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Thesis for the degree of Licentiate of Science in Technology

ASPECTS ON DEVELOPMENT OF PROCESS ENGINEERING IN THE FINNISH PULP AND PAPER INDUSTRY

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Supervisor:	*Professor Ilkka Turunen*
Examiners:	*Professor Kaj Henricson*
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ABSTRACT

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Process development will be largely driven by the main equipment suppliers. The reason for this development is their ambition to supply complete plants or process systems instead of single pieces of equipment.

The pulp and paper companies' interest lies in product development, as their main goal is to create winning brands and effective brand management.

Design engineering companies will find their niche in detail engineering based on approved process solutions. Their development work will focus on increasing the efficiency of engineering work.

Process design is a content-producing profession, which requires certain special characteristics: creativity, carefulness, the ability to work as a member of a design team according to time schedules and fluency in oral as well as written presentation. In the future, process engineers will increasingly need knowledge of chemistry as well as information and automation technology.

Process engineering tools are developing rapidly. At the moment, these tools are good enough for static sizing and balancing, but dynamic simulation tools are not yet good enough for the complicated chemical reactions of pulp and paper chemistry. Dynamic simulation and virtual mill models are used as tools for training the operators. Computational fluid dynamics will certainly gain ground in process design.

Keywords: design, engineering, process, pulp and paper industry, Metsä-Botnia - Joutseno, UPM-Kymmene - Kymi

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Lisensiaatintyö
Valvoja: Prof. Ilkka Turunen
Tarkastajat: Prof. Kaj Henricson, Prof. Markku Hurme

Prosessien kehitystä johtavat tulevaisuudessa kone- ja laitetoimittajat, koska niiden mielenkiinto kohdistuu kokonaisten tehdaslaitosten tai prosessijärjestelmien, ei yksittäisten laitteiden toimituksiin.

Metsäteollisuusyhtiöiden mielenkiinto kohdistuu tuotekehitykseen, koska niiden tavoitteena on menestyksekkäiden tuotemerkkien luonti ja ylläpito.

Suunnittelutoimistojen keskittymiskohde on detaljisuunnittelun tekeminen tehokkaasti koeteltuihin prosessiratkaisuihin perustuen. Niiden kehitystyö kohdistuu detaljisuunnittelun tehokkuuden lisäämiseen.

Prosessisuunnittelu on sisältöä tuottava ammattiala, joka vaatii tiettyjä ominaisuuksia: luovuutta, huolellisuutta, kykyä työskennellä suunnitteluryhmän jäsenenä tiukkojen aikataulujen mukaan sekä hyvää suullista ja kirjallista ilmaisutaitoa. Prosessiinsinöörien tiedontarve kemiasta sekä viestintä- ja automaatiotekniikasta tulee lisääntymään.

Prosessisuunnittelun työkalut kehittyvät nopeasti. Dynaamisia simulointimalleja käytetään koulutuksessa, mutta prosessien mitoitus tehdään pääosin staattisia simulointimalleja käyttäen. Numeerisen virtauslaskennan merkitys tulee kasvamaan prosessisuunnittelun välineenä.

Avainsanat: design, engineering, process, pulp and paper industry, Metsä-Botnia - Joutseno, UPM-Kymmene - Kymi

PREFACE

I have worked as a process engineer in designing new paper mills and paper mill rebuilds in a design engineering company since 1986. Before that, I was working as an analyst defining the profitability of pulp and paper projects, and as a project manager for paper machine supply projects.

Because of my background, I wanted to make an effort to analyse how process engineering has developed during the past few decades and how it can be expected to develop during the years to come.

I would like to express my thanks to the supervisor of this study, Professor Ilkka Turunen, for his kind support during my studies, and to Professor Hannu Manner, who examined my knowledge of paper technology. Professor Karl-Erik Michelsen made me rethink my professional life and contributed to some interesting discussions about the nature of science. Other members of the faculty of Lappeenranta University of Technology have also given me a lot of assistance which is greatly appreciated.

The examiners of this study, Professor Kaj Henricson and Professor Markku Hurme, gave some valuable comments and made their examination work very promptly, of which I am very grateful to them.

I would also like to thank my superiors, Mr. John Lindahl and Mr. Jukka Terho, for their positive attitude towards this exercise, and other colleagues for valuable information. I specially wish to thank Ms. Päivi Lampinen for helping to prepare the graphs for this research and Mr. Olof Andersson for revising the language of this study.

I am especially grateful for the valuable discussions with colleagues in the industry whom I interviewed for this study. Their insights were extremely important for making the right conclusions.

I would also like to thank all members of my family for their supportive attitude. My special thanks go to my father whose working life showed me what mill engineering is all about and with whom I have had numerous taciturn discussions about pulp and paper industry engineering even since I was teenager.

Lappeenranta, 25.11.2004

Pekka Leppänen

Contents

Appendices

1 INTRODUCTION

The study aims to present the development of process engineering during the history of the Finnish pulp and paper industry and to forecast its future trends and development. The research questions on which this study concentrates are:

- What will be the future significance of process engineering in pulp and paper industry projects?

- What will be the tools used by process engineers?

The sources of information for this study consist of literature, archives of case mills and interviews with veteran engineers and engineers who have been or continue to be involved in process engineering activities either as process engineers or as users of process engineering products.

The work flow of the study is presented in Figure 1.

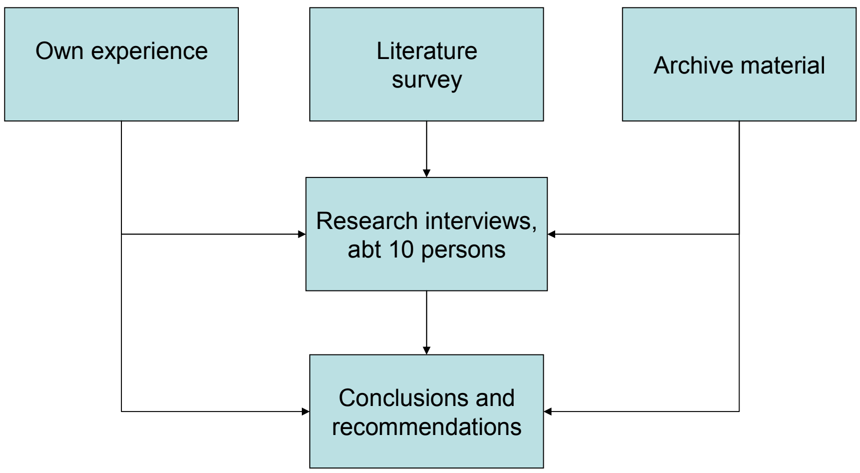

Figure 1 Work flow of the study

2 PURPOSE OF THE STUDY

The pulp and paper industry is one of the cornerstones of the Finnish industry, constituting a very important part of the Finnish economy since the beginning of 20th century. The share of the pulp and paper industry of Finland's gross national product is today around 5 % and the pulp and paper industry accounts for about one-fifth of total industrial output [13].

The Finnish pulp and paper industry is expected to retain its important role in the future, the main reasons being the following [86]:

- Finland cannot afford its position in the forest products industry to erode. The country maintains an intensive focus on the forest products industry and is willing to invest and reinvest the necessary capital to remain on top.

- The Finnish forest products industry invests in its human resources.

- The Finnish forest products industry has a long history of close cooperation with its producer and supplier companies. This has led to major papermaking breakthroughs. There are several major technical centres for pulp and paper engineering in Finland, and new technology is often implemented first in Finnish pulp and paper mills.

In the historic accounts of pulp and paper companies, the names of the architects are often mentioned, because many of the industrial buildings are architectural masterpieces. Less publicity is given to other designers, though from the viewpoint of a mill's economic success the professional skills of process, mechanical, electrical and automation designers is much more critical.

The role of design engineering in an industrial project is vital in gathering relevant information from the project owner, society, local community, equipment suppliers and other stakeholders, and in processing this information into documented plans for building the mill and taking it into operation. Without correctly selected equipment, correct sizing of sub-systems and an optimally functioning process, an industrial plant may not reach its planned capacity or may consume much more raw materials, energy and other resources and cause unacceptable environmental impacts.

The central role of design engineering in an industrial project is illustrated in Figure 2.

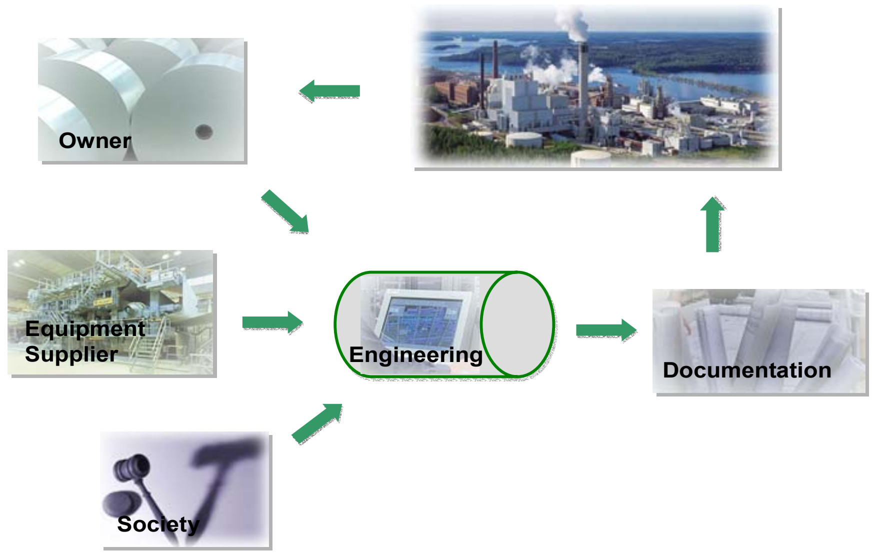

Figure 2 Design engineering in an industrial project

The role of process engineering as a transmitter of information to detail engineering disciplines is illustrated in Figure 3.

