business start-ups of the multinationals (Williamson and Zeng 2004).

Starting up a new business based on complex production processes and the latest technology, requires good timing, a good concept and tools for transferring knowledge, building competences and developing the local organizational capability. World-class start-up of new production plants requires efficient organizational learning and knowledge transfer processes. Starting up a new plant and the production process is especially challenging when the production process is dynamic, and the employees do not have any prior experience in working in such an activity environment. It has been shown that, although it is relatively easy to build a modern paper mill in a greenfield environment, attaining and developing competent personnel is a challenging task even in Europe (Laurila and Gyursanszky 1998) the tacit knowledge of expatriates being one of key factors in knowledge transfer (Tsang 1999).

The importance of knowledge transfer and competence development has been recently emphasized in the mature markets, e.g. in Europe and the US, where the retirement rate of the current working generations is increasing strongly. For example, in the US 25 % of the working population will reach retirement age by 2010, and this has been seen as a serious threat to competitiveness. The current working generations have a long work history and possess a considerable amount of critical knowledge, that needs to be transferred to the newer employees. There is a need to take on a large number of new employees, and the transfer of tacit knowledge based on experiences and organizational learning is extremely important. Some leading companies have started to create formal strategies and tools for knowledge retention, and to create processes for knowledge transfer and information distribution.

The importance of knowledge transfer in business transformation is a critical factor, and the major challenge in the mature markets is the retirement of the current generations and the transfer of knowledge to the new generations. In the emerging markets and new business start-ups, the challenge is to transfer the critical knowledge to local new employees and to retain of the local employees and their expertise.

1.1.2 Knowledge, competence and learning as a competitive edge

The importance of knowledge and learning as a source of a competitive edge has become a key critical success factor in the global competition and represents a critical asset in companies (Davenport and Prusak 1998). Once a company gains a knowledge-based competitive edge, it becomes easier and easier for it to maintain its lead and more and more difficult for its competitors to catch up (Quinn *et al.* 1996).

Based on real operational benchmarking assessments, where the highest efficiency of a production unit is indexed to 100%, the impact of human factors and performance on production unit efficiency can be in the range 5-13 % (Wilson 2004). The efficiency potential in competence, capability and performance development is shown in Figure 1, where the technological asset quality of different production units has been classified on the basis of the efficiency of the unit.

The efficiency of a new paper production unit in business start-up is at a moderate level but, as a result of competence and organizational learning, the efficiency starts to increase. The direction and speed of the efficiency development depends on the efficiency of knowledge transfer, learning, competence and capability of the local organization. From the technological point of view, the efficiencies of the individual production lines at the same technological quality should be at the same level. When comparing the efficiencies of the production lines, e.g. at a 50% technological quality level, the differences are considerable (up to > 10 %), as illustrated in Figure 1.

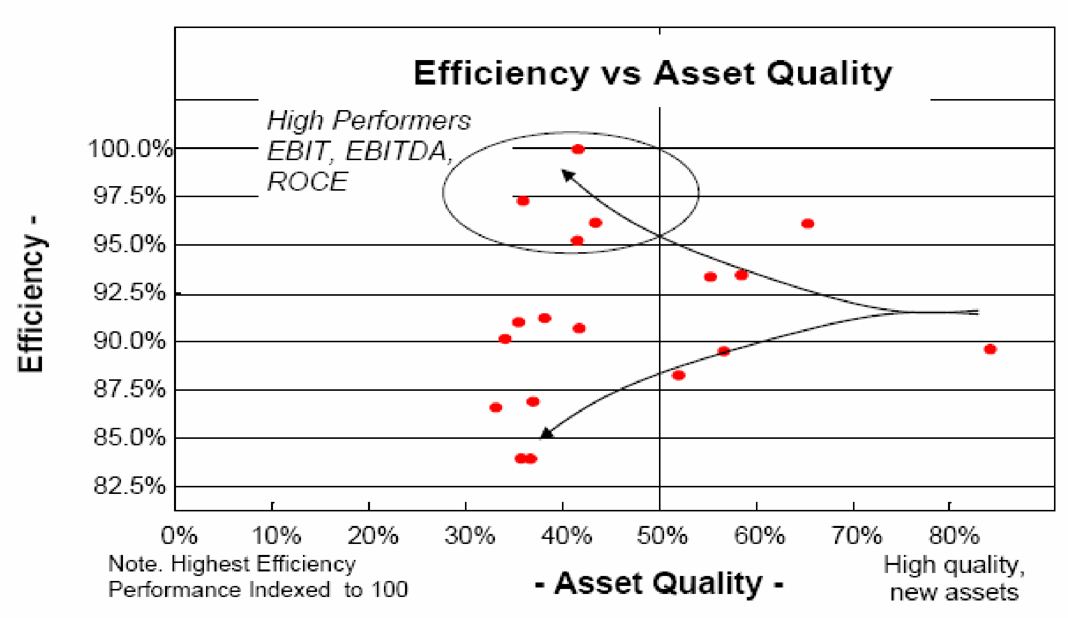

Figure 1. The impact of human performance on the efficiency of a paper production unit based on benchmarking of the individual production units (Wilson 2004)

Knowledge transfer and the sharing of best practices is a difficult part of organizational development in firms at the national level, but it is even more challenging when the scope of operations expands into the new, emerging markets, where the teams are multinational. The life-cycle of knowledge in industrial projects can be very short, thus emphasizing the efficiency of the concept and tools needed in projects. In complex production processes like paper production the challenge is even greater owing to the complexity of the dynamic and integrated production process. The conceptual knowledge needed is broad and multidisciplinary. Knowledge transfer at the organizational, strategic business unit, team and individual levels is becoming a critical part of successful technology transfer and investment projects in the emerging markets.

1.1.3 Technology development

In the paper industry, because the latest technology is globally available for all companies, technology itself can no longer guarantee a competitive advantage. The competence and capability to utilize the latest technology efficiently is extremely important, and this is also emphasized in the emerging markets (see also Figure 1). The development of production and ICT technologies have accelerated the speed and impact of technology development also in the paper industry. The major changes in technology in the paper industry can be summarized as:

(1) The integration and convergence of automation, production management and ICT systems is proceeding rapidly. (2) The level of sensors, instrumentation, process control, automation and production management systems has increased in the paper mills. (3) In a modern paper mill, the following systems are used to operate the process and quality: distributed process control, condition monitoring, quality management, web monitoring, drives control, process analysis, electronic diary, mill execution systems (MES) and enterprise resource planning systems (ERP). (4) The amount of real-time data and information available for decision making has increased considerably. (5) The nature of process control and operation work has changed from manual to knowledge work, in which the decisions are based on real-time information provided by different computer systems. (6) Despite the increased number of the different systems, only 20-30 % of the advanced features in these systems can be efficiently utilized, which emphasizes the new competences required by the production teams (Pikkusaari-Saikkonen 2004).

The current trend in ICT and automation system development is the integration of enterprise resource planning (EPR) systems, production management systems (MES) and process control systems (Figure 2). The automation and MES systems which have traditionally been integrated for production management at the business unit level have been developed further to possess features of ERP systems. The ERP systems used for corporate level resource planning and management are integrating new features that were previously used in MES and automation systems.

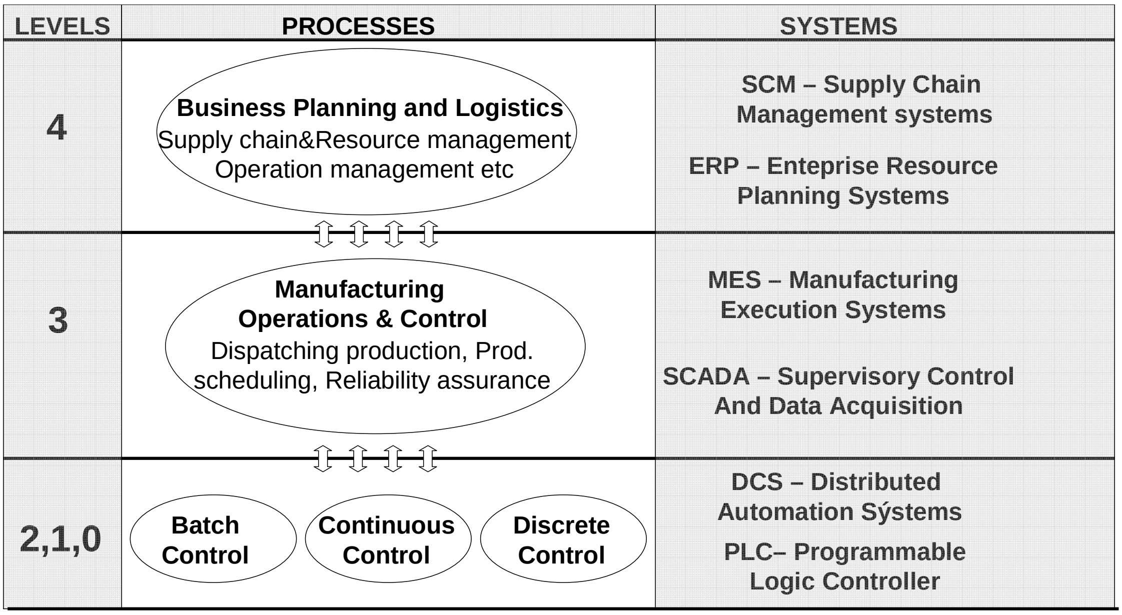

Figure 2. Hierarchy of ICT and production management systems in paper production (adapted from ANSI/ISA – 95.00.01-2000)

During 1990 – 2004 the design speed of modern paper production machines producing printing and writing papers has increased from 1,300 m/min to 2000 m/min. At the same time the design width of the machinery has reached 10 m. The increased design speed and efficiency require more advanced controls and better preventive tools for tracking the potential problems, as well as faster response times of the personnel in disturbances and in troubleshooting situations. It is extremely difficult to operate the complex equipment with embedded automation without computer control systems. The capital expenditure of the new production lines is also very high, emphasizing the competence, skills and knowledge of the production personnel needed to operate and maintain the machinery in the correct way.

Optimisation of the efficiency in the paper machine process is another trend in the development of integrated processes with minimal tank volumes and simplified processes. The operability of a simplified process in transient conditions is enhanced, because the dead-times, which currently cause problems for process control, are minimised. The tanks and silos are feed buffers for the paper machine, but they also filter flow, consistency and pressure fluctuations. In the simplified process, more precise control of process dynamics is required in different situations.

The main major technological changes are: (1) integration of automation, production management and information systems, (2) increased production capability and speed of paper machines and (3) process integration. As a result of these changes, there has been an increase in complexity in paper production and the processes have become complex, integrated dynamic system, in which the problems and disturbances are also integrated.

Because the latest automation and production technology is globally available for all companies, technology itself cannot guarantee a competitive advantage. In the technology transfer projects, the transfer of knowledge, competence and capabilities about how to optimally operate the latest technology should be emphasized especially in the emerging markets like China. On the other hand, the development of ICT technology enables efficient transfer of the latest knowledge and best practices, together with the new collaboration and knowledge support tools that are becoming available in the workplace.

1.2 Research problem, objectives, hypothesis and limitations of the study

1.2.1 Research problem and objectives

The principal objective of the research is to develop a concept and tools for improving knowledge transfer and competence development in complex paper manufacturing processes. This involves the development of a theoretical framework, an operational concept and operational tools which are verified in industrial case studies. The case studies are two fine paper production unit start-up projects in Finland, and one fine paper production unit start-up project in China.

Improving knowledge transfer and competence development during the start-up of a new paper production unit will provide a competitive advantage for the paper producing company. The benefits can be achieved and evaluated at the employee, production unit and corporate levels.

Hybrid knowledge and performance support systems based on modelling and simulation can be used to improve knowledge transfer and competence development in the start-up of new paper production lines.

Modelling, such as user modelling, process modelling and best practice modelling can further improve the process of knowledge transfer and competence development in the start-up of new paper production lines. The development of hybrid knowledge and performance support system is based on this modelling approach.

1.2.2 Limitations of the study

The theoretical framework used in this study is based on the strategic industrial management framework of a firm as an open system, including knowledge transfer, competence and capability development processes. Knowledge transfer, competence development and learning are evaluated from the organizational perspective. Educational and learning theories as well as competence development processes at the individual level are excluded from the scope of this research.

The case studies are based on the results of two case projects in Finland, and one case project in China. The regional, cultural and multicultural differences, e.g. those related to organization, project or work cultures, are excluded from the study.

The focus of the present study as a part of the life cycle of a production unit is illustrated in Figure 3. The study is focused on the capital-intensive part of the life cycle, including the project time, business start-up and the one year period after start-up. Longer term follow-up and comparisons in the continuous development of capability, learning and profitability are excluded from this study.

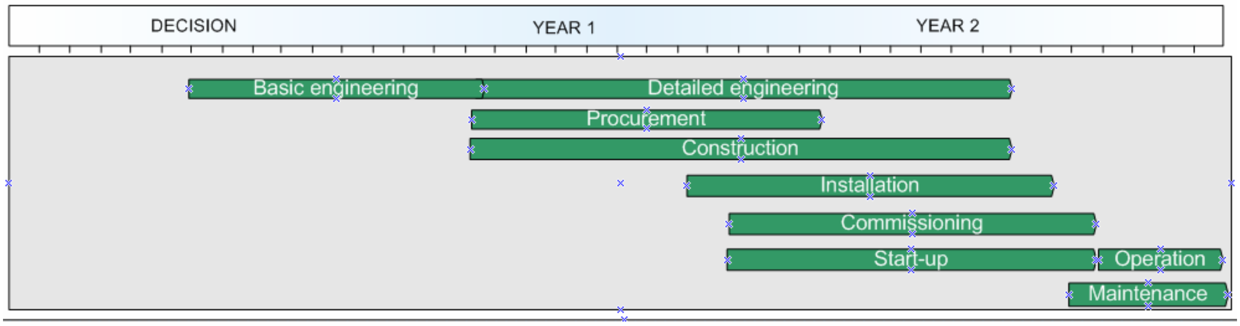

Figure 3. The focus of the study is on the business start-up of a new paper production unit

1.3 Structure of the study

The dissertation consists of the following nine chapters:

Chapter 1 consists of an introduction and describes the present trends in business transformation and the major technological changes in the paper industry. The transformation is a result of globalization and rapid changes in the business environment, the increased role of knowledge, the importance of competence and learning as a competitive edge, and changes in technology development. These changes are the background and motivation for the study and for the development of a new concept.

In Chapter 2, the paper production process is introduced as an example of a complex industrial production environment. A model for a paper production process as a hybrid dynamic system is described. The features of complex and dynamic manufacturing environments are reviewed, and a concept of work process knowledge in these environments is introduced. Finally, the changes in work and workplace, including multi skilled teams, global business processes and knowledge work with ICT systems, are reviewed.

In Chapter 3, the theoretical framework for a resource-based view of a firm as an open system is introduced. The theoretical framework for knowledge management processes, competence-based strategic management and knowledge processes is reviewed. Finally, theories of organizational learning are reviewed.

In Chapter 4, the development of computer-based knowledge and performance support technology, computer-based learning technology and, finally, simulation technology is reviewed. The focus in the review is on applications in the paper industry. In the technologically enhanced workplace of the future, these support technologies will be integrated with the standard automation and production management systems in the workplace.

In Chapter 5, a new concept for knowledge transfer, learning and competence development for complex papermaking processes is presented. The integrated theoretical concept is first introduced. The competence and knowledge strategy processes steer the goals of organizational competence development and individual development, mental models being the mechanism linking individual and organizational level learning. Finally the operational concept for knowledge transfer and competence development in paper machine investment projects is proposed.

In Chapter 6, the new tools and technologies developed in this study for knowledge transfer, competence development and performance support are described. Dynamic simulation, based on hybrid process modelling, is reviewed. The development of KnowPap a web based learning environment for papermaking and paper mill automation, is summarized. The development of an integrated knowledge and performance system is introduced. Finally, the modelling and simulation of the operational best practices with the operational training simulators and best practice toolkits are introduced.

In Chapter 7, the results of four industrial case studies where the new concept and tools have been used are presented. The first study evaluates the use of the dynamic process simulator in a paper machine investment project in Finland. The use of the KnowPap learning environment in a global paper company is evaluated in the second study. In the third study, the use of the concept for a major fine paper machine rebuilding project in Finland is evaluated and, finally, in the fourth study the use of the concept in a paper production unit start-up in China is reviewed.

In Chapter 8, the major results are discussed in the light of previous research. The theoretical empirical and managerial contributions are reviewed. The validity, reliability and limits of the study are also discussed.

In Chapter 9, the conclusions of the study are summarized. Further research on knowledge mobilization and mobile knowledge support systems is proposed.

1.4 Contribution of the thesis and of the author

The theoretical contribution of the study includes the development of an integrated framework and theoretical concept for competence, capability and skills development in complex papermaking production environments. The empirical importance of the study is the development of operational concept utilizing simulation and knowledge support systems. The applicability of the constructed concept and tools is verified in industrial case studies both in Finland and in China.

In more detail the contribution of the author is clarified in the following:

1. **Development of the APMS dynamic process simulation environment (1994 – 1997).** The APMS-Advanced Paper mill simulator is based on the concept for hybrid modelling and dynamic simulation of paper machine processes. The dynamic simulators can be used throughout the life cycle of a paper machine, including also knowledge transfer and competence development. The contribution of the author was the development of the wet end process simulation models for the paper production line simulator, and being one of the developers of the

dynamic simulator used in case study 1.

2. **Development of KnowPap – a web based learning environment for papermaking and paper machine automation (1997 – 2000)**
   The development of a generic web-based learning environment and knowledge support system for paper industry started in 1997, when the author was one of the initiators of the development work and a senior researcher in the development team in 1997-1999. The development of the system and the structure of the environment are presented and discussed in this thesis. Use of the KnowPap system in a global paper company is analyzed in the case study 2.

3. **Development of a new concept for knowledge transfer in investment projects**
   The development of a new concept for knowledge transfer and competence development continue in 2002 in a paper machine start-up project in Finland. The concept and tools were constructed and developed further based on the experiences gained in the earlier projects. The tools used in the operational concept included a web-based knowledge and performance support system, an operational training simulator and best practice toolkits, which were localized and customized to the new paper production unit processes and technology. The author was responsible for the development and utilization of the concept in the project.

4. **Further development and use of the concept in knowledge transfer and competence development in an investment project in China (2002 – 2006)**
   The research included analysis of the knowledge transfer needs and critical competences in the paper production units and the development of the knowledge support tools based on the needs. The concept and the tools including an operational simulator, knowledge and performance support systems were developed further in investment project in China that started in 2002. The web-based knowledge and performance support system developed in the study, was integrated with a hybrid simulator.

The results of this thesis provide an important insight into business transformation in the global paper manufacturing companies and highlights the role of knowledge transfer and competence development in the start-ups of the complex paper production units in the emerging markets. The case studies in this research are real industrial paper production unit start-up projects but the concept developed in this study can be generalized in the future to other complex manufacturing processes. However this would require further research.

2 The paper production process as a complex and dynamic industrial production environment

The chapter starts with an introduction to the paper production process as an example of a complex industrial production environment. Secondly, a model of a papermaking process as a hybrid dynamic system is introduced. Thirdly, the features of complex and dynamic manufacturing environments are reviewed and a concept of work process knowledge in these environments is introduced. The dynamic complexity in the papermaking process system originates from the hybrid dynamics of continuous, discrete, discrete time and static sub-processes in the paper production line. Finally the major changes of the work and workplace in paper production are reviewed including multi-skilled teams, global business processes in local production units and increased information and knowledge intensity of the process control work.

2.1 Paper production as a complex and dynamic process

A modern paper production unit includes the following major sections: raw material handling, stock preparation, paper machine approach system, paper machine process including both wet and dry end processes and paper finishing. The unit also includes very important auxiliary systems like water preparation, water circulation and handling, steam and condensate and chemical preparation systems.

In the stock preparation section the mechanical, recycled and chemical pulps are treated by refining the fibres into a form suitable for papermaking. The pulp components and chemical additives are then proportioned before pumping to the short circulation. The function of short circulation is to dilute the pulp slurry called furnish, for the paper machine, to add the chemical additives needed in papermaking and to remove impurities from the furnish. Centrifugal cleaning and screening are used to remove heavy impurities and fibre bundles from the furnish. Finally, the air and gases are removed in the deculator process, and from there the clean and uniform furnish is pumped to the paper machine. As the consistency in the wet end of the paper machine is ~1 %, one major function of the paper machine is water removal. Dewatering is carried out in the wire section by using gravity and a vacuum, in the press section by using mechanical pressure and, finally, in the dryer section by evaporating off the rest of the water. The final moisture content of paper is normally ~ 9%. The broke system is used to circulate the edge trimmings and off-spec quality paper to the stock preparation. The white water system is used to circulate removed water to the several water consumption points in the paper machine process. A simplified flow sheet of a modern paper machine process is illustrated in Figure 4.

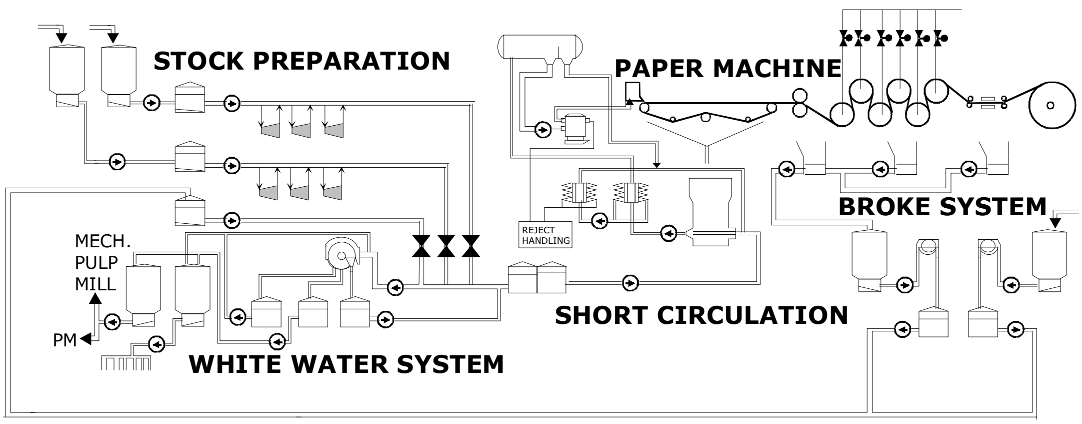

Figure 4. A simplified flow sheet of a paper machine process

2.1.1 Complexity and process dynamics in paper production

The stock and white water system is a complex, hybrid combination of combined/discrete subsystems which interact with each other. It consists of the following interconnected sections: stock preparation and proportioning, white water system, broke system, short circulation, fresh water preparation, and warm water system. The major design and operational factors affecting the complexity of the stock and water system dynamics are listed in Table 1.

Table 1. Design and operational factors affecting the process dynamics in the paper machine (PM) process

Design and operational factors	Value examples in PM lines
Operational state of the paper machine	Normal operation Operational grade changes Web breaks Transient operation situations Process disturbances
Type of paper machine process	Low retention process High retention process
Type of paper machine	Single grade paper machine Multi grade paper machine
Paper grade	Pulp components and chemicals Low basis weight High basis weight
Tuning of the controllers and automation	Loose tuning vs tight tuning of the controllers
Operation of a mechanical pulp mill	Normal operation Transient operation situation Shut down
Use and efficiency of the internal purification system	Use of membrane filtration or other internal purification systems
Operator actions	Operational procedures Generation of disturbances Web breaks

The correct operator actions have a very important effect on the stability and environmental impact of the stock and water systems. The operators' skills and their conceptual understanding of stock and white water system operation prevent spillage, process disturbances and fluctuations in the wet end of the paper machine.

In order to analyze the complex process dynamics of the stock and white water system at a detailed level, the effects of the design and operational factors have to be taken into account. There are also definition parameters at the more detailed equipment level (summarized in Table 2), which increase the complexity of the process dynamics. The following simplifications can be made in training and knowledge transfer applications, where the basic process dynamics is sufficient.

Table 2. Process and control design parameters affecting process dynamics

Parameter	***Effect on process dynamics***	***Simplification***
Dimensions of process equipment tanks, pumps, valves, pipes	Delays in the different parts of the process depend on the dimensions of process equipment. In high fidelity models the relative height levels of the equipment are also taken into account.	The tanks are the only dynamic component in simulator
Circulation of the flows in the integrated process	Integration of the flow network also causes the disturbances to propagate	Steady boundary flow in the model
Major control circuits and selected parts of mill automation e.g. interlockings	The effect of controller tuning on disturbances is very important. Other automation structures, interlockings etc. are needed in training.	Ideal controllers, no other structures included
Equipment parameters, shut-off time of valves, pump dynamics	Important effect on the flow dynamics in the piping network. The device controllers and power supply can also be included in the simulator.	Ideal process equipment
Control sequences e.g. automatic grade changes	Causes dynamic effects throughout whole process	No control sequences included

2.1.2 Development of process control and automation in paper machines

The process control circuits and other selected parts of paper mill automation have an important effect on the paper production process dynamics. The major control circuits of the base paper production process are illustrated in Figure 5. The most important control circuits in the stock preparation area are consistency controls, flow and level controls, raw material proportioning, control of refining energy, and control of retention. For the paper machine there are control loops for headbox, former, press and dryer sections. The control targets for these loops, the controlled and manipulated variables, as well as some typical problems, are summarized in Table 3. Good reviews of process control and automation development in the pulp and paper are presented by Dumont (1986), Kayihan (1996) and Leiviskä (ed) (1999).

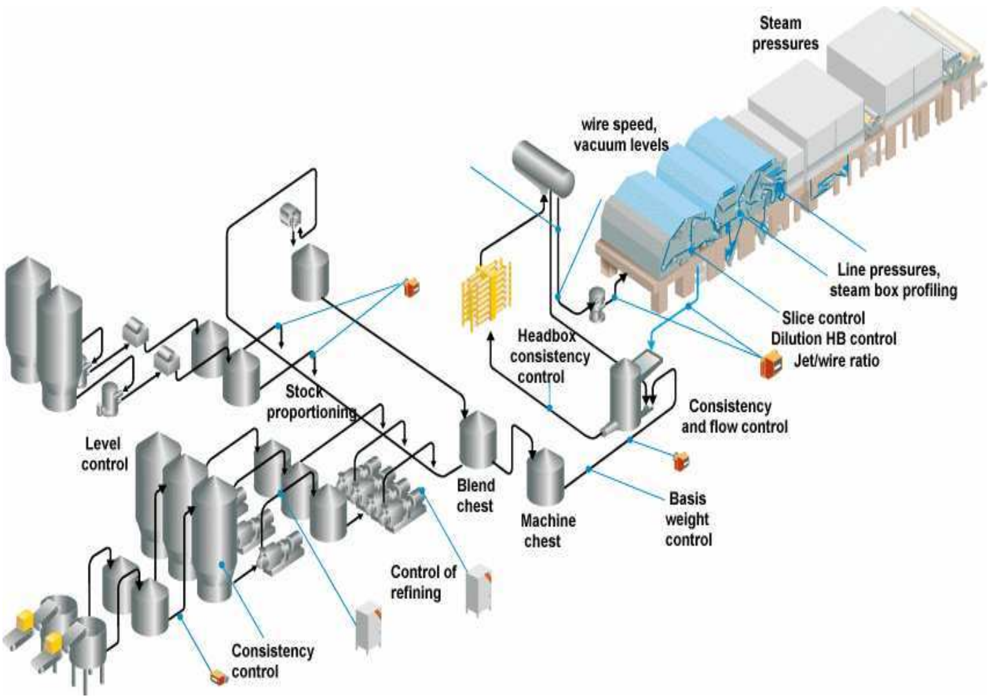

Figure 5. The major controls of a paper machine process (© Metso Automation 2007)

Table 3. Process control issues of a paper machine

	Control targets	Controlled variables	Manipulated variables	Problems
Stock preparation	Optimise the quality properties of the paper. Keep the flow changes between chests slow by managing the chest levels.	Basis weight (BW). Uniform BW. Physical, optical and chemical properties of the paper.	Stock consistency. Chest levels. Furnish composition in proportioning. Consistency and flow control of chemical additives.	Long deadtimes. Dependence of chest level and flow is non-linear. Disturbances in consistency control and proportioning.
Refiners	Optimal strength development, drainability and sheet formation. Sheet density, porosity, opacity and dim. stability are also affected.	Freeness. Consistency. Electrical energy. Specific energy consumption.	Disc gap.	During a power change, the disc plates may contact or refiner stop due to interlockings.
Headbox	Optimal formation by constant stock consistency and Jet/Wire ratio.	Pressure, slice lip. Stock consistency. Jet/Wire ratio. Temperature. Formation.	Operating speed of the fan pump. Slice lip actuators (MD and CD).	The position of the dry line is difficult to predict.
Former	Optimal formation by drainage and turbulence.	Formation. Distribution of fines and fillers.	Wire speed, vacuum. Levels of foils. Foil angles.	The position of dry line is difficult to predict.
Press section	Optimising the bulk by adjusting the linear pressure.	Bulk, surface smoothness.	Line pressure, sometimes in cross direction. Steam box may be included.	Bulk is difficult to predict in the grade changes.
Dryer section	Keeping the moisture content within specification. Co-ordination of machine speed and production rate.	Moisture content of the web in the machine and cross directions.	Steam pressures of drying cylinders. Air temperature. n:o activated elements in air and infrared dryers.	Difficult to predict target values because drying rate depends on many variables. Delays cause oscillation.

2.2 Features of complex and dynamic production environments

According to (Norros 2004), complex and dynamic work environments have three specific features: complexity (C), dynamism (D), and uncertainty (U), as illustrated in Figure 6. Process control and production management are typical working domains for chemical, pulp or paper processes that have the features of CDU environments. The role of process control work has changed from manual work to highly automated work, which is carried out with different process control and automation systems, the user interface for process control being a computer screen. In modern production control environment there are several systems starting from the process control level systems, production management and execution (MES) and ending at corporate level ERP systems.

There are four characteristics in dynamic systems that affect its control (Norros 2004; Brehmer and Allard 1991): the rate of dynamics in the process, the relationship between the controlled process and control process, dynamic delays in the system, and the quality of the feedback information. The features associated with operating in this kind of environment have been defined as (Norros 2004; Brehmer and Allard 1991; Hoc *et al.* 1995):

- operators are asked for series of actions and in some operational situations it is possible that operators are able to correct their actions,
- the decisions and the actions must be made at the correct point in time, which usually implies that the operator must adopt an anticipatory way of acting
- The decisions or actions that are made at different times are interdependent
- The environment and the process change both autonomously and as a function of the operator's actions

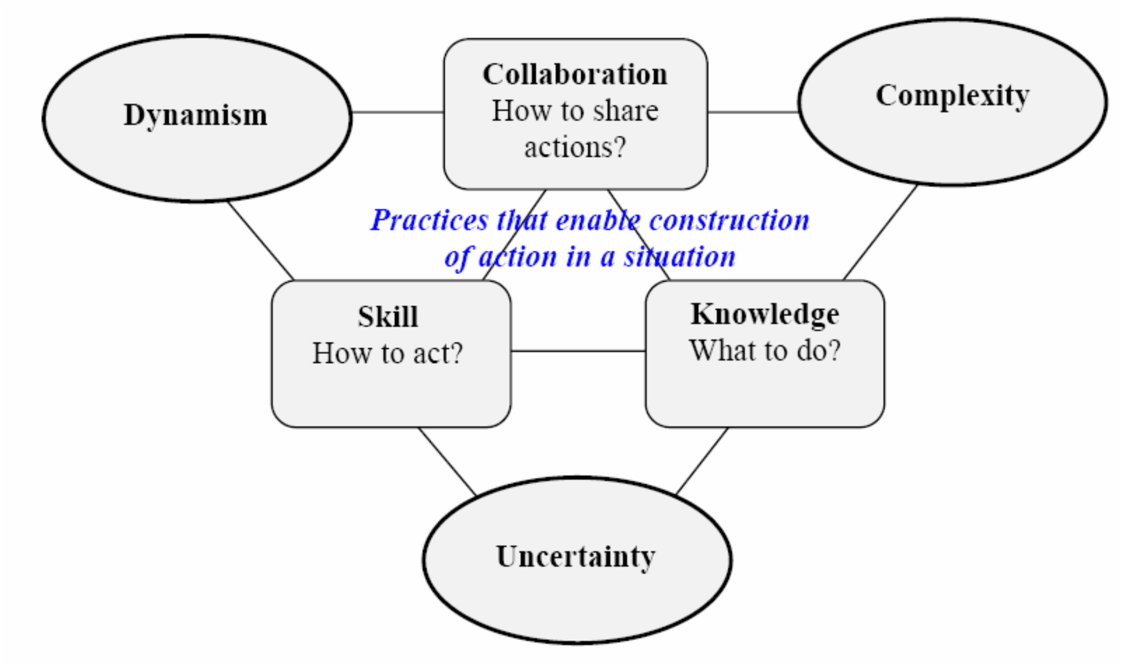

Figure 6. Process control of paper production is a complex, dynamic, and uncertain (CDU) work environment (Norros 2004)

Brehmer and Allard (1991) suggest that operators have three alternative methods for exercising control in dynamic situations: develop a mental model of a task, develop heuristic rules, or rely on feedback and modification of behaviour. The results of their study indicated that difficulties were related to delays in the feedback or understanding the task well enough to fully utilize the available resources. Modelling and computer simulations have been used in many complex processes e.g. in nuclear power plants for learning the operation in different dynamic situations.

2.2.1 Work process knowledge – knowledge of complex processes

The term "work process knowledge" has emerged to describe and study knowledge in increasingly complex work processes. Work process knowledge is regarded as knowledge which is useful for work, and ways of knowing that are integral aspects of work activity and essential to support skilled work in flexible and informated workplaces. This is not, however, considered to be "practical knowledge" picked up from unmediated experience, but it includes a dimension of theoretical understanding (Boreham 2002). The construction of work process knowledge often arises out of efforts to resolve contradictions between what theory predicts will happen, and the reality that confronts them.

The concept of a mental model or a related concept has often been used to describe the work process knowledge which the workers use to control and operate the process, or as one worker states in Zuboff´s (1989, p 86) study, "You have to have a mental picture of what is going on behind the indicators." The concept of a mental model is not unambiguous however. It has been used in studies on work in complex processes (Doyle and Ford 1998), but the vague use of the concept of a mental model has also been criticized (e.g. Norman 1983; Staggers and Norcio 1993). It has been considered important to separate the models used by people playing different roles in the work process. Especially the conceptual model of the target system and the user's mental model of the target system should be separated. A conceptual model is invented by teachers, designers or scientists as an accurate, consistent and complete representation of the target system. Mental models are created by users as they interact with the target systems and may, or may not, be equivalent to conceptual models (Norman 1983; Staggers & Norcio 1993; Vicente 1999). Nevertheless, in a complex process involving not only one person, but also a group of people, co-operation and communication of the group requires accurate, and mutually accepted concepts in order to be able to change information in the critical phases of work processes, e.g. during production disturbances (Leppänen 2001, see also Vicente 1999). Accurate concepts and sufficient knowledge of the work process are also prerequisites for learning from the process events, and for sharing experiences and knowledge in the work community, in order to improve the work process further (Vicente 1999). A method for studying the conceptual mastery of a work process is an example of a method for studying process knowledge (Amaravadi and Lee 2005) at work, and has been used to study the work process knowledge of workers in complex work domains (Leppänen 2001; Nurmi 2001; Norros 2004; Oedewald & Reiman 2007).

2.3 Work and workplace transformation in paper manufacturing

2.3.1 New role and competence requirements for multiskilled production teams

The role of operation teams in paper production units has changed from that of a workforce into a group of multiskilled profit makers who are optimizing the operation and profitability of the production line based on knowledge and information in different systems and processes. In a modern paper production unit the importance of the operators' skills, knowledge and degree of motivation will make a difference in the profitability of the production line (Lehtonen 2002; Wilson 2004). The recent changes in manufacturing organizations, workplaces and work are listed in Table 4. These changes have increased the importance of competence and knowledge in modern complex production environments (Norros 2004; Bullemer *et al.* 2004; Hammer and Champy 1993). The changes also emphasize the need for a higher educational level, multiskilled expertise and efficient organizational learning in production and maintenance teams (Laukkanen 2001).

Table 4. Major change in complex manufacturing organizations and environments (Norros 2004; Bullemer *et al.* 2004;Hammer and Champy 1993)

Changes in manufacturing organizations	***Changes in work environment***
Organizational changes - from a hierarchy to flat, decision-making power on the shop floor	Managers' work changes – from supervisors to coaches
Work unit changes - from functional departments to process teams	Executive work changes – from score-keepers to leaders
Values change – from protective to productive	Operators work changes - job will include many tasks currently handled by engineers
The focus of performance and compensation changes – from activity to results	Educational requirements change – qualification level of personnel has been raised
Advancement criteria changes – from performance to ability	Work changes - from simple tasks to multi-dimensional and multiskilled work
The roles of people change – from controlled to empowered	Job preparation changes – from training to education and learning

2.3.2 Local production teams as a part of global business processes

The core business processes in manufacturing firms typically include product development, and supply-chain management, customer commitment, order fulfilment and customer relationship management processes, which are at the highest level in the enterprise process hierarchy (Becker *et al.* 2003). The roles and responsibilities of the people in these processes are defined in the business process models or in roles and responsibility mapping (Becker, *et. al.* 2003). Enterprise resource planning (ERP) systems are used for the real time management of these processes at the corporate level, while the targets are cascaded down to the local production unit level production execution and automation system.

One of the major top-down changes in the local production environment is that local production teams now have important roles and responsibilities in the global business processes. The use of global processes and ERP systems, has shifted some work previously done by line managers to the production teams. A practical example of this are local warehouse operations, which are now an important part of the global delivery and warehouse capacity optimization process and a part of the global supply chain. The development of enterprise level business processes has remarkably changed the role and the competence requirements of local production teams, as illustrated in Figure 7.

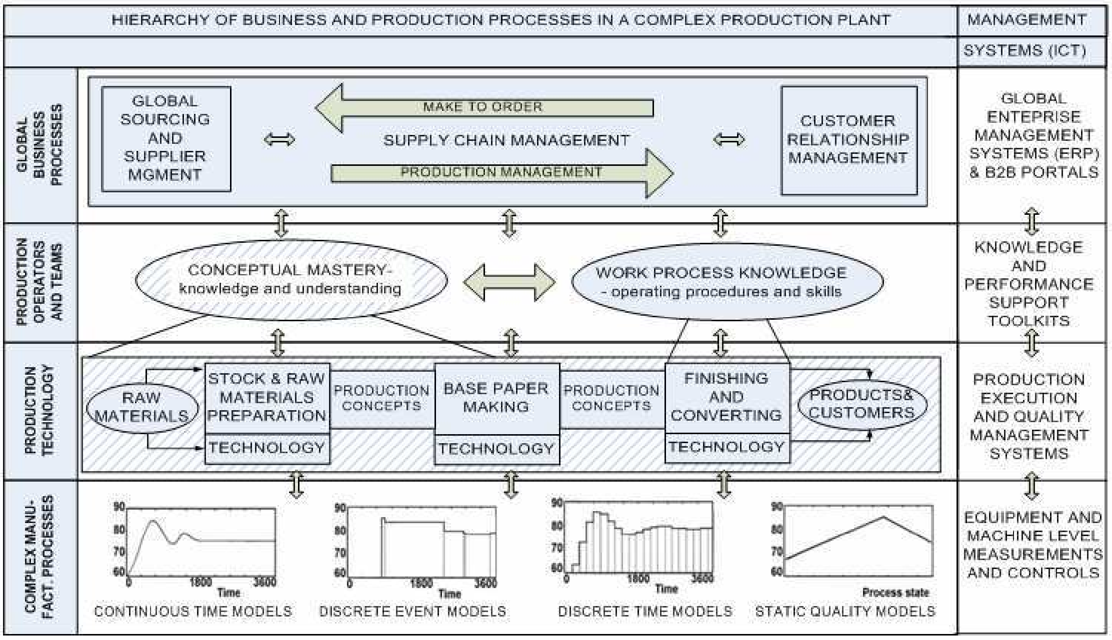

Figure 7. The process hierarchy of a modern paper production line modelled as process and competence models

2.3.3 From manual work to knowledge work in production control

The purpose of the production personnel is to assess, adapt and control the production line manufacturing process and maintenance activities to meet the business production plan and product specification (Bullemer *et al.* 2004). Production personnel will continuously need to identify opportunities for improving process operations and the work environment, to detect and remove any threats in stationary operations, to compensate and correct abnormal situations and to ensure that after disturbances the production will be brought back to the normal operation level (Bullemer *et al.* 2004).

In the modern paper production line, there can be up to ten different ICT systems for production and quality management and therefore the user interface to control the production is a computer screen. The amount of manual work needed has been decreasing dramatically along with the development of ICT, camera and other work support systems. The decisions are made on the basis of the information in these systems, which emphasize the conceptual understanding and efficient use of these tools. The amount of data, information and knowledge needed and provided in the workplace via these systems has increased dramatically. The work has changed from physical work into information processing and knowledge work, where the decisions and troubleshooting are performed on the basis of the computer and ICT systems.