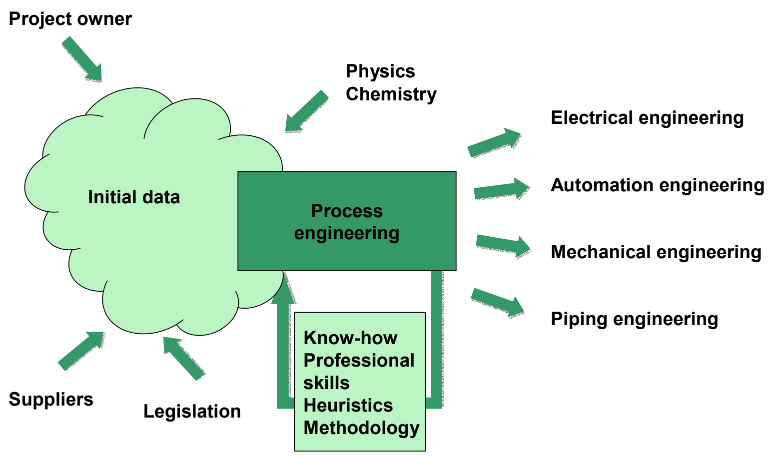

Figure 3 Role of process engineering in the engineering process

The history of process engineering is presented against the background of two case mills, which are:

- The Kuusankoski mills of UPM-Kymmene Corporation, which were established in 1872, and have included various pulp, paper, mechanical pulp and chemical industries over many years

- The Joutseno pulp mill of Metsä-Botnia Oy, which was established in 1908, and has always been a sulphate pulp mill

The histories of the case mills are presented briefly, and their latest projects are described from the viewpoint of process engineering.

3 HISTORICAL SURVEY

3.1 Pulp and Paper Industry in Finland

The history of the pulp and paper industry in Finland dates back to 1667, when the first paper mill started operating at Thomasböle near Tammisaari. It was a small hand paper mill, as all mills were at that time, and paper manufacture in those early years cannot be considered as a process in today's meaning of this term but rather as a series of manual unit operations. The owner of the paper mill was bishop Johan Gezelius, Sr. The name of the first paper master is known: he was Bertil Obenher, who was recruited from a paper mill in Uppsala, Sweden [13]. The paper mill was in operation until 1713 [3].

The first commercial paper mill was founded in 1764 in the village of Järvenoja, near Turku by some merchants from Turku. The mill employed eight people in 1770, making printing paper, note paper, music paper and heavy wrapping paper. By 1794 the mill's ownership was transferred to J.C. Frenckell, who was a printer in Turku [78].

A paper machine designed for continuous paper manufacture was patented by Jean Louis Robert in 1799, and the first paper machines were manufactured by the Fourdrinier brothers in England.

Finland's first paper machine was installed in 1842 by J.C. Frenckell at his mill in Tampere. The paper machine was manufactured in England. Until 1918, the mill used rags for raw material and the paper machine operated at the original site until 1929, when it was transferred to Pori, where it remained in operation for many years [41].

A very important step forward in paper manufacture was the introduction of wood fibres as raw material. As this new raw material was abundantly available in Finland, several groundwood pulp mills and paper and board mills were built in Finland in the late 1860s and early 1870s. These included:

- Hounijoki 1859
- Tampere 1866
- Mänttä 1868
- Nokia 1869
- Ankkapurha (Anjala) 1872
- Werla 1872
- Kuusankoski 1872
- Kymi 1873
- Voikkaa 1873

As the grinding process consumed a lot of power, the mills were built beside rapids, so waterpower could be used to drive the grinding machines. This is why the mills in many cases were quite far from the markets, which caused serious problems in transporting the mills' products.

In 1857 chemical pulping was invented. The first chemical sulphite pulp mill was started in 1874 in Bergvik, Sweden [1].

The first chemical pulp mill was founded in Finland in 1876 in the village of Nurmi near Vyborg in Karelia, manufacturing saleable pulp with an initial capacity of 200 – 300 t/a. In 1890 the mill was converted into a sulphite pulp mill [100].

The second chemical pulp mill in Finland was started up in 1880, when the soda pulp mill at Valkeakoski started production. This mill was converted into a sulphate pulp mill as early as 1886.

As the pulp had a light colour which made it a suitable raw material for newsprint and printing papers, several new sulphite pulp mills were established in the following years. By 1916 there were 20 sulphite pulp mills in Finland.

The next sulphate pulp mills after Valkeakoski were founded after the turn of the century; between 1900 and 1910 six new sulphate pulp mills were started up. The advantage of sulphate pulp mills compared to sulphite was that also other species than spruce could be used as the raw material. A disadvantage was the dark colour of the pulp, which made it unsuitable for printing and writing grades without bleaching. On the other hand, the strength of the pulp made it a good raw material for packaging paper grades.

Before World War I, the sales of pulp and paper were directed almost entirely to Russia, but the Russian revolution and Finland's independence in 1917 closed this market. At this time, Finnish pulp and paper mills joined forces in searching for new markets, establishing in 1918 sales associations for pulp, paper and board: Finncell, Finnpap and Finnboard, respectively. Later also a sales association for paper converters, Converta, was founded. All major producers joined these associations, making Finnish producers much stronger in the market than they would have been on their own.

Most Finnish pulp and paper companies conducted their marketing through these associations who quickly established global marketing networks. Gradually, some companies, notably Kymmene Corporation, started handling their paper marketing independently. The sales associations operated until the 1990s, when the remaining Finnish forest industry companies had become so big through the industry's consolidation that they had the resources to conduct their marketing worldwide by themselves.

3.2 Technology in Pulp and Paper Mills

In the early days of pulp and papermaking, the technology was largely manual and papermaking skills were learnt from older craftsmen, the paper masters. The feeling for stock consistencies, ratios between stock components and other properties came through learning, and controls were made manually.

According to Talvio [14], the difficulties in measuring the properties of process variables in pulp stock slowed down the development of instrumentation for pulp and paper manufacture. The most reliable sensors were the senses of the operators, and thus papermaking was more an art than a science.

The only sensors up to the 1940s were pressure transmitters and thermometers. In the 1960s diaphragm gauges were developed for measuring levels in stock tanks. Magnetic flow transmitters were developed in the late 1950s.

The control of stock measurements was difficult until the invention of ball valves for control purposes in the 1960s. Neles Oy was the first company to launch applications for pulp and paper industry, based on Antti Nelimarkka's development work [47].

Fibre properties are still measured with discontinuous measurements which give only a partial description of properties (CSF, ^{o}SR) [87] [88].

The requirements for measurement and control in chemical pulping continued to increase with the development of pulp bleaching and chemical recovery processes. The problems related to measurements evolved from the heterogeneity of the raw materials to be measured.

Paper properties have also been very difficult to measure. Moisture measurements have been carried out with several different methods.

Central control rooms were constructed in some American pulp and paper mills in the early 1960s. In Finland, the first central control room was built in the Uimaharju pulp mill started up in 1967 [94], and it was considered a break-through in the process automation of a chemical pulp mill.

Computer control of paper machines started developing in the 1960s and the first control packages for basis weight and moisture control soon entered the market.

In the 1970s, field instruments developed rapidly. Microprocessors were invented and based on these, programmable logics, distributed control systems and data highways were developed. Several Finnish companies developed systems for automatic control of pulp and paper manufacturing processes.

The distributed control systems became the normal way of process control in 1980s [15]. The control philosophy acquired in Finland was to integrate both motor controls and automation controls in the same system, unlike the typical American application in which motor controls were implemented with a programmable logic system and automation controls with the process control system.

The first process control systems of the Finnish suppliers were ready to be taken into operation; Damatic by Valmet Oy and Alcont by Altim Control Oy were the brands capturing a major share of Finnish pulp and paper industry installations.

Other applications for the pulp and paper industry were developed among others by Strömberg (drive systems, frequency converters, web fault inspection systems), Nokia (Afora, Autocook, Autobleach), Kajaani Elektroniikka (pulp analyzers), Roibox Oy (web fault inspection systems).

From the 1990s onwards, the main trends in the development of control systems have been combined control systems, which allow the process control system, machine control systems and quality control system to be integrated and controlled from the same operator stations; the development of data freeways for much higher data transfer; and the development of operator station graphics and history data. Today, this has led to increased integration of field systems as well as enterprise integration.

Intelligent field instruments for pressure, level and consistency measurement have also been developed.

Sensor technology has developed in giant steps. In the 1990s and the current decade, several new sensors have been developed for on-line measurements of the stock in the short circulation [28] [43] [62]. The measurements of paper properties can be integrated into machine elements [77] and sensors are becoming smarter and also include condition monitoring capabilities.

ICT technology has also brought wireless technology to process controls, as operator interfaces can today be wireless. A future development may be the wireless sensors that are inserted in the pulp stock, which make the required measurements [57].

Remote diagnostic systems, which keep machine suppliers' experts informed about the status of processes and operating conditions via the Internet and give advice to operators, is gaining popularity in pulp and paper mills. This technology is considered useful in resolving problem situations, while representing a new form of commitment between pulp and paper mills and equipment suppliers [42].

3.3 Kymi Mills

From 1872 to the end of Autonomy

The Kymi Mills were founded in 1872 as two separate companies: Kymmene Aktiebolag on the eastern shore of the Kymmene River and Kuusankoski Aktiebolag in Myllysaari, a little island on Kymmene River in the middle of the Kuusa rapids. Both companies started to build groundwood mills and board machines, and Kuusankoski Ab started its mill in the summer of 1873. It consisted of a groundwood mill with four grinding machines and a board mill with three board machines [102].

The groundwood mill of Kymmene Ab was started in 1874 and it included five grinding machines. It was the biggest groundwood mill in Finland. The mill also included a paper machine and board machines.

During their first years of operation, both companies suffered economic difficulties. The economy of the paper industry started to improve in the late 1870s and 1880s, which was a good period for the paper industry. Kymmene Ab was able to utilize this advantageous situation, as the mills were in good shape after almost 10 years of construction and operation. Kuusankoski was an advantageous location because of the railway connection from Kouvola to St Petersburg, while foreign competitors had to pay customs duties. A second paper machine with three grinding machines was started up in 1882. In 1883 the paper production was 2300 tons, mostly wallpaper, and the groundwood production was 1600 tons. The quality of the wallpaper was very good. In 1883 dividends were paid to the shareholders for the first time.

In 1885, Kymmene Ab decided to build a chemical pulp mill. The basis for this decision was the availability and cost of rags, which had so far been the other main raw material of paper in addition to groundwood. Also, there was a threat that the exemption from Russian customs duties would be lost, so manufacturing costs would have to be reduced. The chemical pulp mill was started up in March 1887. It was a sulphite pulp mill, consisting initially of three digesters; the fourth digester was added in 1889.

Kuusankoski Ab's paper mill, groundwood mill and woodyard were destroyed in a fire in 1881. Other departments were also damaged. The shareholders' meeting held three weeks after the fire made a decision to rebuild the mills, and the new mills started operating in the autumn of 1882. The groundwood mill included six grinders and there were eight board machines. The production in 1883 was 2700 tons.

Kuusankoski Ab decided to build a chemical pulp mill in 1885, at the same time as Kymmene Ab, and the mill was started up in the autumn of 1886. The pulp mill suffered a fire during the installation period, which delayed the start-up by about six months, but fortunately the main machinery had not been delivered to the site before the fire.

After the start of the chemical pulp mills, the mills started operating continuously, as it was impractical and uneconomic to stop the chemical pulp mills for weekends. Earlier the mills had been shut down for Sundays.

A railway from Kouvola to Kymmene mill was opened on October 1, 1892.

In 1890, Kuusankoski Ab decided to install a new paper machine, as the prices of groundwood and board had been sliding because of the increasing production capacity in Finland, Sweden and Norway. The order for the new machine was confirmed right after the decision to build a railway to Kuusankoski. The paper machine was designed especially for wood-containing grades and its width was 80 inches. The paper mill was situated right beside the river, which later caused big problems. For example, in the 1890s, the mill had to be shut down for several months because of flooding.

A second paper machine started operation in 1896. A third machine was started up in the summer of 1897.

By the end of the century, the paper production of Kymmene Ab and Kuusankoski Ab reached 10 000 t/a, and the mills had altogether five paper machines. Their products were wood-containing wallpaper as well as printing and writing paper. Both companies decided to raise the quality of their products by changing over to paper grades containing more chemical pulp.

The Voikkaa mill, owned by Tampereen Kattohuopa ja Paperitehdas Osakeyhtiö, was situated near the Kymmene and Kuusankoski mills along the next rapids upstream of Kymijoki river. By 1902 the Voikkaa mill was the biggest paper mill in Finland with four paper machines and a production of 9 000 t/a.

As there were three mills competing for wood, personnel and customers close to each other, the owners started negotiations aiming for a merger of the companies. The rise of labour unions was one reason contributing to the merger plans. The companies were merged in 1904 under the name Kymmene Ab.

The paper machines of the new company in 1904 are presented in Table 1.

Table1 The paper machines of Kymmene Ab in 1904 [58]

PM	Start-up year	Width cm	Grade	Note
II Ku	1891	203		
III Ku	1896	228		
I Ky	1874	203	Sack paper	Speed 12 – 49 m/min, production 5 – 6 t/d
II Ky	1882	203		Speed 50 m/min
III Ky	1897	257		Speed 30 – 90 m/min, production 10 t/d
I Vo	1898	228		
II Vo	1899	265		
III Vo	1901	228		
IV Vo	1903	228		

Ku) Paper machines of former Kuusankoski Ab at Myllysaari

Ky) Paper machines of former Kymmene Ab at Kymi mill

Vo) Paper machines of former Tampereen Kattohuopa ja Paperiteollisuus Oy at Voikkaa mill

The initiator of the merger negotiations was probably the owner of the Voikkaa mill, Rudolf Elving, who became the biggest owner of the new company and chairman of the board.

The Voikkaa mills were modern and efficient, whereas the Kuusankoski and Kymi mills had old and not so well maintained machinery.

Because of dissatisfaction among employees in the paper sorting department of the Voikkaa mill, where female workers complained about too severe punishments for mistakes in paper sorting and sexual harassment by a supervisor, a strike begun in the autumn of 1904. The workers of the Kuusankoski and Kymi mills joined in the strike, but the management of the company and the governor of Vyborg district took a firm stand against the strikers, part of whom were sacked by the company and also evicted from their houses. This left a bitter division between the management and the employees.

In 1904 the board of the company decided on a large modernisation programme.

The paper grades were divided between the mills so that Kymi mill specialised in manufacturing fine paper, Kuusankoski mill in printing and writing paper and Voikkaa mill in newsprint.

The programme included modernisation of the pulp mills and installation of three new paper machines in Kymi mill for fine paper production, Table 2.

Table 2 New paper machines of Kymi mill in 1905 – 1906 [58]

PM	Start-up year	Width cm	Grade
IV Ky	1905	228	
V Ky	1905	228	
VI Ky	1906	160	Cigarette paper

The paper machine projects were not successful: the deliveries were late, installation works suffered from striking, and the start-up curves of the machines did not reach planned levels. At the same time, the broke percentage of the mill doubled from 10 % into 20 %. The mill management was replaced by Mr. Elving's trusted persons.

On July 1, 1906 the Voikkaa mill was destroyed by a fire caused by a candle flame during a shut-down. The water lines of the mill had been closed for repair, and three paper machines, calenders, winders and the paper sorting room were destroyed; only two paper machines remained intact. The mill was rebuilt by installing three new paper machines which were started up in 1907.

In 1907 the company had 12 paper machines with a combined production of 40 000 t/a. The financial situation of the company was weak because of the recession in the world market and especially in Russia after the Russo-Japanese war. The modernisation programme and the fire in Voikkaa as well as the rise of wood raw material and wage costs had increased the company's indebtedness considerably.

As demand for paper in Russia collapsed, Kymmene Ab tried to find new customers in England and Central Europe. However, the quality of the paper was not good enough for the Western markets except that of newsprint, which could be sold, though at a loss.

In 1905 the political unrest plaguing Russia also spread to Finland, causing a general strike in the country. Basically, the strike was intended to achieve political reforms but in Kymmene Ab the strike was expressly directed towards the company's management. The workers' meeting voted over the destiny of the managers, and decided to save their lives. Later, the strikers at Kymmene also adopted the political goals of the general strike. The workers were paid their wages for duration of the strike, as the management considered the strike a patriotic demonstration.

The paper workers' trade unions were founded in 1906. In February 1907 a strike was begun at Kymmene in favour of higher wages and shorter working days. After the strike, an 8-hour working day for shift workers and 10-hour day for day workers was introduced and minimum wages as well as task-specific wages were agreed. This labour contract was made for two years. It was not accepted by the employers' federation of the pulp and paper industry, and Kymmene resigned from the federation for a brief period.

In 1908, all the paper machines of the Kymi mill were shut down. One of the machines was restarted in September, but its production was only 1 200 t/a of paper compared to 12 000 t/a in 1907.

The general downturn in the economy, heavy indebtedness because of the investments and the quickly rising wage costs forced the company into an intolerable economic situation. Debtors took over the management of the company in 1908 and Gösta Serlachius was appointed managing director. He had studied cost calculation and cost management systems in the USA, noticing that the company's paper machines were not used rationally. He reduced the number of paper grades. He also improved the mills' energy usage by introducing coal as a fuel in the boilers. The working hours in shift work were changed back to 12 h/d except in the most demanding departments.

As the general economy improved and the rationalization of the company took effect, the paper machines could be restarted. In 1911 the production reached the target level of the investment programme.

In 1913 Gösta Bergenheim was appointed managing director of the company. He developed the sales to Russia by introducing new sales agents in the most important cities.

In 1914, the sales developed favourably until the beginning of World War I. The war caused problems in the production because the transport of products and raw materials was restricted. However, demand for paper increased because of the war news in newspapers and in late 1914 the prices of paper were raised. The company achieved a new production record in 1916, producing 63 300 t of paper.

In 1917, the paper production was upset by the March Revolution in Russia, and the collapse of the rouble. A decision was made to serve only those customers in Russia who pay in Finnish marks. Two paper machines in the Kymi mill had to be shut down. However, the company believed in the recovery of the Russian market, investing in office properties for its new sales companies there. After the Socialist Revolution, the properties were lost and exports to Russia ceased. New markets had to be found in other parts of the world.

From the Independence Declaration to World War II

The Civil War in 1918 caused repeated violence in Kuusankoski. At the beginning of the war, the Red troops killed more than 30 managers, including Mr Björkenheim, the managing director. After the White troops had conquered Kuusankoski, 275 reds were executed and 925 were sent to prison camps. The mills had been shut down before the war in December 1917, and they were started again in May - June 1918. Because the Russian market had been lost, all paper machines could not be started.

New markets were sought in 1919, but during the early months of the year the situation became so bad that the Kuusankoski mill had to be shut down because all storages were full. In May 1919 the situation started to improve. The biggest market was England. The company now delivered some orders which had been placed before the

World War at the agreed prices on which the orders had been made. The prices did not even cover freight costs but they made a very positive impression on the customers, which was not easily forgotten.

The common sales organisation of the Finnish paper industry created a network of agents and representatives in the Western main markets. The problem of the industry after the world war was that the paper grades and product quality produced earlier were not right for the new markets. Kymmene was, however, considered as a high-quality producer. In 1920, the company already exported 16 000 t/a to England, which was equal to the amount that had been exported to Russia before the war. The sales organisation, Finnpap, aroused controversial feelings in Kymmene, because most of its agents were former Kymmene agents, and because the low quality of paper supplied by other paper mills caused complaints. The company decided in the early 1920s to sell its own paper to the Western markets, but the sales to the Soviet Union and Finland were handled by the common sales organisation [40].

In the 1920s, new paper machines were installed in the Kymi mills as follows:

- New PM VI started up in 1924. It was 356 cm wide and its design production level was 15 000 t/a. The start-up did not go well and 1926 was the first full production year. It made high-quality printing papers.

- New PM IV started up in 1929. It was a 366 cm wide newsprint machine with a production capacity of 20 000 t/a.

- PM III was rebuilt in 1929.

- Groundwood mills were rebuilt to reach the required capacity.