All of the previous findings and changes emphasize the major changes taking place in the workplace and the importance of conceptual mastery and work process knowledge in production teams, which now form an integrated part of the global delivery chain. The paper machine process is a very complex working environment, requiring a multidisciplinary, broad conceptual understanding of the whole production chain, covering major processes at the different levels, as illustrated in Figure 7.

3 Conceptual framework for knowledge transfer, competence and capability development in complex industrial production environments

The aim of this chapter is to present a theoretical framework for understanding the nature of knowledge transfer and competence development processes and the interdependence between these three areas in industrial production processes. The chapter starts with the strategic framework for the resource-based view of a firm as an open system. Then the theoretical frameworks for competence-based strategic management, knowledge management and knowledge processes are introduced. Finally, the theories of organizational learning, including individual and organizational learning, in single and double loop and a systemic model in building learning organizations are reviewed.

3.1 A resource-based view of a firm as an open system

3.1.1 Organizational resources as the competitive edge of firms

Strategic management has traditionally been focused on finding sources to achieve competitive advantage for a company. The theoretical framework used in strategic management has been focused on the structural analysis of business environments and the concept of value chain (Porter 1980; Porter 1985). According to Porter's models, the competitive environment of a company can be modelled and the competitive advantage analyzed from these external perspectives. Porter's five forces analysis, is a strategic framework for industry and business analysis developed by Porter in 1980. Based on this model, the competitive advantage, the ability to serve its customers and to make a profit of an industrial organization can be analyzed using five forces.

A change in any of these five forces requires a company to re-assess its strategic position (Porter 1980):

1. the bargaining power of customers
2. the bargaining power of suppliers
3. the threat of new entrants
4. the threat of substitute products
5. the level of competition in an industry

After an analysis of the industry has been carried out, the competitive advantage of an industrial company can be achieved by choosing from three basic strategic approaches:

1. Cost leadership
2. Differentiation of products
3. Customer focus

Another important tool developed by Porter is value chain analysis, which identifies the critical phases in the value chain from the perspective of strategy. After analysing its competitors, industry level strategies and the segmentation of different companies can also be studied. The basis in the Porter's analysis is to analyze primary and secondary activities in the companies, with the focus on the external and internal business environment. The value chain analysis models can be extended down to deeper levels in an organization, by defining also the business processes and functions as a part of the model.

Despite the focus in value chain analysis being on business processes and environment, the results concerning the extended value chain also include the competences and knowledge needed in different phases of the value chain. Porter also discussed the role of collective (organizational) learning and organizational culture as a part of competitive advantage. The transfer of knowledge and skills either geographically or in the value chain was also identified as one driver for competitive advantage (Porter 1985)

Because the major focus in Porter's theory is on the analysis of the external business environment, Porter's model has been criticized (Barney 1991; Nonaka and Takeuchi 1995). The main criticism is that Porter's analysis does not consider the internal resources and capabilities of the company as competitive advantage. This new perspective has led to the development of competence-based strategic management and the model of a firm as an open system.

3.1.2 Resources, competences and dynamic capabilities of a firm

The theory underlying competence-based strategic management has been Penrose's theory concerning the growth of the firm as a collection of productive resources, which can be available either as physical capital, human capital or organizational capital resources (Penrose 1959). These resources stimulate the management to search for and find opportunities for the firm's growth. The importance of learning was also emphasized. Barney has proposed that a firm's resources can be sources of sustained competitive advantage when the resources are perfectly homogenous and mobile. These resources enable the company to implement strategies that improve efficiency and effectiveness (Barney 1991). The strategically important resources are those which 1) are valuable exploit opportunities and/or neutralize threats 2) are rare among current and potential competition, 3) are imperfectly imitable and 4) there are not strategically equivalent substitutes. In the development of the resource-based view of a firm, the important dynamic dimension was then added through the concept of a firm's assets such as stocks and flows, leading to the model of knowledge stocks and flows in companies (Sveiby 1997; Bontis *et al.* 2002)

In the early 1990s, Prahalad and Hamel defined the term core competence as "the collective learning in the organization, especially how to coordinate diverse production skills and integrate multiple streams and technologies". Their article was a catalyst for series of articles by Hamel (1994, 1996) and Hamel and Prahalad (1990, 1994), in which the "core competences", "collective learning of the firm" and acquiring the skills and capabilities create competitive advantage for companies. Later, Hamel and Heene (1994) identified goals for a more integrative theory of a firm, with the "concepts, tools, techniques and models" which a firm uses in combining its resources and capabilities to build and leverage organizational competences. The use of the word "core" has also been criticized, because it is an integrated combination of several competencies (Sanchez and Heene 1997). The concepts and definitions for competence management theory have been created by Sanchez and Heene (1996) and Sanchez (2004), and they are good references for a further review of strategic competence based management research.

Hamel and Prahalad further developed the core competence framework and they showed that in a modern competitive environment, continuous improvement is not enough and radically new knowledge and innovations are needed. To sustain the competitive edge, companies have to create new business segments and, in this, the key issue is how to build core competence (Hamel and Prahalad, 1994). Hamel defined the conditions in which a skill cluster can be considered a “core” competence (Hamel 1994, pp. 11-15):

- a competence is a bundle of constituent skills and technologies, rather than a single, discrete skill or technology
- a core competence is not an inanimate thing, it is an activity, a messy accumulation of learning comprising both tacit and explicit knowledge
- a core competence must make a disproportionate contribution to customer-perceived value
- to qualify as a “core” competence a capability must be competitively unique
- a core competence should provide an entrée into new markets.

The management of core competences includes four key tasks: selecting core competences, building core competences, deploying core competences, and protecting core competences (Hamel 1994, p. 25). If the core competence of a corporation has not been identified, then the business growth potential may be lost because core resources and competences are divided into different SBUs. If the (core) competence is not continuously developed it will decline, because it can not be built or protected (Hamel and Prahalad 1994). A key observation is that in order to protect core competences, a company must be able to distinguish between a bad business and the potentially valuable competences buried within that business.

The most recent competence management research has identified the following criteria for identifying organizational competences (Sanchez 2004):

1. The level within the organization at which competence exists
2. The time horizon over which a competence is likely to apply
3. The knowledge base on which competence depends
4. The complexity of processes underlying the competence
5. The scope of applicability of the competence
6. The locus of key assets used
7. The nature of fit between a competence and environmental demands
8. The impact of competence on dynamic versus static efficiency

3.1.3 Theoretical framework for strategic competence management

The following terminology has been developed and used in competence-based strategic management. The organizational capabilities can be categorized on the basis of whether they relate to the lower-order system elements or the higher-order system elements of the firm as an open system (see Figure 8). The notion of higher-order and lower-order control loops (or feedback flows) introduced by Sanchez and Heene (1996) can also be adapted to the categorization of capabilities (Wallin 2000). Higher-order control loops are used to monitor and adjust stocks and flows in a firm's higher-order system elements of strategic logic, management processes, and intangible assets, governing changes in a firm's managerial cognitions. Lower-order system elements refer to tangible assets, operations, and products in the framework of Sanchez and Heene (1996).

Development of organizational capabilities can lead either to competence building and/or competence leveraging: Competence building is any process by which a firm achieves qualitative changes in its stocks of assets and capabilities, including new abilities to co-ordinate and deploy new or existing assets and capabilities in ways that help the firm achieve its goals (Sanchez *et al.* 1996). Competence leveraging occurs when a firm applies its existing competences to current or new market opportunities in ways that do not require qualitative changes in the firm's assets or capabilities (Sanchez *et al.* 1996).

Business modelling is the management process in which the firm develops and decides its future business models. Sanchez and Heene (1996) and Wallin (2000) have stressed the importance of understanding the mechanisms that need to be created to achieve coherence and a common mental model across the firm's many decision makers. Business modelling capabilities would then have to address at least three parts relating to the development, preparation and making of decisions on business models: absorptive capacity, conceptualizing, and timing (Wallin 2000).

Absorptive capacity refers to one of a firm’s fundamental learning processes: its ability to identify, assimilate, and exploit knowledge from the environment and to add this information to their own knowledge base (Cohen and Levinthal 1990). These three processes encompass both the ability to imitate other firms’ products or processes and also the ability to exploit less commercially focused knowledge, such as scientific research. Developing and maintaining absorptive capacity is critical to a firm’s long-term survival and success, because absorptive capacity can reinforce, complement, or refocus the firm’s knowledge base. The capabilities and insight related to the processing of external information are seen as key elements in the definition of absorptive capacity.

Another perspective to competence and capability is to see core capability as organizational knowledge stocks, and knowledge transfer as organizational knowledge flows (Bontis *et al.* 2002). There is a positive relationship between the stocks of learning and business performance, so knowledge stocks and flows should be strategically aligned to core areas (Bontis *et al.* 2002).

Transformative capacity has been defined as the organizational capability to transfer technology over time by choosing the difficult-to-create knowledge, maintaining the knowledge, and reactivating and synthesising knowledge over the time (Garud and Nayyar 2004).

Capabilities can be considered a core if they differentiate a firm strategically. A number of researchers have classified them into distinctive competences, organizational competences or firm specific competences (Hamel and Prahalad 1990). On the other hand, these organizational core capabilities can inhibit the development of new innovation and new knowledge, so core capability can also be core rigidity, as proposed by Leonard-Barton (1992).

Teece *et al.* (1997) define firms as generators of dynamic capabilities that help "in appropriately adapting, integrating and re-configuring internal and external organizational skills, resources and functional competences toward a changing environment". The basis for dynamic capability perspective is the assumption that the performance of the firm depends on combining its capabilities with its strategic objectives. Metcalfe and James (2001) emphasize that the productive opportunities depend on the connection between capabilities and strategic intentions.

The resource-based view of a company argues that sustained competitive advantage can be achieved through the excellent use of resources. To achieve the competitive advantage, firms cannot merely evaluate their business environment, opportunities and threats.

The model of the firm as an open system has been developed by Sanchez and Heene (1996). Sanchez also defined the taxonomy and five modes of organizational competence, which are derived from the organization as an open system view. The different modes and portfolio of strategic options which are illustrated in Figure 8 are classified in Table 5.

Table 5. Five modes of competence results from organizational flexibility (Sanzhez 2004)

Competence mode	*Managerial abilities in the organization*
Cognitive flexibility to imagine alternative strategic logics	Collective corporate imagination of managers in perceiving market opportunities to create value, new products and services
Cognitive flexibility to imagine alternative management processes	Ability to identify the kind of resources (assets, knowledge, capabilities) required to carry out strategic logic and organizational design (allocation of tasks, decision making and information flows)
Coordination flexibility to identify, configure and deploy resources	Acquire or access, configure and deploy chains of resources for leveraging product offers capable of creating value
Resource flexibility to be used in alternative operations	Resource flexibility in which the available resources of an organization can be used in the various operations which firms may undertake
Operating flexibility in applying skills and capabilities to available resources	Operating flexibility and robustness at the working level for using available resources, which is a result of collective capabilities in human resources

The following definitions are connected to the above resource definition (Sanchez *et al.* 1996): (1) Company resources are assets that are available and useful in detecting and responding to market opportunities or threats. (2) Resources include capabilities, as well as other forms of useful and available assets. (3) Capabilities are repeatable patterns of action in the use of assets to create, produce, and/or offer products and services to a market. (4) Competence is an ability to sustain the coordinated deployment of assets in a way that helps a firm achieve its goals. (5) A skill is a special form of capability, with the connotation of a rather specific capability useful in a specialized situation or related to the use of a specialized asset.

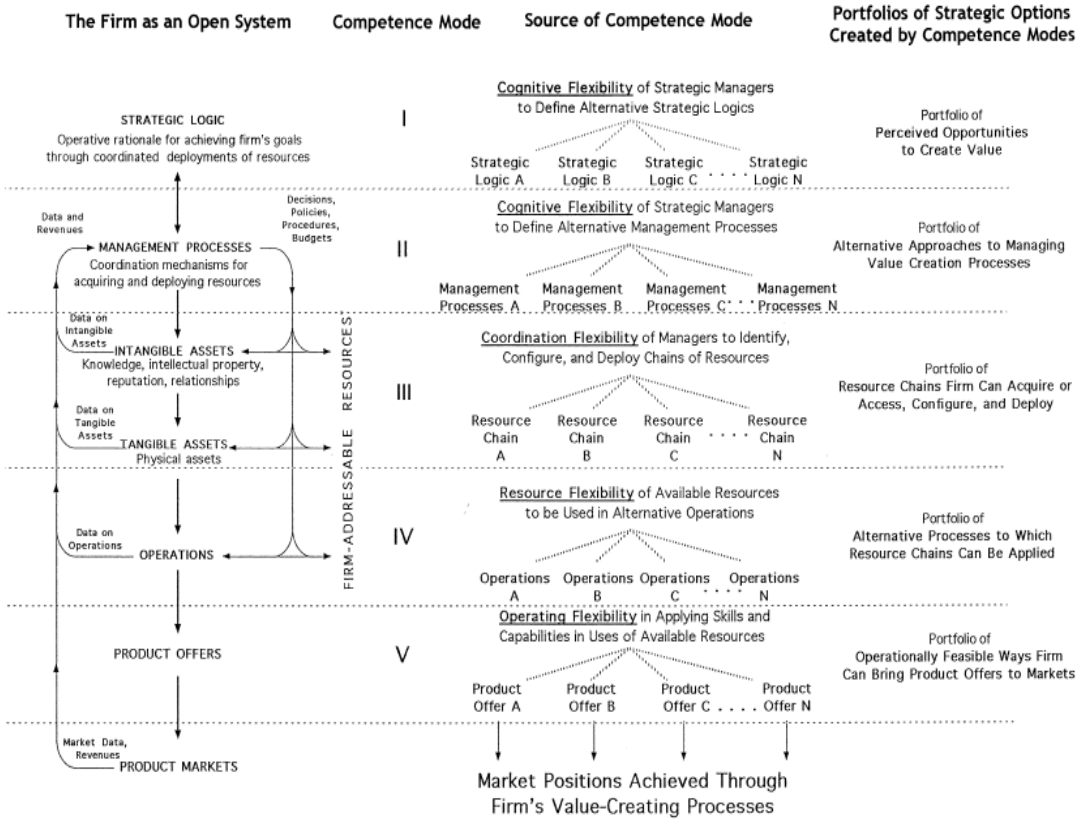

Figure 8. Five modes of competence in a firm as an open system (Sanzhez 2004)

The model of the firm as an open system has been extended by Wallin (2000) by taking the role of the customers and business processes as the central role of the firm. The role of value creation, constellation and capturing also hold larger role in Wallin's model.

3.2 Knowledge management in complex production environments

3.2.1 Definitions and terminology

The traditional definition of knowledge, originally defined by Greek and Western philosophers is "knowledge is a justified true belief" (Nonaka and Takeuchi 1995). The role of knowledge as a competitive business advantage and the future of knowledge workers has received a considerable attention in management and organizational theories (e.g. Drucker 1994; Davenport and Prusak 1998). In complex production environments knowledge has also been defined e.g. as organized information applicable to problem solving or decision making (Woolf 1990), and information that has been organized and analyzed to make it applicable to problem solving or decision making (Turban 1992).

The common hierarchy of knowledge, as a part of organizational information and knowledge management, can be defined as follows: data, information, knowledge, expertise/intelligence and wisdom which are illustrated in Figure 9. The value of data and information increases when it is refined further into knowledge and intelligence but at the same time, it is also more context sensitive (Tuomi 1999).

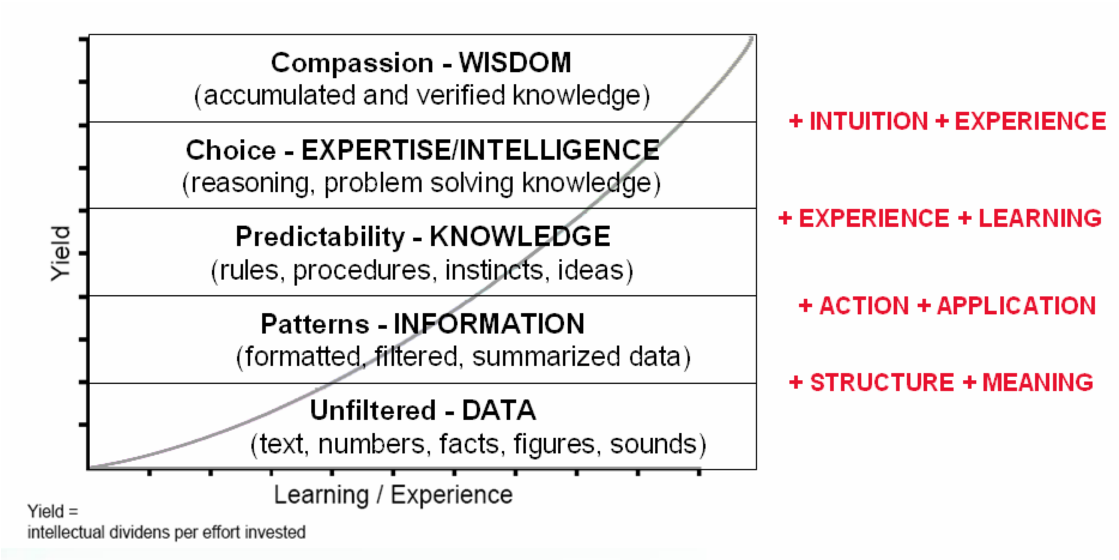

Figure 9. Hierarchy of knowledge (adapted from Tuomi 1999; Beckman 1999)

The value of a firm's intellect increases when moving up the intellectual scale from cognitive knowledge to creative intellect, as illustrated in Figure 10. Most firms however, reverse this priority in their training and systems development activities, virtually focusing their attention on basic skills development and little or none on systems, motivational or creative skills. The result is predictable mediocrity and loss of profit (Quinn *et al.* 1996).

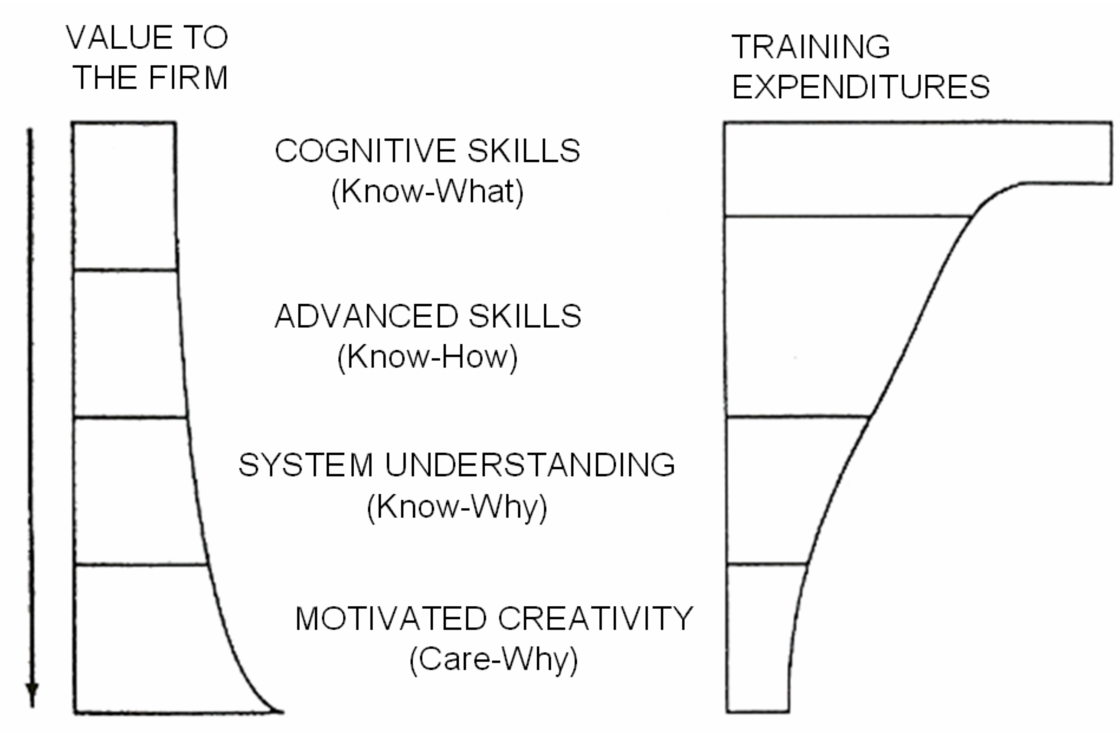

Figure 10. Skills value vs. training expenditures (Quinn *et al.* 1996)

The knowledge creation process in an organization takes place in ontological and epistemological dimensions, as illustrated in Figure 11 (Nonaka, Takeuchi, 1995, p. 57). The epistemological knowledge dimension has been classified into tacit knowledge, which is personal, context specific and hard to communicate, and into explicit knowledge, which is transmittable in formal, systematic language and which can also be integrated into ICT systems and tools (Polanyi 1966; Nonaka and Takeuchi 1995, p.59). The ontological dimension includes individual, group/team, organization and inter-organization levels (Nonaka and Takeuchi 1995, p.59).

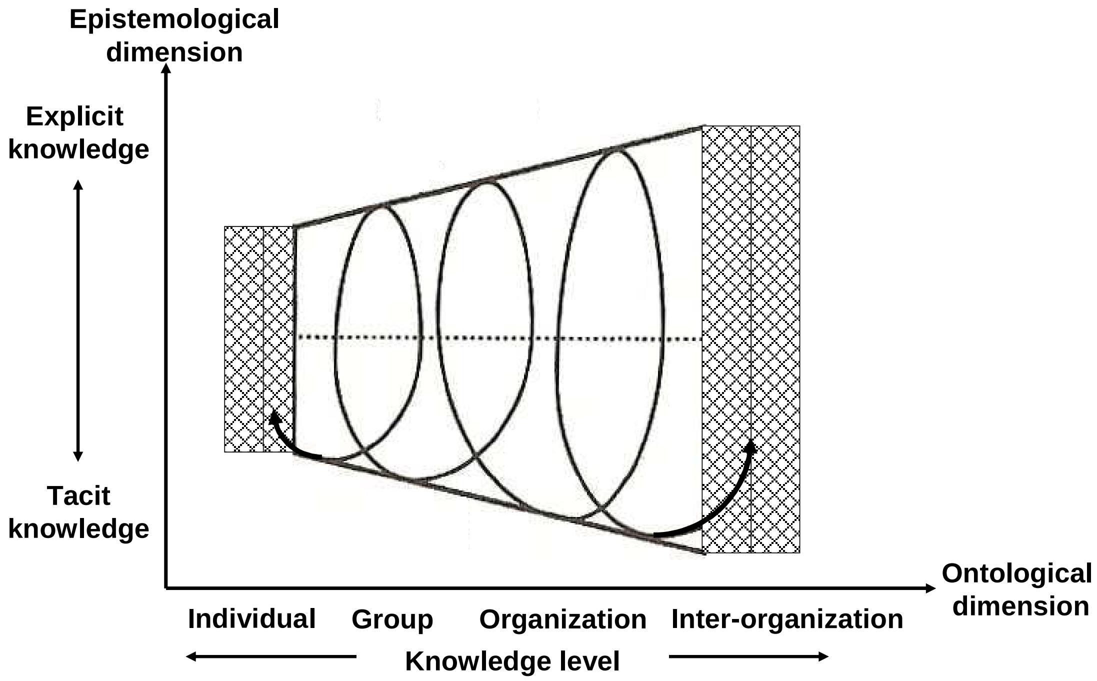

Figure 11. Two dimensions of the knowledge creation process (Nonaka and Takeuchi 1995)

The knowledge creation process in organizations is an iterative, spiral process, in which knowledge is first created at the individual level and then crystallized as a part of the organizational knowledge network, as illustrated in Figure 11 (Nonaka and Takeuchi 1995, p. 59).

Organizational knowledge has also been defined in the strategic management field as knowledge stocks and knowledge flows. The organizational knowledge at a particular point in time can be defined as the "knowledge stock" which also represents intellectual capital in organization and organizational learning (Bontis *et al.* 2002). The organizational learning and the change in knowledge stocks depend on knowledge flows in the organization. These definitions integrate intellectual capital, organizational learning and knowledge management (Bontis *et al.* 2002).

The strategy for knowledge transfer can be either knowledge codification or personalization. In codification the primary approach is to codify the organizational knowledge into different processes, systems and repositories. In the knowledge personalization approach, the primary mode for knowledge transfer is direct interaction among people. In most organizations, both approaches are normally needed, depending on the case.

3.2.2 Knowledge processes in organizations

The major knowledge processes can generally be represented as four sub-processes: knowledge scanning/mapping, knowledge generation, knowledge codification and knowledge transfer/realization (Grover and Davenport 2001). The knowledge scanning and mapping process includes e.g. business and technology foresight, where potential new areas are systematically scanned. The knowledge generation process includes the processes of creation, capturing/acquisition and development of knowledge. The knowledge codification process covers the conversion of knowledge into accessible format and the storing of knowledge. The knowledge transfer process includes the sharing of knowledge from the point of generation or codification to the point of using and applying it in an organization (Grover and Davenport, 2001; Beckman 1999).

Nonaka and Takeuchi (1995) created a model of the knowledge creation process, the so called the SECI model presented in Figure 12. The main idea is that continuous interaction between tacit and explicit knowledge leads to new knowledge, which is developed by individuals; groups and organizations play a critical role in articulating and amplifying that knowledge.

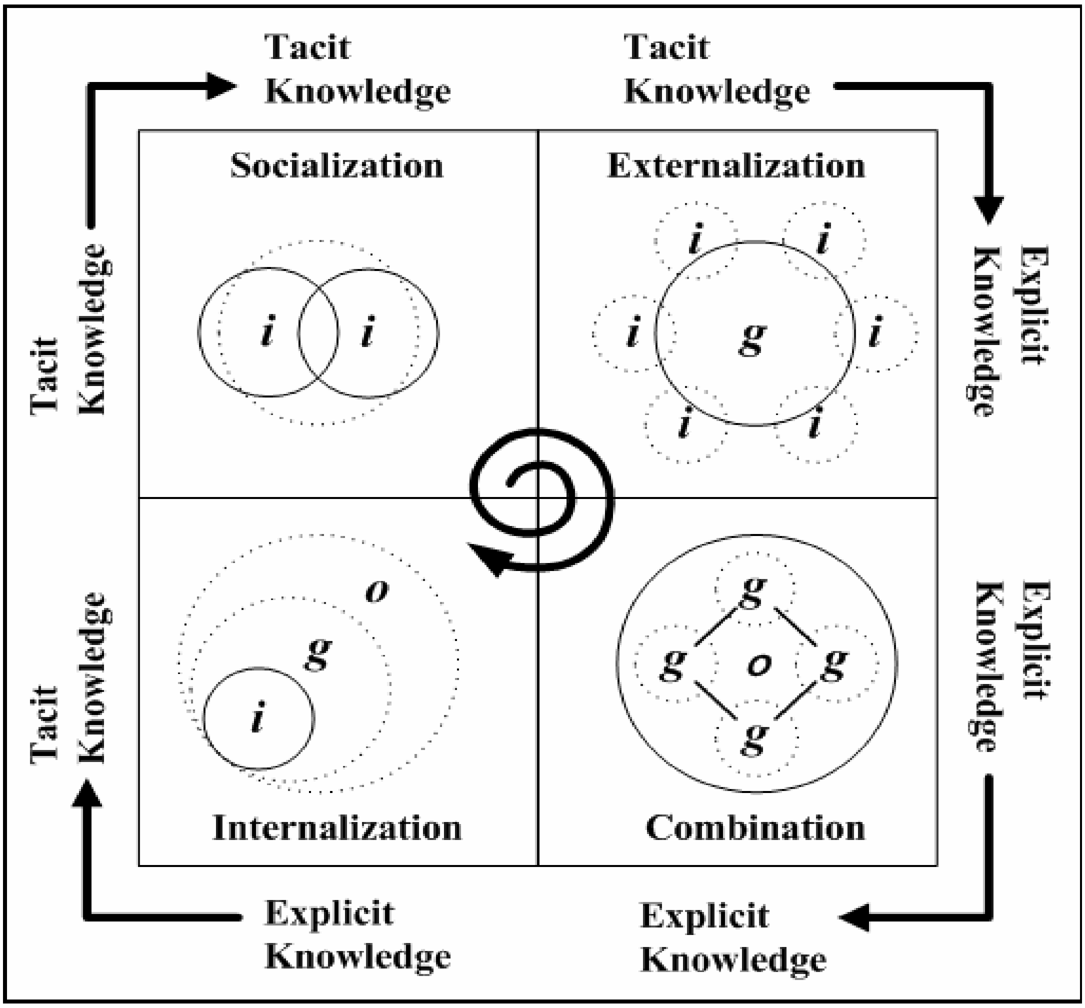

Figure 12. SECI process for knowledge creation in a firm (Nonaka and Takeuchi 1995)

Socialization is a process of sharing experiences and creating tacit knowledge such as mental models and technical skills. It enables the transfer of tacit knowledge through interaction between individuals. Tacit knowledge can be acquired through experience, e.g. on-the-job training or apprentices who learn by observing, imitation and practice, and not only through language.

Externalization is a process of conversion and articulation of tacit knowledge into comprehensible, explicit forms that can be understood by others. Examples include concepts, models, group discussions, presentations and sharing knowledge.

Combination is a process of systemizing concepts into a knowledge system, and the transformation of explicit knowledge into more complex sets of explicit knowledge. Explicit knowledge can be collected and combined with other bodies of explicit knowledge, leading to new knowledge that can be transferred within the members of the organization through media such as documents, e-mails and phone conversations.

Internalization is a process takes place when this explicit knowledge is transferred to organizational tacit knowledge. For example, in training programs explicit knowledge can be embodied in action and practice and then internalized into each individual's tacit knowledge by action learning. Through socialization a new round of the knowledge creation process is again started.

3.2.3 Knowledge transfer processes and concepts

Nonaka (1994) defined the goal for knowledge transfer in organizations as "tapping of tacit, highly subjective insights or intentions of an individual employee and making these insights available for the whole company". Dixon defined common knowledge as the knowledge that employees generate in the act of accomplishing an organization's tasks in new and innovative ways (Dixon 2000). The know-how developed by experience in organizations differs from book knowledge, and has the potential to provide competitive edge also when compared to e.g. customer or competitor intelligence, which is knowledge that is also available for competitors (Dixon 2000, p.11). Another aspect in common knowledge is that across an organization, many people have very similar know-how, e.g. like paper industry corporations having similar production plants. The transfer processes for common knowledge have been classified into serial, far, strategic and expert transfer which are illustrated in the Figure 13 (Dixon 2000).

The serial transfer process involves transferring the knowledge one team has gained in carrying out its task in one setting to the next team that performs the task in a different setting, the repeated action thus occurring in serial fashion (Dixon 2000). Examples of the serial transfer process include the US Army's AAR (After Action Review) sessions, which are used on battlefields for sharing key learning. AARs have also been used in the process industry, e.g. by British Petroleum (BP) in knowledge sharing. Serial transfer can be used in frequent and non-routine tasks and the knowledge can be either tacit or explicit (Dixon 2000).

The near transfer process involves sharing the explicit knowledge one team has gained from performing a frequent and repeated task to be reused by other teams doing very similar work. Examples of serial transfer process include the "Best Practice Replication" developed by Ford, in which the best practices developed in different vehicle operation plants were shared over the Intranet. The near transfer process can be used in frequent and routine task, when the knowledge is explicit (Dixon 2000).

The far transfer process involves sharing the tacit knowledge gained from carrying out a non-routine task and making it available to other teams performing similar work in other parts of the organization, but in different contexts. Examples of the far transfer process in the process industry include British Petroleum's – Peer assist process, in which business units could call other business units in order to share the lessons learned (instead of asking for help from the corporate level). In far transfer, the tacit knowledge delivered in the process has to be customized either by the source team or by the receiving team. The far transfer process is suitable for frequent and nonroutine tasks when knowledge is tacit (Dixon 2000).

The strategic transfer process is designed to transfer the collective knowledge of the organization in strategic tasks that occur infrequently but which are critical for the whole organization. The receiving team performs a task in a new context different from that of the sourcing team, and this has an impact on the whole organization. Examples of strategic transfer processes include BP's knowledge assets, where accumulated organizational knowledge of very specific topics are prepacked to be used e.g. in entering new markets or refinery maintenance shutdowns. Knowledge assets at British Petroleum (BP) are managed by a central knowledge management team that collects important experiences from global operations. Strategic transfer is used in infrequent and non-routine tasks and the type of knowledge can be either tacit or explicit (Dixon 2000).

The Expert transfer process is designed to transfer knowledge in situations where a team is facing a technical question which is beyond the scope of its knowledge and they would need to seek the expertise of other teams in the organization. The receiving team performs a different task than the source team but in the same context. Examples of expert transfer include Chevron's best practice resource maps, which were designed as competence roadmaps for the Chevron organization. Similar expertise locators are frequently used by many other companies. Expert transfer is used in infrequent and routine tasks when the knowledge transferred is explicit (Dixon 2000).

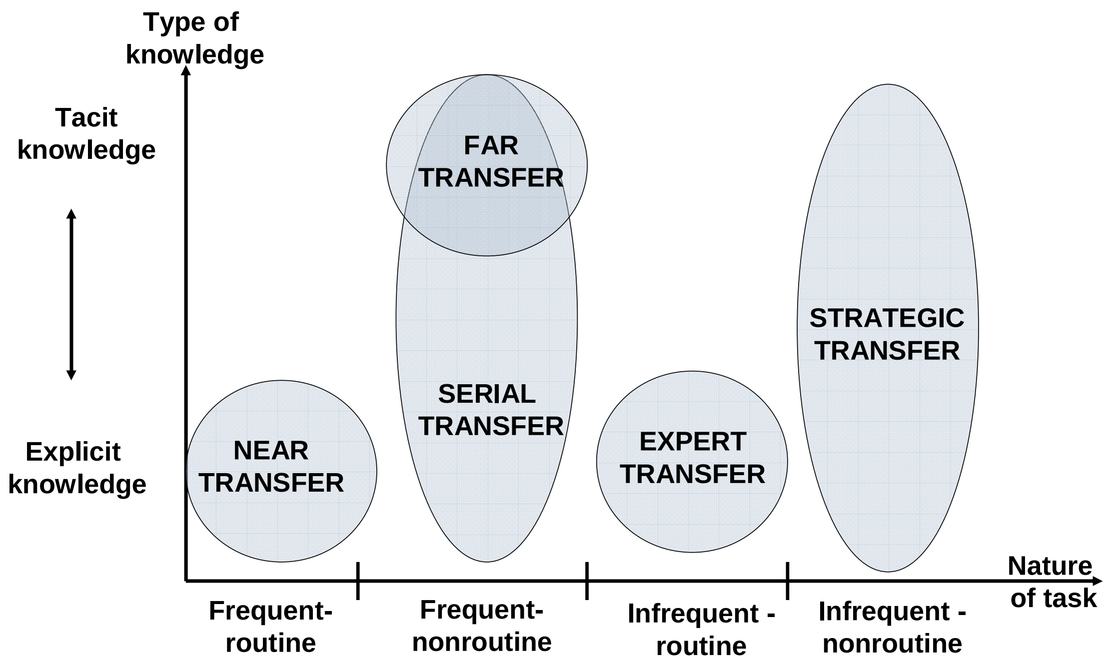

Figure 13. Organizational knowledge transfer processes (adapted from Dixon 2000)

Knowledge sharing in organizational memory systems can also be classified on the basis of topology for organizational knowledge re-use situations into shared work procedures, shared work practitioners, expertise-seeking novices, and secondary knowledge miners, each of the knowledge transfer situation having different requirements (Markus 2001). The major roles in these processes are knowledge producer, knowledge intermediary and knowledge consumer/user. Markus has classified the processes on the basis of the reuse situation into (1) knowledge re-user and what is the purpose of re-use, (2) what re-users need-to know, know and don't know and (3) challenges the re-users face in the different phases of re-use.

In shared work producers, homogeneous or cross-functional teams are the producers of the knowledge, which will be stored and re-used later e.g. for keeping track of status, revisiting decisions or learning how to perform better in the next project. An example of shared work producers is a Finnish paper mill, where the workers use an electronic diary to share operational knowledge of the production process which can be used to e.g. catch up on what has happened during their periods away from the mill (Kovalainen 2002).

In shared work practitioners, the knowledge re-users are people who are performing similar work in different locations, work units or organizations, and who are the producers of knowledge. In this process the knowledge is produced and re-used in a community of interest. Examples of shared work practitioners include oil field maintenance workers or consultants in a practice area, who can acquire knowledge that others have generated or obtain advice on how to handle a challenging situation.

In expertise seeking novices, the expert knowledge is transferred to people who occasionally and rarely need expert knowledge e.g. to solve ad hoc problems. Users can gain access to expertise without needing to acquire the expertise. Examples of the re-use process are manufacturing workers using an expert system for organizational design knowledge or customers accessing technical support.

Secondary knowledge mining is knowledge re-use including data-mining, to find answers to questions or to develop new knowledge through the analysis of records collected by others. Examples of the re-use process include trained analysts solving problems with advanced analysis tools.

3.2.4 Major barriers to knowledge transfer organizations

Knowledge management research has identified the following major concerns related to knowledge transfer processes: How to disseminate the knowledge (knowledge transfer problem), how to locate knowledge holders (knowledge coordination problem) and how to exploit existing knowledge (knowledge re-use problem). Researchers have also found that knowledge is often contextualized and not readily transferable (Huber 2001; Sambamurthy and Subramani, 2005).

Individual behaviours, organizational structures and organizational cultures can also be a major barrier for knowledge transfer. Some barriers to knowledge transfer based on APQC (American Productivity and Quality Center) benchmarking have also been documented by O'Dell and Grayson (1998). The major barriers to knowledge transfer are listed in Table 6

Table 6. The major barriers to knowledge transfer (adapted from APQC 1996; O'Dell and Grayson 1998)

Barrier to knowledge transfer	Key characteristics
Ignorance	Those who have the knowledge don't realize the value of it for others. Those who could benefit from knowledge transfer have no idea that someone possesses the knowledge
No absorptive capacity	Even if employees were not ignorant of the knowledge or best practice, they lacked the money, time and management resources to make it useful
Lack of pre-existing relationship	People absorb knowledge and practice from other people they know, trust and often like.
Lack of motivation	People do not have a clear business reason for pursuing the transfer of knowledge and best practices
Silo Company Inc	The structures of multinational companies can clearly promote silo thinking
Not-invented here company	Prevailing culture values of technical expertise and knowledge creation over knowledge sharing
Babel Company	Lacks a common vocabulary and has departmental dialects
Bolt-It-On Company	It is expected that knowledge transfer and sharing responsibilities can be added on the top of daily work

3.3 Organizational learning in complex production environments

There has been increasing interest in the role of the learning organization as a systematic model to obtain competitive advantage (Senge 1995; De Geus 2002; Marquardt 1996) and in organizational learning processes at the individual, team and organizational levels needed in competence and capability development in organizations (Argyris and Schön 1978). The goal of this learning is to improve organizational performance or to develop the competence needed in an organization, leading to better business results. In a fast changing environment, "the rate at which individuals and organizations learn may become the only sustainable competitive advantage especially in knowledge intensive industries" (Stata 1989), "the only way to preserve the competitive edge on your company is to make sure your company learns faster than competitors" (De Geus 2002) and the " hallmark for tomorrows organizations will be their capacity to learn" (Adler and Cole 1993).

In their book "Organizational Learning: A Theory of Action Perspective", Argyris and Schön (1978, pp. 17, 29) launch the concepts of single-loop, double-loop and deutero-learning to classify organizational learning. According to their model, organizational learning is a process mediated by the collaborative inquiry of individual members. The success criterion in organizational single-loop learning is effectiveness. Individuals as learning agents act in response to errors by modifying strategies and inventing new ones. And they must evaluate and generalize the results of their actions. The norms themselves remain unchanged. For organizational learning to occur, the learning agents' discoveries, inventions and evaluations must be embedded in the organizational memory, in individual images and shared maps of organizational theory-in-use. If this encoding does not occur, individuals will have learned but the organization will not have done so.

In some cases, however, the correction of inconsistencies requires an organizational learning cycle in which organizational norms themselves are modified. Argyris and Schön (1978) call this sort of learning double-loop. The implicit standards and values that evolve in organizations are called norms (Schein 2002). Norms control the functions of the organization. In double-loop learning there is a double feedback loop, which connects the detection of error not only to the more effectively realizable strategies and assumptions but also to the norms, by setting new priorities and weighting the norms, or by restructuring the norms themselves together with associated strategies and assumptions. Double-loop learning consists not only of a change in organizational norms but also of the particular sort of inquiry into norms, which is appropriately described as learning (Argyris and Schön, 1978, pp. 20–26, 29).