At the end of the 1920s, Kymmene was both technically and financially in good condition.

The recession in the early 1930s did not cause production cut-backs in Kymmene’s mills.

In the 1930s, Kymmene purchased two paper mills in England, merging them in a subsidiary, Star Paper Ltd. Shares were also acquired in a metal products company, Oy Högfors Ab.

Major investments were made in both Voikkaa and Kuusankoski.

In Kuusankoski mill two new paper machines with Yankee cylinder dryer sections were installed. The first of them, PM VIII, was started in 1935 and the second, PM IX, in 1936. These paper machines are still in operation, today named PM 1 and PM 2.

Kymi pulp mill was rebuilt in 1932-35 to increase its production capacity from 25 000 t/a to 60 000 t/a. The Kuusankoski pulp mill was also rebuilt to meet the new environmental regulations that had come into force in 1934.

World War II to 1965

During World War II the mills' production was only about 20 % of their nominal capacity due to the lack of export markets, and a shortage of manpower and equipment. The pulp mills and paper machines were shut down for varying periods, and the mills were operated in two shifts only. Air raids disturbed the mills' operation as well.

The paper machines still in operation after World War II are presented in Table 3.

Table 3 Paper Machines of Kymi Mill after World War II [54]

PM VIII	nowadays PM 1
PM IX	nowadays PM 2
PM III	restarted after the war in July, 1945
PM IV	restarted after the war in February, 1950
PM V	
PM VI	

There were no major investments in the paper mill in the period from World War II till 1965. In the 1950s the strategy had been to improve paper quality by using bleached groundwood pulp as raw material and by rebuilding the paper machines for fine paper production. A gloss calender was installed on PM IV for production of rotogravure magazine paper before it was restarted in 1950. A size press to produce fine paper on PM III was installed in 1952 [54].

In 1957, PM V, was rebuilt for production of coated paper grades in the grammage range of 100 – 130 g/m^2, based on an agreement made with an American company, S.D. Warren. The coating colour consisted of clay and starch, and the brand name of the product was Griffin, referring to the emblem of the company.

PM VI was completely rebuilt in 1961 for fine paper production. A surface size kitchen was also built. The capacity of the machine after the rebuild was 70 – 100 t/d, depending on the grammage.

PM 1 was also rebuilt in 1961. Its production capacity was increased by 15 – 20 % by installing a high-capacity hood on the yankee cylinder.

The capacity of the groundwood mill was increased during the period to meet the needs of the paper mill, and a bleaching plant was built for groundwood pulp.

The sulphite pulp mill's capacity was increased by adding one digester, which started operating in 1961.

The original site became to small for further development in the 1950s and in 1961 a decision was made to start a project for building a 90 000 t/a sulphate pulp mill in the Kuusanniemi area, which nowadays is the base of the Kymi Mills' operation. The new pulp mill was started up in 1964.

The pre-engineering for the new pulp mill was done by a design engineering company. During the implementation period the equipment for the various mill departments was purchased from main suppliers who included the department's instrumentation in the supply. For the boiler plant's instrumentation, the equipment supplier sent its own design engineer to the site. The piping engineering for the mill site was also done by the piping contractor's designers.

The period 1966 - 1979

As a new development was the Voikkaa PM 18 project from 1966 until 1968, in which an outside design engineering company was hired as a main engineering consultant for the first time [54].

In autumn 1966 a decision was made to build an off-machine coater in the Kymi mill. The production capacity of the coater was 50 000 t/a, the width of the paper web 370 cm and the maximum speed 900 m/min. Paper made on PM 4 and PM 6 was used as base paper. A separate coating colour kitchen was built beside the coater plant.

To improve the quality of paper produced on PM 4 and coater C1 a Billblade unit for precoating the paper on the paper machine was installed in 1972, which made it possible to produce base paper similar to that produced by PM 6. As a result, it was now possible to produce Medium Weight Coated paper. In 1979 the press section of PM 4 was rebuilt and the paper machine's production raised to 40 000 t/a.

The decision to build the first paper machine in the Kuusanniemi complex was made on June 24, 1969, and the new paper machine, PM 7, was started up on December 22, 1970 [54]. The reason for making this decision was the strong growth of woodfree paper demand due to the increasing number of printers in automatic data processing systems. During previous years, the increased production of coated grades in the Kymi mill had decreased the relative share of uncoated paper capacity.

PM 7 was at its time the biggest fine paper machine in Finland. Its planned capacity at the time of the go-ahead decision was 40 000 t/a, its speed 750 m/min and the trimmed width of the paper reel 456 cm. However, the design capacity was set at 50 000 t/a, which was reached in 1971.

A sheeting plant was included in the investment. Its capacity was 43 000 t/a, and it included four sheet cutters. Both the paper of PM 7 and paper from the old Kymi mill were sheeted in this same sheeting plant.

For taxation purposes, the machine was scheduled to start up during 1970. This led to a situation where the main machinery supplier and the main engineering consultant were the same as in the paper mill project of Nordland Papier GmbH, which was jointly owned by Kymmene Oy and Kaukas Oy. In Nordland, a similar paper machine was being planned. This led to a situation where the modifications proposed by Kymmene's own paper engineers were unacceptable, as the most important details had already been agreed upon in the Nordland project [54].

PM 7 was initially operating in the acid pH range, with clay was used as a filler. In 1975 a transfer was made to neutral papermaking. The use of calcium carbonate as filler started after the PM 8 project when a slurry plant was built.

In 1973 a decision was made to build a second coater in the Kymi mill. The coater was placed alongside coater 1. The base paper for the coater came from PM 3 and PM 5, whose operation would not be secured without an improvement in product quality.

A reservation for also coating board from Juankoski mill and purchased base paper was taken into account, so the capacity of the coater was set at 60 000 t/a, whereas the capacity of PM 3 and PM 5 would only amount to 35 000 t/a.

PM 3 was totally rebuilt during the coater project. The rebuilt machine included a Billblade pre-coating unit.

The coater was started up by the end of 1975. The coater's capacity after start-up and prices of coated grades developed slower than forecast during the project decision. However, a second winder was installed within two years after start-up to handle the increased capacity.

A decision to shut down the sulphite pulp mill and to build a new sulphate pulp line was made in 1974. An exceptionally in-depth pre-engineering report was reportedly made for this project [54].

The sulphate pulp line was originally designed for manufacturing pine pulp with a capacity of 160 000 t/a. However, it was decided during the project to use birch as raw material instead, so the capacity would be 180 000 t/a.

The new fibre line started up in June 1977. The wood handling and effluent treatment plants had been started earlier. The project was successful and the new line secured the raw material supply for the expansion of fine paper production in the 1980s.

The main features of the project organisation model used by Kymmene in 1973 were the following:

- Each project had a project council, which consisted of the line management of the product division and departments participating in the project. This project council decided on the big issues and main principles of the project.
- Each project had a project group headed by the project manager.
- In bigger projects, the project manager was assisted by area project managers responsible for their respective areas.
- The project organisation included responsible persons for different disciplines.
- In every project organisation there was a person appointed responsible for the process. This person acted as a liaison to the mill and was also responsible for the training of personnel as well as the commissioning and start-up of the plant.

The period 1980-1986

A decision to merge Kymi Kymmene Oy with Oy Strömberg Ab was made in late 1982, and the new company was named Kymi-Strömberg Oy.

Kymi's old paper machines were outdated compared to the new double forming technology. As early as 1978 studies had been started to examine the possibilities of installing a new paper machine in Kuusanniemi. The project go-ahead decision was made in 1980, and the new paper machine, PM 8, was started up in March 1983.

The project organisation was formed according to the principles described earlier. An outside main consultant was hired for the project as well as engineering companies for civil, architect, noise abatement and HVAC engineering.

PM 8 was at its start the biggest fine paper machine in the world. The web width on the reel was 8560 mm.

The project included many modifications in the mill site as well as departments serving the whole paper mill; the production capacity of the new paper machine was threefold compared to that of PM 7.

The project was a success. The timing of the start-up was also successful, as paper demand was growing rapidly. In addition, the paper machine's production during the 1980s was considerably greater than forecast. The PM 8 project was regarded as a logical continuation of the development that had started with the construction of PM7. Without these paper machines, the profitability of the Kymi mills would have been much poorer and the continuation of operations might have been endangered [54].

The period after 1986

In 1986, Kymi-Strömberg Oy and Kaukas Oy were merged and the new company was in 1987 named Kymmene Corporation.

The mills of the new corporation were divided into two divisions: Kaukas - Voikkaa, producing wood-containing paper grades, and Kymi, producing woodfree grades. The investment management and technical administration were combined and directed from Lappeenranta.

The first major project of the new company was the PM 9 project in Kuusankoski, whose go-ahead decision was made on January 22, 1987. Pre-engineering for the project started in July, 1986. This project finalized the integration of the Kuusankoski mills so that all chemical pulp produced could be used on the company's own paper machines.

The width and type of the paper machine were similar to those of PM 8. Its design production was, however, higher. The project included extensive rebuilding of the raw material handling department and a new sheet cutting line.

The project succeeded well. The paper machine was started up on November 10, 1988. It produced saleable paper from the very beginning. One reason for the success was the experience gained with PM 8, and the fact that the Kymi project team consisted mostly of the same persons as the PM 8 team. The paper machine operators came partly from PM 8 and also the other staff had been trained on PM 8 [54].

When PM 9 was started up, three old paper machines were shut down. PM 3 was shut down on June 1, 1988, PM 4 on October 2, 1988 and PM 6 on April 30, 1989.

At the same time with the PM 9 project, the future of PM 7 was critically examined, as its competitiveness weakened considerably following the start-up of the new machine. At the beginning of 1988, a decision was made to rebuild PM 7 for making on-machine coated paper grades, and the design capacity for the rebuilt PM 7 was set at 115 000 t/a.

PM 8 was rebuilt in 1990-1991 with a new-generation surface sizing unit, which increased the machine's drying capacity, and, accordingly, its production. At the same time, the capacities of stock preparation and broke systems were also increased.

For PM 9 a new sizer unit was installed in 1996 and the refining capacity was increased in 1996.

The coater plant C2 lost its competitiveness because of its small size and complicated logistics of paper, so it was shut down in 1999.

In the late 1990s, a strategic decision was made by UPM-Kymmene's Fine Paper division to increase the share of woodfree coated grades. This decision was based on the higher growth of demand for coated grades compared to uncoated grades in the 1990s. As PM 8 required major revamping to maintain its competitiveness, it was chosen as the target for a feasibility studies concerning a coated paper production line in Kuusankoski. Several alternatives were studied, and in May 2000 a decision was made to rebuild PM 8 completely and to build a new state-of-the-art off-machine coating plant.

The totally rebuilt PM 8 was started up on September 5, 2001, and the coating plant on October 28, 2001.

Selected projects

The author has collected archive material concerning the four latest major paper machine projects of the Kuusankoski mills, currently named UPM-Kymmene Corporation, Kymi:

- Paper machine PM 7
- Paper machine PM 8
- Paper machine PM 9
- ARTTI project, which included a complete rebuild of PM 8 and a new off-machine coating plant C3

Some of the key figures of the projects are listed in Table 4. The data is collected from Kymi's project archives, author's archives as well as [54] and [58].

Table 4 Key figures for Kymi's latest paper machine projects

		PM 7	PM 8	PM 9	ARTTI PM8 (*
Start-up year		1970	1983	1988	2001
Production	t/d		550	740	1 170
	t/a	50 000	140 000	220 000	370 000
Paper machine width	mm at reel	4 560	8 570	8 570	8 540-8 660
Paper machine drive speed	m/min	650	1 000	1 200	1 500
Amount of piping	t			150,8	195,6
Amount of piping	m			17 253	14 540
Number of electrical loops	ea	552	400	555	674
Number of automation loops	ea	206	940(**	629	1969
Project time schedule	months (from PM purchase to start-up)	18	26	20,5	15,5

*) only the rebuild of PM 8 and the modifications of the raw material department are included.

**) before dismantling PM 8 for complete rebuild. The number of instrument loops in 1983 could not be traced.

Comparison of the projects is not easy, because the information on the original material and loop numbers of the projects has disappeared. All the machines are still running and they have been rebuilt several times.

The project durations are dependent on external circumstances:

- The schedule of the PM 7 project was extremely tight because of the taxation laws and could only be implemented because a paper machine had been ordered for an associated company, which was then transferred to Kuusankoski. Engineering solutions were largely similar to those worked out for the associated company's project.

- The PM 8 project took longer than normal, because the company's board of directors decided to postpone - when the project was already in progress - the start-up of the paper machine by 6 months due to the recession in the paper market.

- The PM 9 project's duration can be considered reasonable for a new paper machine.

- The schedule of the Artti PM 8 project was tight, but it could be kept because the new machine was installed in an existing building. The time for engineering was short.

Control systems have changed completely during the past 30 years. PM 7 was designed with pneumatic controls and manual control stations were located in control panels and desks. The process information to operators was given on a mimic diagram, which showed the status of motors and on/off valves with indicator lamps, and by using loggers which recorded the status of controls. PM 8 and PM 9 were implemented with digital process control systems, which controlled the operation of the stock preparation, broke, water, steam and condensate as well as starch machine circulation systems. Control actions were activated from the operator station keyboards, and the status of the process could be seen on the control system display. The paper machine controls were implemented with a separate programmable logic system, which had the required wired connections to the process control system to ensure the proper functions (e.g. the start-up of the right pulper when there was a break at the paper machine). The paper quality control system was a separate system with its own operator stations. In the Artti PM 8 project, the process controls and machine controls as well as paper quality controls were executed by using compatible systems with the same operator stations. The paper machine condition monitoring system is also controlled via the same operator interface.

The number of electrical loops has not changed as much as the number of automation loops. The PM 7 project included a large number of ventilation equipment, as the offices' and the sheeting department's ventilation was included. Over one third of the motors were ventilation blowers. In later projects, offices or sheeting department have not been included in the number of electrical loops.

The number of automation loops has grown considerably due to the increased requirements for the stability the papermaking process, which stem from higher product quality requirements and increased paper machine widths and speeds. All these changes demand much more monitoring of process conditions.

3.4 Joutseno Mills

The Joutseno pulp mill has been a sulphate pulp mill from its very beginning. Before the beginning of the 20^{th} century there had been only one sulphate pulp mill in Finland, but during the first decade of the century six sulphate pulp mills were built. The mill built by Pulp Osakeyhtiö was the first sulphate pulp mill on the Vuoksi waterway [30].

The founder of the pulp mill in Joutseno was a Norwegian engineer, Johan C. Wiese, whose idea was to build a pulp mill that would use the chips from adjoining sawmills as its raw material. As there were several sawmills in the Saimaa region, Wiese bought in 1907 a land area on the southern shore of lake Saimaa and founded in 1908, together with two companions, a new company named Oy Pulp. The design production of the mill was 6 000 t/a of unbleached sulphate pulp. The first technical manager of the mill was also a Norwegian engineer, Petter Midelfart [50].

The civil works were started in early 1908. The architect was K.H. Segerstad. The civil contractor completed construction works in the spring of 1909.

Machine installation works started in the summer of 1908, proceeding as planned, and the production started in June 1909. The main machinery was German, the steam engine was from Germany and the pulp drying machine from the Karhula engineering works.

The start-up of the mill did not go without problems. Difficulties were caused by the new type of machinery, which had not been tested enough. The professional skills of the operators were most probably not good enough, and the language barrier between Mr. Midelfart and the workers caused additional problems. In the beginning, pulp cooking was ineffective and half-cooked pulp was discharged into Lake Saimaa, so even the mill’s harbour was filled with pulp. The maintenance crew was under heavy stress, and help was needed from the Lappeenranta Engineering Works, where parts were manufactured and modified. Men from Lappeenranta also came to assist the Pulp personnel in maintenance [50].

The early years of the Joutseno pulp mill were economically difficult, and in 1911 Mr. Wiese resigned from the company. Mr. Midelfart took over as resident manager.

The mill continued operating until 1917, when it was shut down due to the lack of demand, as exports were banned during World War I [49].

After Finland’s independence and the end of the civil war, the owners of Oy Pulp decided to sell the company, as a considerable capital input would have been needed to restart the mill. On September 18, 1918 Oy Kaukas Ab bought the mill, and the Pulp mill became a profit unit of the Kaukas mills.

In 1950 a new company, Joutseno-Pulp Osakeyhtiö, was formed, of which Repola-Viipuri Oy, later Rauma-Repola Oy, and Oy Kaukas Ab both owned half. This company owned the mill and equipment. Hannes Jansson was appointed managing director of the new company.

A decision to increase the production capacity from 20 000 t/a to 60 000 t/a was made in 1951. The investment included a new 40 000 t/a fibre line, and a new 60 000 t/a lime and recovery line. The existing fibre line was kept in operation also after the investment, as the pulp markets were booming because of the Korean War [21].

A new continuous cooking system was selected for the cooking method, as it was considered to be the cooking process of the future [21]. Some continuous digesters were already in use in other European countries, but none in Finland. Two new digesters were installed. The cooking process was not sufficiently developed and the start-up was not successful. One problem was the lack of storage capacity between the pulp mill departments, causing the whole mill to be shut down in the case of problems in one department [49]. The strength properties of pulp were weak. In the early stages of operation, the mill was operated by the equipment supplier's personnel who made modifications seemingly without planning [2]. The engineering work for the cooking and washing departments was made by the equipment supplier. The rest of the engineering work was done by the mill's own engineering team. According to the equipment supplier, only a small buffer was needed between cookers and washers. Considerable modifications were made, and a new cold-blowing system was invented by Einar Olsen, Joutseno-Pulp's engineer [2]. The mill personnel's impression of the early production stage was that the mill served as the equipment supplier's pilot plant [5].

The drying section of the pulp drying machine was also of a new construction, causing great difficulties, because the construction was too weak, resulting in web breaks at higher running speeds.

It took until 1958 for the mill to reach its design production.

In 1959 it was decided to increase the mill's production to 240 000 t/a. The expansion project was completed in 1962. The batch cooking method was selected because of the bad experience of the previous project [52]. The engineering was done by the mill's own engineering department, but a lot of installations were made by pointing out the pipe routes in the field. The plans were reviewed in Jaakko Murto's engineering office, but this was not considered very useful [2].

The second expansion stage was completed in 1969, raising the production to 170 000 t/a of semi-bleached and 75 000 t/a of unbleached pulp. In this project, the engineering work was done by Jaakko Pöyry's engineering office.

In the 1970s also stumps were collected from the forest and used as raw material by Joutseno-Pulp. In 1975 a sawdust handling line was taken into operation.

In 1980, Rauma-Repola Oy became the sole owner of Joutseno-Pulp Oy, when Oy Kaukas Ab sold its share [102].

In 1982 the ownership was again restructured, when United Paper Mills Oy, Kansallis-Osake-Pankki and two insurance companies became co-owners of the company. Later that year 40 % of the shares were acquired by United Paper Mills.

A bleaching plant was started up in 1984. Since then, all the pulp has been fully bleached.

The Joutseno mill's pulp has had the reputation of being a very strong long-fibre pulp used as reinforcement pulp in paper grades whose chemical pulp content is minimised.

One reason for the good strength is the big share of sawmill chips in the raw material, so the share of long fibres is bigger than in normal roundwood. The Super Batch cooking process has also contributed to the good quality.

In 1988, Rauma-Repola Oy decided to build a fine paper mill in Joutseno. The company also announced its interest to acquire more than 90 % of the shares in Joutseno-Pulp. United Paper Mills felt that this plan would clash with their interest, and negotiations ultimately led to a decision according to which United Paper Mills acquired the whole company. The paper mill project was cancelled immediately [102].

In 1990, the Joutseno pulp mill became a profit centre of United Paper Mills, ceasing to operate as a separate company.

After the merger of United Paper Mills Oy and Kymmene Oy into UPM-Kymmene Corporation, the Joutseno pulp mill and the Simpele mills were sold to Metsä-Botnia Oy in 1997 [76]. The capacity of the mill at that time was 320 000 t/a.