Organizations need to learn how to restructure themselves, so as to take advantage of the new strategies, technologies and processes generated by new research and development. Or, in other words, organizations need to learn how to carry out single and double-loop learning. This sort of learning to learn called 'deutero-learning', i.e. 'second-order learning'. Argyris and Schön (1978, p. 27) point out that when an organization engages in deutero-learning its members learn about the precedent context for learning. They reflect on and inquire into the previous episodes of organizational learning, or of the failure to learn. They discover what they did that facilitated or inhibited learning, they invent new strategies for learning, they produce these strategies, and they evaluate and generalize what they have produced. When an organization engages in deutero-learning, its members learn about organizatinal learning and reflect on it in the organizational learning practice (Argyris and Schön 1978, pp. 26–29; Kolb 1984).

Organizational learning generates inertia and can finally cause a crisis in the organization. Thus the role of continuous organizational unlearning has been emphasized in dynamically changing and complex environments (Nystrom and Starbuck 2004). Unlearning as a systematic process includes the identification of weak signals, exploiting opportunities and experimenting. The importance of unlearning in organizational development is well in line with the conclusions of Leonard-Barton's studies on core competence and core rigidity (Leonard-Barton 1992).

3.3.1 Theoretical framework for individual and organizational learning

Learning theories that have exerted the most influence over the past 50 years can be grouped into four clusters (Schramm 2002). The best conditions for workplace learning are described in Table 7 and are summarized here:

(1) Learning as behaviour is a model that asserts that any change in an individual's behaviour is the result of events, known as stimuli, and the consequences of these events. Experts and expertise are the sources of learning.

(2) Learning as understanding is based on cognitive learning theories (learning as understanding) and view learning as a process of understanding and internalizing the principles, connections and facts about the world around us. This conceptual know-how is also associated with the ability to apply and to explain the learning points to other people. Content is in the centre of learning.

(3) Learning as knowledge construction is based on constructivist theories that view an individual as an active agent in their own learning stating that all knowledge is personal and exists in people's minds. The learner is the centre of learning.

(4) Learning as a social practice is based on social theories that do not contradict other theories, they simply state that learning is more effective when it arises and is applied in a social setting. Social patterns are a source of learning e.g. problem solving within an established work process.

Table 7. Learning theories in work environments (Schramm 2002)

Learning Theory		Learning for work	Learning at work	Learning through work
BEHAVIOR	Approach	Priming	Training	Guiding
	Examples	Courses, seminars, conferences and professional updates	Coaching and tuition Induction programmes, training courses, computer based training	Formal direction and feedback Supported practice
COGNITIVE	Approach	Engaging	Enriching	Problem-solving
	Examples	Books, journals, videos, CD-ROMs, www.	Case studies, lessons learned, exemplar projects, benchmarking Manuals, codes of practice and internal reports	Analytical framework Knowledge bases Performance support
KNOWLEDGE CONSTRUCTION	Approach	Reflecting	Enquiring	Immersing
	Examples	Personal and professional logs Records of achievements Supported online learning	Mentoring, diagnostic tools Brainstorming, workshops, discussions with colleagues/ customers/ suppliers	Special projects Job rotation and secondments
SOCIAL PRACTICE	Approach	Networking	Participating (in communities)	Team working
	Examples	Professional bodies, committees, interest groups and associations	Personal networks, communities of practise, internal committees and management groups	Project, functional, multidisciplinary and virtual teams

Training and learning always start with a need and a situation. The training need defines the depth of learning topics, i.e. the required level of knowledge or skills. One way to define targets for knowledge and competence levels is known as Blooms taxonomy, which is illustrated in Figure 14.

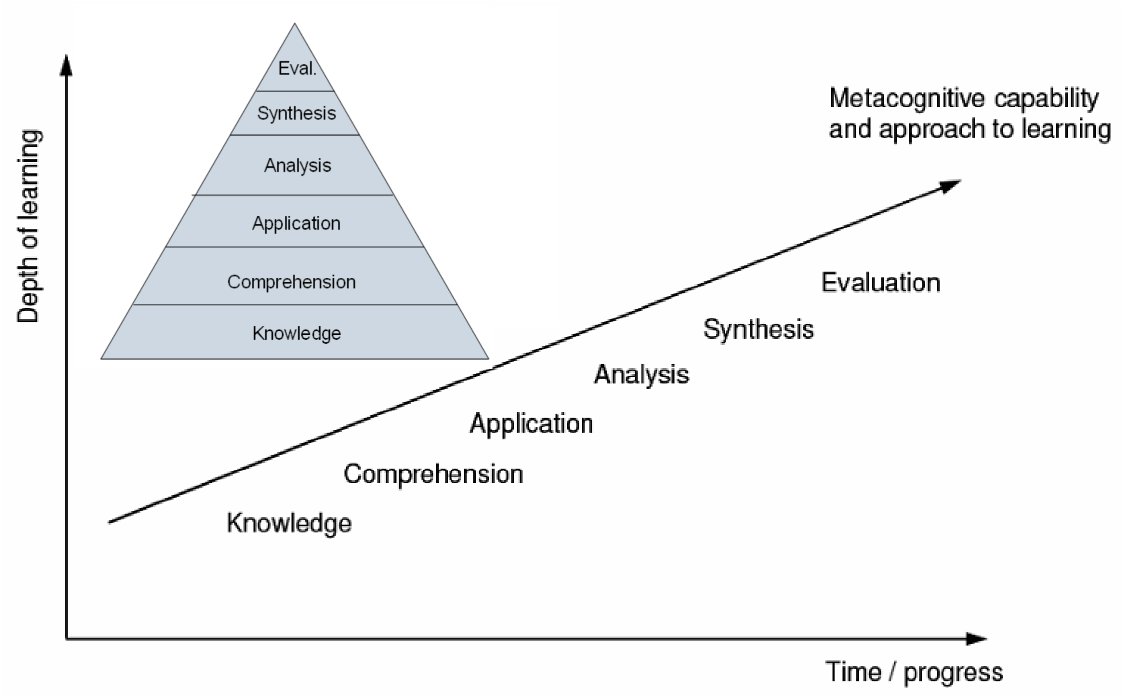

Figure 14. Bloom's taxonomy for learning (Alamäki and Luukkonen 2002)

There are always expectations interlinked with learning, instance a hope for a wider use of new knowledge or skills outside the learning context. Learning new things is always based on prior learning, otherwise each new learning situation would start from scratch. Our experiences from prior learning events may encourage or alert us to leap into further learning (Rauste-von Wright and von Wright 1994).

3.3.2 Transfer of learning

The transfer of learning is defined as applying the skills, knowledge, and/or attitudes that were learned in one situation to another learning situation. This speeds up the learning of other similar things. The basic question is what kind of influence the learning of one skill has on the learning or performance of another. Will a knowledge of paper technology help a person to learn converting technology easier or does mastering one sport make it easier to learn another similar event? The answer is most likely yes. (Garavaglia 1993; Rauste-von Wright & von Wright 1994; Clark 2004)

The interface between learning and the transfer of learning is not very clear. It is difficult to define what the original learning situation and the other learning situation are, what is transferred knowledge and what is newly learned knowledge. Often it is not even meaningful to try to define and measure it accurately, the result is more important than how it was reached. We benefit (or suffer) from our prior experiences. People improve in their ability to learn new skills more proficiently because of prior practice on a series of related tasks. This helps us to acquire new views on a topic by looking at the task from a different approach, which strengthens our understanding of the topic. For example, practicing to drive a variety of cars provides experience with different stimulus situations and makes new learning easier (Clark 2004). The lack of knowledge and skills can be the main barrier for stagnant development in job performance, and the aim for improving performance often leads to specific training programmes. To produce positive transfer of learning, it is necessary to practice under a variety of conditions (Clark 2004).

The benefit of multi-skilled training comes from versatile individuals, who are more capable to adapt their learning into job performance. It takes a longer time to learn several skills than just one, but eventually that is the way to become faster in adopting new skills and using them in complex events such as problem solving. It also provides the learners with the confidence and expertise required for transferring their newly acquired skills to the job. (Clark 2004)

Transfer of learning can de divided into positive and negative, near and far transfer: (Clark 2004, Rauste-von Wright & von Wright 1994):

- Positive transfer of learning take place when the skills, knowledge, and/or attitudes that were learned in one situation A assists learning in another situation B.
- Negative transfer of learning hinders the transfer of learned issues from A to B.

- Near transfer of learning takes place when skills and knowledge are applied in the same way every time the skills and knowledge are used. Near transfer training usually involves tasks that are procedural in nature, i.e. tasks which are always repeated in the same order. This type of training is easier to go through and the transfer of learning is usually a success, but the learner is unlikely to be able to adapt their skills and knowledge to changes.
- Far transfer of learning involves tasks, in which the skills and knowledge being applied in changeable situations. Far transfer tasks require instruction in which the learners are trained to adapt guidelines to changing situations or environments. Although this type of training is more difficult to instruct and the amount of transfer of learning is less likely, it does allow the learner to adapt their new skills to new situations.

According to Argote *et al.* (1990) the conventional measure of learning, i.e. cumulative output, significantly overstates the persistence of learning. The amount of knowledge or skills transferred to a job and used persistently often remains fairly minor. Labour turnover is usually not the main reason for this conclusion; it is usually more about incapable organizations than incapable individuals. To gain long-term positive effects, not only the training but also the circumstances in a workplace need to be supportive.

Transfer of training is based on the theory of transfer of learning. It is the extent to which the learned behaviour from the training program is used on the job (Phillips 1997). When the transfer of training has been successful, the skills, knowledge, and/or attitudes that were learned in a learning event are effectively and continually applied to the job environment. For someone who is sponsoring training participants, it makes sense to be interested in the results and the payback. To be able to show good returns on investments in training, it is necessary to find out whether and to what extent the skills and knowledge taught in training get transferred over to the job. Put in other words, the extent to which a training program increases job productivity is one of the basic questions to be set when starting the training evaluation process. (Garavaglia 1993).

3.3.3 Evaluation of training and learning outcomes

Evaluation of the consequences of the various training interventions in work life is becoming increasingly important (e.g. Phillips 1997; Warr *et al.* 1999), and the evaluation should cover both the subjective reactions of the participants regarding the training received, learning and job behaviour. The consequences on organizational indicators, e.g. productivity, quality, and staff turnover, should also be measured. Measurement of these organizational indicators is, however, regarded as difficult, because the organizational indicators are affected by several factors that cannot be controlled or measured (Warr *et al.* 1999). As a result, systematic evaluation of organizational indicators "have hardly ever been reported" (Warr *et al.* 1999). The learning outcomes should be derived from the training objectives based on the training needs assessments, and measures should be taken over an extended period (Phillips 1997).

Training in business-related actions differs slightly from general education. The basic idea and needs for training evaluation come from the efficient use of resources. Business decision making should be based on known facts – also in training events. Training evaluation should demonstrate improved on-the-job performance and financial results. There has been an important and steady trend during the last decades towards more relevant training programmes, impact and results of which are monitored, evaluated and reported. The ultimate objective of the training is to influence job performance, to gain on-the- job impact. That is the basic idea of result-based human resource development (HRD) and training evaluation (Phillips 1997; Garavaglia 1993).

Evaluation should be made at the end of the training in order to determine how much the trainee has learned, immediately on-the-job to assess the initial improvement from training, and at a later time (usually from six months to one year) to determine whether what was learned is being persistently used.

Donald L. Kirkpatrick presented his Ph.D. dissertation a four-stage model of training evaluation, nowadays known as Kirkpatrick's Four-Level Model. The Kirkpatrick Four-Level approach is probably the most well-known one for classifying four-level-model evaluation: reaction, learning, application and results (Kirkpatrick 1996; Phillips 1997). Jack J. Phillips developed Kirkpatrick's model further by including measurement of the return on investment level in the evaluation. He slightly modified and added a fifth step to Kirkpatrick's four levels, return on investment, as seen in Table 8 The first four levels in Phillips model are more or less the same as in Kirkpatrick's model, but the fifth, return on investment (ROI) is an added measure. Even though level 4 can give results for business, it does not totally answer the question whether the assets spent in training really have been worth it. By calculating the ROI it is also possible to evaluate the training programme as a whole. The ROI is usually expressed as a percentage of e.g., increased profitability versus training costs (Phillips 1997).

Table 8. Training evaluation at different levels (Phillips 1997)

Level		Brief description	Recommended targets *
	Indicators	This is the traditional approach to reporting training data. For instance: number of employees trained, total training hours, cost per participant etc.	
1	Reaction and satisfaction	Measures participants' reaction to the program, stakeholder satisfaction with the program and the planned implementation. For instance: relevance of training to job, recommendation of training to others, importance of information received, intention to use skills/knowledge acquired.	100%
2	Learning	Measures skills, knowledge or attitude changes related to the program and implementation. For instance: understanding of the skills/knowledge acquired, ability to use skills/knowledge acquired, confidence in the use.	60%
3	Application and implementation	Measures changes in behavior on the job and specific application and implementation of the program. For instance: the importance of the skills/knowledge back on the job, the frequency of use of the new skills/knowledge, the effectiveness of the skills/knowledge when applied on the job.	30%
4	Business impact	Measures business impact changes related to the program. Depending on the training programs' performance and business objectives, data may me gathered on the following: productivity, quality, cost control, customer satisfaction etc.	10%
5	Return on investment	Compares the monetary value of the business impact with the costs for the program.	5%
	Intangibles	Intangible benefits are measures that are intentionally not converted to monetary values because of the conversion to monetary data would be too subjective. For instance: increased job satisfaction, reduced conflicts, reduced stress, improved teamwork etc.	* % of programs evaluated at that level (Phillips)

Another approach to evaluationa is the model for evaluating knowledge and skills proposed by Marshall and Schriver (1994) consists of formative and summative evaluation. The methods most extensively used for gathering data are surveys and questionnaires, interviews, observation, and different kinds of productional curves, sales amounts etc. One widely used method for level 2 assessment is the use of competence exams administrated at the end of training. They can be organized in written (paper and pen) or practical (hands on) form. They measure how well knowledge and skills (partly) are transferred in training.

3.4 Summary

Knowledge in organizations including what the organization knows, how it can utilize the knowledge in business with its customers and how fast it can learn and know something new, can offer a sustainable competitive edge for organizations (Alavi and Leidner 2001; Davenport and Prusak 1998). The strategic intentions steer the systematic knowledge creation and knowledge management processes, which need to be integrated with learning, competence and capability development at the team and individual levels. The focus should be on strengthening the sustainable competitive advantage and core competence of an organization (Nonaka and Takeuchi 1995).

In a framework of a firm as an open system, knowledge transfer, competence and capability development are critical organizational processes which take place at five levels. These processes should be integrated with existing business and organizational development processes, confirming the knowledge stocks and flows in the different levels of the organization. The top leaders should create an environment and conditions that enable and facilitate knowledge transfer and learning, breaking the silos and other barriers to knowledge transfer found in multinational, industrial organizations. However, the core capability can also become a core rigidity, if it inhibits the development of new innovations and creation of new knowledge as proposed by Leonard-Barton (1992).

At the individual level, competence development and learning are tools for strengthening the competitive edge, where the targets should be cascaded down from the strategic targets of the organization. From the organizational perspective the learning is not enough if it does not develop the organizational knowledge or capabilities. Individuals and teams are in the key role both in the creation of the new knowledge and in the transfer of tacit knowledge in an organization. The collective knowledge of an organization consists of people, networks and communities, organizational processes and systems, management systems, procedures, manuals, databases and ICT systems. Optimally, all the critical knowledge should be integrated as a part of organizational knowledge, and should be available for the whole organization either through systems and processes or through people networks and communities.

Despite the need for an integrated concept for knowledge transfer, learning and strategic competence management, the proposed frameworks in the literature reviewed in this study have been theoretical and tend to lack the industrial experiences (e.g. Davenport and Prusak 1998; Sydänmaalakka 2002; Kim 2002; Senge 1995). These frameworks have also lacked a direct link with core organizational processes like strategy implementation and performance evaluation. The research related to knowledge, competence and learning as a competitive edge has been carried out in different disciplines, including strategic management, knowledge management, education and learning, performance improvement, and organization learning, therefore causing problems and confusions because different terminology is used in different disciplines. The concept of an intelligent organization with agile dynamic competence and capability development processes is so far the best example of an attempt to integrate the processes of knowledge management, strategic competence management and learning into an organizational framework (Sydänmaanlakka 2002).

4 Technologies and tools for learning, knowledge and performance support

The aim of this chapter is to review the development of knowledge and performance support technology, computer-based learning technology and finally simulation technology, with the focus on applications in the paper industry. In the technologically enhanced workplace of the future these support technologies will be integrated with the standard systems, tools and processes in the workplace.

4.1 Knowledge and performance support systems

4.1.1 Definitions of electronic performance support systems

The development of computer-based, performance support tools started in the late 1980s and early 1990s in the US (Gery 1991; Raybould 1995; Rosenberg 2001). The concept of the electronic performance support system was first introduced by Gloria Gery (1991). Her definition of EPSS was "an integrated electronic environment that is available to and easily accessible by each employee and is structured to provide immediate, individualized on-line access to the full range of information, software, guidance, advice and assistance, data, images, tools, and assessment and monitoring systems to permit job performance with minimal support and intervention by others."

Some of the benefits of EPSS listed by Gery (1991) included:

1. reduction of the complexity or number of steps required to perform a task
2. providing the performance information an employee needs to perform a task, or
3. providing a decision support system that enables an employee to identify the action that is appropriate for a particular set of conditions.

The following terminology is used in the area of performance support systems. Performance support (PS) and performance support systems (PSS) are any system, that provides support for the users. If computer or communication technology is used to deliver the support, then the corresponding terms are electronic performance support (EPS) and electronic performance support systems (EPSS). Also terms information support system (ISS) and knowledge support system were defined by Kasvi (2003). Broader, organizational level systems can be called organizational performance support systems (OPSS) or organizational memory. In these systems the focus is on organizational knowledge instead of individual or team knowledge. Also the terms web based performance support system (WBPSS) or multimedia performance support system (MPSS) have been used, when web or multimedia technology is used to manage and deliver the support (Kasvi 2003; Dickelman 2003)

Electronic knowledge and performance support systems have been an active research area and as a source of good reference information (see e.g. Raybould 2000; Kasvi 2003; Dickelman 2003). In the latest research, Raybould introduced performance support mapping methodology, and Kasvi emphasized the role of knowledge support, adaptive functionality of these systems in learning organizations, and the collaborative features of the systems (Kasvi 2003).

The rapid development and convergence of multimedia, www and mobile technologies have further increased the application possibilities of EPSS. PDAs and mobile computers can be used for running www -based EPSS systems. Mobile users can access support systems via wireless networks. Some features of knowledge and performance support systems have been directly integrated into process control and automation systems. A good reference for the latest EPSS applications is EPSS Central (EPSS Central 2007).

4.1.2 Summary and the future of knowledge and performance support systems

The major applications of knowledge and performance support systems in paper production can be divided into the areas listed in Table 9. The major workplace applications in the workplace are information and knowledge sharing. Critical knowledge is available in the systems when needed. Information and knowledge can be used for orientation, training and competence development of the employees in the workplace. Business unit and corporate level applications include knowledge transfer between different units and transfer of best practices. Furthermore the multimedia material in these systems can be used in meetings, presentations and communication

Table 9. Applications for knowledge and performance support systems

Application area	Description of applications
Knowledge support	- information sharing between different control rooms - knowledge support e.g. in troubleshooting situations - detailed knowledge and information about equipment
Performance support	- sharing of best practices related to infrequent tasks -checklists and multimedia documentation of procedures - real-time support for operative decision making
Competence development and learning	- customized materials and learning paths for training and development (e.g. apprenticeship or on-job-training) - multi-skilled workplace learning
Knowledge transfer	- transfer of expert knowledge in organizations - transfer of critical production knowledge in organization - transfer of knowledge in business start-up projects
Other applications	- orientation of new employees - multimedia presentation tool for visitor presentations - databank for communication materials

4.1.3 Review of information and knowledge management systems in paper production

The focus in knowledge and information management in paper production has been on the computer and automation systems developed for on-line process control and production management. These real-time systems are data warehouses for production data and information, including efficient tools for data trending and analysis and interfaces for operating the production line. In the latest versions of these systems the suppliers have also integrated new features and tools for knowledge management, including tools for collaboration and knowledge sharing in the workplace. The latest tools for collaborative workplace include forums for threaded discussions, tools for documentation of recent changes, tools for integrating process control documentation, and collaboration tools for the systems.

Traditionally, one of the major tools for sharing knowledge in production control has been a diary. In modern mills, electronic diaries have been developed and used for knowledge sharing (Kovalainen 2002). In these diaries the users can document the disturbances and share key learning points and information related to process operations. A list of different tools and systems developed for knowledge and information management in the paper industry is summarized in Table 10.

Table 10. Information and knowledge management tools used in the paper industry

KM Tool	*Application areas*	*Developer/Refencences*
Shaman/ Electronic Diary	Electronic diary for paper production units, where users can share experiences and knowledge related to processes and disturbances	Kovalainen (2002)
ABB Industrial^{IT}	Information and knowledge management systems for paper production units, including APSweb knowledge management applications. Also other optimization, SPC and computational routines can be combined.	ABB Industrial http://www.abb.com
Metso DNA	Information management systems for paper production units, including also knowledge management activity. Control engineering or experience-based knowledge can be directly integrated with the system. Metso DNA is also having an electronic diary as an extension.	Metso Automation http://www.metsoautomati on. com
Honeywell Experion PKS	Information management systems for paper production units, including a knowledge repository. The right information and knowledge can be delivered to the right persons at the right time. Additional extensions include Operations Logbook, Event and Log analysis tools	Honeywell
FlowMac	Steady-state and dynamic simulation of pulp and papermaking processes, focusing on TMP and RCF plants and paper mills. Mass and energy balances, troubleshooting, wet end chemical balances	PaperMac AB http://www.papermac.se
KCL-Wedge	KCL Wedge is an on-line process analysis system used for process analysis and control. KCL Propose is a dynamic simulator based on KCL Wedge and identified models	KCL http://www.kcl.fi
KCL-Guru	KCL Guru is a knowledge and event management tool	KCL http://www.kcl.fi
KnowPap	Learning environment and knowledge support system for papermaking and paper mill automation knowledge. The content can be used but not customized.	KnowPap http://www.prowledge.fi

4.2 Computer-based learning technologies

4.2.1 Definitions for computer-based e-Learning technologies

Computer-based learning or e-Learning is a relatively young, and fast growing development area of employing technology to deliver training. The development started in the 1980s following the development of computers, and it has been speeded up by the development of www, communication and information technologies which have permitted unprecedented access to information and resources. These technological advances have dramatically changed the landscape of training and development (Welsh *et al.* 2003).

e-Learning has been defined and is also called CBT (computer-based training). e-Learning is a general term that relates to all training that is delivered with the assistance of a computer. Delivery of e-Learning can be via a CD/DVD, the Internet, or shared files on a network. Generally, CBT and e-Learning are synonymous, but CBT is the older term, dating from the 1980s. The term e-Learning evolved from CBT along with the maturation of the Internet, CDs, and DVDs. e-Learning also includes Internet-based Learning, Web-based Learning, and Online Learning. Related terms include: distance teaching, computer-assisted teaching, educational technology, compare internet-based learning (IBL) or web-based learning (WBL)". (Wikipedia, 2007)

Rosenberg (2001) states that computer based training (CBT) or web-based training (WBT) or Internet-based training (IBT) are too limiting descriptions of e-Learning. Rosenberg defines e-Learning as including any system that 'generates and disseminated information and is designed to improve performance'. According to Rosenberg, e-Learning can be divided into synchronous e-Learning, where all the learners sit in front of their computers at the same time, e.g in a virtual classroom session. e-Learning can also be asynchronous, where the users can access the modules from any place at any time (Rosenberg 2001). Rosenberg also defines three fundamental criteria for e-Learning:

1. e-Learning is networked, which makes it capable of instant updating, storage/retrieval, distribution and sharing of instruction or information.
2. It is delivered to the end-user via a computer using standard Internet technology.
3. It focuses on the broadest view of learning – learning solutions that go beyond the traditional paradigms of training

The content delivered via e-Learning is related to (a) instructional goals, (b) specific instructional methods, (c) selected media, and (d) knowledge and skills for achieving individual or organizational goals (Rosenberg 2001).

e-Learning has also been criticized as inefficient, i.e. students having problems with technology tend to give up the courses. The latest development trend is called blended learning, where e-Learning and computer-based learning tools are combined with traditional training and development methods, including e.g. classroom and on-job-training (Bielawski and Metcalf 2002).

4.2.2 Review of industrial training and development paradigms

The most important concepts for industrial training have been on-job-training (OJT) and classroom education. Some new concepts utilizing computer technology have been developed: Blended learning is a concept in which computer based learning is combined with traditional training and development e.g. classroom training, OJT and coaching (Bielawski and Metcalf 2002). Another new paradigm is workplace learning, in which asynchronous and synchronous learning tools are integrated into workplace giving any time and any place flexibility for learners.

In the traditional training and development paradigm, the instructor is the centre of the knowledge and the classroom is the fixed location for knowledge transfer taking place in a fixed time. In the new paradigm, the employee/learner is a knowledge seeker having constantly changing learning needs and in different time frames. Asynchronous and synchronous learning tools enable access both to knowledge resources, including computer-based learning tools, and to human networks which gives more just-on-time flexibility. The shift from training to blended learning is illustrated in the Figure 15.

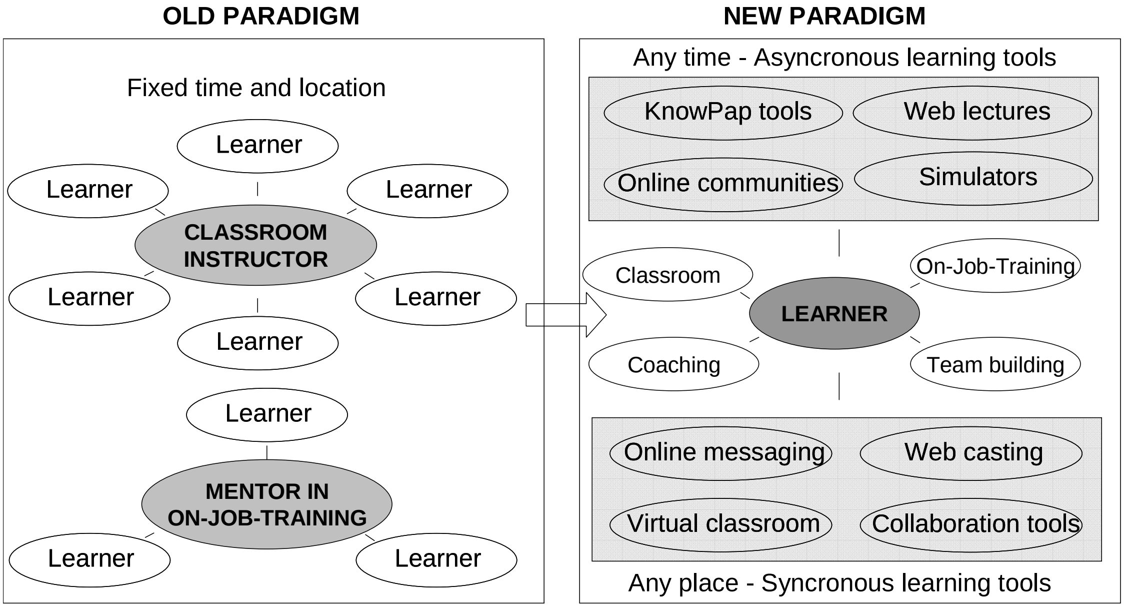

Figure 15. A shift from training to blended learning

Alamäki & Luukkonen (2002) used a term *digital know-how development (DKD)*, which integrates education and learning with the capability to use information and communication technology, e.g. digital communication or interactive multimedia. A further aspect in DKD is the learning goals which define the requirements and content for learning. While the traditional training paradigm functions in a fixed time and place, DKD is most suitable as a continuous learning process integrated into working situations and, in this way, supporting continuous learning (Alamäki and Luukkonen 2002).

Workplace learning supports the knowledge and performance needs of a learner in the workplace, enabling opportunities for continuous competence development. In the training programme- or course-based paradigm, competence development and learning are focused in classroom modules. As a result, there is no marked development between the modules, and learning retention can also be a problem. In the workplace-learning model, the development is optimally continuous which as illustrated in Figure 16.

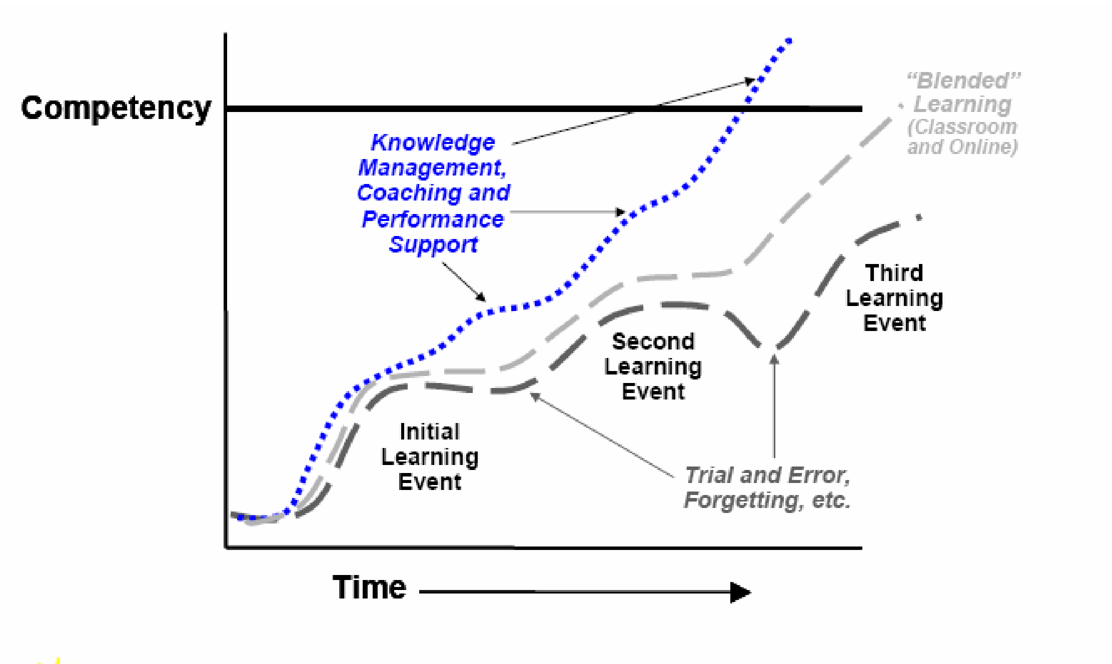

Figure 16. Time against competency learning curve in traditional and blended learning (Rosenberg 2005)

4.2.3 Benefits and challenges of computer-based learning

Some of the major benefits of using e-Learning according to Rosenberg (2001) and Welsh *et al.* (2003) have been listed in Table 11:

Table 11. Major benefits of e-Learning (Rosenberg 2001; Welsh *et al.* 2003)

Major benefits	Summary of benefits
Provide consistent, worldwide training	Companies use e-Learning when there is a need to deliver training to many people quickly. Learning is not restricted by instructor or classroom capacity. The message in the training is consistent and can be localized to different regions and languages.
Reduce delivery time	The delivery cycle is not limited by classroom capacity
Increase learner convenience (learning is 365/24/7)	Learners have access to asynchronous learning at any time, which is very convenient e.g. in shift work in production units. For a global company, time zones are a daily challenge. The "just in time – any time and anywhere" approach makes an organization's learning operations truly global
reduce information overload	By delivering some information asynchronously before training, the information can be delivered over a longer period of time, reducing information overload and improving retention
e-Learning lowers costs	Despite rather high initial development costs, e-Learning is often the most cost-effective way to deliver training to a large number of people in a global environment. The costs can be reduced in travel expenses, travelling time and in a reduced need for classroom infrastructure and instructor resources.
Content is more timely and dependable.	The content can be easily and quickly updated, and then distributed immediately enabling up-to-date knowledge support in accelerating change. The content can either be uniform for all or customized to different learners based on learning goals.
Improve tracking	Another advantage of e-Learning is the ability to track learning activities and mastery of materials, e.g. with evaluations or follow-up tracking tools

Some further benefits listed in Wikipedia (2007) are: "e-Learning is flexible, convenient and allows you individually to proceed at your own pace. It also enables you to communicate with fellow learners from around the world, it can bring more variety in the learning experience with the use of multimedia and the non-verbal presentation of teaching material, and it makes it easier to update learning content worldwide."

There are also disadvantages in e-Learning and successful implementation requires resources, significant planning and effort. Some of the disadvantages listed by Welsch *et al.* (2003) are the up-front development costs of courses, software and hardware, lack of networking between the people in training, and a too simplistic mindset related to some e-Reading applications. According to Wikipedia, some of the drawbacks of e-Learning are a lack of face-to face interaction, a lack of collaboration with fellow-classmates, a feeling of isolation, motivation problems, a need for equipment and software, as well as the computer-skills needed with different systems. Some of the users can feel a fear of the new technology, and others drown in the flood of information. There are also new requirements for instructors, who are going to use e-Learning. The development of high quality, engaging, pedagogical e-Learning modules can be complex and time-consuming. The latter disadvantages are related to challenges with the technology and completion rates. Studies suggest that the completions rates of e-Learning courses are lower than those of instructor-led classes. If the technology does not work well, e-Learning can be an extremely frustrating experience (Welsh *et al.* 2003).

Based on the learners' learning orientation, there are also different kinds of learners,; eLearning is just a tool that needs to be adjusted to these different orientations but there is still a lot development needed. Today's younger generation is very familiar with computers, mobile devices, multimedia and games even before going to school. They are very capable of searching for information rapidly from a variety of sources and using the different asynchronous learning, synchronous learning and collaboration tools. Students must learn how to be information producers, and not only consumers (Jonassen *et al.* 1999). On the other hand, the companies should be prepared for these new kind of learners, who are native users of different e-Learning tools and who are also expecting the companies to have the infrastructure and the latest tools already in place.

4.2.4 Summary and the future of computer-based learning technologies

A shorter lifecycle of products, the increased speed of change and implementation of new technologies in workplaces, together with the increasing instability of employment, all lead to a need for continuous learning throughout their working lives. Continuous development of professional knowledge and skills, or the development of new competences, is becoming more and more important. There is a need for supporting tools for workplace learning and the border in knowledge work between working and learning is blurred.

A successful organization has to recognize its core competence and capabilities which are the basis of its existence. The role of ICT networks is to feed and support the development of these processes as a distribution channel and media for new just-in-time information and virtual interaction. Primarily, e-Learning systems should focus on supporting the maintenance and development of the core know-how and, secondary, concentrate on other educational issues. (Alamäki and Luukkonen 2002)

Computer-based learning is a relatively young field, and the speed of developments is very fast. As a result, the studies carried out on it easily become outdated within just a few years. The rising trend in e-Learning is the web 2.0 concept, which is based on convergence of the latest collaboration, learning and communication technologies, as illustrated in Figure 17. Good references and reviews of the future learning technologies have been published by Hall (2007) and Adkins (2007).

The major change of e-Learning in the future is based on the development of two way collaboration tools. As a recent example, there has been an enormous rise in the number of "social network sites" that connect people to online communities of practice (CoP). In the communities it is possible to discuss with others, share information, ideas, opinions or materials or to maintain a web diary (called a blog) and there are knowledge management technologies integrated into these community tools. Good examples of such services are Wikipedia, LinkedIn, or Youtube. The transformation with Web 2.0 is considered not only a technological, but also a social and cultural revolution (Downes 2005).

Another development area is virtual workplaces and virtual environments which have been used in computer games but can be applied e.g. in business simulations. Virtual collaboration and communication technologies are typically integrated with these on-line virtual reality environments like Second Life. There are also tools for teams, social and virtual networking with experts. The convergence of these technologies will provide totally new opportunities for knowledge and performance support in the workplace.

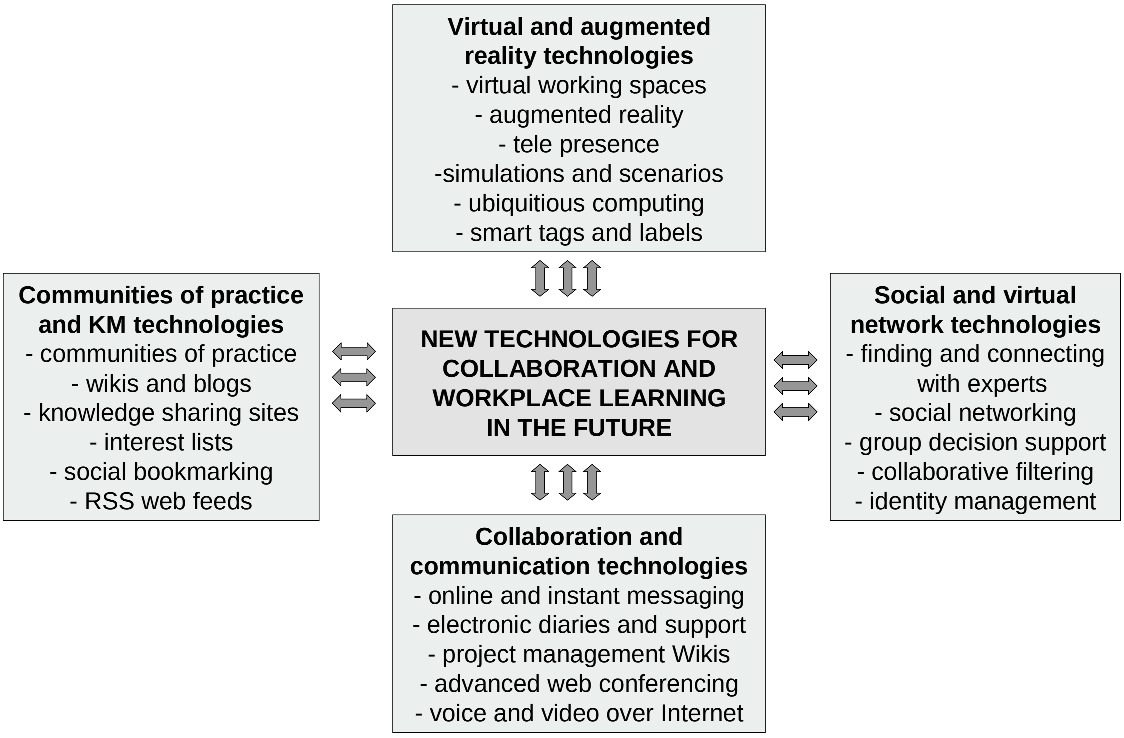

Figure 17. Convergence of learning and communication technologies

4.3 Computer-based training simulators

Computer based educational and training simulators are developed primarily to nurture specific learning goals with the support of human coaches and facilitators (Aldrich, 2004). The first computer based simulators in process industry were developed in the 1950s and 1960s with pneumatic and analogue computers. Some of the leading companies in the development of process simulators in the chemical process industry have been Shell, DuPont, Fluor and BASF. These companies have been very active developers and users of process simulators in process development, process design, control concept development, process optimization and operator training (Braunschweig and Gani 2003, Bausa and Dünnebier 2006, Cox *et al*. 2006).

The use of process simulators in BASF in the development of new chemical production processes follows optimally the life-cycle of the plant. The development starts with process development and engineering where a steady-state simulator is used for process flowsheeting, followed by process control engineering and process optimization where the dynamic simulator is used. Optimally, a result of process and control engineering is a dynamic simulator which can be customized and used also for operator training. Operator training simulators require sufficient fidelity to describe accurately transients of a process, reliability to cover the operating range used in process, and efficiency to run under real-time. Simplifications and customization is often needed in the high-fidelity dynamic models to meet the criteria (Bausa and Dünnebier 2006).

DuPont company has used process simulators since 1950s and the first dynamic process simulator, Dyflo was developed by Franks in 1972. Today both commercial and in-house dynamic simulators are used in DuPont. The goal is to integrate the dynamic simulators both in chemical engineering and in training and education. The operations should first be experienced with virtual process simulator, based on dynamic simulator and a real DCS system. DuPont has in-house simulators and built simulation interfaces to five different DCS systems, which makes development and commissioning of operator training simulators very inexpensive and efficient (Cox *et al*. 2006).

Operational training simulators in chemical process industry are often full-scope simulators which are integrated with a simulated control room environment and a distributed process control system. The basis for these training simulators is a detailed dynamic plant model including also the major control loops and parts of process automation. The control and automation can either be a part of the simulator or optimally a part of a real distributed process control system where the major control loops and automation system displays are defined and operated.

The results from the chemical process industry indicate the benefits of training simulators as decreased start-up time by efficient and realistic training, optimized operating procedures and improved control concepts which can be pre-tuned with the simulator. Training simulators in chemical industry have proved to be economically feasible and by reusing the models the economic advantage can be further improved. Number of reported applications in the chemical process industry is still relatively small, usability and open communication of the simulators should be developed and more standardization is needed in the future so that the different simulation tools from different suppliers can be integrated (Bausa and Dünnebier, 2006).