A new recovery line for the mill was constructed in 1998-1999, which raised the production level to 415 000 t/a.

A new fibre line was built in 1999-2001. This project raised the capacity to 600 000 t/a, which makes it the biggest single-line softwood pulp mill in the world [76]. In this project the cooking process was changed back to continuous cooking.

4 PROCESS ENGINEERING TASKS

4.1 Definitions

The author’s definition of **pulp and paper industry processes** is the following:

Pulp and paper industry processes are combinations of machinery and equipment, pipelines and control hardware and software that form an entity capable of producing the desired quantity and quality of end product from defined raw materials using given resources.

Pulp and paper industry processes can be continuous or batch processes.

Process is defined as a transformation that adds value. Every process has inputs. The outputs are the results of the process. The outputs are products, tangible or intangible. Every process involves people and/or other resources in some way [90].

Process is also defined as a set of inter-related resources and activities which transform inputs into outputs. Resources may include management, services, personnel, finance, facilities, equipment, techniques and methods. [31]

According to Webster’s definition **process** is:

- A natural progressively continuing operation or development marked by a series of gradual changes that succeed one another in a relatively fixed way and lead toward a particular result or end: a natural continuing activity or function
- Particular method or system of doing something, producing something, or accomplishing a specific result, esp.: particular method or system used in manufacturing operation or other technical operation [103].

The **chemical process** is defined as follows: A chemical process is the continuous or batch wise conversion of raw materials into products and by-products via physical, (electro)chemical and biochemical transitions, through the application of processing agents, and use, consumption and generation of utilities [24].

In the author’s opinion, this definition is also valid for forest industry processes.

Process and **process industries** are defined by Concidine as follows: The term **process** normally connotes a series of operations, more appropriately expressed as a series of chemical unit operations. The design and operation of a processing plant essentially involves a serious exercise in the management of materials and energy.

The term **process industries** is rather loosely used to describe those industries which depend heavily upon chemical and metallurgical technology [9].

Project is defined as a unique process, consisting of a set of coordinated activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements, including the constraints of time, cost and resources. An individual project may form part of a larger project structure. In some projects the objective(s) is (are) refined and the product characteristics defined progressively as the project proceeds [31].

Process research and development is defined as follows: The aim of process research and development is to adapt a laboratory-scale procedure to a commercial process. Further input may be needed to resolve problems that arise on start-up and for optimization of performance. During process development, a stage may be reached where further research and development is transferred to a plant technical staff; the latter phase is called process improvement. Process research and development combines experimental work with technical and economical calculations, which are guided largely by chemical and chemical engineering principles. The focus of process research is on experimental work of a chemical engineering nature [44].

The **process design basis** is the documentation that contains all the information necessary for the engineering and design of the plant. The extent of this information varies according to the requirements and experience of the engineering group responsible for the project. The process design basis usually contains specifications for the optimum operating conditions and resulting selectivities and conversion for reactions, and an overall processing scheme with a flow sheet and material and energy balances. A competent engineering group can develop and optimize a process design from such information [32].

An **industrial process** is defined as a set of operations which basically perform a physical or chemical transformation or a series of such transformations [99].

The **development of an industrial process** is a creative activity, which is aimed at finding and coordinating all the information and data required for the design, construction and start-up of a new industrial unit, in order to guarantee an economically profitable operation [12].

According to Backhurst and Harker, **process development** is the translation of the bench scale chemistry into a means whereby the material can be produced on a large scale [7].

Baasel defines **process design** as follows: Design is a creative process whereby an innovative solution for a problem is conceived.

Process engineering is the procedure whereby a means for producing a given substance is created or modified [6].

In a chemical plant the process consists of some or all of the following steps:

1 Feed storage

2 Feed preparation

3 Reaction

4 Product purification

5 Product packaging and storage

6 Recycle, recovery and storage

7 Pollution control

These steps are analogical to the unit operations of the pulp and paper mills.

The author's definition of **process engineering** is the following:

Process engineering consists of defining the optimal unit processes to produce the desired end product, selecting and sizing correctly operating equipment and piping and other sub-systems, defining the required controls to make the process evenly and easily operative and presenting the operation of the process in the form of process flow diagrams and process descriptions to the other engineering disciplines as well as to the operators and maintenance crew of the process.

Terms **process engineering**, **process design** and **process engineering design** are used in literature and in practice as synonyms. Also in this study they are used alternately.

According to Yang et al, **process design** is a complicated and time consuming procedure because many compromises of conflicting interest shall be made especially in the phase of equipment selection. There is no unique solution for selection since many qualitative judgments in addition to the quantitative calculations must be made, and each designer often makes different qualitative judgments. At the preliminary design stage, it is incumbent on designers to survey the range of basic equipment types available and to select the one or few candidates most applicable to their particular process requirements [106].

Process design is defined by Douglas as follows:

Process and plant design is the creative activity whereby we generate ideas and then translate them into equipment and processes for producing new materials or for significantly upgrading the value of existing materials. Process design actually is an art, i.e. a creative process. Therefore, we might try to approach the design problems in much the same way as a painter develops a painting. Of course, numerous scientific principles are used in the development of a design, but the overall activity is an art. In fact, it is the combination of science and art in a creative activity that helps to make process design such a fascinating challenge to an engineer [10].

Process engineering design is defined by Ludwig:

Process engineering design is the application of chemical, mechanical, petroleum, gas and other engineering talents to the process-related development, planning, designs and decisions required for economical and effective completion of a process project. Process design is usually a much more specific group responsibility in engineering contractor organizations than in a chemical or petrochemical production company, and the degree of distinction varies with the size of the organization [56].

According to Vilbrandt and Dryden a basic step in making a preliminary plant design for cost estimation or for establishing a detailed commercial plant design is to work out a **process design**. Briefly, one presents the basic chemical and physical operations of a process. Examples of the latter type include filtration, drying, mixing, and other chemical engineering operations. These facts are illustrated in flow sheet form. It is then possible for an engineer to apply industrial stoichiometry principles to the process as outlined to obtain material and energy balance flow sheets. After all these facts are available the designer is ready to specify the type of equipment to do the job. By knowing the cost of such equipment, the start of a plant cost estimate has been made [104].

The problems in **process design** are divided by Hougen et al. in the following manner: The design of the chemical process involves three types of problems, which although closely interrelated depend on quite different principles. The first group of problems is encountered in the preparation of the material and energy balances of the process and the establishment of the duties to be performed by the various items of equipment. The second type of problem is the determination of the process specifications of the equipment necessary to perform these duties. Under the third classification are the problems of equipment and the materials selection, mechanical design, and the integration of the various units into a coordinated plan.

These three types may be designated as process, unit-operation, and plant design problems, respectively. In the design of a plant these problems cannot be segregated and each treated individually without consideration of the others. However, in spite of this interdependence in application, the three types may advantageously be segregated for study and development because of the different principles involved. Process problems are primarily chemical and physico-chemical in nature; unit operation problems are for the most part physical; the plant-design problems are to a large extent mechanical [29].

Engineering is defined as the science by which the properties of a matter and the sources of energy in nature are made useful to man in structures, machines, and products [103].

Design is defined as the process of selecting the means and contriving the elements, steps, and procedures for producing what will adequately satisfy some need (industrial design) specifically: the drawing up of specifications as to structure, forms, positions, materials, texture, accessories, decorations in the form of a layout for setting up, building, or fabrication [103].

Quality of processes is a success factor for the production plant that shall be thoroughly verified during the life cycle of the plant [91]:

- Planning of processes should ensure that these proceed under controlled conditions in the specified manner and sequence.
- The operation of processes should be specified to the necessary extent by documented work instructions.
- Processes should be verified as being capable of producing product in accordance with specifications.
- Verification of processes should include material, equipment, computer system and software, procedures and personnel.

According to Edgar et al. typical problems in chemical engineering process design or plant operation have many, and possibly an infinite number of, solutions. Optimization is concerned with selecting the best among the entire set by efficient quantitative methods. Computers and associated software make the computations involved in the selection feasible and cost-effective. But to employ them requires (1) critical analysis of the process or design, (2) insight as to the what the appropriate performance objectives are, i.e., what is to be accomplished, and (3) use of past experience, sometimes called “engineering judgment”, before useful information results.

Engineers have to use judgment in applying optimization techniques to problems that have considerable uncertainty associated with them, both from the standpoint of accuracy and the fact that the plant operating parameters and environs are not always static [11].

According to Moulijn et al. in chemical process technology various disciplines are integrated. They can be divided according to their scale as follows:

- Scale independent
  - Chemistry, Biology, Physics, Mathematics
  - Thermodynamics
  - Physical Transport Phenomena
- Microlevel
  - Kinetics
  - Catalysis on molecular level
  - Interface Chemistry
  - Microbiology
  - Particle Technology
- Mesolevel
  - Reactor Technology
  - Unit Operations
  - Scale-up
- Macrolevel
  - Process Technology and Process Development
  - Process Integration and Design
  - Process Control and Operation

Of course, this scheme is not complete. Other disciplines such as applied materials science, information science, process control, and cost engineering also play a role [67].

4.2 Process Synthesis and Analysis

According to the definition of chemical processes, process engineering is divided into Process Synthesis and Process Analysis [10].

The definition of process synthesis is “making assumptions about what process units should be used, how those process units will be interconnected, and what temperatures, pressures and process flow rates will be required”. The difficulty of process synthesis is the big number of ways in which the same goal can be accomplished [10].

Process analysis is the activity by which the most optimal solution is sought. The solution shall have the lowest costs, it shall be safe, satisfy the environmental constraints, be easy to start and operate etc. According to Douglas, in some cases rules of thumb (heuristics) can be used to eliminate certain process alternatives from further consideration, but in many cases it is necessary to design various alternatives and then to compare their costs. The amount of work that is needed for this kind of evaluation is dependent on the experience of designers, as experienced designers can often guess the costs of a particular unit or group of units, by analogy to another process [10].

In pulp and paper processes the equipment and the unit processes are very much supplier-dependent, which means that the process analysis and process synthesis are maybe more interdependent and simultaneous than they are for chemical processes.

4.3 Engineering Methodology

The traditional engineering method in process industries has been sequential engineering, in which the different engineering disciplines follow each other. This approach of engineering methodology is described by Douglas [10]. The work flow of sequential engineering is shown in Figure 4.

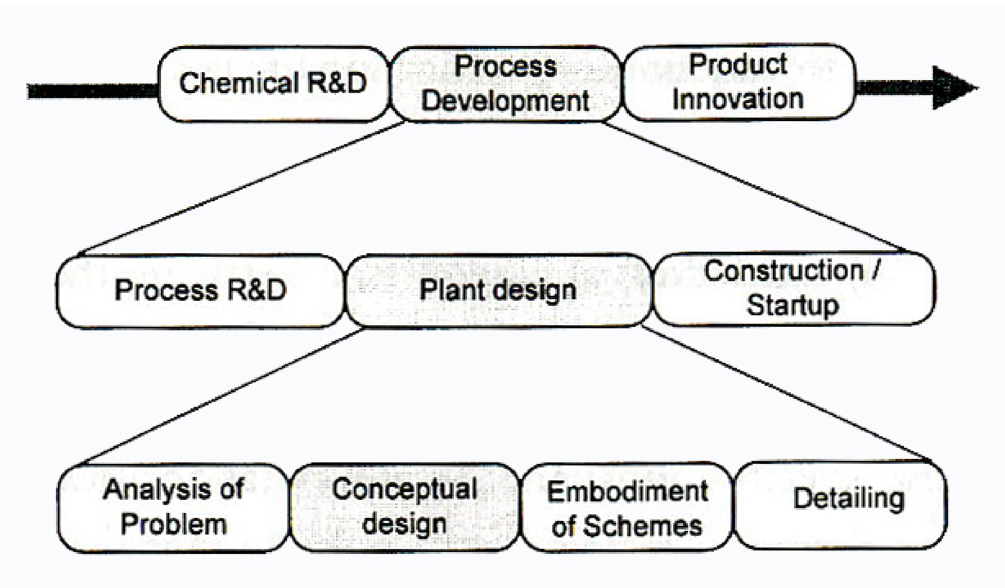

Figure 4 Simplified embedding of the plant design process in other development processes [24]

This method is said to have the following advantages:

- Minimum need for resources in the beginning of the engineering
- Minimum costs accrued if the project does not materialise
- The plant design process is divided into a number of well-defined project stages

The drawbacks of sequential engineering are said to be:

- Need for iteration
- Changing one of the early design decisions implies a large amount of rework and extra money
- Long execution period
- Many quality factors are not considered during the early phases of the project

Quality factors are divided into internal and external quality factors. Internal quality factors are those that can be affected by the process designer, but the external factors are “factors that influence the design process or the design of the plant but can not be manipulated by the process design engineer, thus posing either constraints or opportunities to the designer.” [25].

A solution to the drawbacks of the sequential design approach has been found in the “concurrent engineering” concept [24]. It is a design approach that is based on parallel execution of design tasks in each stage, thereby reducing the time that is needed for each design stage.

One of the main purposes of the concurrent engineering approach is to perform each design step in the most optimal and concurrent way. This means that, whenever possible, the design tasks are executed in parallel, instead of sequentially. The concurrent engineering concept was developed initially for consumer products that have a relatively short life span.

The concurrent process engineering concept is defined as follows: Concurrent process engineering implies that, in addition to the basis of design, all factors of possible relevance to the process design are being considered in all stages of the design process [24].

In this concept, the quality factors have to be considered in all stages of the design process, and the process design engineer is forced to consider aspects in parallel from the entire life span of the plant already in the early design phase.

The problem here is that the processes and decision-making become too complex when too much is considered in parallel, and thus a balance has to be found, when the decisions are made [24].

The reduction of engineering time compared to sequential engineering is described in Figure 5.

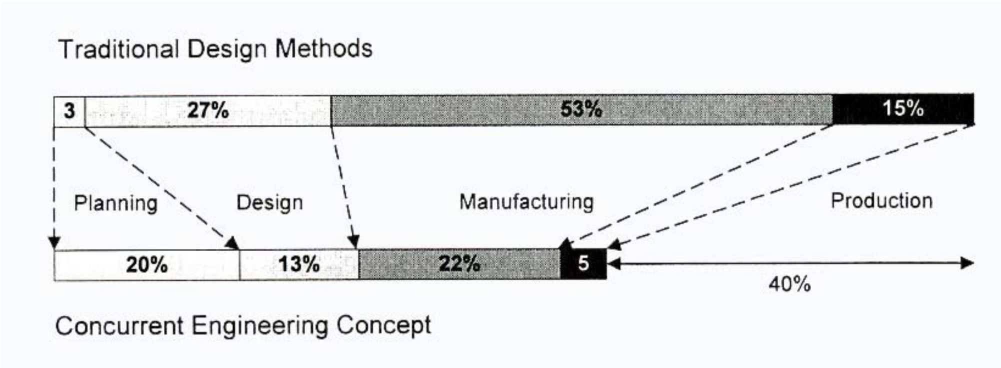

Figure 5 Engineering time reduction achieved by concurrent engineering [24]

4.4 Process Integration

Process integration was defined in the IEA Expert Meeting in Berlin 1993 as systematic and general methods for designing integrated production systems, ranging from individual processes to total sites, with special emphasis on the efficient use of energy and reducing environmental impact [20].

Later in the 1990s, the objectives of process integration were broadened to include:

- Reduced capital investment
- Improved raw material utilisation
- Better operability, flexibility and controllability
- Reduced emissions

Process integration can be used for planning, design and to some extent operation of process plants [20].

In the 1990s, process design in the chemical processing industry has developed so that Process integration has become a discipline. For many years the Unit Operations concept was the basis of design, but new design paradigms are based on basic phenomena such as chemical reaction, separation, mixing, and the main objective has been to find new design solutions in which more than one phenomenon takes place within one piece of equipment. So it is seen that process integration will occur more within units instead of integration between units.

Process integration can be seen to make an impact on the environmental agenda. The emphasis should be placed on labelling it a ‘clean technology’ accepting that the route to this is via energy efficiency and conservation and waste minimisation etc. [19].

The pulp and paper industry is considered to have good energy utilization. Still, the potential for further reduction of the energy demand is considered to be high. In traditional process integration studies, where existing process equipment is accepted, potential savings of 5 - 10 % in steam consumption can be realised. If process integration is used in strategic process planning, and allowing process modifications, much larger savings are possible, up to 50 % [17].

Process integration analysis in the pulp and paper industry differs in many ways from the process industry analysis developed for other industries because of the different structure of the plants. The differences include [17]:

- Traditional process integration heading for minimum area is not always applicable
- A unique mix of operations that is not found elsewhere
- The internal fuel production

4.5 Tasks of Process Engineer

A process engineer designs a plant to produce a given chemical [6].

Baasel defines the tasks of a process engineer as follows: The process engineer is the person who constructs the process flow sheet. He decides what constitutes each of the seven steps listed in section 4.1 above and how they are interconnected. He is in charge of the process and must understand how all the pieces fit together. The process engineer's task is to find the best way to produce a given quality product safely – "best", at least in part, being synonymous with "most economical" [6].

Factors in problem solving

With each of the aforementioned problems, the process engineer begins by gathering all the information he can about the process. He talks with research, development, engineering, and production engineers who might help him, and takes copious notes. He reads all the available literature and records anything that may be of future value. While doing this he develops a fact sheet on each of the substances he will be dealing with. This fact sheet should include all the chemical and physical information he can find.

Becoming intimately familiar with a process takes time. For a process engineer this may take two weeks or more, depending on the complexity of the system and the engineer's previous experience. This time is not reduced substantially by the presence of large computers. It is a period for assimilating and categorizing a large amount of accumulated information.

The initial goal of the preliminary process study is to obtain an economic evaluation of the process, with the minimum expenditure of time and money. During this stage, all information necessary to obtain a reasonably accurate cost estimate for building and operating the plant is determined. It is expected that these costs are within 10 % of the actual costs [6].

Responsibilities of the process engineer are defined by Ludwig as follows:

The average process engineer has the following responsibilities:

1. Prepares studies of process cycles and systems for various product production or improvements or changes in existing production units

2. Prepares economic studies associated with process performance

3. Designs and/or specifies items of equipment required to define the process flow-sheet or flow system

4. Evaluates competitive bids for equipment

5. Evaluates operating data for existing or test equipment

6. Guides flowsheet draftsmen in detailed flowsheet preparation

The process engineer must understand the inter-relationships between the various research, engineering, purchasing, expediting, construction and operational functions of a project. He must appreciate that each function may and often does affect or influence the process design decisions. Some specific phases of a project which require process understanding include plant layout, materials of construction for corrosion as well as strength, start-up operations, trouble shooting, maintenance, performance testing and the like [56].

The tasks of process engineers include [36]:

Chief process engineer

He/she is the leading expert in his/her process area, such as kraft pulping, recovery, energy, TMP, PGW, newsprint, woodfree, LWC etc.

He/she is responsible for conceptual and basic engineering of the plant. In particular this means the following subjects:

- Process design criteria
- Balance calculations
- Block or line process diagrams
- Identification data for major equipment and streams
- Power requirements of processes
- Inquiry specifications for major equipment
- Bid analyses of the same
- Scope of deliveries of the same
- Process control concept
- Manpower plan

- Preliminary plot plans (checking)
- Mill site layout (checking)

The Chief Process Engineer works full-time during the early phase of the project. During the detail engineering and construction phases he is called in, if any changes are proposed or must be done in the above areas.