The benefits of simulator training have spread from the chemical process industry to the pulp and paper industry. Modern paper mills are highly automated and, because a large number of separate control systems are needed to control the processes, computer based or full-scope simulators can be very efficiently used. As the frequency of emergency and disturbance situations has been reduced, the operators nowadays have fewer opportunities to gain experience and prepare for potential problem situations. These scenarios can be learned by simulation.

4.3.1 Definitions for process modelling and computer based simulation

Process modelling and simulation are terms which are increasingly being used with different meanings in different contexts. Under the term process simulation model, over 10 different methods can be found. In order to ensure consistent use of the terminology in this thesis, the terms are defined in the following.

Process modelling has been defined by Zeigler (1984) as “Modelling means the process of organising knowledge about a given system”. Process simulation was considered by Korn and Wait (1978) as “performing experiments on a model so that knowledge about a given process can be collected”. Steady-state process simulation is the solution of mass and energy balances for a given process operating in a stationary state. Mathematically, a steady-state model is defined by a set of non-linear equations, where the calculated output values depend only on the current input values and model parameters. In dynamic process simulation, the conservation equation for mass, energy and/or momentum are solved as a function of time. Mathematically, a dynamic process simulation model is usually described as a set of ordinary or partial differential equations. The values of the state variables in the model depend on the initial and on the historical state values. The dynamic simulation model often also includes time dependent changes. A simulation experiment was defined by Cellier (1991) as “An experimental frame defining a limited set of circumstances under which the model is to be observed or subjected to experimentation”. The software tools, which support model development, i.e. the preceeding and succeeding phases of it, can be called a simulation environment. The central part of a simulation environment is a simulation programme, which is used to develop simulators. A process simulator is equipment, unit operation, process or a plant-specific computational application in which the connections, equipment parameters and behaviour of the model correspond to the real process. In deterministic simulation models, all feed streams, model parameters and disturbances are known precisely, whereas in stochastic simulation models the feed streams and the disturbances include statistically random behaviour. The model fidelity describes how accurately the model corresponds to reality. A hybrid simulation model is generally a combination of different simulation paradigms and, in the present work, is defined as a combination of coupled discrete and continuous system simulation models that interact with each other. Traditionally, the term has also been used to describe combined analogue/digital approaches in computation. A Hybrid phenomenon was defined by Barton and Park (1996) as a system that cannot be observed as a purely continuous system or a purely discrete system. In a real time simulation model, the timing of execution in a simulation is equal to or faster than the timing of the real system's operation. In operator training simulators, the timing of the simulator must correspond with or be faster than the real process operation; the functionality and operability of the simulator must correspond to the operability of the real process. When the user interface, the use, functionality and scope of the simulator are very close to the real operation room in a paper mill, the simulator is called a full-scope training simulator.

The use of simulation in training has also been defined by Vartiainen (1985) and Ruohomäki (2002) as "Simulation is a working representation of reality based on an abstracted, simplified or accelerated model of a system, process or environment. It includes the critical elements of a real-life system. Models may be e.g. verbal descriptions, diagrammatic representations or pictures, physical, mathematical or statistical by nature. The goal of training simulation is to develop and transfer an internal mental model of system which can be done outside the normal work environment and before doing the actual work"

4.3.2 Benefits and challenges of training simulation

Winter (1992) reported that simulator-based operator training improves operations by speeding up operator response to process upsets, reducing the risk in emergencies and cutting the start-up time for new and existing process units. Simulator-based training improves the conceptual understanding and enhances the capability to diagnose and control the process in different operational situations. Dynamic simulation and scenarios are especially suitable for addressing issues related to the operation of plants, because the plant operators deal with, and recognise, dynamic responses.

The benefits of using computational simulators in training are often descriptive rather than quantitative. Elgood (1997) reported the following benefits:

• Economic efficiency, the costs of computer-based simulator training are much lower than training with pilot or production scale processes. The training is more efficient, because it can focus on the important training situations. Operational faults can be minimised.

• Clarity of the simulation experiments. The operation of complex systems can be clarified with simulation, where the phenomena and systems are easier to observe and measure than in the real process.

• Repeatability. Difficult operational procedures and situations can be rewound and repeated many times. The control variables of the system can be varied and the consequences followed. Controlled analysis studies are possible.

• Safety. Through the use of simulators, it is possible to study the analysis of operational situations which are dangerous, either to the operators or to the process equipment.

Some additional benefits from the educational point of view (Ranta 2002) are:

• Better control of the training event and learning

• Adaptable exercises based on previous experience and knowledge

• Augmented reality - supportive tools and knowledge can be integrated into a simulator

Elgood (1997) also classified the different uses of simulators in training:

• Educational demonstrations; the illustration of essential situations increases conceptual understanding

• To transfer of know-how; experiences and know-how are transferred between the participants during simulator training.

• To stimulate the thinking/brainwork; the thought processes are stimulated by putting applied questions to the participants, who do not know the exact answers; the perception of insufficient or faulty thinking and mental models activates and motivates the participants to improve their know-how.

• Performance evaluation; the level of performance in difficult operational situations can be evaluated with simulation training.

• Skill training; in well-defined training situations, the decision-making, problem formulation, goal-setting, and information analysis skills can all be enhanced; the comparison of alternatives can also be undertaken.

• To predict changing conditions; changes in operational procedures and the learning of new practices can be done by using a dynamic simulator.

• Enhancement of group working skills; in simulator training, the participants become acquainted with each other; in the common simulator training, the experience of meeting the goals and reaching new levels of results as a group can be experienced.

• The enhancement of communication, interaction and co-operation.

In the interactive simulation experiments, the learning process and positive learning experiences are emphasised. Improved communication and teamwork are the extra benefits of training as we reported in the previous study Laukkanen et al. (1997a).

The greatest challenges in training simulators are related to the resources needed in the developing the simulators, keeping the simulation models up-to-date, and emulation of the functionality of the systems. The transfer of learning in simulation depends on how realistic the environment and the user interfaces are, which requires resources both during development but also after development. The life cycle of the detailed model can be very short, because model development is typically based on as-designed engineering information. Already during commissioning and start-up there are typically many changes made, which optimally should be updated in the simulator as well.

4.3.3 Past research on modelling and simulation in the paper industry

A paper production line is a very complicated process for modelling and simulation both in terms of the raw materials, which include e.g. fibres and chemicals, and in terms of complex processes and equipment like a paper machine. The interactions in the process are complex, and the final quality of the paper is a complicated and nonlinear combination of raw material recipes, equipment and process parameters, process control settings and operator actions. There are substantial time delays in the process, which is integrated and thus makes real-time process control challenging. For process control purposes there are not enough reliable on-line measurements. Process control actions in many sub-processes are still based on indirect measurements and, in many cases, on the skills and experience of the operators, instead of advanced automatic control concepts. This all increases the role played by the knowledge and skills of the operators.

All these factors are the reasons why the scope of modelling and simulation applications is not as complete in the paper industry as in many other process industries. A summary of the major tools and applications for process modelling and simulation in the paper industry is presented in Table 12. There are both steady-state and dynamic simulation programs used in the paper industry. More extensive information about the programmes and applications can be found in references and in the following reviews: "Use of simulation during the life-cycle of a paper machine context" by Laukkanen (2001), in "Paper machine modelling and automation studies point of view" by Lappalainen (2003), and recently also in the COST action 36 workgroup (Cost E36 workgroup 2005).

Table 12. Modelling and simulation tools used in the paper industry

Simulator	*Application areas*	*Developer/Refencences*
APROS/ APMS	Dynamic simulation of pulp and paper processes: automation engineering, disturbance dynamics, flow dynamics, verification of process control concepts, automation and control systems	VTT / Technical Research Center of Finland, Juslin K. (2005), Lappalainen J. (2004), Laukkanen, I. (2001)
BALAS	Steady-state material and energy balances, heat integration analysis, chemical and water management studies. Simulation of tank dynamics	VTT / Tech. Research Center of Finland http://www.vtt.fi/ene/balas
CAPS	Simulation programme developed for the training of paper machine operations covering wet-end and paper machine processes	
DynaChem	Dynamic simulation programme for chemical processes and water systems. Used mainly in the chemical industry but also in the pulp and paper industry	OLI Systems Inc http://www.olisystems.com
FlowMac	Steady-state and dynamic simulation of pulp and papermaking processes, focusing on TMP, RCF plants and paper mills. Mass and energy balances, troubleshooting, wet end chemical balances	PaperMac AB http://www.papermac.se
KCL-Propose KCL- Wedge	KCL Wedge is an on-line process analysis system used for process analysis and -control. KCL Propose is a dynamic simulator based on KCL-Wedge and identified models	Keskuslaboratorio http://www.kcl.fi
Ideas	Dynamic simulation with the focus on kraft pulp processes, process control and automation systems. Originally developed for design and engineering applications.	Simons Technologies Inc http://www.simonstech.com
Aspen Dynamics	Dynamic simulation program developed for chemical process simulation, but also having applications in paper processes e.g. modelling of the wet end of paper machine	Aspen Technology Inc http://www.aspentech.com
Wingems	Steady-state and dynamic simulation programme of pulp and papermaking processes which is widely in use. Wide model library and applications for different pulp and paper processes.	Metso Automation http://www.metso automation.com

4.3.4 Summary – the technologically enhanced collaborative workplace

It is assumed that virtual reality will reshape the interface between people and ICT systems by offering new ways for the communication and visualization of processes. Virtual reality has already been used e.g. in safety training (OSHA) in US, in aerospace flight simulators, in medical training simulations and in oil platform training. In paper process, the final goal in the development of simulator, learning, knowledge and performance support systems is a virtual papermaking environment for paper product and process development. In the virtual environment, the existing knowledge of papermaking is formulated as hybrid simulation models and knowledge support systems such that the best characteristics of different modelling methods are combined. Virtual reality paper production unit models can simulate the physical equipments and layouts, while computational simulation models and learning tools can be directly linked in this environment. This kind of environment would be ideal and realistic for learning the new processes before they are built, thus, bridging the reality and virtuality in paper production unit development illustrated in the Figure 18.

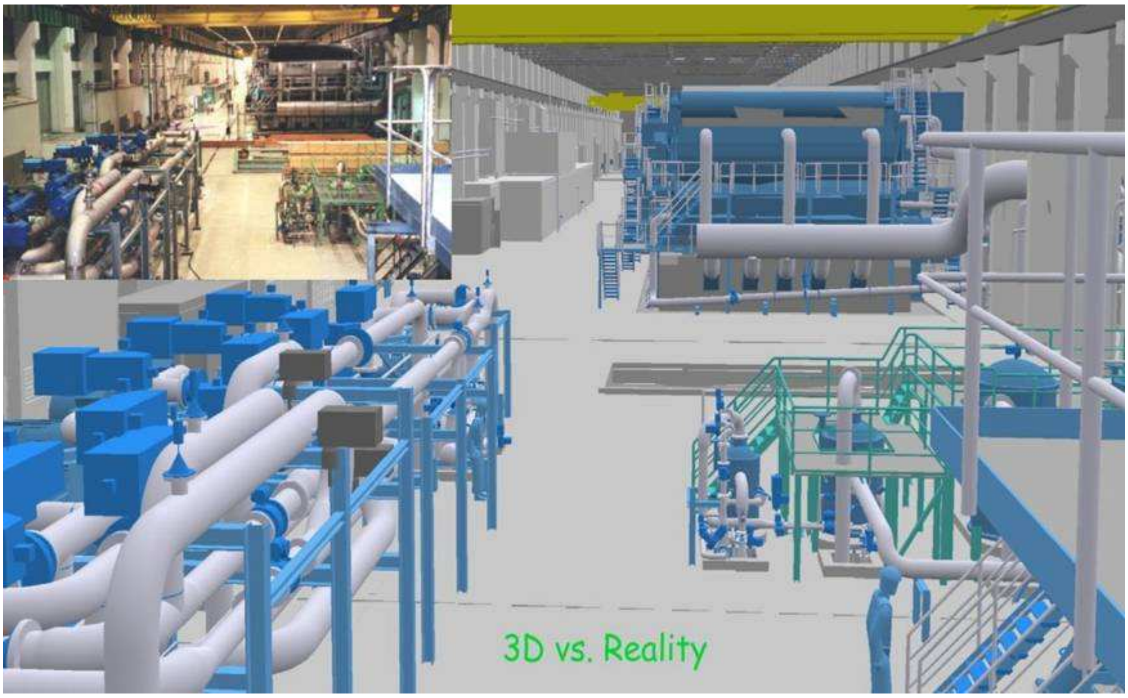

Figure 18. A virtual paper machine environment is very close to reality (Höynälänmaa and Aminoff 2005)

5 An integrated concept for knowledge transfer and competence development in paper production unit start-up projects

The aim of this chapter is to present a new, integrated concept for strategic knowledge transfer, learning and competence development at both the organizational and team/individual levels. Firstly, the integrated theoretical framework is introduced. The strategy implementation process sets the targets for the organizational competence, capability and knowledge development. These targets are cascaded down into team and individual level development plans. The shared mental models are the transfer mechanism between the individual and organizational levels, including both single and double loop learning. Secondly, the operational, integrated concept for knowledge transfer and competence development in paper production unit start-up projects is introduced. The concept combines advanced knowledge transfer tools, including knowledge and performance support systems and operational simulation tools with traditional development methods like classroom training and structured on-job-training. The planning, development and application of the tools in the projects are reviewed.

5.1 Theoretical framework for knowledge transfer, competence development and learning

In chapter 3, the development of knowledge management, strategic competence development and learning processes were reviewed, as separate research disciplines, within the framework of a firm as an open system. These disciplines are separate research areas, each having its own terminology, perspective and processes. In real firms these organizational development processes are integrated into the existing strategic management processes, creating an integrated framework which is developed and proposed in this chapter.

5.1.1 Integration of knowledge transfer, competence development and learning processes

The strategy implementation process is the key steering process also for learning, competence, capability and knowledge development in organizations. The strategic targets of a business or of a project define the key success criteria and, based on these success factors, the needs for knowledge, competence and capability development should be planned at the organizational, as well as the team and individual levels. This planning is a systematic process, which is integrated with existing processes, followed by implementation of the planned process.

The integration of the strategy implementation, competence, capability and knowledge development processes within the framework of a firm is illustrated in Figure 19. These processes create an organizational process management framework both for organizational level capability development and also for individual level competence development levels. Optimally, all this development creates new knowledge that is integrated as a part of organizational knowledge systems or social networks.

5.1.2 Continuous creation of new organizational knowledge via individual and organizational learning

The plans for competence and capability development and knowledge creation in an organization are drawn up on the basis of the strategic targets, and the focus in the development of new capability, competence and knowledge are tailored to reach these goals. These strategic plans are cascaded down from the corporate level to divisional, business units, and finally to the team and individual levels. The development of organizational capability, knowledge and competence can either be based on organizational development projects or on team and individual level competence development, as illustrated in Figure 19. In the organizational development projects, the focus is on the development or re-engineering of business processes, on the development of enterprise level systems to support these processes and, finally, on defining the necessary organizational structures, roles and responsibilities. The ultimate goal of this development is improved organizational capability. As a part of this development, new organizational knowledge is created and shared either as codified knowledge in the processes, systems and tools or as tacit knowledge shared in the people networks.

The organizational development can also be based on the development of teams and individuals, and the targets of these development plans are cascaded down from the strategic organizational level targets. Although the team and individual development takes place in development programmes, including different training and development events based e.g. on classroom training, coaching and on-job training, in the new concept this also includes operational simulation and the sharing of knowledge with knowledge and performance support systems. Depending on whether the knowledge is tacit or explicit, these individual tools can be used for knowledge sharing. The new development approach combines the best features of the different tools both for development of the conceptual knowledge framework and for development of the work process skills needed to reach the strategic targets. The proposed use of the different tools in the concept is illustrated in Figure 20.

Learning in organizations takes place at the individual level in a learning cycle, based on individual level active experimentation, and collecting the experience and reflecting and observing the work community response. This is also called single loop learning at the individual level in organizations. Even the implementation of single loop learning can be difficult in organizations. Based on the reflections and observations, individuals can assess and re-design the individual actions as key learning points. A team can be viewed as collective individuals, and the operational actions can also be based on team-work, as illustrated in Figure 19.

At the individual level double loop learning, the individual learning is systematically transferred into the conceptual frameworks and work routines used by individuals in the teams. The shared mental models are the knowledge transfer mechanisms between individuals. The individual level learning and competence development optimally is seen as improved performance and the performance evaluation process is used to confirm that the strategic targets are met. The training and development scorecard is a good follow-up tool for both individual and team level competence development. Also competence gap analysis and competence evaluation is used in the systematic planning process.

The best work routines and conceptual frameworks at the individual level are systematically integrated into organizational knowledge as processes, routines or conceptual frameworks. The shared mental models are the transfer mechanisms between individual/team and organizational levels. The updated processes, routines and frameworks can then be codified into enterprise level ICT systems and distributed via computer networks in the global organizations. Another way to transfer tacit knowledge is to build social networks and communities of practice and to distribute the knowledge via these networks. Also the formal HR and HRD systems, e.g. for safety orientation, can be used for knowledge sharing. In organizational level single loop learning (OSLL), the individual actions are interpreted and responded by organization and work community, which are then observed and reflected by individuals. In organizational double loop learning, the individual level learning is compared with existing best practices, and the new learning is integrated as a part of organizational knowledge, as illustrated in Figure 19. Organizational responses are observed and assessed also in individual/team level learning cycles, so that the operational actions in the future are based on the organizational learning cycle.

Part of the critical organizational knowledge should be codified into knowledge and performance support systems, which support the work performance of the individuals in the workplace and which can also be used in training and development events. Operational simulators can also be used to codify the operational procedures and best practices related to operations. These systems can also be used in individual level learning and knowledge transfer, as illustrated in Figure 19. The development of these tools is, in its optimal form, an organizational learning process, in which the critical competences and knowledge are defined, e.g. in relation to a fine paper production unit start-up. This knowledge is the created, stored, and codified into systems, tools and networks. Finally, the knowledge is systematically transferred and applied and, through this, the use of the latest organizational knowledge is ensured.

In complex production environments, the competence in teams is more important than individual competences and skills. The results of all the learning in an organization will be seen in the improved capability and performance, both at the organizational and individual levels. In the concept proposed in this study, the organizational processes are linked to individual and organizational level, single and double loop learning, as illustrated in Figure 19.

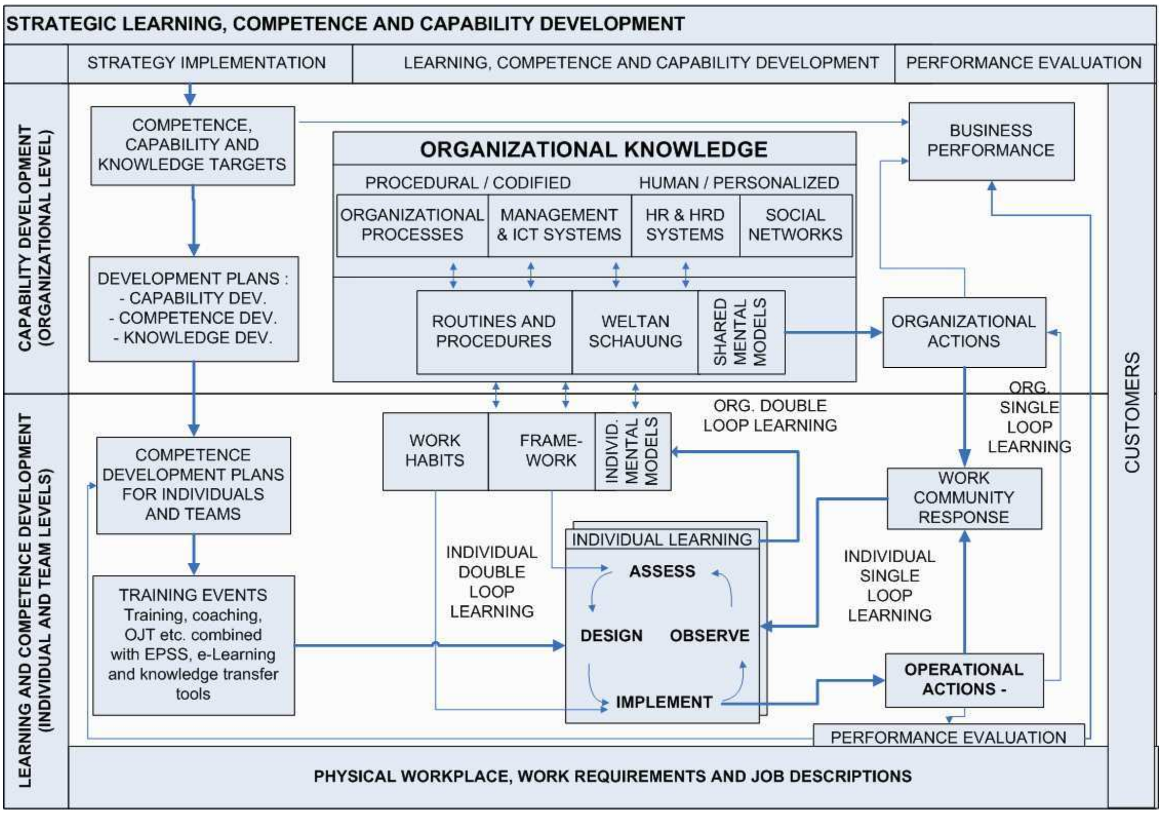

Figure 19. Integrated processes for learning, competence and capability development in organizational and individual levels.

The teams and the individuals with their shared mental models together form the key transfer mechanism between individual and organizational level learning. Efficient knowledge sharing requires a common conceptual framework for it to be successful, emphasizing the need for multi-skilled learning. Organizational learning, optimally, leads to an organizational knowledge development and organizational memory, which broadly includes everything that is retrievable: explicit, implicit and tacit or widely recognized knowledge (Kim 2004). Through the latest collaboration and knowledge sharing tools, the organizational knowledge is available for all production units, teams and individuals.

One factor limiting competence and capability development in organizations is the knowledge capacity of an organization, which can also be a limiting factor in organizational transformations. Also the resistance to change, especially between corporate and unit levels, can hinder capability development. In global organizations the organizational inertia and absorptive capacity can also be problems. Also the major barriers to knowledge transfer in organizations reviewed in section 3.2.4 can be limiting factors for knowledge transfer, and they need to be eliminated.

Competence and capability development processes optimally is a systematically integrated part of the strategy implementation process. The results of individual and organizational learning can be seen in improved capability and performance, which is the result of successful learning and competence development.

5.2 Operational concept for knowledge transfer and competence development in paper production unit start-up projects

5.2.1 New operational concept for knowledge transfer and competence development

The new operational concept for knowledge transfer and competence development is based on both top-down strategic targets and bottom-up work process requirements, as illustrated in Figure 19. The competence development at the team and individual levels can be divided into development of conceptual knowledge or development of work process knowledge and skills. Different methods and tools are needed for these different areas, as illustrated in Figure 20.

The training and competence development in industrial paper machine line start-up projects has traditionally been based on classroom and on-job training (Laurila Gyursanszky 1998; Nurmi 2001; Leppänen 2001). The role of on-job-training has been to develop work process knowledge and skills, while classroom training has been used for the development of conceptual knowledge and frameworks.

In the new concept the operational simulations are a complementary tool used to develop work process knowledge and skills, as illustrated in Figure 20. Part of the expert knowledge can be codified and the operational best practices can be modelled into these tools, which can then be used for transferring the best practices and latest knowledge within the organization via computer networks. The development of work process knowledge and skills is based on structured on-job training, combined with these operational simulation and best practice tools. This concept can be applied in problem-based learning, sharing of best practices and learning new operational concepts, with or without expert facilitation.

The development of conceptual mastery has been traditionally carried out through classroom training. In the new concept, web lectures, knowledge and performance support systems and simulations are combined with traditional classroom training. The classroom training concept can be based, e.g. on problem-based learning with the different tools. The knowledge and performance support systems can also be integrated with the operational simulation tools, so that multimedia support knowledge is available when needed in simulator training.

All these new tools provide an opportunity and flexibility also for workplace learning, knowledge and performance support, making the learning and knowledge sharing continuous and by providing just on time support, e.g. related to infrequent procedures carried out in the workplace. The latest knowledge is available at the workplace any time when needed and anywhere in the global organization.

The new, operational concept for competence development and knowledge transfer in paper production unit start-up projects is illustrated in Figure 20. The important part in the development concept is competence and capability assessments, which identify the competence gaps to be used in the development plans and which also can be used as competence evaluation tools. The evaluation of conceptual knowledge and work process skills is an important part of the concept, which can lead to formal professional qualifications.

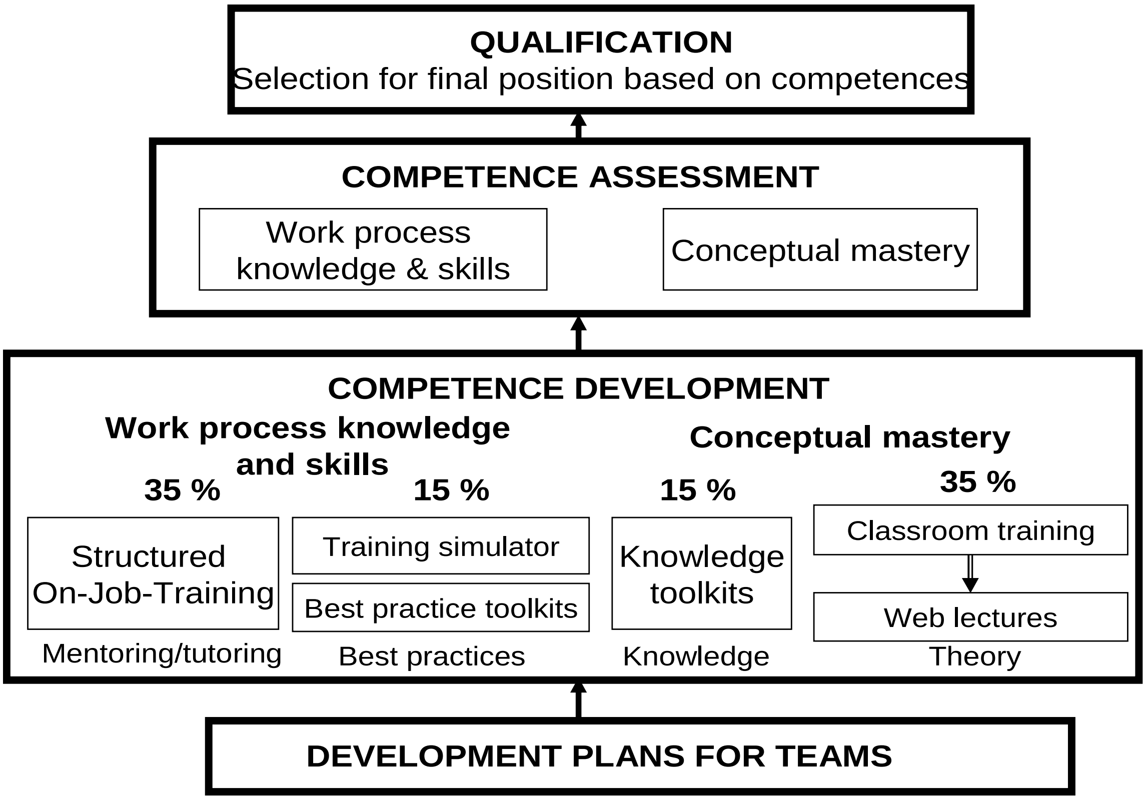

Figure 20. A new operational concept for knowledge transfer and competence development (Laukkanen 2005)

5.2.2 The life cycle of the knowledge and performance support systems in industrial production plants

The development of the knowledge transfer and competence development tools optimally follows the life cycle of the production unit. The development preferably starts during the basic engineering phase of the paper production unit start-up project, as illustrated in the Figure 21. More information and knowledge about the new production unit are available from e.g. process trials in the detailed engineering phase, and this knowledge can be transferred into these systems. The major part of the knowledge transfer and competence development in training programs is carried out already before the commissioning of the production unit. The commissioning and process trials are very critical phases in the project for confirming the operation of the new equipment and systems, but also for gaining new experiment-based knowledge about the new process and equipment. Efficient sharing of this knowledge is highly critical for organizational learning and successful start-up, because the first equipment modifications are made already in this phase. The major part of the knowledge in the formal project training programme is based on as designed knowledge of new processes and equipment, while in commissioning and start-up the first modifications are already made and the perspective to process and equipment knowledge is as build and as modified. During the commissioning and start-up phases the knowledge sharing related to these modifications should be done systematically both via social networks and with ICT tools, which can be supported by operational simulations. Preparations for the start-up can also be done by simulating the procedure first with the operational simulator, and then confirming that all the teams and individuals have the same mental model about the start-up sequence, and the different roles and responsibilities related to the sequence are understood in a similar way.

After the start-up, when the new production unit and new organization is in operation, the knowledge and performance support systems is updated on the basis of the lessons learned during the commissioning and start-up periods. Operational simulation tools are also be updated and fine-tuned on the basis of real measurement data and on individual and team based learning, in accordance with the concept as illustrated in Figure 21. At this point it is also very important to define the knowledge roles and responsibilities concerning the knowledge updates into these tools and systems. It is also important to create a systematic process for these updates and for the further use of the tools in systematic competence development and multi-skilled learning.

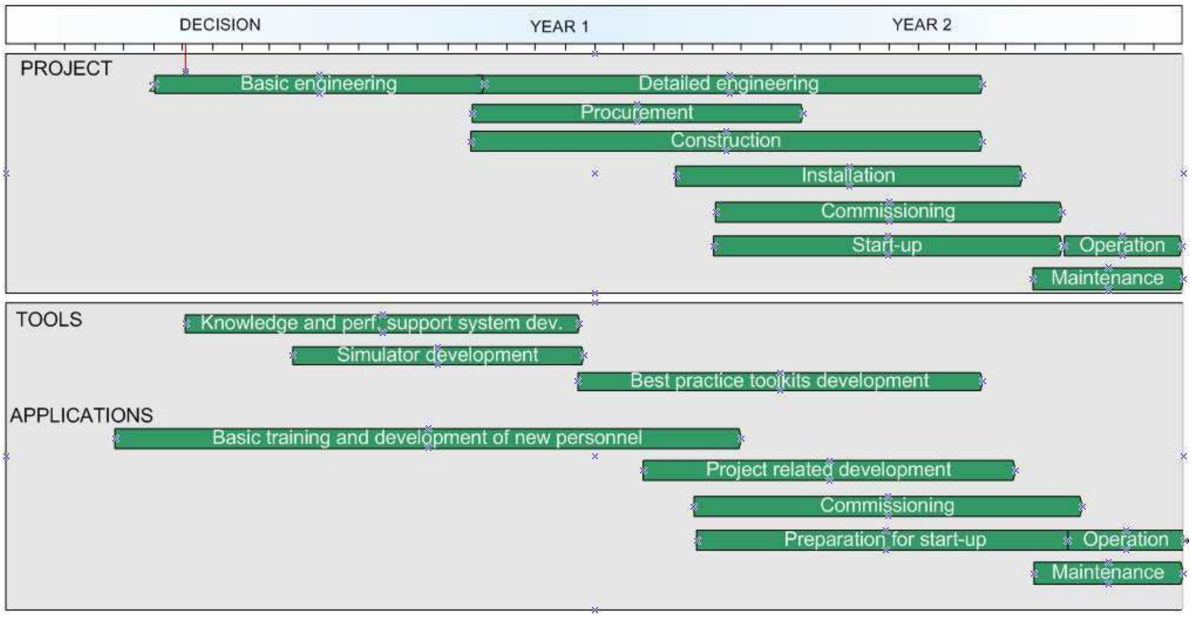

Figure 21. Use of the operational concept in the investment project (Laukkanen 2005)

One challenge during and after the start-up is that there are multiple organizations present at the paper production unit site: start-up helpers, and key project personnel from the company and from the suppliers working together with the new local organization. At this phase, it is very important to confirm and maximize the opportunities for knowledge sharing between the local organizations and suppliers, as well as between the different supplier organizations, thereby forming a virtual start-up organization at the mill site. Another challenge for systematic knowledge sharing in production unit start-ups is the amount of new knowledge created in the commissioning and start-up phases, which needs to be transferred to the local organization. The time pressure is also high, and is often further accentuated by the technical problems which need to be solved immediately. In this kind of setting, interpersonal knowledge transfer is the most efficient way to share systematic knowledge. In a multicultural project work environment, the language or cultural differences can also be barriers to knowledge transfer between project and local organizations.

The continuous development of the production unit efficiency depends strongly on organizational knowledge sharing within the company and with the suppliers. The new concept and tools can provide efficient support for this sharing. The best practices developed in different locations can be efficiently transferred, using these tools, into other global units.

5.2.3 The development of knowledge and performance support systems in paper production unit start-up projects

The development of knowledge and performance support systems is a systematic process combining the knowledge management process, strategic competence analysis and individual learning, as illustrated in Figure 22. The development process is based on a collaborative process of strategic competence modelling, which is carried out by subject matter experts both from the project team and from the major suppliers. This competence mapping defines the strategic competences and capabilities to be developed with the concept. The development of the knowledge and performance support systems is based on knowledge management process, starting with knowledge scanning and mapping, followed by knowledge creation, codification and storage, transfer and application, as illustrated in Figure 22.

The existing knowledge and best practices from the project supplier network are optimally integrated into these tools. Process modelling is one systematic way to codify also parts of the tacit knowledge into operational simulators, which can then be used to transfer the knowledge as troubleshooting or best practice exercises. The major roles in the development are played by the development team, subject matter experts and steering group. The development of the tools themselves is an organizational development process. These knowledge, performance support and simulation tools are used together with traditional training and competence development tools like structured on-job-learning and classroom training, forming a blended development model, which is illustrated in Figure 20. The major application areas for the tools are knowledge transfer and competence development during the project time. After the start-up the tools can be used for knowledge and performance support and workplace learning.

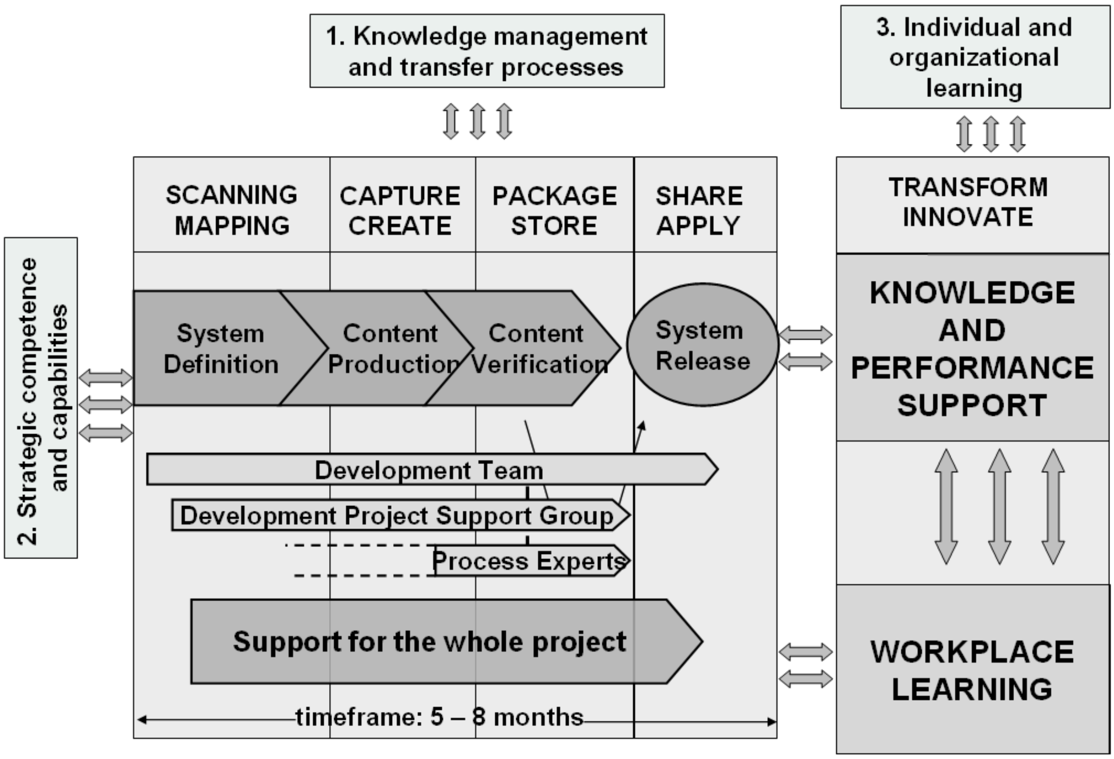

Figure 22. Proposed methodology for the development of the knowledge transfer tools (Laukkanen 2005)

Modelling the physical processes, teams, users and work processes is in a very critical position in the development of knowledge, performance support and simulation tools. The modelling project, optimally, follows the life cycle of the production plant, starting at the engineering phase where the process and automation engineering can be verified with the use of the simulation tools (Laukkanen 2001). The life cycle follows the different phases, including training and organizational development, commissioning, process start-up and process development and optimization after the start-up. After start-up, the tools are a part of the organizational memory and can be integrated as a part of the local and global knowledge and performance support systems.

The methodology proposed for user modelling is based on knowledge management concepts for the tool specification and development. The knowledge modelling process can be divided into three phases: strategic competence analysis/definition, knowledge creation, and content development and content verification. The development team, which consists of process experts, defines the structure of the system. The knowledge and best practices are then systematically collected into this system, which is a part of the organizational knowledge repository. The development process facilitates collaboration between experts and is also a learning process for the whole project organization.

The starting point for finding the operational best practices is benchmarking, i.e. finding the best performers or the best performing teams in the organization and in the supplier network. The next phase includes systematic modelling of the best practices and lessons learned. In this development phase a team of the best experts is needed to collaborate and model the process at the same time as the developer or development team is implementing the user modelling process. The efficiency of the development process can be improved by using standard templates, which are re-usable, and using systematic methods like re-usable learning objects in content creation.

The knowledge, performance support and simulation tools developed with this process can be integrated to organizational knowledge and used further in the areas of electronic performance support and organizational learning. This provides a basis for a continuous improvement and learning cycle, because the toolkit can be further expanded in organizational double loop learning.

The knowledge, performance support and simulation tools can be classified into basic and advanced level tools, which can be used for developing conceptual knowledge and work process knowledge and skills, as illustrated in Figure 23. The basic level tools include web lectures and best practice toolkits, while the advanced level tools are customized knowledge and performance support systems and the operational simulation tools. All these tools form the advanced toolbox for efficient knowledge sharing.

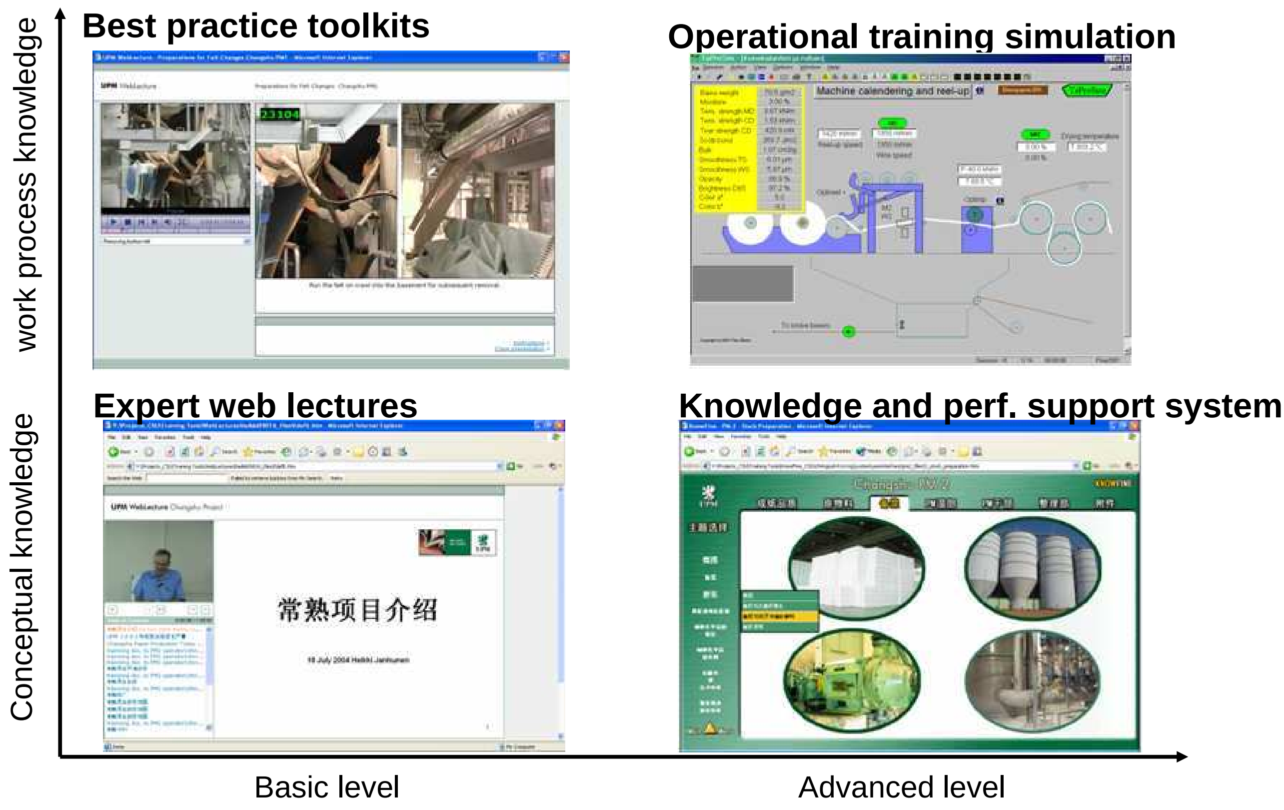

Figure 23. Basic and advanced level tools for competence development, knowledge and best practice transfer (Laukkanen 2005)

5.2.4 Development of hybrid training simulators

The operational training simulation tools used in the paper industry have traditionally been based on simulation of the process and emulation of the process control system. The recent development of multimedia technology has also made it possible to generate a visual simulation of the work processes, based on work process modelling. The differences between these tools can be seen in Figure 24.

The results of using a rigorous, scientific engineering simulator in initial training indicated that, for some users, the process dynamics and complexity exceeded the absorptive capacity of the personnel (see also section 6.1). In order to rectify the situation, this drawback was taken into account in the development of the KnowPap system, as well as the simulation models it contains, by limiting the scope of the simulators to the unit operation level and by designing user-friendly interfaces.

The goal for the operational simulation models was to transfer the knowledge about how paper quality can be optimized and about how to operate the critical control parameters (e.g. calendaring) in the unit processes. The emphasis in the modelling was on the paper quality properties, which were modelled using statistical multivariable models. The algorithm is based on piece-wise linear models. The benefit of these models is their general applicability, numerical stability and easy customisation for new processes. Use of the models is, however, limited to processes which do not include strong correlations between the input variables. In the operational training simulation, the financial and production efficiency are the other perspectives that can be learned with these tools.

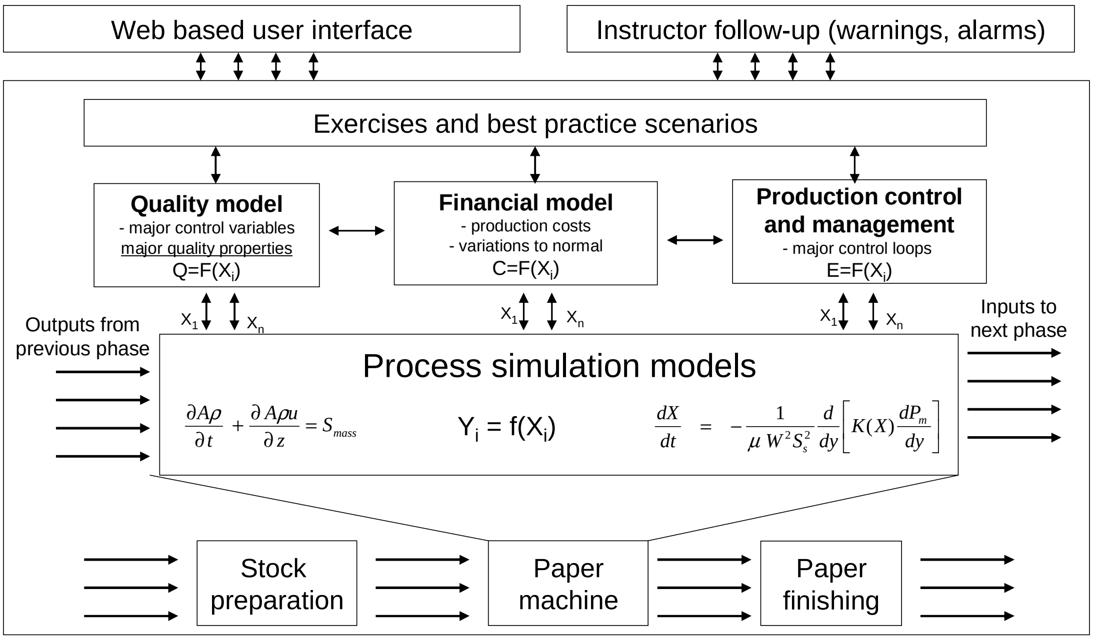

Figure 24. The structure of a hybrid training simulator for a paper machine process

5.2.5 Evaluation of conceptual mastery of the work

The outcomes at the level of learning were evaluated by measuring the conceptual mastery or explicit knowledge of the work. Conceptual mastery of work is regarded as an important mediator in the transmission of work process knowledge in the work community. Mastery of the basic concepts of the work process is the prerequisite for participation in the creation of work process knowledge. The increase in work process knowledge can also be analyzed through the mastery of basic concepts and their relationships in the work process (Leppänen 2001). The conceptual mastery indicating the progress of competence development and knowledge transfer at the individual level is optimally measured twice in the concept. The first evaluation is carried out before the project HRD programme in order to assess the competence levels and to identify the competence gaps before starting the training and development programme, and the second assessment optimally is performed half year or one year after the start-up

In this study the assessment was used to measure the conceptual mastery of work in different change situations and start-ups of European paper production lines (see Leppänen 2001; Nurmi 2002). The major areas covered the assessment were in the production line, and included raw materials handling, wet end processes, dry end processes, finishing, customers, quality management, operations management, production economics, maintenance and automation. Some examples of the questions are shown in Table 14.

The questions in the different areas were customized to the new production line process. The questions dealt with the goals and raw materials of work, the functionally important characteristics of the tools used, essential quality parameters and the factors affecting them. The test included typically 100-150 questions, each having 4-5 items, and a sum score was used to assess the percentage of correct answers. The results were calculated for each job position and for each area of conceptual mastery.

Table 13. Examples of questions and items in different categories of conceptual mastery.

Purpose of the work	The purpose of the short circulation is to …? - remove air and other impurities from the pulp - proportiong and mix the chemicals - adjust pulp recipe of the paper - minimize consistency and pressure variations
Functionally important characteristics of the paper machine	The drying cylinders dry paper most effectively -when there is a thin layer of condensation water inside the cylinder -there is no water in the cylinder -the cylinder is full of water -the web presses tightly against the surface of the cylinder
Essential quality parameters and the factors affecting them	How does the refining affect the quality parameters of paper: - the tear resistance decreases - the tensile strength increases - the opacity decreases - the tensile strength decreases
Factors affecting the production economy	Cost of paper rises when -the chemical pulp layers become thicker -the amount of talc increases -the beating of mechanical pulp increases -the dehydration ability of the press felts and drying wires decreases
The functional relationships between e.g. the functioning of the machine and certain quality parameters.	Do the following factors affect fibre orientation -speed of the wire -pulp concentration -edge showers -pressure of the head box

Every sub question has three alternative answers. I agree, I disagree, I don't know.

In addition to these assessments, operational simulations were used to assess the skills and work process knowledge of the trainees relating to the different procedures involved in PM operation.

6 New tools for knowledge transfer, competence development and learning

The aim of this chapter is to describe the new tools and technologies developed in this stydy for knowledge transfer, competence development and performance support. The chapter starts with a development review of dynamic simulation, based on hybrid process modelling. Secondly the development of KnowPap a web based learning environment for papermaking and paper mill automation is reviewed. Thirdly the development of an integrated knowledge and performance system is introduced. Finally the modelling and simulation of the operational best practices with the operational training simulators and best practice toolkits is introduced.

6.1 Modelling and simulation of a paper production process as a hybrid dynamic system

As an introductory of the basic principles of dynamic simulation first, the principles of hybrid process modelling of the paper machine process are defined. Secondly a dynamic simulation tool, called APMS is reviewed. Finally the principles of the process simulation of the paper machine wet end with the dynamic simulator are described.

Dynamic process simulation is a relatively new tool in the paper industry. The design of the paper machines has traditionally been based on steady-state simulation models. Recently, however, the new challenges for the operation of the paper machine process have increased the use of dynamic simulation in the paper industry. A driving force has been the requirement for high-fidelity analysis of the complex, integrated processes. To specify the combined response, both of the process equipment and the process control system, does not have any alternative other than dynamic simulation. To study the operation of the process in transient situations, the dynamic simulator is a good tool.

The use of the hybrid dynamic system simulation models in the paper industry is also motivated by the fundamentally hybrid nature of the process transients. The dynamic behaviour of a paper machine exhibits significant discrete aspects in addition to the normal continuous behaviour. The paper production process is a complex, hybrid combination of discrete and continuous system models as illustrated in Figure 25. There are many transient situations in which discrete phenomena are superimposed on the continuous process behaviour and the dynamic behaviour is more correctly viewed as a network of the combined and interacting discrete and continuous subsystems rather than a series of the continuous process models. Furthermore, the combination of the batch, semi-batch or periodic processes in a continuous simulation model can also be viewed as a hybrid system. An example of such a combination is a paper machine producing coated grades, where the coating preparation operating as a batch process is combined with continuous coating and papermaking processes.

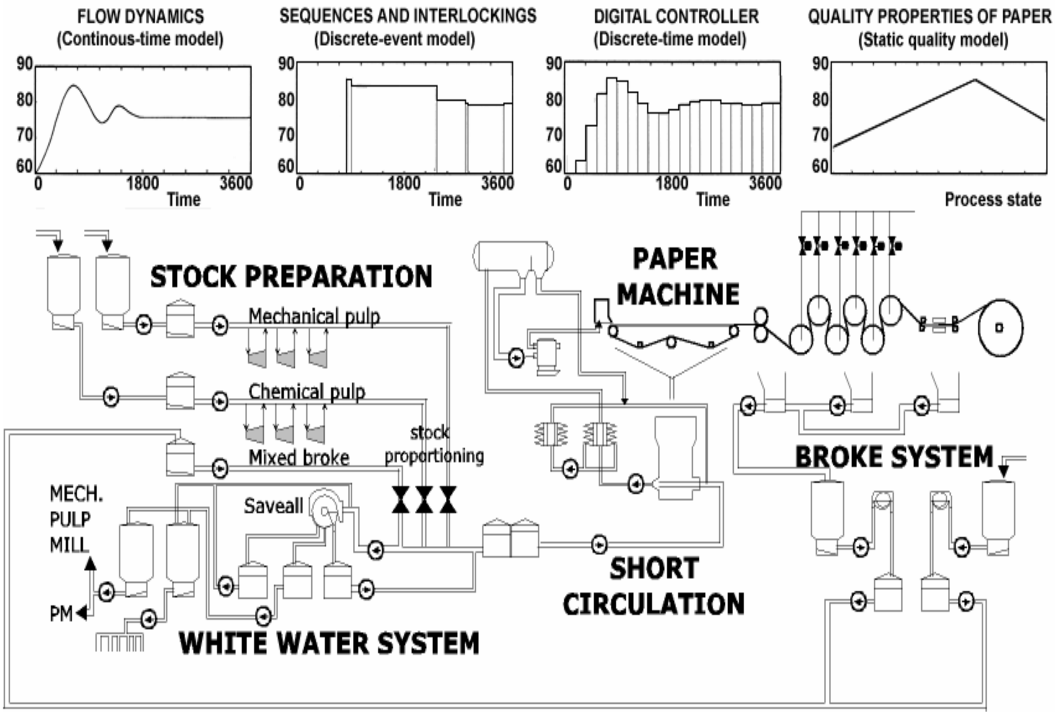

Figure 25. The paper machine process as a hybrid dynamic system

6.1.1 Continuous time models

In a paper machine simulator, the continuity of materials, energy and concentrations in piping networks are modelled using continuous time models e.g. flows in the stock and white water systems. The characteristic of the continuous time models is that within a finite time span, the state variables can change values an infinite number of times. These models are defined as a set of ordinary or partial differential equations (ODEs or PDEs).

6.1.2 Discrete event models

In discrete event models, within a finite time span, a finite number of the state variable changes may occur. The discrete behaviour in chemical processes can be classified into two categories: physicochemical discontinuities or discrete controls and disturbances.

Physicochemical discontinuities arise from the physical behaviour of the real process systems when the system behaviour is studied over large enough region of state-space. Examples include phase changes, flow reversals, shocks and transitions, discontinuities in equipment geometry, internal features of vessels (e.g. overflows of weirs), etc. Barton and Park (1996) found out that the discrete behaviour occurs also as a consequence of the process moving through operational state-space.

In a paper machine process simulation, discrete events arise e.g. from the control actions of operators, operational sequences, interlockings or PCS, logic and automation system operations. Some special situations such as web breaks can be modelled in the simulators as discrete events.

6.1.3 Discrete time models

In discrete time models the time axis is discretised into finite steps and the models are represented as a set of difference equations. In a dynamic paper process simulation, e.g. digital controllers are modelled as discrete time models. Discrete controls and/or disturbances are very common in the study of process operations. Examples of discrete controls include the use of hybrid controllers in a highly non-linear continuous process, the action of passive protective devices investigated by Barton and Park (1996), planned transient operational changes such as start-ups, shutdowns, or the optimisation of grade changes using dynamic optimisation methods studied by Välisuo *et al.* (1996) and Lappalainen (2004).

6.1.4 Static quality property models

The modelling the paper quality properties can be done by using statistical multivariable models. It is possible to combine a statistical paper quality models with a dynamic simulator, so that the effects of the control actions can be seen as a time-dependent change in the paper quality.

6.2 APMS - simulation environment

APMS (Advanced Paper Mill Simulator) is a dynamic simulation environment for the modelling and simulation of pulp and paper mill processes. It is based on the APROS (Advanced PROcess Simulator) simulation environment, which has been developed for the simulation of nuclear and power plant processes (Silvennoinen *et al.*, 1989; Juslin, 2005). The APROS simulation environment provides model libraries and solution algorithms for modelling different kinds of flow, heat and mass transfer processes. Although the main application area of APROS has been power plants, there have been a number of applications in the pulp and paper industry e.g. simulation of recovery boiler operations by Juslin and Tuuri (1992), simulation of displacement pulping process by Juslin and Pollari (1994), simulation of black liquor evaporation plant by Juslin and Niemenmaa (1994), simulation of rotary lime kiln by Karhela *et al.* (1998) and simulation of paper machine grade changes by Lappalainen (2004).

A hybrid paper machine simulator, developed with APMS, consists of three interconnected sections: 1. stock and white water systems, 2. paper machine and 3. process control system as illustrated in Figure 26. These sections can be studied separately, but to study the interactions in the process all these parts have to be included in the simulator.

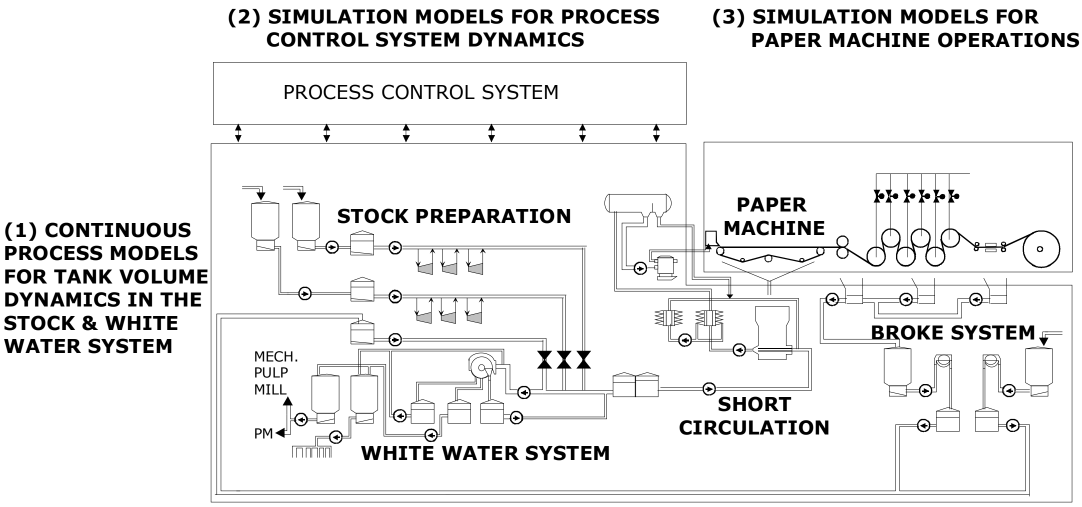

Figure 26. The structure of a paper machine simulation model

In this first case study, a modern paper machine was modelled using APMS environment and the model was incorporated into the APMS model libraries. The four major components of APMS, which are illustrated in Figure 27, are a graphical user interface, simulation model libraries, a calculation engine and a communication interface to the external programs. The functions of these parts are:

1. Simulation model libraries

The piping networks of the paper machine e.g. stock and white water, steam, condensate and vacuum systems are modelled using *thermohydraulic flow models,* which are described in Section 6.2.1.

The modelling of the paper web properties is based on the moving element method, which is combined with mechanistic grey-box models used in the calculation of the dewatering and drying operations. The simulation of the paper machine models is presented in Section 6.2.2.

The modules of the *automation system library* e.g. control circuits, measurements, analogue and binary signals are used in the modelling of the analogue and binary automation used in the process control of the paper machine. Both basic and higher automation can be included in the simulation model.

2. Executive system

The executive system interprets the commands given by users and, according to these commands, manages the database, controls initialisation and execution of the simulation runs and trend displays. The major part of the system is the calculation engine, which includes solvers for sparse matrix, stiff ODE and DAE systems. Semi-implicit differential equation solvers, with adaptive step size control, are used in APMS.

Real-time simulation database. The object-oriented, real-time database of the simulator includes both graphical and process module definitions. Before running the simulation, the state variables and equipment parameters are retrieved from the database and the simulation experiment is initialised. During simulation, the state variables are updated. After running the simulation experiment, the results are stored in the database.

The physical property databank includes thermodynamic property data for the chemical components used in the simulations. Each point in the simulator refers to a user-specified fluid section, which determines the chemical components and correlations used in the simulation.

3. Graphical user interface

In model definition and analysis simulations a *CAD-type designer's interface* is used. In operator training either an emulated or real process control system can be used.

5. Communication interface to external programs

The communication interface is used to define the data transfer between the dynamic simulator and external programs e.g. input data pre-processing, process control systems, in-house simulation models or post-processing programs. The following data transfer standards are currently supported: OPC (OLE For Process Control), DLL (Dynamic Link Library), TCP/IP (Transmission Control Protocol/Internet Protocol) or DCOM (Distributed Component) or CORBA (Common Object Request Broker Architecture).

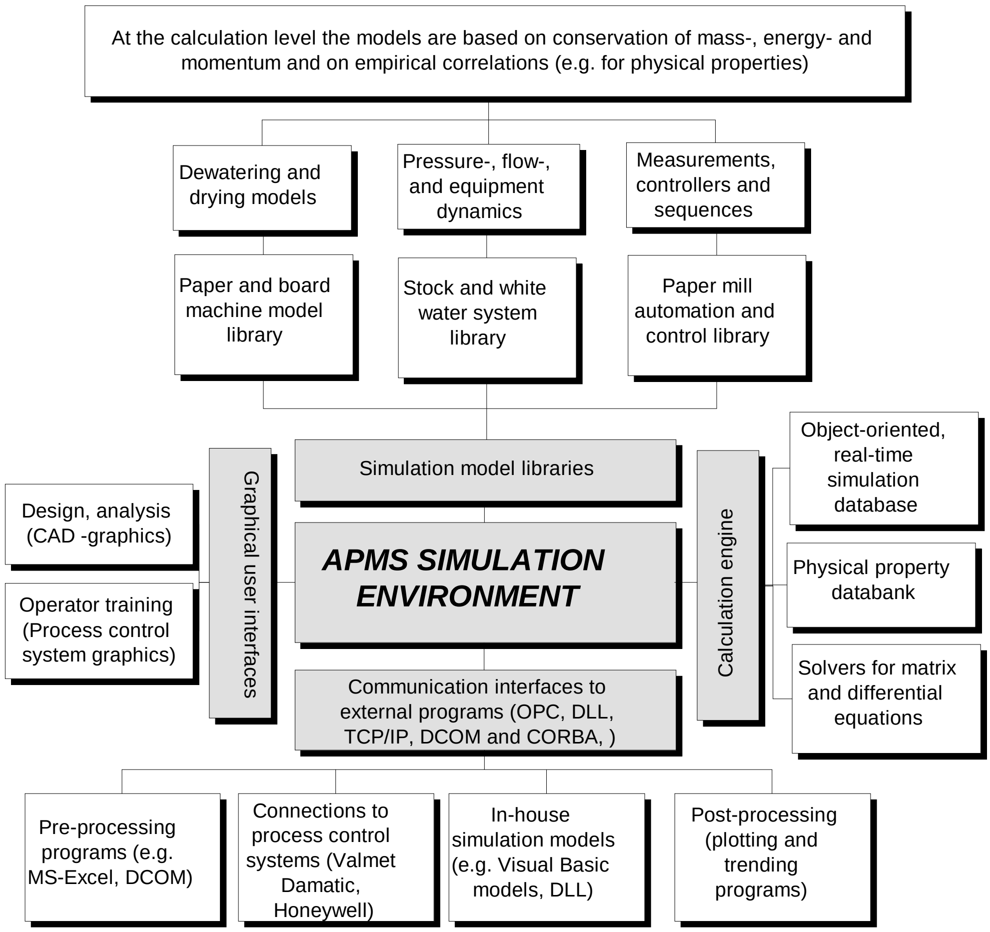

Figure 27. Structure of the APMS simulation environment (Laukkanen 2001)

6.2.1 Thermohydraulic flow network models

Thermohydraulic flow network models are used to solve the flow dynamics in the piping networks of the paper machine. These models are used in the analysis of the stock and white water system and the other piping networks of the paper mill including:

- fresh water preparation
- warm water systems
- vacuum system
- steam and condensate systems.

The flow network consists of parallel thermohydraulic and fluid section networks, which are illustrated in Figure 28. At the calculation level, the networks consist of the thermohydraulic points (nodes) and process modules (branches).

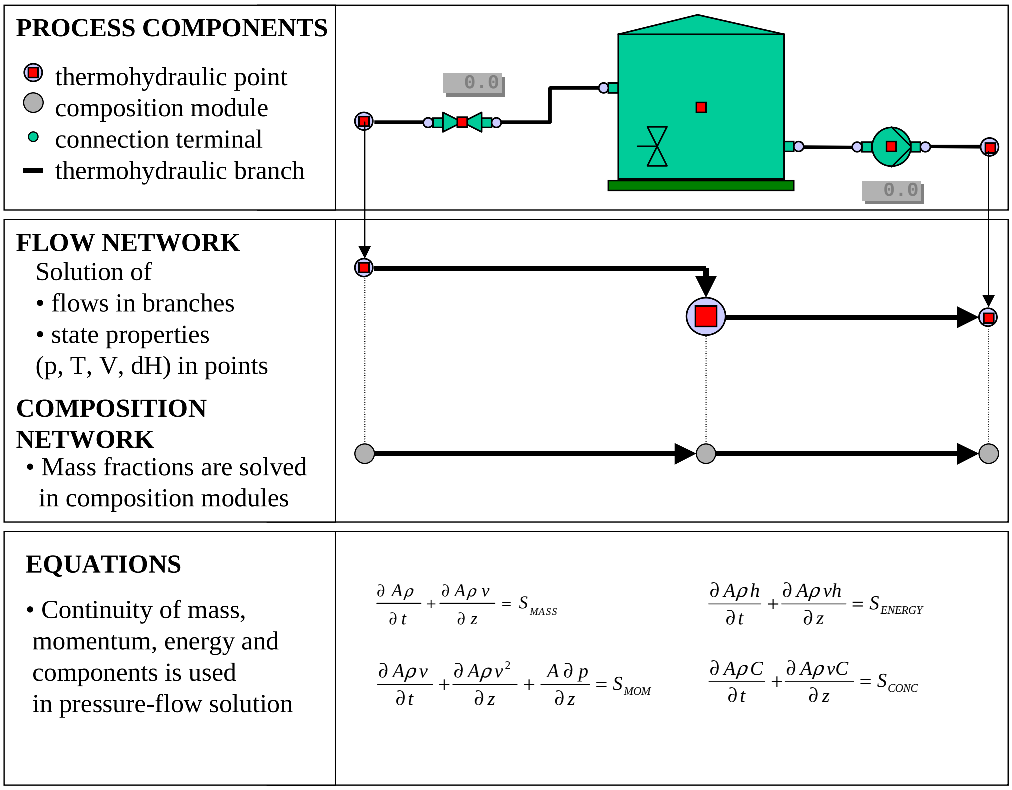

Figure 28. Structure of a thermohydraulic flow network model

Thermohydraulic points (nodes) are volume elements at a specified pressure, temperature, enthalpy, composition and height level. Points are connector modules in the network and a process component is always connected between two points. A fluid section is a parameter which defines the chemical components and the material properties used in the composition calculations. The concentrations are solved at each point, react-ions between fluid components can be defined and section specific physical property correlations can be used. Properties, which are solved at thermohydraulic points, are pressures, temperatures, enthalpies, void fractions and compositions.

Process equipment modules (branches) are equipment modules between two points. The dead-times inside the flow network depend on the flow rates, dimensions and operational parameters of the equipment given by user.

Properties, which are solved in process components are flows and equipment specific data. Each simulation model has boundary nodes, where the pressure, temperature and compositions are fixed. For the rest of the network, the pressure-flow relationship is calculated and updated as a function of time. The flow direction depends on the pressure difference between the points. The solution technique used in the APMS allows also flows in the reverse direction (negative flows). This characteristic is very important in the analysis transients including backflows.

The homogenous thermohydraulic flow model is used in this study and it is based on the following assumptions: (1) all phases form a homogenous mixture and (2) flow velocities, temperatures and directions for each phase are equal.

The dynamic behaviour of a thermohydraulic flow network can be described with the conservation equations for mass (Eq 1), momentum (Eq 3) and energy (Eq 5). The solution of the equations gives the pressures, compositions, enthalpies and temperatures at the points and flows in the branches. The solution technique is based on the discretisation of equations as a function of time and space (Eqs 2, 4 and 6). Mathematically, the simulation model of a paper machine forms a sparse matrix, which is solved numerically. APMS is an equation-oriented simulation program in which the whole simulation model is solved simultaneously, without the need to define tearing streams. Conservation equations for mass before (Eq. 1) and after discretisation (Eq. 2) can be written as:

$$\frac{\partial A\rho}{\partial t} + \frac{\partial A\rho u}{\partial z} = S_{i1} \tag{1}$$

$$\frac{V_i}{\Delta t}\left(\rho_i - \rho_i^{(t-\Delta t)}\right) + \frac{V_i}{\Delta t}\frac{\partial \rho_i}{\partial P_i}\left(P_i^k - P_i\right) = -\sum_{\substack{ij \\ j\neq i}} W_{ij}^k + S_{i1} \tag{2}$$

Conservation equations for momentum, before (Eq. 3) and after discretisation (Eq. 4) are:

$$\frac{\partial A\rho u}{\partial t} + \frac{\partial A\rho u^2}{\partial z} + \frac{A\partial p}{\partial z} = AF + S_{i2} \tag{3}$$

$$\frac{L_{ij}}{A_{ij}}\frac{\left(W_{ij}^k - W_{ij}^{t-\Delta t}\right)}{\Delta t} - P_i^k + P_j^k + \frac{1}{2}K_{ij}W_{ij}\left|W_{ij}\right| + K_{ij}W_{ij}\left(W_{ij}^k - W_{ij}\right) + \frac{W_{ki^2}}{\rho_{ki}\, A_{ki^2}} - \frac{W_{ij^2}^k}{\rho_{ij}\, A_{ij^2}} = S_{i2} \tag{4}$$

Conservation equations of energy, before (Eq. 5) and after discretisation (Eq. 6) are:

$$\frac{\partial A\rho h}{\partial t} + \frac{\partial A\rho u h}{\partial z} = S_{i3} \tag{5}$$

$$V_i\,\frac{\left(\rho_i\, h_i^k - \rho_i^{t-\Delta t}\, h_i^{t-\Delta t}\right)}{\Delta t} - \underset{IN}{W_{ij}^k}\, h_j^k + \underset{OUT}{W_{ij}^k}\, h_i^k = S_{i3} \tag{6}$$

The solution of the conservation equations above is based on staggered grid discretisation, which is used both in flow and in heat conduction models. The principle of discretisation is based on the following assumptions: 1. State variables are in points, 2. flows are calculated at the border of two points (branches) and 3. the upwind principle is used in numerical solution. The number of stiff differential and algebraic equations depends on the scope of the simulator and the equations are solved simultaneously by using the solvers of the simulation environment. The user defines the relevant process variables and parameters like pressures, temperatures and concentrations and the simulation platform solves the flows and compositions for the whole flow network.

6.2.2 Modelling and simulation of a paper machine and paper web

Modelling of the paper machine process is based on the moving element method, in which one or more volume elements called web cross sections are moving through the paper machine, as the real paper web runs with the speed of the machine. The headbox is a connector between the thermohydraulic flow network and the paper machine. Each element takes an initial amount of furnish depending on the flowrate in the headbox and each time an element passes a unit operation module e.g. a press nip, mass and heat transfer calculations are performed and the new state variables are updated.

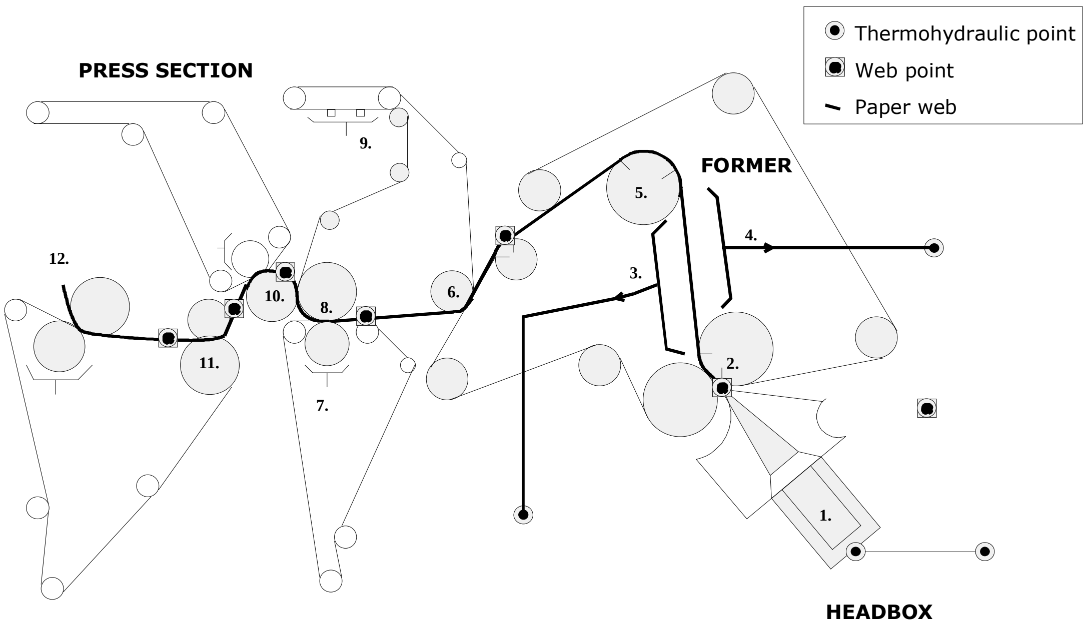

Figure 29. The structure of the paper machine simulator (wet end of machine)

The paper machine simulator consists of the following modules: (1) paper webs, (2) web cross sections and elements (3) web points, (4) wet end and (5) dry end unit operation modules. The functions of the modules are:

- *Web* is the basic module for the modelling and simulation of the paper web in a paper machine. Several interconnected webs can be used to simulate the layered or non-homogenous structure of the web.
- *Web cross sections* are volume elements and data structures carrying the paper property data. After the element passes a unit operation, the mass and heat transfer to the surrounding flow network is calculated and the properties updated respectively. The cross sections are volume elements, which can be discretised both in cross and z-directions by dividing them into finite number of elements.
- *Webs points* measure the properties of a paper web at a specified section of the paper machine. When the cross section passes a web point, flow and composition data is updated from the element to the point. Unit operations modules are always connected between two web points.

Wet end unit operations are used in modelling the dewatering of the web in the wire and press sections. Dewatering can be calculated using the following models, which are incorporated into simulator: (1) A modified Darcy's equation model is used to calculate pressure-flow solution through porous and compressible fibre network, (2) A semi-empirical Kelvin element type of model or (3) an empirical splitter coefficient model. The wet end models are connected to the surrounding thermohydraulic networks.

Dry end unit operations include simulation models for drying section, glue press, coating stations, IR and airfoil dryers. The evaporation of the water and the drying of the web can be modelled using either: (1) the enthalpy difference method , which can be used for thin paper webs or (2) Stephan's equation developed for the higher basis weight e.g. paperboards. Further details of the drying models incorporated in the APMS program were presented by Niemenmaa *et al.* (1996).

The distance between the subsequent web cross-sections in the machine direction is equal and the sections are moving through the machine at the speed of the machine. Each element also carries compositional data of the furnish components such as water, air, fibres and fillers. Each paper web consists of X x Y x Z web elements, where X,Y and Z are the number of discrete elements in machine, cross-machine and web thickness directions. The approach can be used for modelling both uniform and layered paper webs.

6.2.3 Modelling of wet pressing – Kelvin element model

The dewatering of wet paper web is based on modelling the water flow through a porous and compressible fibre mat. The fundamental aspects of the filtration models have been discussed in numerous articles, most of them describing the flow through rigid materials. When the fluid flows through compressible media, the difficulty is in the mechanical loads, which also deforms the media. The theoretical models are based on a two-phase flow through porous media, while the empirical models are based on the modelling the viscoelastic behaviour of the fibre mats under stress.

The mathematical models for wet pressing were reviewed by El-Hosseiny (1991) and he divided the models into two categories: (1) web models, in which the dewatering resistance of the paper web is the limiting factor and (2) felt models, in which the web/felt interface or the permeability of the felt is the limiting factor in the dewatering. In this study, the focus is on web models which are better for thin paper webs.

The following mathematical models which fulfil real-time requirement were used in this study and incorporated in the APMS -simulation program:

- The Kelvin element model, which is a semi-empirical, rheological model. This model was applied to paper web dewatering by Caulfield *et al.* (1986).

- A Modified Darcy's law model, which is a theoretical model based on the modelling of the water flow in the fibre network. This model was developed from the Darcy's law by Jönsson (1983).
- The most important correlations for compressibility and permeability, which are used in the Darcy's equation model

A rigorous analysis model of wet pressing was developed by Kataja *et al.* (1992). This kind of detailed model can not yet be incorporated into a paper machine simulator, because of the execution speed requirements and also because some numerical difficulties were reported in their study. The detailed model, however, can be used to calculate data and parameters for a semi-empirical model.

The wet paper web can be considered as a viscoelastic medium consisting of water, fibres and, to lesser extent, air. Viscous elements characterise the degree with which the medium components move with time, whereas the elastic elements characterise the structural integrity of the medium. The dewatering time constant and the apparent compressibility modulus describe the viscous and elastic characteristics of the web, respectively.

The Kelvin body model is an empirical, rheological model, which consists of a simple presentation of a viscoelastic medium. The viscous elements of the medium are described by a dashpot with the viscosity η. The elastic elements are symbolised by a spring with effective spring constant *C*. With the application of stress, the stress is split between the dashpot and the spring, so that the strain of the elements is equal.

The dewatering response of a paper web can was developed by Caulfield *et al.* (1986) and can be described as:

$$\frac{\Delta MC}{MC_{IN}} = \frac{P}{C'}\left(1 - e^{\frac{-t}{\tau}}\right) \qquad (7)$$

where

MC is the moisture content of the web

(MC/MC_{IN}) is the fractional change in the moisture content

P is average press pressure

t is the nip residence time

C' is web apparent compressible modulus

τ is web dewatering constant.

The time constant and compressive modulus, which are the empirical parameters of the Kelvin body model, can determined by off-line press nip, whose line pressure and residence time can be adjusted. Fractional moisture change of the paper web can then be evaluated from the measured dewatering responses as a function of nip residence time and pressure. Rewetting can not be considered in the Kelvin element model.

6.2.4 Modelling of wet pressing – permeability and compressibility correlations

Theory of the laminar flow through a homogenous porous medium is based on an experiment originally performed by Darcy in 1856. Darcy's law describes how the volume rate of flow *Q* through the bed of cross sectional area *A* is dependant on the frictional pressure drop ΔP.

$$Q = \frac{K_D A \Delta P}{\mu \Delta L} \qquad (8)$$

where

K_D is the specific permeability of the porous medium

μ is the fluid viscosity

ΔL is the thickness of the medium.

Darcy's law is accurate only for rigid materials. The theory has been extended to compressible materials by Jönsson (1983) by adding an equation which describes how porosity and the fluid flow are influenced by mechanical or hydraulic pressure. The material properties influencing the dewatering are compressibility and permeability, both of which are taken into account in this extended model.

Permeability of fibre beds

Permeability is a measure of the ease with which the fluid may traverse the medium under the applied pressure. Permeability depends on the: porosity of medium, shape and orientation of the particles, the surface exposed to fluid and the pore size distribution. The permeability correlations which have been used for fibre beds are summarized in Table 15.

Table 14. Permeability correlations for fibre beds

Permeability correlation	Expression
Kozeny- Carman correlation is developed for a medium in which the shape and the diameters of pores are non-uniform, but the average surface area is constant Carrol's correlation for the Kozeny coefficient k is valid when porosity of the cellulose bed < 0.96	$k = \frac{\left(1 - cv_s\right)^3}{KS_0^2\left(cv_s\right)^2} = \frac{\varepsilon^3}{KS_0^2(1-\varepsilon)^2}$ $K = 5.0 + e^{[14.0*(0.2 - cv_s)]}$
Davis' model is valid for porosity ε < 0.60	$k = \frac{1}{S_w}\frac{\phi^{-3/2}}{a_1 * (1 + b_1 * \phi^3)}$
Happel's model for parallel cylinders	$k = \frac{4\phi - \phi^2 - 3 - 2 * \ln\phi}{2S_w^2 * \phi}$
Happel's model for perpendicular cylinders	$k = -\frac{(\ln\phi + (1-\phi^2)/(1+\phi^2))}{2S_w^2 * \phi}$

Compressibility is a measure of the volume change of a system subjected to a compressive stress. The compressibility β is defined as the rate of variation of volume V with pressure P_m at a constant temperature:

$$\beta = -\frac{1}{V}\left(\frac{\partial V}{\partial P_m}\right)_T \quad (9)$$

The compressible materials, such as fibre beds, present a problem when attempting to relate the fluid flow and applied pressure. The problem is due to the variation in the bed porosity through the bed during filtration. For a wide variety of materials, it has been found that the correlation of the physical compressibility to applied pressure, during the first compression of the material, follows the following relationship found by Grace (1953):

$$\beta = NP_m^{-b} \tag{10}$$

where N and b are material-specific parameters. Jönsson and Jönsson (1992b) found out that the value of N varies widely for different materials, whereas $b \approx 1$ for most materials examined. Numerous efforts have been made to correlate the solids content in a fibre bed under compressive pressure. Empirical relationships applicable to different pressure regions have been derived. The compressibility correlations, which have been used in the fibre beds, are presented in Table 16.

Table 15 Compressibility correlations for fibre beds

Compressibility correlation	**Expression**
Qviller's model	$C = M * p_s{}^N$
Gurnham's model	$c = m - n * \ln(p_s)$
Jönsson's model	$c = c_0 + \frac{1}{(v_f + v_a + v_v' * (\frac{P}{P'})^{-a})} = c_0 + \frac{M_1 * P^{N_1}}{K_1 * M_1 * P^{N_1} + 1}$ $M_1 = \frac{1}{v_v'} P'^{-a}$
Han's model	$M_1 = 160 * (1.68 * 10^4)^{-N_1}$

6.2.5 Modelling of wet pressing - modified Darcy's law for compressible media

Darcy's law, which is commonly used to describe the physics of flow through rigid, porous media, fails to predict the relationship between fluid flow and compressible stress. This model has been further developed for compressible media e.g. for wet paper webs by Jönsson and Jönsson (1992a,b). The extended model is based on the following assumptions:

- The volume flow is primarily controlled by the void ratio in the compact layer, where the water leaves the fibre medium
- Permeability and compressibility correlations are combined in the model

The numerical calculations can be simplified by defining the void ratio *X* as a ratio between the void volume (V_v) and volume of solid material and absorbed water (V_{sa}):

$$X = \frac{V_v}{V_{sa}} \tag{11}$$

The permeability function in Darcy's law can be defined in the new coordinate system:

$$K(X) = \frac{K_D}{1+X}\left(\frac{S_s}{V_{sa}}\right)^2 \tag{12}$$

Static conditions

As a result of the simplifications and combinations of the compressibility and permeability correlations, the Eq. 13 is derived for static flow J_{ssf} through the porous fibre bed:

$$J_{ssf} = \frac{V_{sa}}{\mu W S_s^2} K(X_{y=0})\ P_h \left(1 + \alpha N \frac{P_h}{2 P_{\max}}\right) \tag{13}$$

Dynamic conditions

In the dynamic model, the porous medium is divided into a finite number of layers in the z-direction. Jönsson (1983) made the following assumptions in the model: volume of solids and adsorbed water is regarded as incompressible and there is no mixing between the layers.

The relation of the void ratio change *dX/dt*, i.e. compression of a media, can be expressed as a function of the permeability of the media and the pressure on the media as follows:

$$\frac{dX}{dt} = -\frac{1}{\mu\, W^2 S_s^2}\frac{d}{dy}\left[K(X)\frac{dP_m}{dy}\right] \qquad (14)$$

where

$K(X)$ is the permeability of the web

P_m is the mechanical pressure in the bed

S_s is the surface exposed to the fluid per unit mass of solids

W is the basis weight of the web

μ is the viscosity of the fluid, and y is the depth imaginary coordinate.

6.3 KnowPap® – a generic learning environment for papermaking and paper machine automation

6.3.1 Development of the KnowPap system

The results of using the full-scope dynamic simulator in training indicated that some exercises were too difficult, because the model was too complicated. The need for on-line knowledge support material related to process operations, equipments, process control and automation concepts was noticed (Laukkanen 2001). On the basis of these results, a web-based multimedia learning environment, called KnowPap, was developed in a co-operation with major forest cluster companies and research partners listed in Figure 30. The key firms in the development are in the inner circle, while companies providing expertise and/or materials to the project are listed in outer circle. The project was managed by Technical Research Centre of Finland (VTT) and Helsinki University of Technology was another research partner in the project (Laukkanen *et al.*, 1999; Hämäläinen *et al.* 1999, Hämäläinen *et. al.* 2001). KnowPap is a registred trademark of Technical Research Center of Finland (VTT).

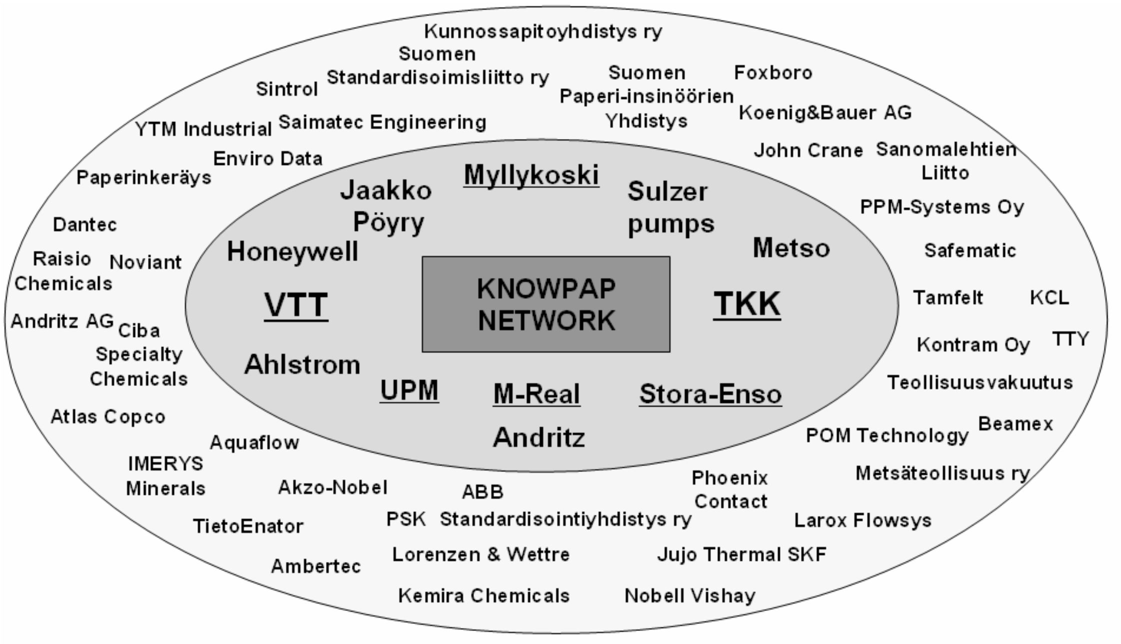

Figure 30. The major Finnish forest cluster companies participating to development of the KnowPap system (KnowPap® 7.0)

6.3.2 Scope and structure of the KnowPap system

KnowPap system is an example of a modern, web based learning and knowledge support system, which can be accessed though the Intranet by using a standard web browser. The goal was to develop a web-based system with the latest knowledge of papermaking and paper machine automation collected as multimedia material and combined with simulation models. The target users for KnowPap were paper machine operators and production teams. The scope of the system cover the following areas: raw materials, paper technology, paper and board products with their properties, process control and automation, environmental protection, economy and safety, process control and automation, operation and maintenance and simulation models. The main user interface of KnowPap is illustrated in the Figure 31.

Figure 31. The main user interface of the KnowPap system (KnowPap® 7.0, 2005 © Technical Research Centre of Finland (VTT))

To manage the knowledge included in KnowPap, the content is divided hierarchically into four levels: main user interface, subject, display and multimedia levels. The target was to provide fast access to the material for the user e.g. in sequence main user interface ⇨ subject level ⇨ display level ⇨ multimedia material. In practice, however, the subject level consists of sublevels, causing browsing to be more complicated. The KnowPap system is a separate part including the common user interfaces, style and font definitions, icons and functions used throughout the system. The structure of the KnowPap learning environment is presented in the Figure 32.

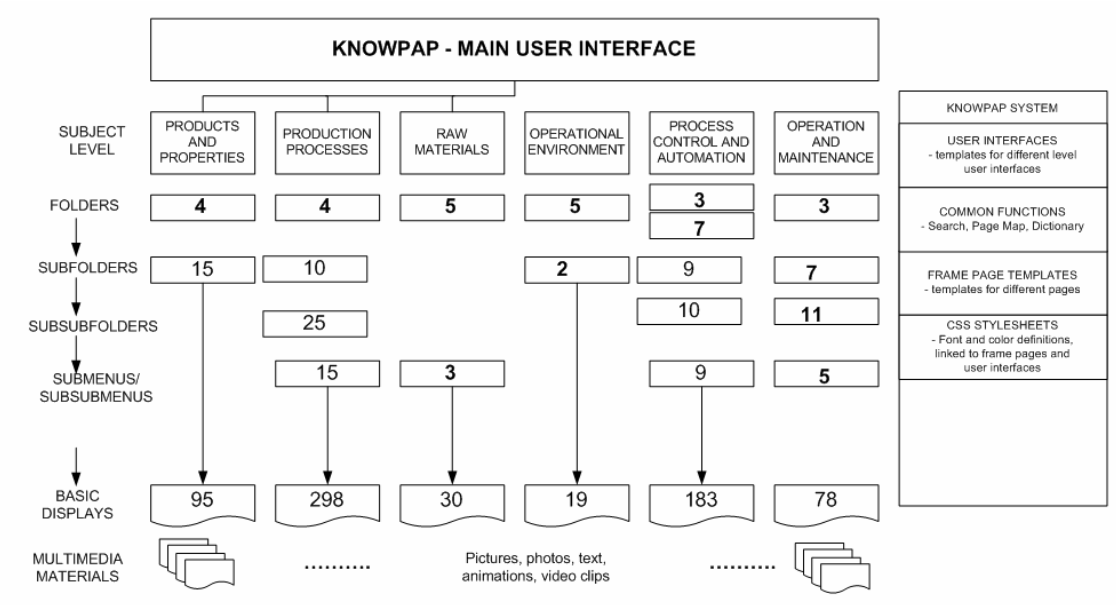

Figure 32**.** The structure of the KnowPap learning environment

The multimedia material includes photographs, diagrams, illustrations, digital videos, animations and text. The simulation models were developed by using JAVA programming language and were combined with the supportive multimedia material (Laukkanen *et al.* 1999; Honkio 1999).

The different user levels with their different needs were taken into account in the design of KnowPap. For *expert users*, fast access to information needed and the flexibility are key factors. A net-type crosslinking of the subjects provides the possibility of switching directly from a subject, e.g. stock preparation, to a related display in automation or other subject area as illustrated in the Figure 33. *For basic users*, the predefined functionality and limited complexity are important. For them, the trainer can construct learning paths by choosing just the displays which are needed, and linking them into a specific order. The paths can be implemented on different detail levels e.g. for non-technical employees, for operators or for experienced professional operators.

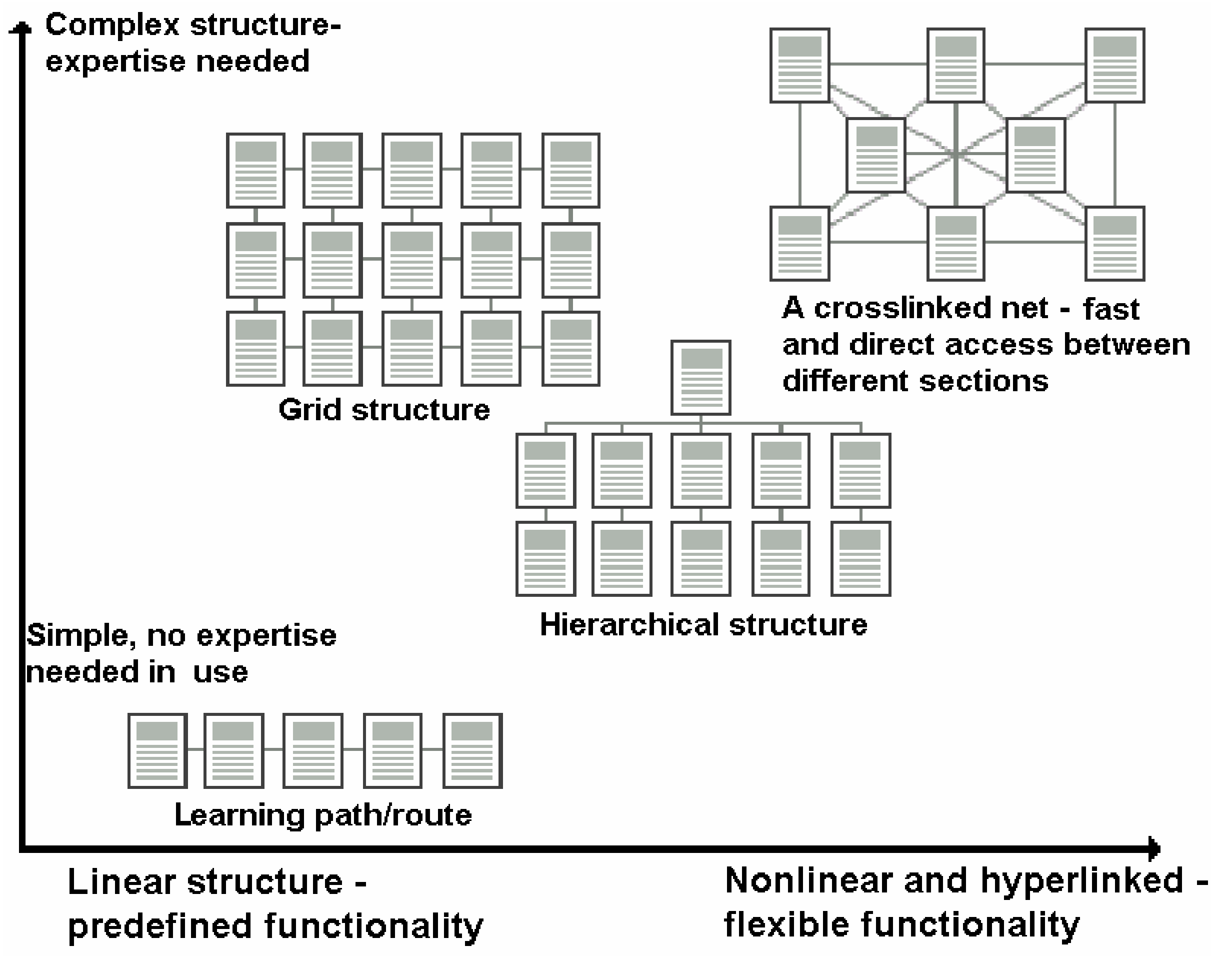

Figure 33. The KnowPap system tools for novice and expert users

6.3.3 KnowPap training simulation models

The results of using the full-scope dynamic simulator in initial training indicated that, for some users, it was too complex (Laukkanen 2001). In the development of KnowPap's simulation models, this drawback was taken into account by limiting the scope of the simulators on an unit operation level and by designing user-friendly interfaces based on sliders and graphs.

The goal for the models was to train how paper quality can be controlled and how to run unit processes. The emphasis in modelling was to model the paper quality properties by using statistical models. The algorithm is based on piece-wise linear models. The benefit of these models is general applicability, numerical stability and easy customisation for new processes. The use of the models is, however, limited to processes which do not include strong correlations between the input variables.

The goal for the simulator is to train problem solving. The starting point is an operational situation in which some of the critical quality properties of the paper are not at the required level. The task for the user is to control the process so that the quality variables reach the desired level.

The user interface for the simulator is presented in Figure 34 and consists of two parts: (1) *Control panel for operating the control variables*, which in this case can be changed by moving the sliders of the panel and (2) *Graphs for paper quality properties*.

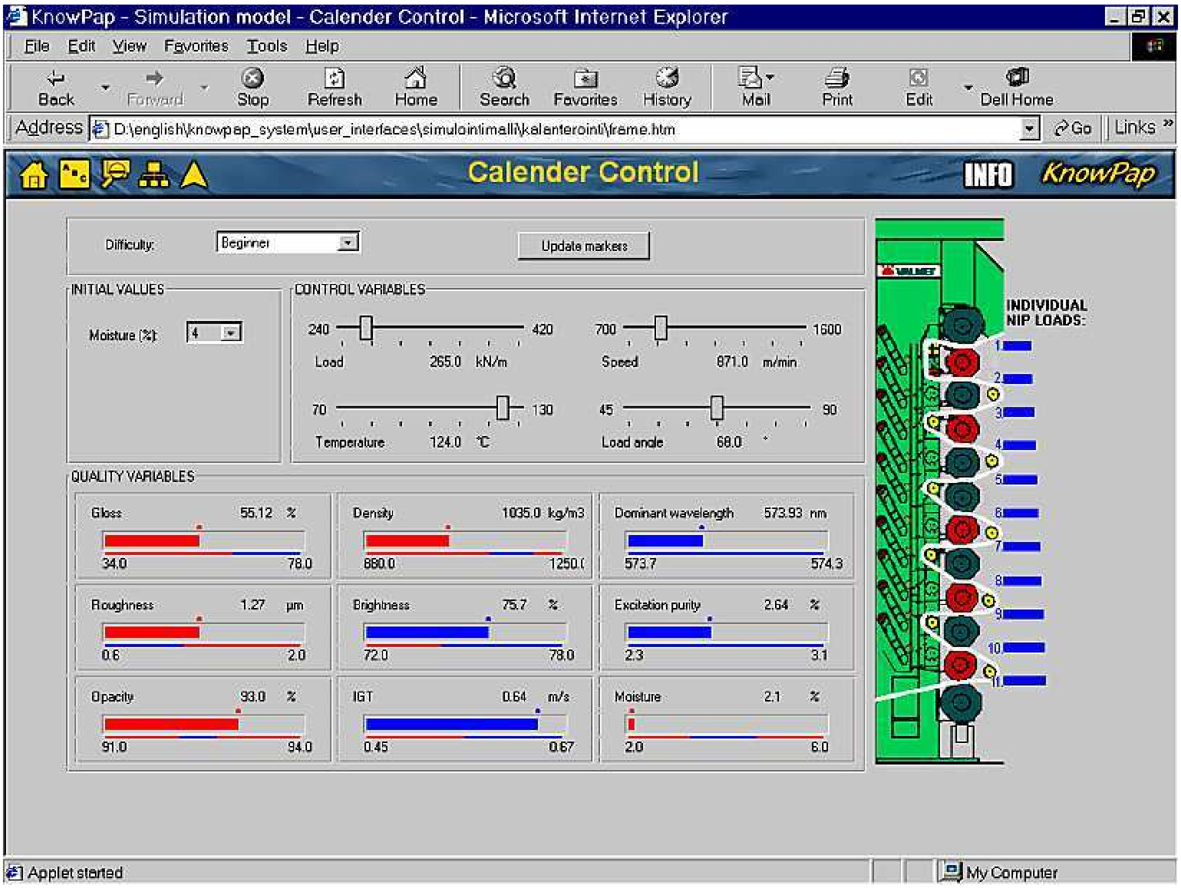

Figure 34. User interface of the supercalender simulator (KnowPap® 7.0, 2005 © Technical Research Centre of Finland (VTT))

6.4 KnowFine – tailored knowledge and performance support system for fine paper production

6.4.1 Development of the tailored knowledge support systems

KnowPap as a generic knowledge support system is a good tool for learning basic information related paper mill operations, maintenance and automation. A problem from industrial usage point of view is that the material is too generic because some of the materials are based on technical marketing documents, which has been provided by equipment suppliers. Another problem with the generic knowledge is that people working in a specific paper production unit do not find the relevant information, because the knowledge support material does not necessarily cover specific production processes or equipments related to their production unit. The novice users do not necessarily even know what knowledge is relevant to them, when they are working in a specific production unit. The materials in KnowPap are broad but at very basic level.

Based on these results a customized knowledge and performance support system, called KnowFine was developed. The principal structure of the system was similar to KnowPap, but all content and materials were customized to a specific fine paper production line, having specific customers, products, raw-materials, production processes and technologies. In the development, the structure and the scope of the system was based on the strategic competence analysis.

The system was first developed in a paper production unit rebuild project in Finland and the results of using the system in the project are described in Section 7.4. The developed system was then customized and further developed for a investment project in China, where all contents and also the language was localized. The localization of the system was very important, because the users working at the shop floor could not use the tools in English. The main user interface for the system is illustrated in Figure 35.

Figure 35. KnowFine as a customized knowledge and performance support system developed for a Chinese paper production unit (Laukkanen 2005)

6.5 Modelling and simulation of operational best practices

6.5.1 Operational training simulators - case supercalendering

The results of using rigorous, full-scope engineering simulator in initial training has indicated that, for some users, it has been too complex method. These challenges were taken in the development of operational training simulators by limiting the scope of the simulators to unit operations, shifting from detailed process models into models based on basic balances and by designing the user- interfaces more into emulated process control system interfaces.

The goals for the operational simulators were to train product quality management, product cost management and how to operate the unit processes in the whole production line. The emphasis in the simulation was to model the paper quality properties by using statistical multivariable models and the algorithm is based on piece-wise linear models. The benefit of these models is general applicability, numerical stability and easy customisation for new processes. The use of the models is, however, limited to processes which do not have strong correlations between the input variables, which has to be taken into account in the modelling. The calendering model was developed for a modern supercalender. The basis for the model was measurement data collected from the trial runs of a real supercalender. The data was further validated with the process experts. The user interface is presented in the Figure 36 and the control of quality variables in Figure 37.

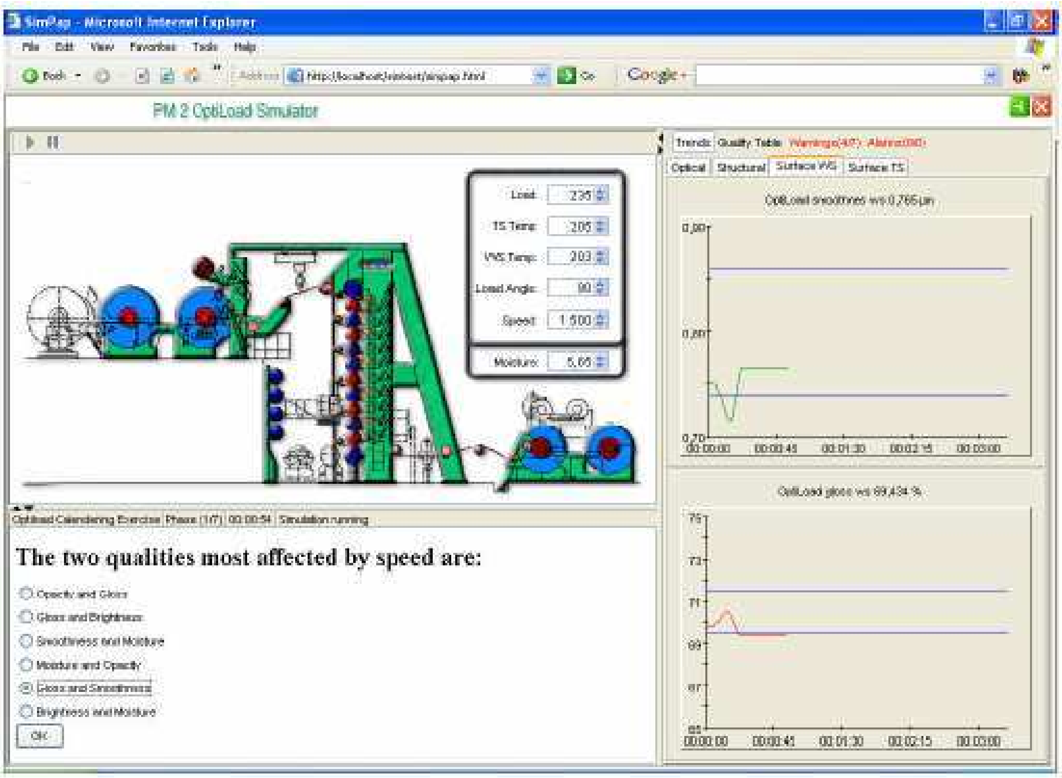

Figure 36. The user interface of a supercalendering simulator (Laukkanen 2005)

Statistical Quality model

The quality property vector $\underline{X}$ is calculated as a product of process control variables $\underline{\mathrm{A}}$ and scaled coefficient matrix $\underline{C}$ (Eq. 15). The coefficients were identified from the real measurement data. In the supercalendering unit process simulator, there are 5 control variables $(A_1 \dots A_5)$ for controlling the 9 quality properties $(X_1 \dots X_9)$ (Honkio 1999)

$$\begin{bmatrix} C_{a1,x1} & C_{a2,x1} & C_{a3,x1} & C_{a4,x1} & C_{a5,x1} \\ C_{a1,x2} & C_{a2,x2} & C_{a3,x2} & C_{a4,x2} & C_{a5,x2} \\ C_{a1,x3} & C_{a2,x3} & C_{a3,x3} & C_{a4,x3} & C_{a5,x3} \\ C_{a1,x4} & C_{a2,x4} & C_{a3,x4} & C_{a4,x4} & C_{a5,x4} \\ C_{a1,x5} & C_{a2,x5} & C_{a3,x5} & C_{a4,x5} & C_{a5,x5} \\ C_{a1,x6} & C_{a2,x6} & C_{a3,x6} & C_{a4,x6} & C_{a5,x6} \\ C_{a1,x7} & C_{a2,x7} & C_{a3,x7} & C_{a4,x7} & C_{a5,x7} \\ C_{a1,x8} & C_{a2,x8} & C_{a3,x8} & C_{a4,x8} & C_{a5,x8} \\ C_{a1,x9} & C_{a2,x9} & C_{a3,x9} & C_{a4,x9} & C_{a5,x9} \end{bmatrix} \times \begin{bmatrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{bmatrix} = \begin{bmatrix} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 & X_7 & X_8 & X_9 \end{bmatrix} \qquad \textbf{(15)}$$

where $\underline{C}$ coefficient matrix

$\underline{A}$ control variables,

$\underline{X}$ quality properties

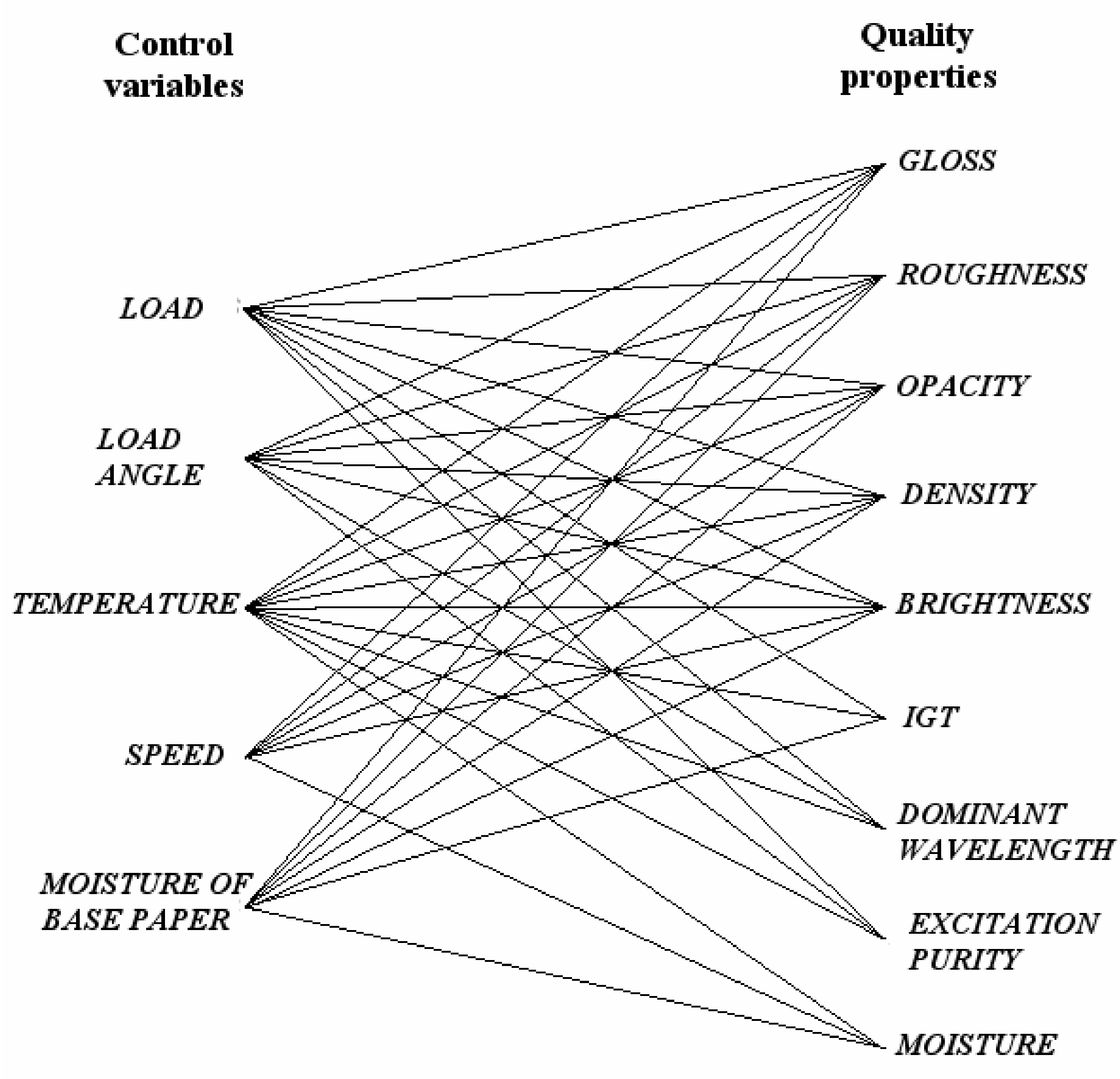

Figure 37. The control variables and paper properties in the supercalender simulator (Honkio 1999)

The operational simulator was implemented as a JAVA applet and it can be operated on an Internet browser. The model was validated against real measurement data and also with the process experts as illustrated in Figures 38 and 39. The result of validation is that the hybrid model is sufficiently accurate for training purposes.

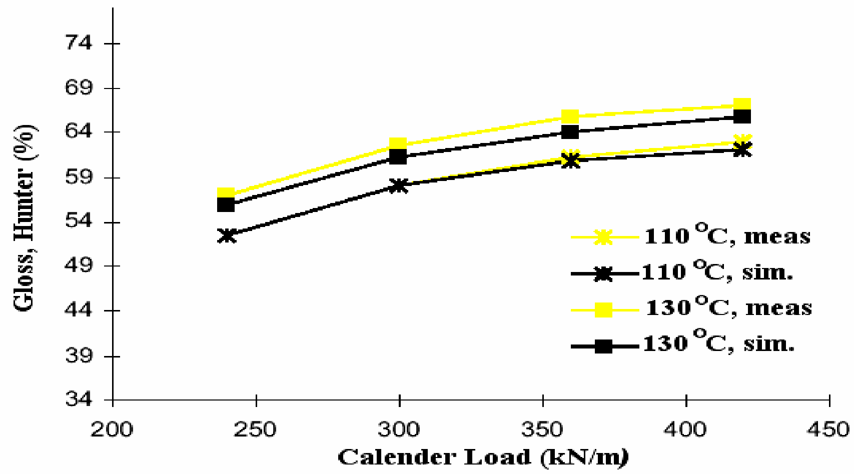

Figure 38. The effect of the calender load on paper gloss (meas=measured, sim.=simulated) (Honkio, 1999)

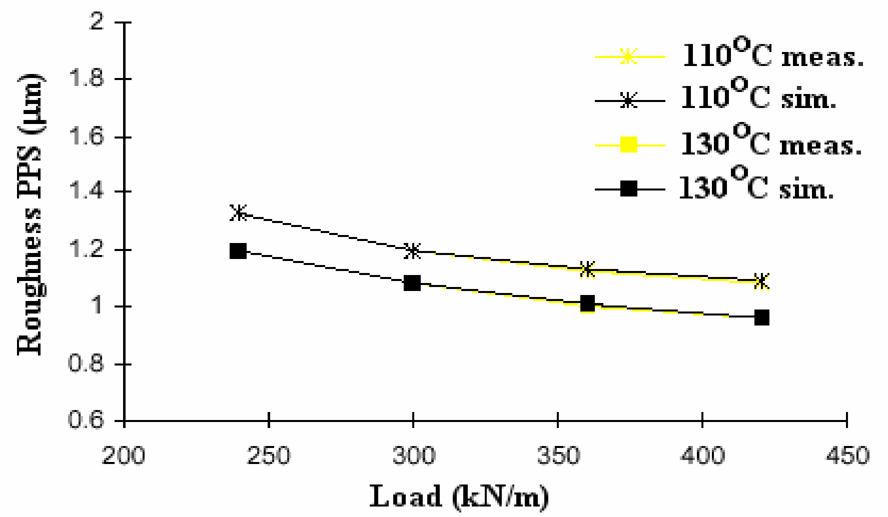

Figure 39. The effect of the calender load on paper roughness (meas=measured, sim.=simulated) (Honkio, 1999)

6.5.2 Operational best practice toolkits

Operational best practice toolkits can be developed for critical job tasks or work processes. The development of these toolkits can be carried out systematically by following the principles of structural team based on-job-training (OJT) process.

The development starts with systematic competence analysis, identification of best practices via benchmarking, job task modelling, project team formation, project planning and implementation of the best practice recording session. The modelling of the work process is critical part of the toolkit development. There are different roles and responsibilities needed in the modelling ranging e.g. from subject matter experts, project coordinators, video recording team and approval team.

After work process and best practice is modelled the next step is to carry out the work process in realistic setting highlighting the best practice way of doing it. This session is recorded with a digital video camera and the edited recording is then a basis for best practice toolkit.

The operational best practice toolkits can be used for the documentation of the infrequent tasks, sharing best practices related to complex technical procedures or sharing of best practices related to safety critical tasks. The concept can be used for the documentation of the best practices created by different teams, creation of documentation material e.g. for old equipment, where there is no up-to-date documentation available or for sharing the tacit knowledge related to certain job tasks. An example of operational best practice toolkit developed for knowledge transfer in paper machine maintenance is presented in Figure 40. The toolkit is a multimedia documentation of the best practice procedure providing visual information, which is very important especially in the emerging market countries like China where the language can be a barrier for knowledge sharing.

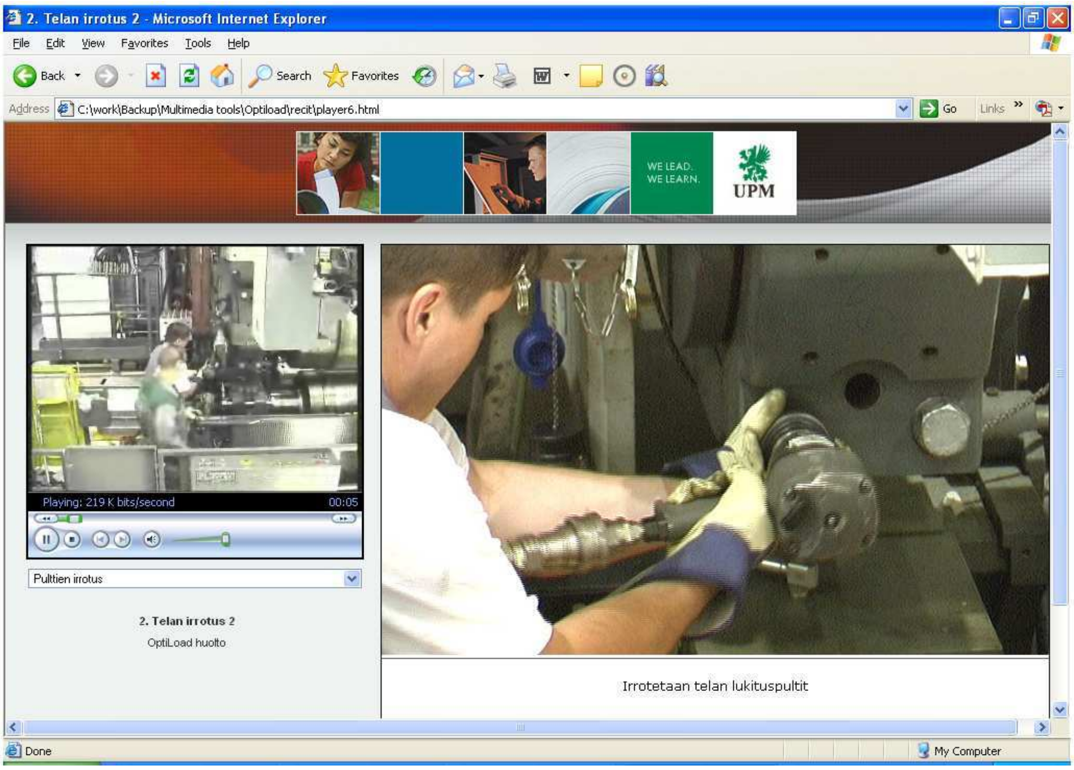

Figure 40. An example of the best practice toolkit for PM maintenance (Laukkanen 2005)

6.6 Summary

The tools and technologies reviewed in this chapter were developed for knowledge transfer, competence development and performance support in complex papermaking production environments. The applicability of these different tools for conceptual knowledge-, work process knowledge- and operational skills development is proposed in Figure 41.

Knowledge support systems are basic level tools aimed for development and sharing of critical knowledge related to processes and equipment. This knowledge should be customized for different production processes. Similar basic level tool for skills development in operational best practice toolkit, which can be used for transferring knowledge related to operational best practices.

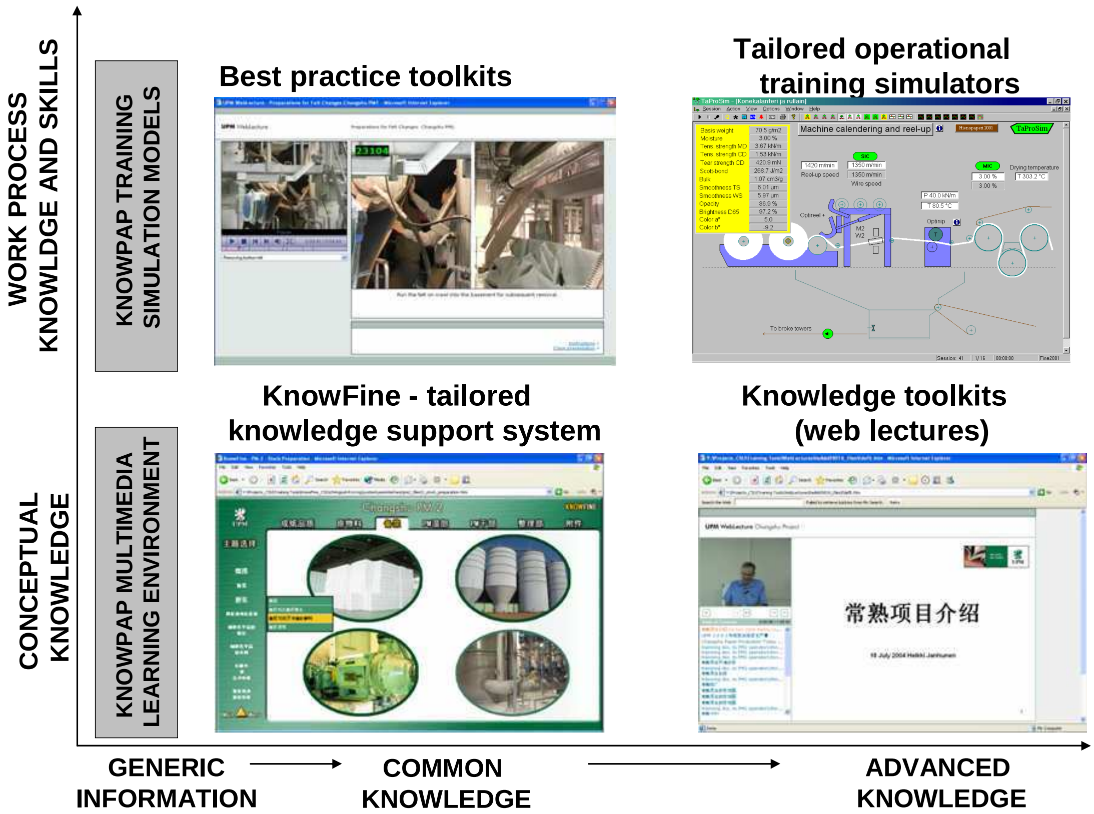

Figure 41. Basic and advanced level tools for competence development and knowledge transfer

7 Assessment of the constructed concept and tools

In this chapter the four industrial case studies are analyzed both longitudinally and latitudinally. The analysis describes the concept used for knowledge transfer and competence development, with the focus on the new tools used and developed in the case projects. Each description initially presents the goals of the project and the process of knowledge transfer and competence development linked to the project. The first study evaluates the use of the dynamic process simulator in a paper machine investment project in Finland. In the second study, the use of the KnowPap learning environment in a paper company is evaluated. In the third study the use of the concept for a major, fine paper machine rebuild in Finland is evaluated and, finally, in the fourth study the use of the concept in a paper production unit start-up in China is reviewed.

7.1 Research methods, data collection and concept implementation

7.1.1 Constructive research approach

A major goal of the research has been to construct a new, integrated concept and tools for knowledge transfer and competence development. According to Kasanen *et al* (1993), the constructive research approach means problem solving through the construction of e.g. models, diagrams, plans or organizations. Constructive research has been used in the technical sciences, industrial management, mathematics and operational analysis, and it can be seen as a type of applied research. It is also suitable for studying the interaction between personnel and industrial production processes, in which the understanding gradually increases while exploring and developing related issues (Kasanen *et al.* 1993).

Kasanen *et al.* (1993) emphasize that the practical usability of the managerial construction should be demonstrated and validated through "market tests". A successful, strong market test indicates that the construction has provided financial benefits, while a weak market test is passed if the construction of the question is being applied by someone in practice. In this study, the new concept is constructed and evaluated in different case studies in Finland and China.

The novel construction should have both a connection to practical applications and links to the theoretical framework of Kasanen *et al.* (1993). The new concept was developed by utilizing state-of-the art academic research and practical, industrial project experiences. The link to the theoretical framework has been introduced in the previous chapters, while the usefulness is validated in the case study projects.

7.1.2 Multiple case study research approach

Case study research has been widely used in modern qualitative research in studying complex organizational changes or development processes, and case studies already have a well established role in scientific study (e.g. Eisenhardt 1989; Yin 1993). Case studies are primarily used for exploratory investigations that attempt to understand and explore new topics, provide descriptions, evaluate outcomes and generate a new theory. A case study is suited for studying complex processes, where it is difficult to separate the variables in the phenomenon from the context. Case studies are dependent on the real context and naturalistic settings, which cannot be controlled in the same way as in experimental research designs (Eisenhardt 1989; Yin 1993).

A case study typically combines several data collection methods and numerous levels of analysis, and it can include single or multiple cases in the study. Case studies are complex because they generally involve multiple sources of data and produce large amounts of data for analysis. The evidence can be qualitative, quantitative, or both. (Eisenhardt, 1989, Yin 1993, Stake, 1995).

Researchers from many disciplines, e.g. industrial management and operational analysis, use the case study method to produce a new theory, to challenge a theory, and to explore or to describe a phenomenon.

The advantages of the case study method are its applicability to real-life, contemporary, human situations and its public accessibility through written reports. Case study results relate directly to the ordinary reader's everyday experience and facilitate an understanding of complex real-life situations (Eisenhardt 1989; Yin, 1993; Stake 1995).

This study includes four case studies where the new concept and tools are developed, explored and evaluated in the production management of a paper machine line context. The multiple cases in this study are selected to provide maximum insight into the created constructs in question, to ascertain the validity of the construct, and to make cross-case comparison.

7.1.3 Advantages and drawbacks of case studies

According to Eisenhardt (1989), there are several major advantages for theory building based on case studies. The use of case studies is likely to mean that the resulting theoretical contributions are innovative. The theory is also likely to be empirically valid, because the constructs and hypothesis have been verified during the theory development process. Case studies are frequently used in business processes for these reasons.

One possible risk proposed by Eisenhardt (1989) is the formulation of too complex a theory that lacks an overall perspective. This can occur if the volume of the empirical data is very large, while the information content is very dense. There can also be the opposite situation, in which the generality of the theory is too low owing to the narrow range of the data available.

In this study the first risk is avoided by using constructive methodology, which ensures the general applicability of the constructs. The empirical material in this study is derived from one firm operating in a specific field of business, which limits the usability of the results in different industrial contexts.

7.1.4 Methods of data collection and analysis

The most common methods of data collection in case studies are observation, interviews, questionnaires and the use of documents and records (Robson 2002). All these methods have been used in this research. In the present study the major part of the data analysis is performed using qualitative data.

In the analysis of qualitative data, the credibility, transferability and conformability of the data must be considered. Credibility can be confirmed when the enquiry is carried out by ensuring that the subjects of the enquiry are accurately identified and described (Robson 2002). Transferability corresponds to the ability to generalize conventional quantitative research (Robson 2002). In this research, credibility and transferability are confirmed by providing and linking the theoretical framework on the basis of a literature survey and by carrying out conceptual analysis with the operational concept. The topics for the empirical case studies are derived from this framework, and the general applicability of the results is analyzed and discussed. Conformability and validity are ensured by providing comprehensive descriptions of the cases presented.

7.1.5 The research process – concept implementation in the case studies

The research process used in this study is based on the constructive research approach. The research concept is constructed in the case studies and developed further on the basis of the results and experiences gained in the studies. The goal of the case studies is the development and implementation of the concept in the industrial case projects. The elements and tools used in the case studies are illustrated in Table 17.

Table 16 Concept development and elements used in the different case studies

	Dynamic Simulation	Knowledge Support System	Operational training simulators	Best practice toolkits	Competence evaluation tools
Case 1	X				X
Case 2		X	X		
Case 3		X	X	X	
Case 4		X	X	X	X

7.2 Case 1: Development and use of the full-scope, operator training simulator in the paper machine investment project in Finland

7.2.1 Project description

The starting point for the research study was a new paper machine in the design phase. The environmental regulations for the mill were very strict. The environmental impact of the new machine, as well as its fresh water usage, should be minimal. To meet these requirements, a new water usage concept was designed, including ultrafiltration as a new unit process. As there were no industrial-scale experiences of the operability and controllability of the process, this was a very important reason for the simulator development.

There were three goals for the simulator development in this study: 1) to verify the controllability of the new process, both in normal operation and in transient disturbance situations, 2) to train the operators responsible for running the new paper machine, which is the focus of this case study, and 3) to analyse the operation of the new process in both normal and transient situations. The simulator was developed on the basis of a hybrid, discrete/continuous modelling method, and was incorporated into the APMS simulation programme. Optimally, the development of the simulator follows the life cycle of the plant, based on the model developed during engineering and design (Laukkanen 2001).

7.2.2 Critical role of environmental protection technology

The current trend in paper machine design is zero discharge processes with minimal environmental impact. The environmental goal of minimising paper mill effluents, leads to the minimal use of fresh water in the process. The reuse and circulation of white water can cause chemical problems in the wet end process. Precipitation and paper chemistry problems can also cause runnability problems. Flow and consistency disturbances can propagate through the integrated flow network and process stability can be difficult to achieve.

As an example, one Finnish paper mill, which is the case process of the study, installed CR filtration units for treating white water. The permeate filtrate is used in showers, sealing and makeup to replace fresh water. The excess production from the filter is returned to the filtrate tank. The system is fully automated and is run 24 h/d from a control room. Elias and Van Cleef (1998) analysed the performance of the new process and found that the installed ultrafiltration units showed good performance in white water purification. The principal flow diagram of this process is presented in Figure 42.

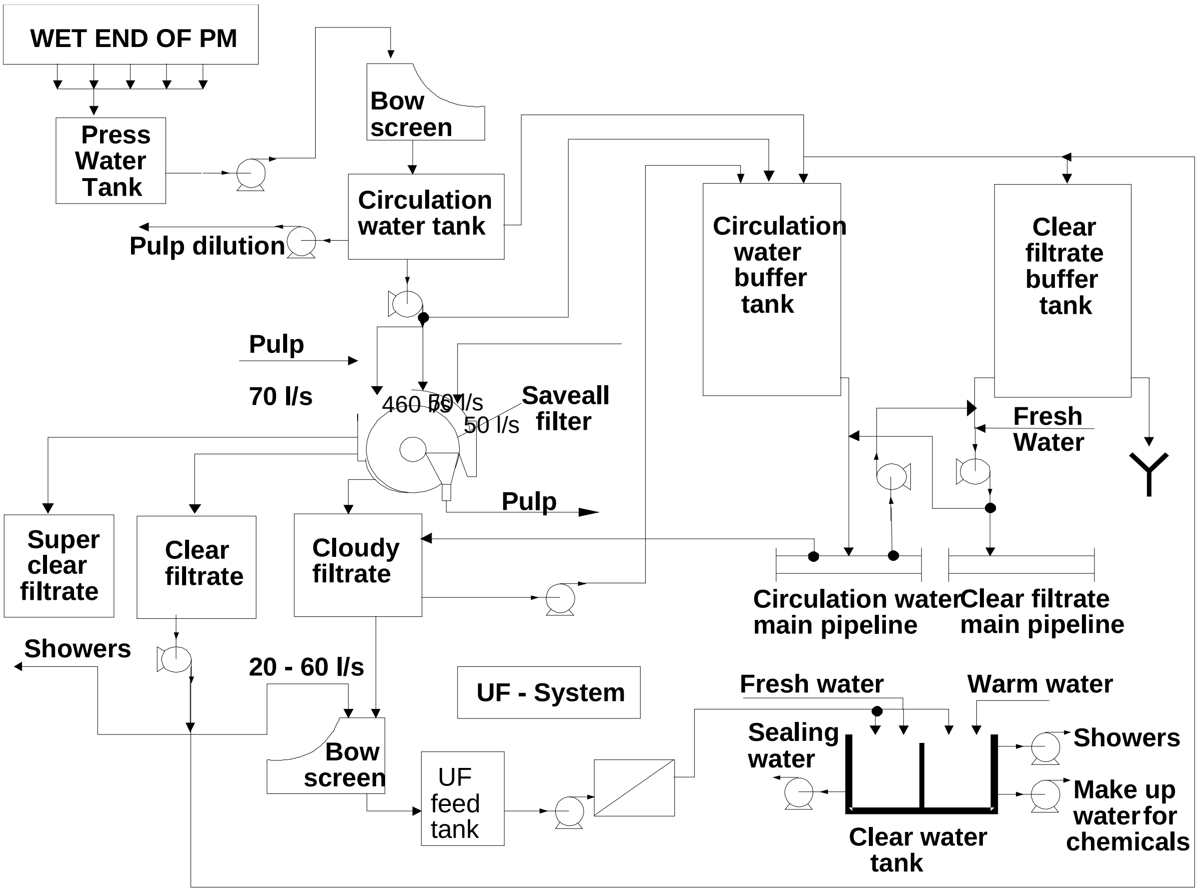

Figure 42. Water system of a closed-cycle paper mill (Elias and Van Cleef 1998)

Careful analysis of the process requirements is needed in closing the white water system. The operability of the membrane units at a specified water usage level can be analysed, or the effects of process disturbances on the operation of the filters can be used as examples of complex and dynamic operational situations.

7.2.3 Development of the concept and tools

A modelling project started during the design of the new paper machine. The parameters used in the mechanistic models were based on the process design documents, such as flow, PI and layout diagrams and equipment parameters. The most important control loops of the base paper production process and part of the mill automation were included in the simulation model. Operability specifications were used to combine the process and control structures in a dynamic simulator. The APMS simulation environment was used to model the base paper production process. Validated mechanistic simulation models, which are based on the dimensions and operational parameters of the equipment, do not necessarily require measurement data.

The simulator includes the following sections of the process:

- Mechanical pulp mill (as a water consumer)
- Chemical pulp disintegrators (as a water consumer)
- Stock preparation section
- White water system
- Broke handling system
- Pulper system
- Fresh water preparation and warm water systems
- Short circulation
- Paper machine including shower water system
- Former and press sections
- Dryer section
- 57 control circuits of the mill

The modelling project was carried out in co-operation with a Finnish paper mill. The time spent on developing the model was 6 man-months and was carried out during 3 calendar months. The calculation speed of the simulation model is 1.5 - 3 times faster than the real time in an HP 9000 series UNIX workstation. The extent of the model in terms of flow network components and process equipment is presented in Table 18.

Table 17. The scope of the dynamic simulation model in terms of process equipment

Process component	*Number of components in the simulation model*
Thermohydraulic point	245
Tank or silo	41
Pump	37
Pipe	133
Control valve	93
PI-controller	57
Analogue signal	918
Binary signal	214

7.2.4 Results of the modelling project

The controllability of the paper machine process was verified as a part of the modelling. An important subsidiary result of the modelling was that two incorrectly designed control circuits were identified. The redesign and fine-tuning of these loops could be carried out before the start-up of the mill. It was estimated that the redesign in this phase saved 2 – 6 hours in start-up and troubleshooting time. A dynamic simulator, based on the hybrid models, proved to be a good tool for verification of the operation of the process during both normal and transient situations.

The mechanistic building blocks for the models used in the APMS simulator for modelling flow, heat and mass transfer processes are validated in several transient tests. The paper machine library models of the simulator have also been validated against real measurement data in a paper mill simulator project (Lappalainen 2004). The validation tests have been carried out both for paper machine components and for the flow network models.

The validation of the model developed in this study was based on the following test runs:

1. Normal operation of the plant
2. The effect of web break on water usage
3. The effect of a grade change

The results from these tests were analysed by the process experts and experienced operators. The simulation experiments for the above case show good performance for the applications in which the simulator is used.

7.2.5 Life cycle of the concept and tools

The life cycle of the simulator started in 1996 when the design of the new paper machine was almost complete. The model was developed in 3 months and the total time needed in simulator development and training simulator arrangements was 6 man-months.

The simulator was used during the project:

1. *To analyse the controllability of the new paper machine in different situations.* Possible problems in a new design typically occur in special situations, so in normal operation it is often impossible to discover the problems. A detailed dynamic simulator, including both process and control structures of the machine, is often the only tool able to verify the controllability.
2. *To train the operators of the new mill.* The operator actions are of major importance, having a direct effect on the environmental impact of the paper machine. Incorrect actions can cause an extra environmental load e.g. as spillage. Simulator training was an important part of the training programme for the personnel responsible for running the machine.
3. *To improve the transfer of know-how between operators.* The backgrounds of the operators were very different; some were skilled professionals, while others were inexperienced. The simulator training was carried out as production team training, which was an efficient way to transfer know-how.
4. *To broaden the operability scope of the mill personnel*, so that the operators working in the dry end of the paper machine would also understand the operations undertaken in other parts of the mill, e.g. in the stock preparation section.
5. To analyse the process dynamics, with the focus on the water usage of the paper machine during operational transients.

7.2.6 Use of the simulator in the training and knowledge transfer

Operator training with a full-scope simulator was an important part of the training programme and the second application for the hybrid simulator developed in this study. The reasons why simulator training was needed were reported by Laukkanen *et al.* (1997) as:

1. **The differences in the professional backgrounds of the operators**
   Some operators were experienced professionals, but there were also some inexperienced "freshmen". To transfer know-how and to equalise the differences in working skills, the simulator training was carried out on a team basis, meaning that the more experienced operators could instruct their less experienced colleagues. A photograph of a typical training session is presented in Appendix 1.

2. **The strict environmental limits of the mill**
   The environmental impact of the machine should be within the strict limits set for the operation of the mill. To achieve this goal, the mill should be operated flawlessly in all situations in order to avoid leaks, spillage and other extra environmental loads. Another goal was to instruct the operators about how to minimise fresh water usage by operating the closed-cycle process in an optimal manner.

3. **To deepen and broaden the conceptual understanding of the operators**
   The simulator was used in training to create a mental model of how a modern paper mill process operates, how the process equipment and the control system interact, and what are the interactions in the different parts of the mill. Regardless of the position or the responsibilities of an operator, it is important to understand and have a holistic view of these interactions.

4. **To improve operator skills and increase confidence**
   Prior to operating a real paper machine, simulator training provides flexibility for operating the process in different situations, including normal operation, grade

changes, web breaks and process disturbances. By preparing the operators to handle all these conditions in a simulator, both their skills and their confidence can be increased.

5. **To train operators for the first start-up**
   Simulator exercises included operability studies aiming at the first start-up of the paper machine.

The key operators responsible for running the paper machine were chosen for simulator training. The major goals of training were to teach the process operations of the new mill, to teach the dynamic behaviour of the new process, especially water usage aspects, and to broaden the operability scope of the personnel. The full-scope training simulator was implemented on the basis of the dynamic simulator developed during the design stage. The following adjustment steps were needed for the model:

- Justification of the model fidelity for real-time operation
- Planning of realistic training situations (both instructor led and self-study)
- Design of instructor and trainee user-interfaces
- Definition of the data communication between the simulator and the DCS

The goal for the simulator training and the environment was to make both the functionality and operability of the system as realistic as possible. (Laukkanen *et al.*, 1997a). The simulator should give a realistic "hands-on feeling" of paper machine operation. Because some operators were skilled professionals, the fidelity requirements of the simulator were high, as was the requirement for realistic training situations. The motivation for training will suffer if the model's behaviour differs from the dynamic behaviour of the real process. These requirements were met by using detailed, hybrid simulation models in the simulator, and by using a real distributed control system (DCS) as a user interface to operate the simulator.

7.2.7 The scope and structure of the training simulator environment

The training environment consists of three parts, which are illustrated in Figure 43:

1. dynamic simulation of a paper machine process, 2. instructor station, and 3. training stations. The UNIX workstation (HP 9000 series) was used for running both the simulator and the instructor stations. A distributed process control system (Valmet Damatic XD), including two process stations and four displays, was used as a training station.

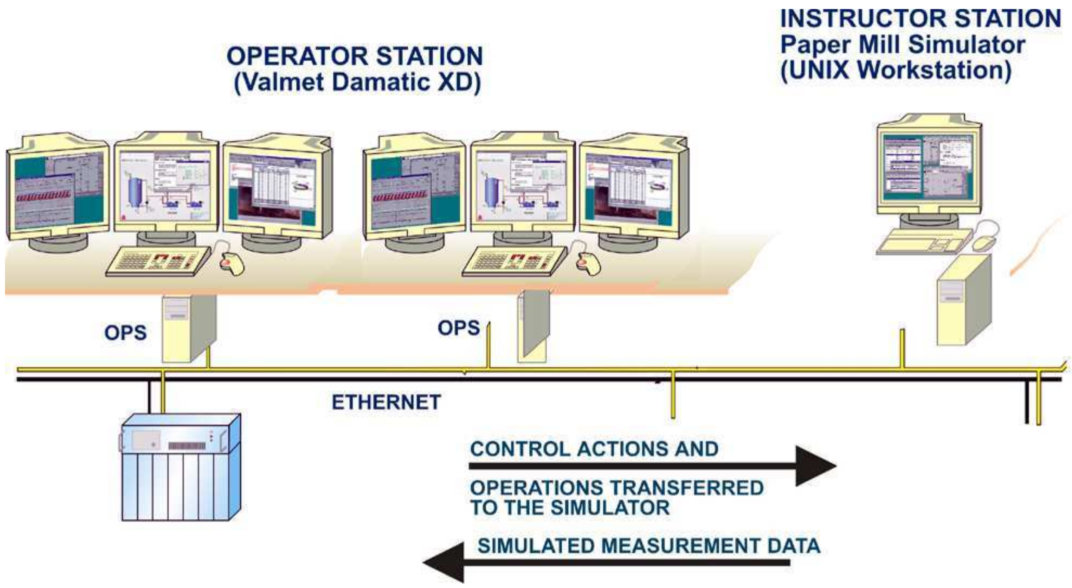

Figure 43. The structure of the full scope training simulator environment

The simulated measurement data were transferred from the simulator to the DCS through an Ethernet network. Simultaneously, the control actions of the operator were transferred from the DCS to the simulator, as illustrated in Figure 43. The instructor station was used to create realistic training situations, such as malfunctions (e.g. web breaks) or process disturbances (e.g. consistency fluctuation). The operators' actions and the most important measurements were followed from the trend curves in the instructor station.

The operator user interface consists of 15 operational DCS displays to control the paper machine process. In addition to learning the process dynamics, the operators also become familiar with the new DCS system before the first start-up. Both the functionality and the picture hierarchy were learnt. The operators also learnt how to operate the process using the displays of the DCS. After training, the same DCS system was installed in the paper machine.

7.2.8 Training situations

The training situations can be classified under four categories: (1) normal operation of the plant, (2) operation of the plant during a grade change, (3) operation of the plant during a malfunction or a disturbance, and (4) studies on the dynamic behaviour of the plant. The training sessions consist of realistic problem-solving exercises, so that the operators have to provide answers to the problems by using the simulator. Some typical scenarios are presented in Table 19.

Table 18. Examples of problem-based scenarios for the simulator training

Simulation exercise 1 (normal operation, easy)	How much excess white water is circulated from the wire section to the short and long circulations (kg water/kg stock)?
Simulation exercise 2 (grade change, moderate)	How long does it take to change a grade from basis weight G1 to basis weight G1? (should this be G2? (G1=Grade 1, G2=Grade 2)
Simulation exercise 3 (disturbance situation, advanced)	What kind of effects do you see in the process when the fresh water intake is decreased by 30% from the normal level? How you can you compensate for the situation using the ultrafiltration units?

7.2.9 Results – competence development and knowledge transfer

The results of the simulator training were tested in the final examination, one part of which included questions from the simulator training sessions. These questions tested how well the operators have learnt from the hands-on sessions. The average result from a question testing how the paper machine uses fresh water in different situations was 72% correct. The average results of the other questions concerning the operation of the stock and white water system were 70 – 80% correct. It was found that, as a result of simulator training, even relatively minor details could be recalled, which indicates good motivation and efficient learning.

Systematic feedback from training was collected as a measure of training satisfaction. There were two kinds of feedback from the simulator training. Some operators considered that the training problems were too difficult and were not very motivated. To understand, e.g. the interactions of the stock and white water systems, the operator should have experience in mill operation and a good mental model of the paper machine process. Some operators complained that the paper quality properties should be the goal in simulator training, rather than process operations. On the other hand, most of the operators were satisfied, and some of the experienced operators were even very interested in the simulator training. They were also capable of understanding and handling even the most challenging scenarios. The experienced operators were also capable of, and interested in, planning some new training situations.

7.2.10 Results - business results

The overall experiences from simulator training were good. Simulator training turned out to be an efficient way of teaching the dynamic behaviour of the basic paper production process, and to teach how the process should be operated during normal and transient situations. The training greatly facilitated the efficient start-up of the plant.

7.3 Case 2: Use of the KnowPap learning environment in a global paper company during 2001-2006

7.3.1 Project description

The starting point for the development of the KnowPap learning environment was the results obtained in case 1. The scientific dynamic simulator proved to be too difficult for some users, and the full scope simulator system was also very complex and extensive. At the same time the development of www technology and graphical user interfaces made the web- and server-based simulation tools possible.

The KnowPap learning environment was developed as a learning environment and knowledge support system for paper technology and paper mill automation. The goal in the project was to develop a system, which could be used both for self-studies and as a training tool. The scope of the system was defined to fulfil the multi-skilled competence requirements needed in the paper mills. On the other hand, the system was also designed to be used in the universities as a tool for linking the theory to the practice. The major target users were companies whose goal was technical and professional training of personnel. The current users of the system are listed in Table 20.

Table 19 Different companies and universities using KnowPap system 2006 (Prowledge 2006)

COMPANIES AND TRAINING ORGANIZATIONS	POLYTECHNIC UNIVERSITIES
AEL	South-Carelia Polytechnic
Ahlstrom	EVTEK Polytechnic
Andritz	Häme Polytechnic
Honeywell	Jyväskylä Polytechnic
Jaakko Pöyry Group	Kymenlaakso Polytechnic
M-real	Savonia Polytechnic
Metso	Tampere Polytechnic
Myllykoski	UNIVERSITIES
Educational ministry of Finland	Lappeenranta University of Technology
Sulzer Pumps	University of Oulu
UPM-Kymmene Group	Tampere University of Technology
VTT	Helsinki University of Technology

The first version of the KnowPap system was taken into use in a global paper company in 1998. The system was installed first in the local Intranet, because there was no global Intranet network available at the time. In many of the units where the system was demonstrated, there were not even local Intranet networks available. At the same time, the Intranet systems were developed for the company and the system was taken into use, site-by-site.

The system was launched for global use in 2000, and a very important part of getting KnowPap system into use was the extensive communication and training campaigns in the individual units. There were special training and introduction sessions arranged for local employees in the different units, who could then train the local employees in how to use the system.

7.3.2 Results - use of the KnowPap system in a global paper corporation during 2001-2006

The use of the KnowPap knowledge support system in a global paper company has been analysed during the period 2001-2006. As the analysis has been based on server log analysis, the mobile people who have their own local systems are not included. The system has been accessible through the corporate Intranet, and therefore most of the employees have access to it.

The average number of user sessions annually during 2001-2006 was 4446. The number of session varied between 2695 and 6217, as illustrated in Figure 44. The average number of unique users was 1483 annually, and the average varies between 1032 and 1751, as illustrated in Figure 45. The reason for the decreased number of sessions and number of users is the development of tailored knowledge and performance support systems for the different paper production units, which took place during 2001-2006. The first tailored system was developed in 2001 for the Finnish paper mill, and in 2006 there were altogether 17 tailored systems developed for the individual paper production units.

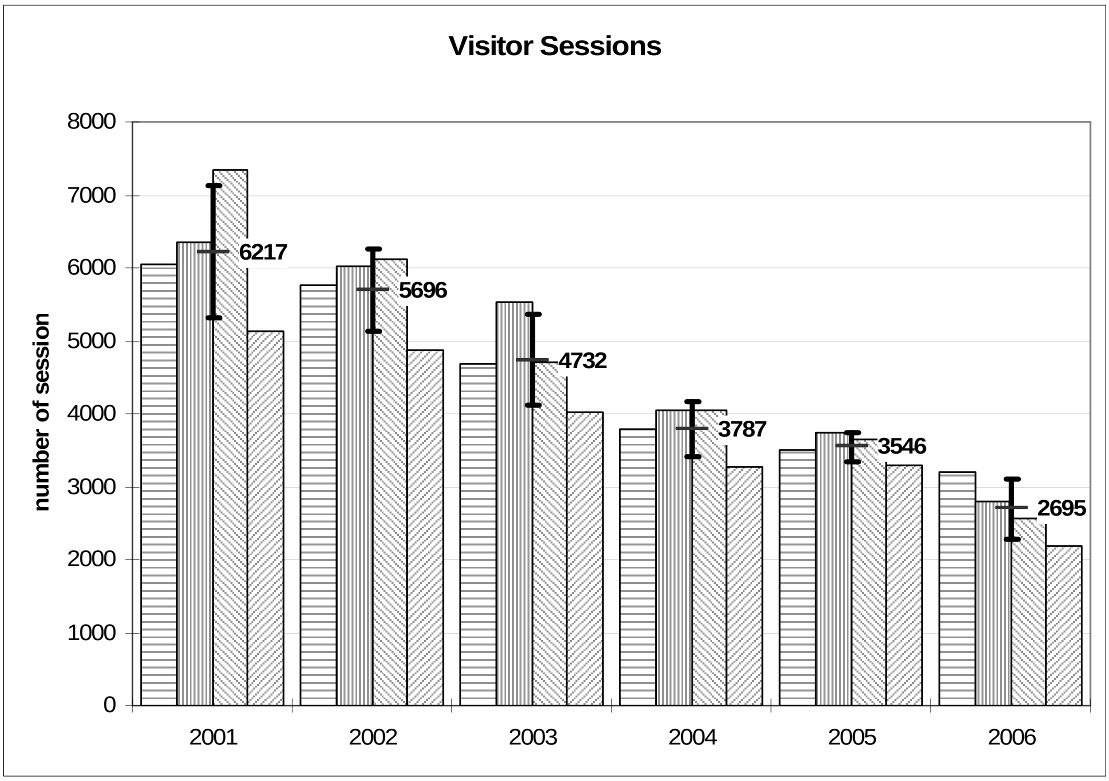

Figure 44. The average number of KnowPap user sessions.

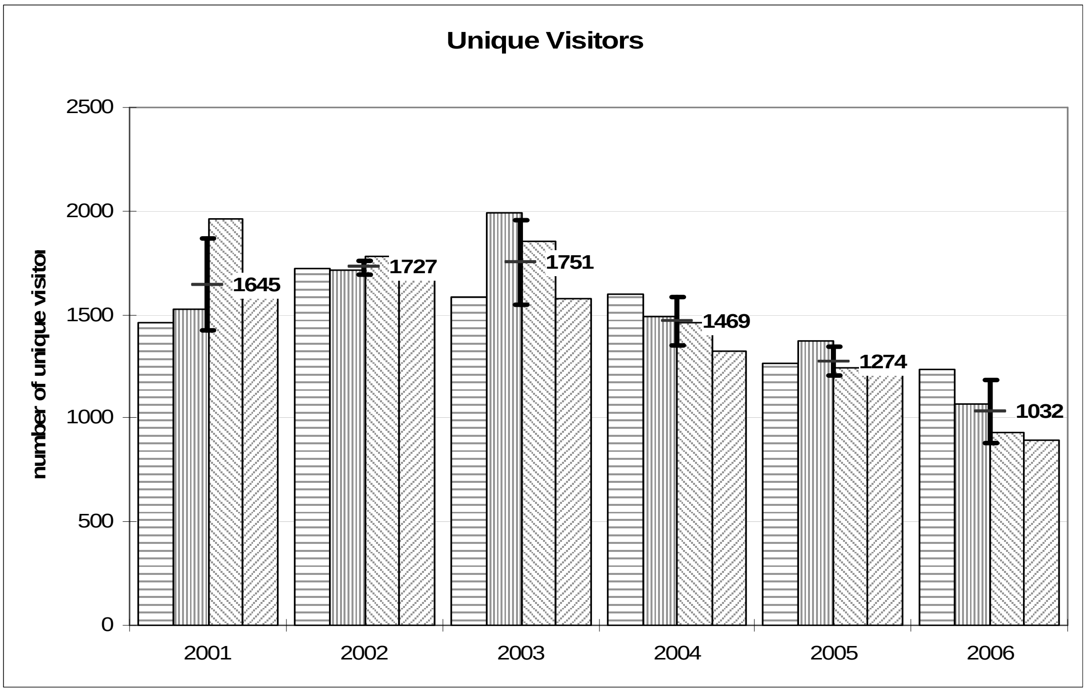

Figure 45. The average number of unique users during 2001-2006.

The average session length varied between 10 minutes 9 seconds and 10 minutes 49 seconds, as illustrated in Figure 46. The activity levels of visitor sessions for different hours of the day is illustrated in Figures 47.

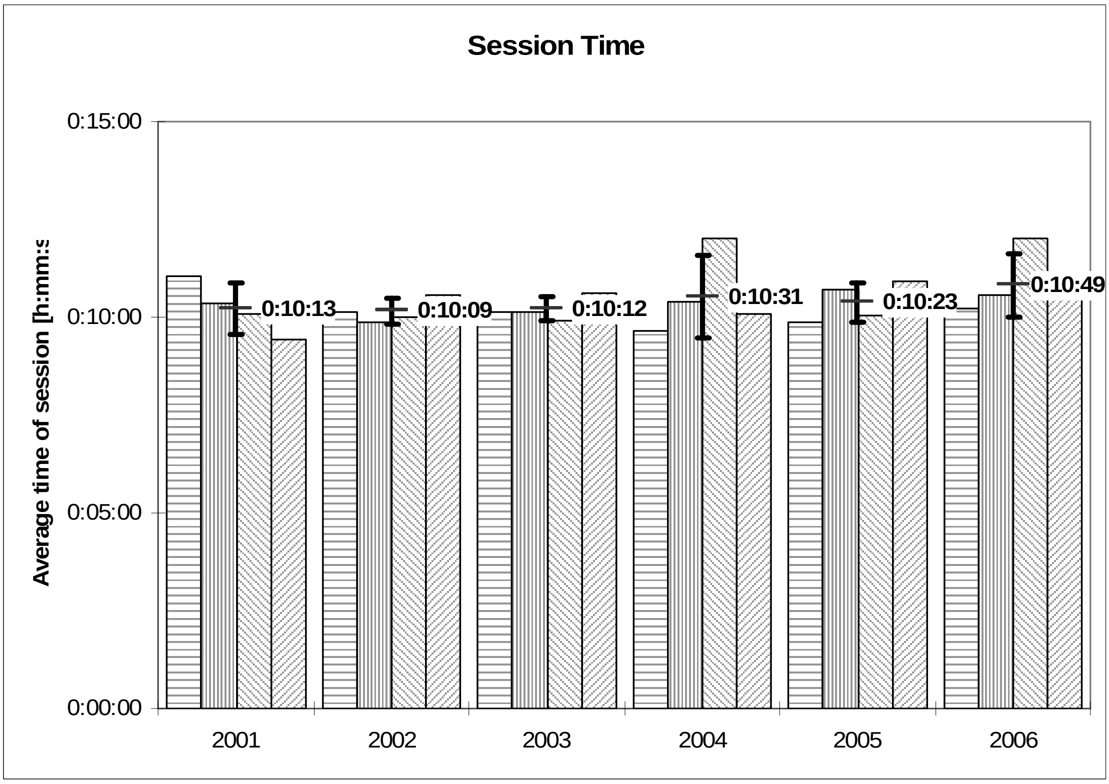

Figure 46. The average length of KnowPap usage session during 2001-2006.

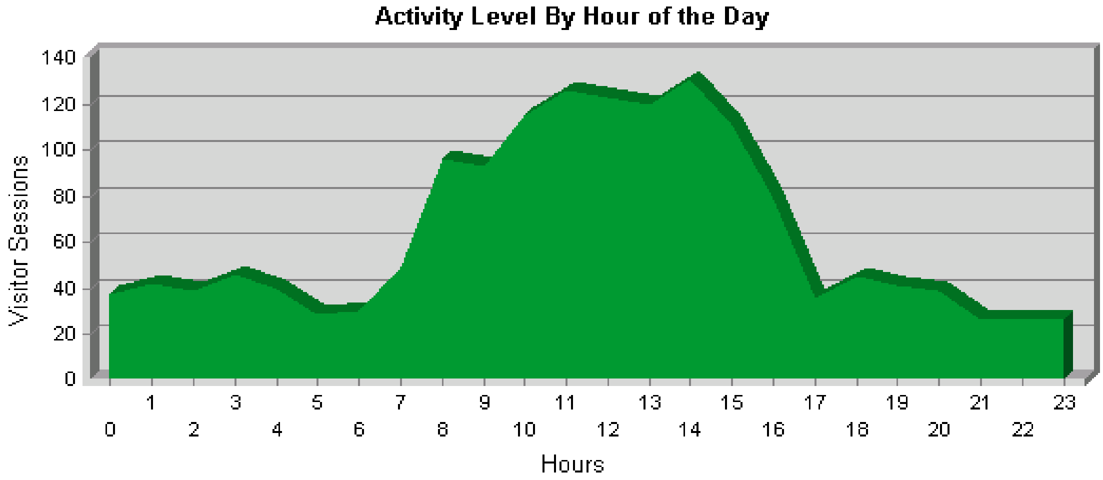

Figure 47. The activity level of the KnowPap system usage through hours of the day

7.3.3 Results - usability of the KnowPap system

The usability of the KnowPap system for operator training was tested in the study. Ten subjects volunteered for the usability test, which was carried out as a questionnaire study. All of the volunteers were students of an industrial vocational school who, within one year, would be working as paper machine operators. In this study, the KnowPap system was used as the primary tool for teaching papermaking, and it was used throughout the course for problem-solving exercises and self-study. The results of testing the usability of the KnowPap system are illustrated in Figure 48.

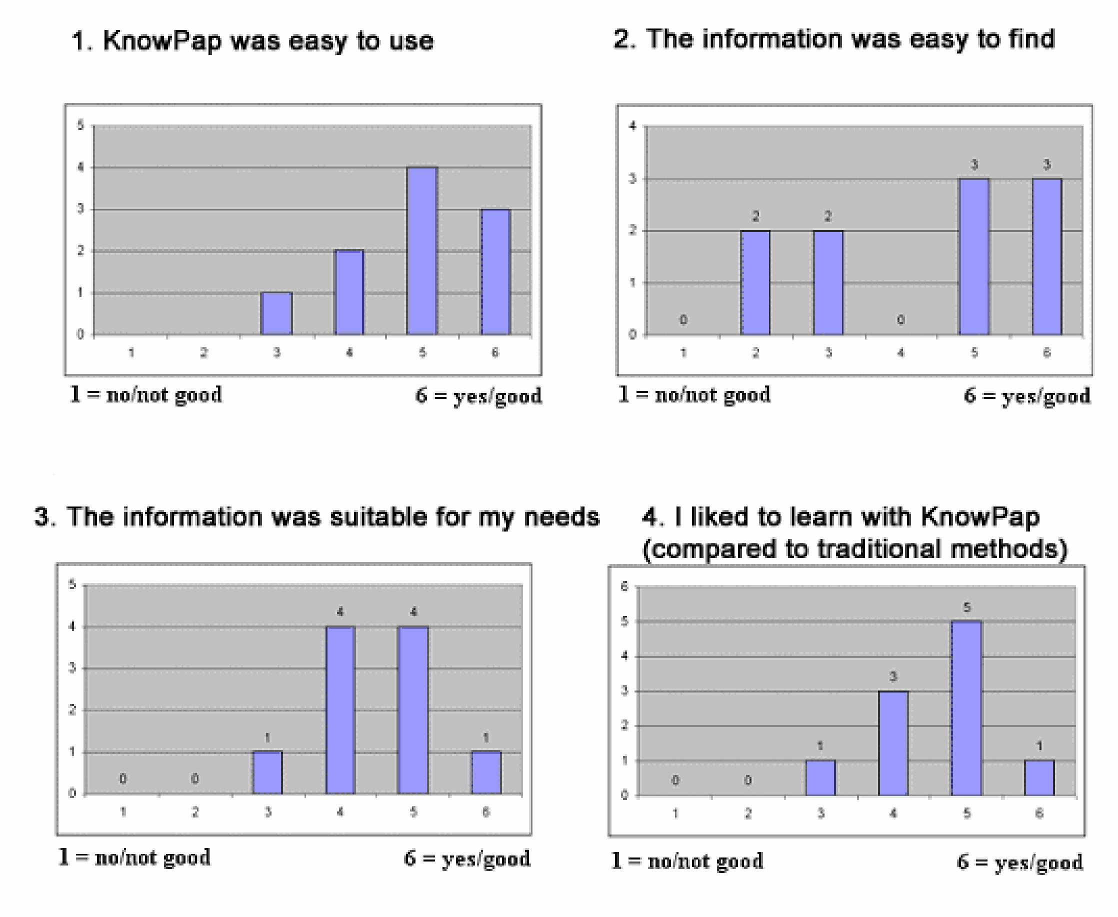

Figure 48. Results from the questions 1-4 testing the usability of the system

Generally, the students found the KnowPap system to be a good tool for studying paper technology. Although the information was at a suitable level for them, sometimes the information needed was not easy to find. Most of the students liked to use KnowPap and found that it was easy to use for self-study. The results testing the motivation of users and interactivity of the tool are illustrated in Figure 49.

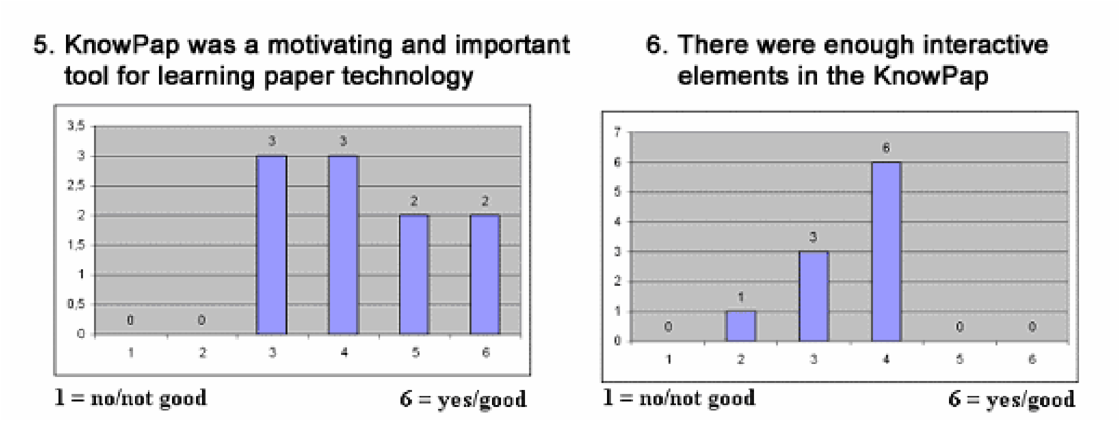

Figure 49. Results from the questions 5-6 testing the usability of the system

The results indicate a significant trend, which was independent of the user group. The subjects were asked "What multimedia elements do they consider to be the most useful in training?" The hybrid simulation models, e.g. the calendering model, were ranked as the most useful multimedia in the system. The feedback from question 6 indicates that more simulation models are needed. In the free feedback section, the users were asked, "How can the learning system be further improved?" In most of the answers it was suggested that a greater number of interactive simulation models should be developed. A general negative feedback concerning the usability was that there is too much text material. Text was found to be the least useful multimedia material in the system. This result is in agreement with the previous findings of usability studies: the reading speed from a computer screen is 20% lower than that from paper and that the computer screen is not yet the optimal medium for reading.

7.3.4 Results of learning testing

Some questions in the questionnaire tested the learning experiences of the operators. The subjects were satisfied with the material they had found in the system. This was also found to support the way the operators like to study. Some operators, however, wanted more detailed material and some other support material for training. The results of the learning experience testing are illustrated in Figure 50.

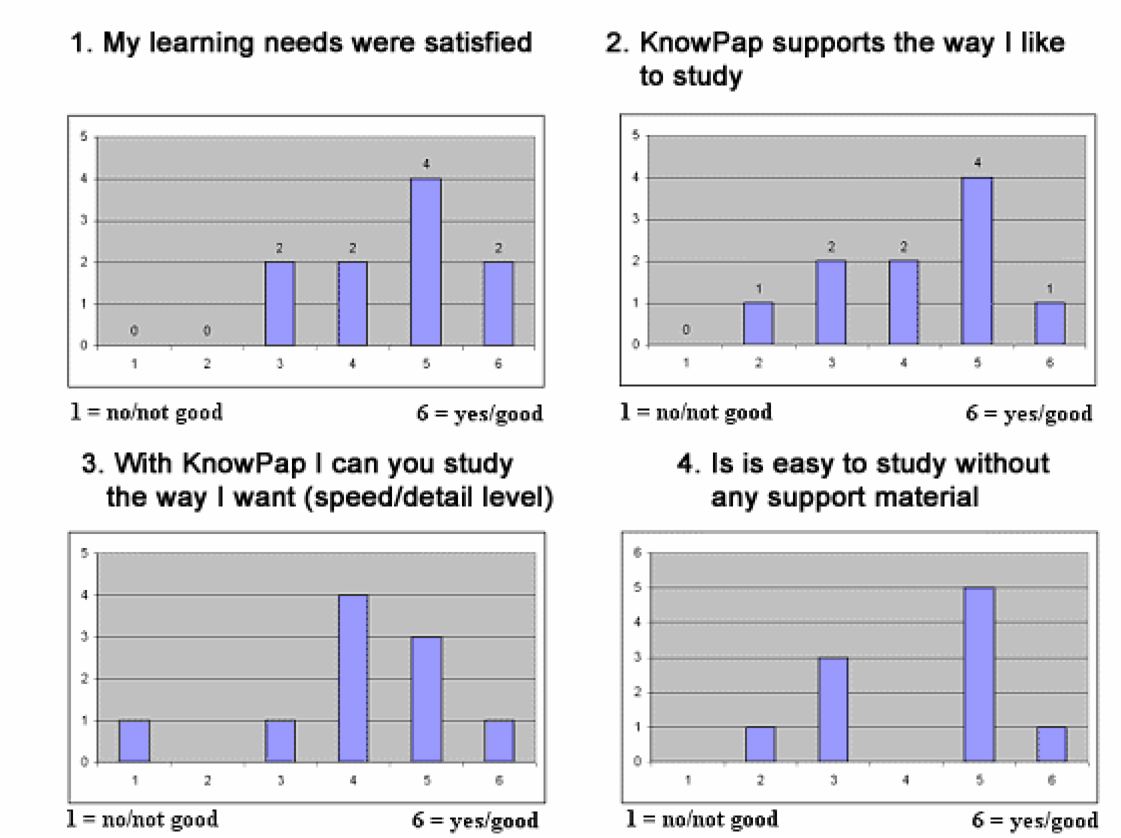

Figure 50. Results from the questions 1-4 testing the learning experiences

One very clear result from this study is that web-based systems offer optimal support for traditional classroom training. Trainers are still needed, but their role will change to that of coaches or facilitators for the students. In using these systems, the students must accept more responsibility for learning than in traditional classroom training. These results indicate that web-based training will be a very important tool in the future. Compared to traditional trainer-led training, it was found to be a very good method. As the sample size of this study was relatively small and these preliminary results are indicative rather than statistically significant, further research is still needed in this area. The results of the learning preference testing are illustrated in Figure 51.

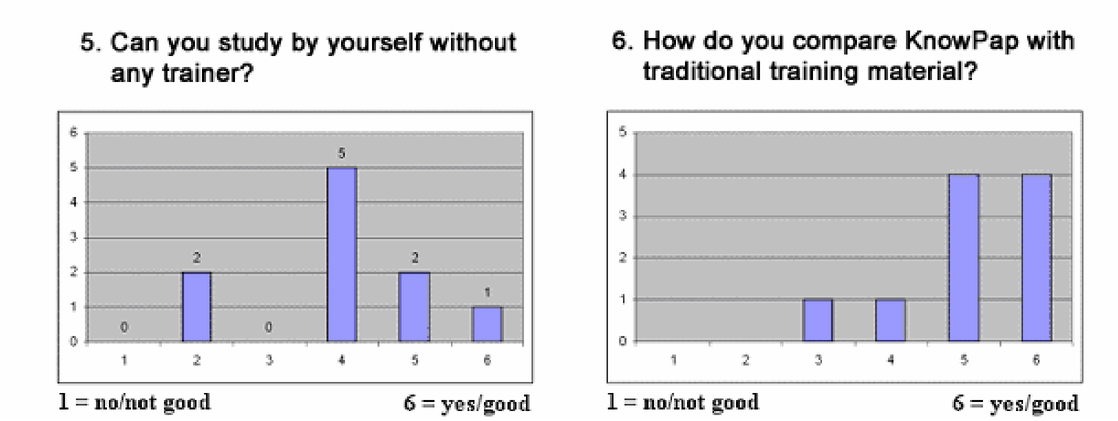

Figure 51. Results from the questions 5-6 testing the learning

7.3.5 Results - use of the KnowPap system as a trainer's tool

The usability of the KnowPap system as a trainer’s tool was also evaluated by interviewing trainers and developers working in the global company who had used KnowPap system as a trainer’s tool. (T1 = Trainer 1; T2 = Trainer 2; T3 = Trainer 3; D1 = Developer 1; D2 = Developer 2). The summary of the answers is presented in Table 21.

Table 20. Results of trainer/developer interviews of using KnowPap as a trainer tool

QUESTION	*ANSWERS*
Does KnowPap provide a practical tool for successful self-studying of paper machine technology?	Requires a teacher's guidance and support in use (T1, T3) Learning evaluation is needed (T1,T2) Learning paths, including pre-test and feedback are important (T1, T2, T3) It can be difficult to find essential things from the extensive amount of information (T3) There is a need to emphasize the core information in the mass of material (D1, D2) One successful concept has been problem-based self-studying. The students are given a question list of the most important areas and they are asked to find the answers to the questions (T1 and T2)
What is essential when customizing the learning paths?	To have the possibility to simulate how things work (T1) Incentives, rewards (humour for example) (T1) Clear goal/ aim, instructions (T1,T2) Situation related feedback (T1,T2,D2) Clarifying why this kind of learning path exists (T2) Materials, chemicals, economically optimal process, all these should be within the same learning paths (T3) Presentation advancing from general knowledge to more detailed (T3) The pre-test, post-test and other assessment are important (D1)
What kind of training concepts have proved to be efficient with KnowPap?	We have set some questions and the students have tried to find the answers from the KnowPap. The results/ feedback has been given to the students as well. (T1) The assessment is necessary and the students have to be told there will be tests in this area (T1) The teacher goes through the material by him/herself and sets some questions from the area. The students find the answers to the questions. By doing this, the teacher can confirm that the focus is at the right level. In the learning paths the idea is probably the same. (T2) Questions beforehand to the students and the test of the area (T3) Feedback is important in the studying process. The programme should make some checking questions of the area and provide some feedback and give links to incorrectly answered areas. The essential points have to be raised by the teacher because the system is so extensive (T2, D1)

The trainers have noticed that problem-based case studies are a good studying method for using KnowPap in the classroom. The clear goals and objectives for learning are very important, as well as the need for new learning paths. A task, which is set in an appropriate and interesting way, also has a motivating aspect. Tasks which are closely related to job functions are motivating, and transfer thus takes place. Multimedia-based learning objectives should also include an appropriate amount of interactions and 'force' the user to utilize the material in multiple ways. Assessments and feedback are elements, which many of the trainers and developers mentioned as being development needs. In some cases, too, the extensive amount of information in KnowPap makes it difficult to find the essential information, which is not always in a logical location.

7.4 Case 3 – Competence development and knowledge transfer in rebuilding a paper production unit in Finland

7.4.1 Project description

The starting point for the case study was a fine paper production unit rebuild project in Finland. The rebuild covered raw material preparation, base paper production and finishing processes. The target for the upgraded production line was a totally new type of paper with a unique quality combination of light weight and brightness. There was no corresponding process in existence at the production scale and this was an important reason for developing both a training simulator and a knowledge and performance support system tailored for the new production line process. On the other hand, the experiences gained in previous projects had shown that a high-fidelity operational training simulator is, as such, not enough for competence development and knowledge transfer.

The goals of this case study were: (1) to develop the skills and competences of the key production personnel in operating the new production line, (2) to transfer the latest knowledge related to new production line process, and (3) to confirm that the quality targets for the new paper grade and capability targets for the new production line are met by skilled and motivated employees.

The operational training simulator was developed on the basis of a hybrid, modelling concept. The simulator was customized for the major production unit processes and for selected, most important paper grades produced in the production line. For the simulator exercises, there were three focus areas: (1) how to optimize the quality of selected products, (2) how to minimize the production costs, and (3) how to carry out grade changes.

An extensive workforce development programme was planned and implemented as a part of the project. The use of the knowledge and performance support tools formed an important part of the programme. All the tools were developed in co-operation with the major suppliers of the project, and all the materials and knowledge were customized for the new production line process. The focus in the knowledge and performance system was to collect critical process, equipment and automation knowledge related to the new production line into a single system, where it would be accessible for all employees. After the project the knowledge and performance support system was available on the local Intranet.

7.4.2 Development concept and tools

A new, operational concept for competence development and knowledge transfer, including a training simulator and knowledge support system, was developed and used for the first time in this project. The basis for the development was competence and capability targets defined by the project targets, and the development plans for the different groups were defined on the basis of these targets. The development of the knowledge transfer and competence development tools follows, optimally, the life cycle of the project. The existing knowledge and best practices from the project supplier network is integrated into these tools. These tools were used together with traditional training and development tools, like structured on-job-learning and classroom training, to form a blended development model.

7.4.3 Training and development interventions for competence development

The major training interventions carried out in the development program are listed in Table 22. All the 73 employees followed in this study, were selected for operations and maintenance positions in the new PM line. They had more extensive training programmes, including structured OJT, operational simulator training and the use of knowledge and best practice toolkits. Also assessment tools were used to follow the learning curve and competence development of the employees.

The goal of the programme was to develop high level conceptual mastery for the key positions, as well as equal level for the whole production line Another goal of the project was to develop the conceptual mastery of the new employees to a level similar to that of experienced employees. This would be a good starting point for further development.

Table 21. Training interventions, their participation ranges and the theoretical and real sumscales of participation in each area of intervention

Type of intervention/ sum variable	Specific intervention/ part variable	Number of parti-cipants	Range of partici-pation (days)	Average partici-pation (days)
1) Formal classroom training	- customers and end-uses - raw materials - maintenance systems - production planning - processes and equipment - automation and IT systems	73	29 – 53	44
2) Struct. on-job-training	- stock preparation area - PM area - finishing area	73	16 – 40	35
3) Simulator training	- operational exercises	73	2-3	3
4) Web lectures	- some classroom trainings sessions converted into streaming media and web lectures	73	-	2
5) Knowledge and best practice toolkits	- customers and end-uses - raw materials - maintenance systems - production planning - processes and equipment - automation and IT systems	73	5-90	10

7.4.4 Results – competence development and knowledge transfer

The biggest challenge in this case study was the very tight project schedule for concept development. The decision on concept development was made during the detailed engineering phase of the project. The new product was a very advanced combination of quality properties, and there were no similar simulation models available. The knowledge related to the new production line was scattered over the network of key people employed in the investment project and key suppliers.

The development of a knowledge support system and operational simulator was performed within four months in collaboration with the key suppliers.

7.4.5 Results – business results

The business targets, technical capability and speed development for the production line were exceeded during the first 12 months. The production line broke the world speed record for fine paper machines in 2005, which indicates the excellent competence and capability of the production personnel (Metso Paper, 2002).

7.4.6 Results - usability of the knowledge and performance support tools

The usability of the tools was tested with a questionnaire and the scale was from 1=not good to 6=excellent. The results indicate that new personnel found the KnowFine knowledge and performance support system (4,18) and web lectures (4,35) easy to use and user friendly. The operational training simulator is a more complex and advanced tool, which is reflected in the usability results (3,35). As such, all the tools support knowledge transfer but they do not replace expert trainers. In the operational simulator, the expert trainer plays a very important role in going through the best practices for these new personnel (3,32)

Compared to traditional classroom training, the users found the use of KnowFine system (3,91) operational simulator (3,94) and web lectures (4,03) as a better and more motivating way of learning. They found the tools interesting and motivating learning tools (4,09/4,12/4,09), but a more extensive content should be available. From the practical performance support and troubleshooting point of view, the most useful tools were the KnowFine system (3,98) and the operational simulator (3,81).

The participants found it important to have the tools available after start-up. The tools can be used for further training in regular simulator training sessions (4,21) and to have KnowFine (4,03) and web lectures (4,15) installed into the local Intranet network as knowledge and performance support tools. The results are summarized in Table 23.

Table 22. Usability of the knowledge and performance support tools used in the project (scale from 1= not good to 6= excellent)

USABILITY	**KnowFine system (KM)**	**Oper. simulator (SIM)**	**Web Lectures (WL)**
Statement	**Average ± StDev**	**Average ± StDev**	**Average ± StDev**
It was easy to use KM/SIM/WL	4,18 ± 0,80	3,35 ± 1,25	4,35 ± 0,77
It was easy to find the information I needed	3,82 ± 0,83	-	3,82 ± 0,90
It was easy to use without support/instructor	3,76 ± 0,85	3,32 ± 1,47	-

LEARNING	**KnowFine system (KM)**	**Oper. simulator (SIM)**	**Web Lectures (WL)**
Statement	**Average ± StDev**	**Average ± StDev**	**Average ± StDev**
Use of tool compared to classroom training	3,91 ± 0,79	3,94 ± 0,95	4,03 ± 0,94
Motivating and interesting learning tool	4,09 ± 0,71	4,12 ± 0,91	4,09 ± 0,87
There was enough content in the system	3,82 ± 0,76	-	3,76 ± 0,92
Tool was useful from practical point of view	3,98 ± 0,88	3,81 ± 1,01	3,68 ± 0,88

FUTURE USE/PERFORMANCE SUPPORT	**KnowFine system (KM)**	**Oper. simulator (SIM)**	**Web Lectures (WL)**
Statement	**Average ± StDev**	**Average ± StDev**	**Average ± StDev**
How important to have tool available in future	4,18 ± 0,87	4,21 ± 0,91	4,18 ± 0,87
Installation of tool as org. performance support	4,03 ± 0,76	-	4,15 ± 0,86
Arrangement of regular simulator training	-	4,21 ± 0,88	-

7.5 Case 4 - Knowledge transfer and competence development in the fine paper mill project in China

7.5.1 Project description

In 2002-2005 a new paper mill project was launched in China. The major goals of the project were: 1) to build a world leader, fine paper machine in efficiency with a 450 000 tons annual production capacity, 2) to rebuild and upgrade the existing paper machine to produce a new generation product for the China markets, 3) to keep its leading position in environmental protection, and 4) to recruit and develop skilled and motivated workforce which will enable the other goals Kinnunen, (2006).

One of the primary business goals for the project was to attain a skilled and motivated personnel, so a very important part of the project was a local Human Resources Development (HRD) programme for 252 new employees, who were recruited for the different departments and functions of the new plant. In addition to the development of these new employees, a major part of the existing mill employees were trained for new positions, resulting from the upgrades in different parts of the mill.

The following major questions and challenges related to competence development were identified (Laukkanen, 2007):

1) How to confirm the knowledge and skills transfer for all 252 new employees? The first goal was to develop the professional skills needed to operate the new equipment and complex processes of the paper machine line. Production efficiency and speed were set as business targets for the first year. Although several other factors affect to this goal, the competence and capability development of the personnel were core elements in the productivity and efficiency of the new mill.

2) How to follow-up the competence development of 252 individuals during the 3 year project? The second goal was to develop a concept and tools for competence assessment to be used throughout the life cycle of the global project, i.e. 2002-2005.

3) How to confirm the knowledge transfer in the global investment project with a multicultural project team, with 60 supplier companies from different countries and more than 150 trainers? The third goal was to develop and to evaluate a new concept for knowledge transfer in the global investment project, in which there were more than 60 major suppliers for equipment and raw materials. The project team was multicultural, as was the case for the organization developed for the new production plant. In order to confirm the knowledge transfer, a concept based on utilization of the latest personnel development tools, including performance support systems, best practice toolkits, process training simulator and competence assessment, was developed. The feasibility of the localization and utilization of these tools was analyzed. The experiences of localizing and using these tools in China were also an important part of the project. The goal was to develop a concept, and to mobilize the knowledge and best practices related in this case to papermaking operations.

4) How to prepare new employees to be competent to operate the most modern, fine paper PM, which is a complex and dynamic process? The fourth goal was related to production efficiency. The target was set for the new machine to be the world leader in production efficiency in the selected fine paper grade. This would require a very high level ofcompetence and professional skills for the whole production personnel in order to achieve the business goals.

7.5.2 Development concept and tools

The investment project of this case study was carried out during 2002-2005. The major phases of the project were: engineering, procurement, construction, installation, commissioning and, finally, start-up of the new plant, as illustrated in Figure 52. A new, operational concept for competence development and knowledge transfer was also adopted in this project. The development of the knowledge transfer and competence development tools follows optimally the life cycle of the project. These tools were used together with traditional training and development tools, like structured on-job-learning and classroom training, to form a blended development model. The development of the knowledge and best practice tools was synchronized with the major milestones in the project, so that the tools were ready to use when the local HR development programme started.

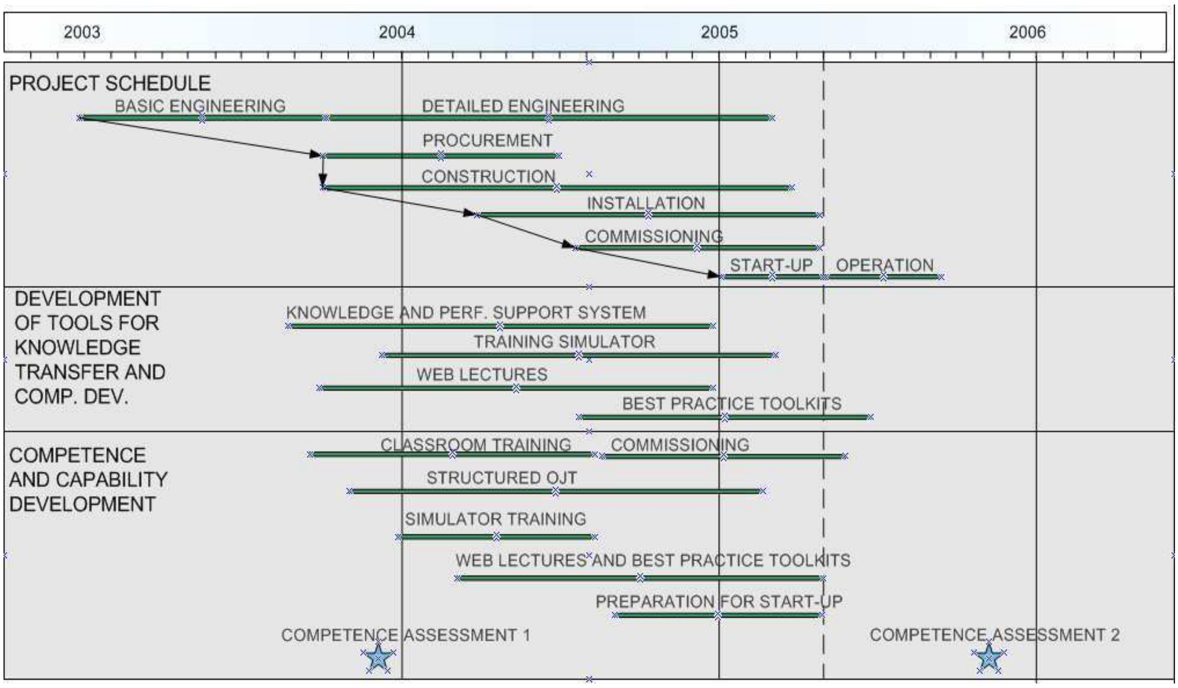

Figure 52. The use of the concept and tools synchronized with the major phases in the project (Laukkanen and Leppänen 2007).

7.5.3 Training and development interventions for competence development

The major training interventions carried out in the development program are listed in Table 24. All of the 118 employees followed in this study were selected for operations and maintenance positions in the new PM line. They had more extensive training programmes, including structured OJT, operational simulator training and use of the knowledge and best practice toolkits. Assessment tools were also used to follow the learning curve and competence development of the employees.

The goal of the programme was to develop high level conceptual mastery for the key positions, as mwell as an equal level for the whole production line Another goal of the project was to develop the conceptual mastery of the new employees to a similar level as that of the old employees. This would be a good starting point for further development.

Table 23. Training interventions, their participation ranges, and the theoretical and real sum scales of participation in each area of intervention (Laukkanen and Leppänen 2007).

Type of intervention/ sum variable	Specific intervention/ part variable	Number of parti-cipants	Range of participa tion (days)	Average participa tion (days)
1) Formal classroom training	- customers and end-uses - raw materials - maintenance systems - production planning - processes and equipment - automation and IT systems	118	1 – 90	45
2) Struct. on-job-training	- stock preparation area - PM area - finishing area	118	0 – 90	60
3) Simulator training	- raw materials - operational exercises	118	5	5
4) Web lectures	- classroom trainings were converted into streaming media	118	-	5
5) Knowledge and best practice toolkits	- customers and end-uses - raw materials - maintenance systems - production planning - processes and equipment - automation and IT systems	118	5-90	10
6) 1st Compe-tence assesment	different competence areas are assessed	118	0.5	0.5
7) 2nd Compe-tence assesment	different competence areas are assessed	54	0.5	0.5

In the training interventions 68 % of the employees were new, and were recruited during the project, while 32 % were existing employees who were retrained to take up new positions. Of the new employees, 21 (12 %) were graduates from paper technology universities and they did not have any production unit work experience. The average age of the new recruits was 20.5 years. Of all participants in the HRD programme, 88% were men, while 12% were women. The participants of the training intervention were the key operations and maintenance personnel of the new production line. Altogether 118 employees participated in the study, which was carried out as a part of the project HRD programme. In the HRD programme, 39 % worked in paper production, 12% in paper converting and 18 % in maintenance. The others were working as general staff and in the support functions. The 118 employees who participated in this study were responsible for production and maintenance operations of the new production line.

7.5.4 Results – competence development and knowledge transfer

The level of conceptual mastery of the local PM production process personnel increased by about 18 % and 22 % between the first and the second measurement both in the group working on paper production and in the group working in paper finishing operations, respectively (Table 25). The level of conceptual mastery of work was highest in the professional group of team leaders, but improved the most among those working on winder operators.

Table 24. The results of conceptual mastery in the paper production line in China (Laukkanen and Leppänen 2007)

	Assessment 1			Assessment 2			
AREAS	**average**	**std. dev**	**n**	**average**	**std. dev**	**n**	**t-test**
Production	61,9	9,1	41	79,7	6,2	24	8,4***
Finishing	47,4	9,9	77	69,3	9,4	30	10,3***
JOBS							
Team leaders	76,8	3,1	5	85	4,3	5	3,1**
PM operators	71,6	4,5	15	81,2	6,4	12	4,4**
Winder	38,7	18,3	43	70,5	8,3	30	8,8***

Assessment 1 = Assessment carried out before start-up training   *p < 0,05, **p < 0,01, ***p < 0,001
Assessment 2 = Assessment carried out 8 months after start-up

The conceptual mastery in three major jobs, team leaders, machine operators and winder operators, was evaluated and the results are presented in Table 25. The results indicate a clear 8% and 10% improvement in the conceptual knowledge in the team leader and PM tender positions, where the selected candidates already had a good work experience and basic knowledge before the HRD programme. The greatest development in these jobs occurred in winder operators, which is often a kind of entry position in the production line and many of the employees in this category were new.

Table 25. Results from the conceptual mastery evaluations compared with the results from three Finnish paper production units (Laukkanen and Leppänen 2007)

	Assessment 2, China		B (FIN)			C (FIN)			D (FIN)		
	averag±stdev	*n*	*averag±stdev*	*n*	*t-test*	*averag±stdev*	*n*	*t-test*	*averag±stdev*	*n*	*t-test*
AREAS											
Production	79,7 ± 6,2	41	69,3 ± 4,5	20	6,1***	79,5 ± 7,0	20	0,1 (n.s.)	83,5 ± 6,0	29	2,2*
Finishing	69,3 ± 9,4	30	57,1 ± 15,8	58	3,8**	62,3 ± 13,5	46	2,4*	79,5 ± 8,9	79	5,2***
JOBS											
Team leaders	85,0 ± 4,3	5	79,8 ± 6,1	10	0,8 (n.s.)	-	-	-	-	-	-
PM operators	81,2 ± 6,4	12	69,3 ± 4,5	20	6,0***	85,0 ± 7,3	5	1,0 (n.s)	83,5 ± 6,0	20	1,0 (n.s)
Winder	70,5 ± 8,3	43	52,3 ± 17,1	30	5,2***	78,0 ± 6,1	30	2,0**	78,2 ± 8,8	30	2,6**

*p < 0,05, **p < 0,01, ***p < 0,001

Before the start-up of the new production line the team leaders mastered almost 77 % of the conceptual knowledge in the production process. The results improved to a level of 85% when the assessment was made after the start-up. The people working in the other key jobs essentially improved their conceptual mastery during the follow-up period, as illustrated in Table 25.

The results of the conceptual mastery that was evaluated eight months after the start-up have been compared with the results of three Finnish production lines representing different training concepts. The level of conceptual mastery on the Chinese paper machine was comparable with the results of the two newest Finnish production lines, as summarized in Table 26. The results of the whole finishing area of the Chinese production unit fall between the two newest Finnish production units, but the results of the winder operators are slightly lower in China than in the two new production lines in Finland. The conceptual mastery of the team leaders of the Chinese production line was higher than that on the only Finnish production line where the team leaders' conceptual mastery was assessed Table 26. The statistical significance of the results was tested with the t-test.

The results of the evaluation were compared with the results of a similar competence evaluation study carried out in Finland in a similar situation (Nurmi, 2002) or in a comparable machine line (Leppänen 1996). When comparing the results with the previous findings, the following differences were evident. The conceptual mastery in the new production plant in China was at a lower level compared to the results of the latest mill project in Finland where the extensive HRD programme was carried out. In other respects the levels reached in China are higher than those of the two high performing paper production lines in Finland.

7.5.5 Results – business results

The major business goals for the project were (1) to develop skilled and motivated people, and (2) to reach a good capability and speed development in the new production line very quickly after the start-up. In the second month the actual production capability was 2.4 % greater than the planned level. In the third production month the production capability was 12 % lower than the target. During the 6th and 12th months the world record target was not reached, the gap being 15 % and 17 %, respectively. The world record start-up curve in production capability, which was set for the production line, proved to be very challenging.

Despite the fact that the target value was not reached, the production line reached and improved on two occasions the world record speed for paper production lines, indicating how high the targets originally were. The first world speed record was broken 8 moths after start-up and the second speed record was accomplished 11 months after the start-up (Metso, 2006). Based on the interviews, the competence and the skills of the operating personnel played an important role in this world record start-up.

7.6 Summary of the results

The major results including both the outcomes and the challenges of the individual case studies are summarized in Tables 27, 28 and 29.

Table 26. Summary of the results from the case study 1

	Outcomes	Challenges
CASE 1 PM Project in Finland	- The simulator was a good tool for the verification of control design both in normal and trouble-shooting situations - Two incorrectly designed control circuits were identified during modelling (2-6 h saving in troubleshooting was estimated) - The simulator was also used in the HRD programme to learn how to operate the new process - Some very good feedback about active ways of learning, instead of passive classroom training - Overall experience good and start-up of the plant was easy	- For some operators the dynamic scientific simulator was too complex to use - All functionality in DCS system used for user interface was not activated and there were some complaints - The complexity of the process in some exercises was too difficult especially for novice users -The full-scope simulator system was very extensive and technically complex - The simulation models were local and could not be used via www

Table 27. Summary of the results from the case study 2

	Outcomes	Challenges
CASE 2 Use of KnowPap in global company	- KnowPap was found to be an easy to use tool for studying paper technology and related multi-skilled competence areas - KnowPap was a good tool for self-study, and the information was at the right level - Interactive simulations were found to be the most useful part of the system - The student takes more responsibility in learning when they are using the systems, e.g. in troubleshooting - The trainers found the system to be good especially, for problem-based learning	- For some users, KnowPap was too extensive and complicated. All the information was not in logical places - There was too much text material which was complicated to read - The information in KnowPap was too generic for knowledge and performance support in industrial applications - The trainers found that the system was sometimes too complicated and too extensive - Competence assessment tools were missing

Table 28. Summary of the results from the case studies 3 and 4

	Outcomes	Challenges
CASE 3 PM project in Finland	- Competence development at the individual level was very positive - The results of using the concept were good. People preferred the active learning in groups with the tools compared - The usability of the concept and tools was good - Start-up of the plant was easy, all the efficiency goals were exceeded, and the paper machine line broke the world record in speed - The tools were updated and taken into active use after the project	- In the project, there was too much traditional classroom training instead of more active learning - The training simulator was too difficult as a self-study tool for some participants (without an expert trainer) - No systematic individual level competence evaluation was made
CASE 4 PM project in China	- Competence levels of individuals and teams are comparable to good Finnish paper mills, despite that 68 % of the people were new - Citical knowledge developed in a Finnish paper mill, was transferred and localized very efficiently - The concept and tools is a good basis for continuous training of new people in China site - Paper machine made a world speed record 8 months after start-up	- More focus should be on active learning with the tools, facilitated by experts - In emerging markets, knowledge transfer and competence development should have a larger role in the future

8 Discussion

The aim of this chapter is to assess the contribution of this thesis both in terms of its theoretical contribution to scientific research and its practical contribution to the field of application, based on the results presented in the case studies. The reliability, validity and limitations of the study are also discussed.

8.1 Main conclusions and implications of the study

The major findings gained in the different cases studied are diverse. Therefore the main conclusions and recommendations concerning the concept are presented before going into the individual findings in more depth.

The development of a systematic concept for knowledge transfer and competence development has been based on the business needs in paper production unit start-up projects. The projects studied in this research were carried out in Finland and in China. The future business needs of the paper industry are in the emerging markets, which increases the practical importance of the concept for global corporations. On the other hand, the personnel retirements in the mature paper markets requires efficient knowledge transfer for new employees. This leads to the following recommendations:

- In the technology transfer projects in emerging markets, greater emphasis should be placed on knowledge transfer and competence development of local personnel. The impact of human performance on production unit efficiency can be >10%, which means considerable savings.
- The life cycle of the concept should optimally follow the life cycle of the new production unit, starting when the decision for the project is made and following through the start-up and production phases.
- Development and use of the concept and tools should not be a separate project, but should be closely integrated with the production unit start-up project and with

the planned work system. The collaboration between the project team and the individual suppliers should be very close.

- The project documentation, including process and automation engineering, should be integrated with knowledge and performance support systems.
- Use of the concept in the project itself is an organizational learning and development effort
- In the future, virtual mill models could be used for training and competence development before the start-up of the production unit
- The development of the simulator should also optimally follow the life cycle of the project and should be developed during the project, starting with process and automation engineering. The models should be simplified in order to facilitate their utilization in knowledge transfer and in competence development.
- After the start-up, the concept and tools should follow the life cycle of the production unit. The practical experiences gained in commissioning and start-up should be integrated with the systems. Optimally, the systems should be linked with the existing tools in the workplace.
- The future knowledge and performance support systems should support work tasks, and also include integrated communication and collaboration tools for global knowledge sharing and workplace learning.

The focus in the following conclusions is on the project carried out in China, where the latest concept and all the elements constructed in this study were used.

8.1.1 Outcomes at individual and team levels

The team leaders and new operations personnel of the most challenging part of the paper production line mastered 80 % of the work process conceptually after the start up. Workers in the finishing part of the production process mastered 70 % of the concepts. The levels of the conceptual mastery of the work process were very similar in both the Finnish and Chinese production lines after the start-up of a machine line (Leppänen *et al.* 1996; Nurmi, 2001).

The level of conceptual mastery improved about 20 percent units during the first 8 months of production. This indicates that work process knowledge increases while working, as is to be expected (Boreham 2002). Laurila and Gyursanszky (1998) previously concluded that the different levels of competence among employees in different parts of a new paper mill were due to differences in their training in the field. The possibility to actually operate a running process had increased their competence. These results indicate that the training programmes should be continued in greenfield mills after the start up of a production line in order to enhance learning by supporting the dialogue between theory and practice. The focus in the programmes should be shifted from before the start-up to after the start-up.

The level of conceptual mastery of the work process on the Chinese production line were comparable with those of the Finnish production lines on which comprehensive training programs have been executed during the building up of a new production line. The objects of the learning were conceptual mastery and work process knowledge related to work. The content and method of learning were classroom training, on-job learning and the use of simulation tools, knowledge and best practice toolkits for conceptualization of the work process.

Simulation has proved to be an efficient tool for transferring the latest knowledge and best practices. Simulation and games have also been regarded as a future way of learning for the new generations (Aldrich 2004). The trainees also positively assessed the training methods used after the training programme. The didactic principles applied in this development programme in this study have been used to a frequently increasingly extent in schools and at universities, but are rare on the shop floor. The application of these principles would support organizational efforts to learn from everyday work and to share such knowledge. The fact that 50 % of the employees were novices before the start of the development programme, highlights the results even more.

8.1.2 Outcomes of organization capability development

Reports and results of the outcomes of development programmes at the organizational level are rare. One of the major business targets for the new production line was a world record, start-up curve in the production line capability, which is a measure of production efficiency. This target value was reached for the first two months after start-up but, after that, the gap in the production line capability was lower than the target. Despite this, the production line broke the world speed record just 8 months after the start-up, and the speed record was then again exceeded a second time 11 months after start-up. These results indicate a very good organizational capability throughout the whole production line, and also confirms that the original targets for capability were too stringent.

In investment projects the major focus has traditionally been on the engineering and technology. We argue that, in investment projects involving the application of complex manufacturing technology in the emerging markets, much more focus should be directed at competence and capability development, because the greatest challenges are most probably people related.

Currently, the greatest challenge in China to continuous organizational capability development is the high turnover of the employees, which can annually be as high as 20-30 percent. In order to ensure continuous organizational development, it should be focused on efficient induction and orientation processes and on codification of the best practices. This is a major challenge in complex production processes, because the time needed for development is high compared to that in the traditional manufacturing industry. The knowledge and best practice toolkits developed in this project will also provide a tool for modelling and transferring the best practices for future use in an organization.

8.1.3 More attention to the process of knowledge transfer

Although the results at both the level of individual competence and of organizational capability are very positive, both the Chinese and Finnish experts experienced problems in the communication, information exchange, and in the transference of knowledge between the Chinese and the Finns. Similar problems have been reported in other studies (Laurila and Gyursanszky 1998; Tsang 1999; Marcotte and Niosi 2000). Experts working in projects abroad should be trained and supported also in the issues of communication and knowledge transfer. The creation of work process knowledge in complex work domains continues after the formal training has finished. The fact that the knowledge and experience of different experts are very valuable for the learning of novices, and that sharing the knowledge is as important as adjustment of the technology, should be understood thoroughly.

The diagnostic tests of conceptual mastery of work are tailored for each production line. However, when the results for questions that are common for several production lines, and the results for questions unique to the production line, are compared, the proportion of correct answers to both sets of questions varies only from 1 – 8% (Leppänen *et al.* 1996). On new production lines, the difference between the common and the unique questions is 1%. These results indicate that the level of conceptual mastery of both the general principles of paper making and of context-dependent aspects are at the same level on the same production line, therefore allowing rough comparisons of the results of knowledge in different production lines.

8.1.4 The major benefits of the concept at unit and corporate levels

From the corporate point of view, the major benefit of the concept was a successful business start-up and the development of a practical system for mobilizing and transferring common knowledge within a corporation. The business start-ups in China have not always been successful. In this study, simulation and modelling tools proved to be very beneficial in the business start-up project setting. Knowledge transfer in corporations is not easy, and many times lacks the sort of practical system which people like to develop and use. Based on the results of the case studies, the concept developed in this study proved to be very useful and the feedback and the experiences in using these tools were also very good.

The modelling of processes at different levels develops organizational learning, new knowledge and best practices, and this can be codified into the tools. From this point of view, the process is one tool for organizational capability development. In the area of simulation and modelling the focus has traditionally been on technical processes and equipment. In this study, the modelling of competences and the work processes was integrated with these technical models. In the future, this kind of approach could be generalized to cover other business areas as well.

8.2 Summary of results and key findings

8.2.1 Theoretical contribution: an integrated framework for knowledge transfer, competence development and learning

The essential theoretical value and contribution of this dissertation are related to the effort to develop an integrated concept for knowledge transfer, competence development and organizational learning in industrial firm settings. This is recognized as a relevant theoretical topic (Sydänmaalakka 2002; Kim 2004) and an important challenge for strategic competence based management (Sanchez 2004). In this study, the scientific bases of knowledge management, strategic competence-based management and learning at both the individual and organizational levels have provided the foundation for developing the new, integrated concept. The integrated concept is also an enhancement to the existing theories of corporate knowledge transfer and competence development.

The central contribution of the study was the creation of a theoretical concept for strategic knowledge transfer and competence development as an integrated concept. The new concept integrates the essential factors of strategic competence management (Sanzhez Heene 1996, Sanzhez Heene 1997, Sanzhez 2004), knowledge management (Nonaka 1994; Nonaka Takeuchi 1995; Davenport Prusak 1998; O'Dell Creyson 1998; Dixon 2000; Alavi Laidner 2001) and organizational learning (Leonard-Barton 1992; Senge 1995; Kim 2004).

The theoretical concept developed in this dissertation has some similarities with the concept of linking individual and organizational learning, developed by Kim (2004), in terms of integrating organizational and individual level learning. There are also similarities with the concept of intelligent organizations developed by Sydänmaanlakka

(2002). The new concept developed in this dissertation integrates the organizational strategy implementation process as a steering mechanism into capability and competence development and the creation of new knowledge. An important part of the process is also performance evaluation, which states that organizational competence and capability development should be reflected in improved performance at both the organizational and individual levels. According to Wilson (2004), the effect of human and team performance on production unit efficiency can be > 10 %.

The major challenges in knowledge transfer can be related to either the organizational or individual level, and they have been reviewed in the study. An important part of the new concept is modelling of e.g. the papermaking process, work processes and strategic competences. The work requirements can be modelled from a bottom-up perspective starting with the requirements of the physical workplace and process, as well as top-down starting from the strategic targets and competences needed to reach the targets.

Using the theories of strategic competence-based management and of knowledge management, it was shown that both theory backgrounds partly contribute to explaining the organizational knowledge transfer in complex production processes. Special attention should be paid in the future to integrated knowledge transfer and mobilization.

8.2.2 Practical contribution: development and use of the concept and new knowledge transfer tools in a paper machine start-up project

The central criterion used to assess the results of the case studies was the practical usefulness of the concept and the tools developed in this study. The case study approach therefore emphasises the practical relevance and functionality (Kasanen *et al.* 1993; Yin 1993).

The practical contribution of the research was the development and use of the operational concept in real industrial case studies. The development and use of the new knowledge and performance support systems and operational simulation tools in knowledge transfer was an important practical contribution of the thesis. The operational concept and tools were used in three industrial case studies in the context of the start-up of complex paper production units. The results have been evaluated at the individual, strategic business unit and corporate levels. The overall results were positive. At the individual level, the users found this new concept and the new tools to be preferable compared to traditional development approaches. The business targets set for the projects were met and new organization knowledge was created as a result of using the concept. The concept was also a tool for transferring knowledge developed in one location to another location, which is well in line with the common knowledge research framework (Davenport Prusak 1998; Dixon, 2002).

An important part of the concept development was the systemic process based on modelling and simulation of both technical and work processes, which represents an enhancement compared to the traditional simulation and modelling approach in which these two areas are treated separately. The practical importance of this kind of concept will be highlighted in the future when businesses and production facilities are started up in new emerging areas with no previous experience of complex processes. In these kinds of project, the mobility of knowledge and expertise will play a critical role in achieving successful business start-ups.

8.3 Evaluation of the approach and methods

8.3.1 Validity of the study

Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure (Yin 1993). In case study research, the validity of the research can be divided into construct validity, external validity and internal validity. Construct validity means that the constructs made solve the research problems. External validity means that the results can be generalized, and internal validity measures causal relationships, i.e. does the research measure what it was intended to measure (Yin 1993).

The constructs presented in this research, i.e. the new concept and the tools, have been designed to answer the research hypothesis and problems. As novel constructs, they are valuable for future research.

In this research, the cases are applied and focused on companies in the paper industry, which might limit the extent to which the results can be generalized. The companies in the case studies represent modern and successful multinational, industrial corporations. However, the cases should be evaluated against different lines of business in order to obtain more external validity. Further development of the concept for other industries will take time and effort.

Concerning the internal validity of the research, one advantage has been working for the projects during the case studies. Understanding the work practices and businesses has helped in formulating the right research questions and understanding the comments related to the different cases. This has also helped in the analysis phase of the research.

8.3.2 Reliability

Reliability refers to how the operations of a study can be repeated to achieve the same results, and stability and equivalence are two perspectives of reliability (Yin 1993). Research is stable if the same researcher can repeat it with the same elements. Equivalence deals with the impact of different persons or samples of items on error.

The stability of the research has been verified in a different case project that was carried out parallel to this thesis research. Is would also be relatively easy to repeat the research in another organization using the same concept developed in this study. The method is, however, very much dependent on the management of the projects and on the activity of the companies and persons participating in the project. The impact of the research team was found to be important, and the efficiency of using the concept improved continuously in the different project settings.

8.3.3 Limitations of the study

Being a case study, the limitations of this research lie in generalization. In addition, no systematic follow-up has been carried out after the projects have been implemented. This research represents the situation in 2007, and it would be interesting to perform a follow-up study of the continuous development. Furthermore, these cases do not necessarily represent the situation in the whole paper industry because there are major differences between the different companies.

9 Conclusions

The complexity of modern papermaking has increased continuously and it includes most of the features of a complex manufacturing system. The traditional object of the work, i.e. operation of the process, has changed from physical work into knowledge intensive, information processing and knowledge work, which is performed using different computer-based automation and process control systems. Modern work requires multi-skilled conceptual mastery and work process knowledge, because the operation teams also nowadays carry out simple maintenance and automation tasks.

Another change in the global companies is the advent of enterprise level processes, which are integrated to the local production level work systems. In practice, this means that the actions carried out in the mill can have a direct effect on a global process. Although the work in operations management is very demanding, the training and competence development programmes have still varied considerably. The methods used in this study proved to be effective from the viewpoint of both individual competence and organizational capability development. However, the process of transferring knowledge from the members of expatriate organizations to the members of a greenfield mill must still be improved.

In the near future, the major part of the future business growth in the manufacturing industries will take place in emerging markets like in China, India and Russia. The latest technology and engineering will be available for all companies. An increase in the profitability of businesses can and will be achieved by developing a world class organizational capability based on high competence levels and use of the latest knowledge. The mobility and transfer of the knowledge and skills can give a competitive advantage to the manufacturing companies. More research in the future should be focused on the efficient processes and tools for knowledge mobilization and transfer in multinational and global companies. Also more emphasis should be paid to the challenges in knowledge transfer in multicultural projects teams, where the differences in cultural background can be a barrier to knowledge transfer.

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