Area process engineer

He/she is a senior process engineer. He/she should know well the mill area (department) designated to him/her. He/she is an Engineering Manager in his/her area. In other words, he/she is responsible for the following:

- That all physical items which are needed to make his/her area a complete production unit are considered
- That all tasks needed to implement the area are clearly defined
- That the sequence and the timing of the tasks are correct
- That all tasks are clearly assigned to an entity
- That the cost estimate is prepared and the budget is followed
- That the information flow between various entities functions as planned

What is said above, is valid for the whole project scope of his/her area as well as for the engineering office's own part. For engineering work, the Area Process Engineer in particular

- carries preliminary process flow diagrams through different phases up to PIDs
- leads the layout design from the beginning to the approved layout
- supervises the specification and procurement of secondary equipment (pumps, valves, agitators, service systems, HVAC, etc.)
- supervises the engineering data schedules and data expediting
- ensures that each design group has, at any point in time, a work plan and a budget, and a corresponding resource plan
- supervises the progress of the work of all disciplines in his/her Area through checking on the spot the real situation against the reported time schedule follow-up line and against the estimated-to-complete manhours

Area systems engineer

Process engineering is the main source of information for other disciplines. If this source is well taken care of, the whole project runs smoothly.

Area systems engineer is a mechanical engineer capable of working out the details of process engineering. His/her role is one of an "Information Manager".

In order to fulfil the above obligations, he/she functions as the main expeditor of vendor's data.

5 ENGINEERING ACTIVITIES DURING THE LIFE-CYCLE OF A MILL

Engineering activities during the life-cycle of a mill can be divided into the following phases:

- Pilot runs and laboratory tests
- Preliminary surveys
- Pre-engineering
- Detail engineering
- Rebuild engineering
- Maintenance engineering

5.1 Pilot runs and laboratory tests

Pilot runs using the pilot machines of research institutes and machine suppliers' pilot plants are arranged to:

- Develop new products
- Develop new raw materials to produce the products
- Develop new machinery or equipment to produce products more efficiently

Laboratory tests are used to define product properties.

Normally, the pilot plants consist of unit processes that form a part of a production plant. The raw materials used to test unit processes are often semi-manufactured products from the production plants, which are transported to the pilot plant. It is also possible to make pilot runs with a mobile pilot plant that can be connected to a side flow of the production plant.

The problem with pilot runs is their batch-type operation, which does not allow all the factors affecting continuous mill operation to be taken into account. Pilot runs are, however, an excellent way of observing differences caused by changes in machinery parameters or changes in raw materials or chemical proportioning.

According to the author's view, process engineering does not play a significant role for these tasks.

5.2 Preliminary Survey

The preliminary survey is also called pre-feasibility study.

The purpose of a preliminary survey is to define a product and production capacity for the planned production unit and calculate its investment cost and profitability in order to give the decision-makers of the client company enough information to decide whether the project is worth further examination. This is done with the aid of market, competitiveness, resource and alternative analyses.

Normally, archive material from previous projects and surveys as well as heuristics of experienced analysts and engineers are used when the investment estimate and profitability calculations are worked out.

The accuracy of the investment estimate is typically ±15 % at this stage of the project's life-cycle.

5.3 Pre-engineering

Pre-engineering starts from the point where the product and the production capacity have been fixed.

The purpose of pre-engineering is to fix the project concept in sufficient detail to allow a reliable investment estimate. The accuracy of the calculation shall be in the range ±3...5 %, depending on how much work is put into it. This estimate serves as one of the key inputs in making more accurate profitability calculations.

In the pre-engineering phase, the process and mill concept for the chosen product are developed so that a reliable investment estimate can be made. In addition, a realistic target time schedule is prepared and applications for necessary municipal permits, e.g. environmental permits and building permits are prepared.

The purpose of pre-engineering is to gather all the information, data and permits required for a go-ahead decision.

The scope of process engineering in the pre-engineering phase is typically limited to the following engineering documents [37]:

- Main dimensioning and design criteria
- Preliminary process flow diagrams for main processes
- Connections between process departments
- Equipment lists for investment budget
- Mill description by department
- Technical enquiry specifications
- Comparisons of tenders

In addition to discipline-specific design documents, the final report includes a written description of main process systems and all departments. Conclusions and recommendations are collected into the summary of the report.

5.4 Basic Engineering

In the basic engineering phase, engineering documents are worked out on the basis of information concerning purchased machinery and equipment. Because this information become available at different points in time for different engineering disciplines, basic engineering cannot be easily and clearly separated from detail engineering. This is why basic and detail engineering are often performed and understood as one entity, called implementation engineering.

Process engineering provides a basis for all subsequent engineering and it is begun immediately after the project has been defined.

Most of the process engineering activities have to be performed at once and during a reasonable short time. Later changes must be avoided as far as possible, because they cause a lot of extra engineering work and are difficult to get through to all parties involved.

In addition to having the necessary process know-how, it is important to know the content of process engineering activities, their logical order, their timing and their dependence on other engineering activities.

Documents prepared during the basic engineering phase include the documents needed for procurement of equipment, process flow diagrams based on the equipment selected and process descriptions serving as a basis for control system configuration. During this phase, timely and correct process design is crucial for avoiding later re-engineering or modifications.

5.5 Detail Engineering

The detail engineering work includes all engineering and documents needed for civil construction and field installation, commissioning and start-up as well as for maintenance of the mill. Also the material needed for training the operators is prepared during the detail engineering phase.

During the detail engineering phase, process engineering focuses on preparation of operating instructions, start-up planning and complementing the process design done during the basic engineering phase in close cooperation with piping engineering and electrical and automation engineering disciplines.

5.6 Rebuild Engineering

At some stage during the life span of a pulp or paper mill, a rebuild is normally contemplated. The reasons for rebuilds are normally a need to increase the production and/or upgrade product quality, as the mill loses its competitiveness against new, bigger and more efficient plants.

When a major rebuild is considered, all the project phases presented above are involved, and the role of process engineering is the same as described above.

A rebuild project is more demanding as an engineering exercise than a greenfield project, because the capacity and condition of existing equipment has to be evaluated to determine its usability in the new process.

Other factors that make a rebuild project more challenging are the limited time available for shut-downs and the space restrictions caused by existing buildings.

A rebuild project is made even more difficult by the fact that the personnel in charge of production and maintenance before the rebuild (and who will also be operating the rebuilt mill) are normally responsible for the mill's production during the rebuild project, and therefore cannot focus exclusively on the project's needs.

5.7 Maintenance Engineering

During normal production, regular maintenance keeps the equipment in good shape. Normally, the role of process engineering is less important, if wearing or spare parts are replaced.

Minor rebuilds may also be done as maintenance work, not as separately resourced projects, in which case changes in process systems and equipment have to be sized and documented by process engineers as described above. After successful completion of a minor rebuild project, all process engineering documents are updated into as-built versions just like in bigger projects.

6 DEVELOPMENT OF PROCESS ENGINEERING ACTIVITIES

6.1 History of Design Engineering

During the early years of the forest industry's development, processes were relatively simple. They consisted of equipment units connected by pipelines and controlled by manual valves. Batch processes were commonly used in cooking, repulping, refining etc. The processes were defined by the equipment suppliers, who also sent their specialists to install the equipment and assist in the operation during the initial phase of operation.

The supervisors in pulp and paper mills were mostly foreigners, because the owners did not consider Finnish engineers to be competent enough [64].

By the beginning of World War II, the mills' engineering departments had improved their skills considerably. Engineering work for projects was generally done by the mills' own engineering departments, and visits were made to foreign mills to gain more experience. There also emerged independent process engineering specialists who were hired by the mills to serve as their consultants during projects. For example Eero Kalaja and K.J. Mattas participated in building projects at several pulp mills in the 1930s.

In 1911, the industry founded a society to carry out boiler plant engineering and operational surveys, called Energiataloudellinen Yhdistys EKONO. The association operated as an engineering company until 1993, when it was merged with the Jaakko Pöyry Group.

World War II meant a change in internal as well as foreign policy in Finland. The left-wing parties urged the state to assume responsibility for the most important sectors of society, and also the country's right-wing parties agreed on the importance of the state in controlling the engineering effort for rebuilding and for war indemnities to Russia. The most important engineering organisation was Soteva, which was established to design, organise and complete the war indemnities [64].

The origin of consulting engineering companies in Finland can be traced back to Soteva. In 1952, when the war indemnities had been paid, Mr. Kaarlo Amperla, an engineering manager in the Soteva organisation, founded an engineering company and recruited a number of experienced designers to join him. With a staff of around 7, this company did the mill engineering for several Finnish and foreign companies. Dr. Jaakko Murto, later professor of chemical pulping technology in the Helsinki University of Technology, was working as a part-time process specialist in Amperla's engineering company. His main job at that time was as technical director of Metex, the export organisation of Finnish metal industries. Metex's scope often included engineering in major equipment supply projects [23].

The year 1958 was a turning point in the history of design engineering in Finland: Dr. Murto and Jaakko Pöyry were awarded the engineering contract for a new sulphate pulp mill in Äänekoski. This project is considered to mark the start of the Jaakko Pöyry Group's development into a world-leading consulting engineering firm [23].

In the early years of consulting engineering, a large part of the process know-how was derived from the customers' production personnel, who often worked during the engineering period in the engineer's offices.

Mill visits and visits to suppliers' works were made in the 1950s and 1960s mainly to the United States, from where new innovations were imported to Europe at that time.

According to Jaakko Pöyry, the key to his company's success in early projects was the fact that his designers went to the clients' offices to work in close cooperation with the clients' staff, doing what the customer wanted. In contrast, the established foreign design engineering companies of that time had strict instructions for how the engineering should be done [89].

The use of consulting engineering companies was established during the 1960s and 1970s, when today's major consulting engineering companies were established.

The engineering departments of many pulp and paper companies were still at that time very strong and some of their managers considered the consulting engineering companies as competitors, so some companies were still in the 1970s quite independent of outside engineering expertise.

In the 1980s, pulp and paper mills started concentrating on their core business, and the mills' engineering departments became more like a project management organisation than an engineering organisation. Engineering services are normally purchased from engineering companies either on the basis of annual contracts for small jobs or separately for bigger projects.

This development accelerated when the forest product companies outsourced their engineering and maintenance departments into separate companies whose shares were sold to other companies specialising in maintenance operations.

The number of companies specialising in industrial design engineering and their staff have developed as shown in Figure 6. This figure includes all industry sectors in which member companies of the Finnish Association of Consulting Firms (SKOL) are active, i.e. energy, chemical industry, pulp and paper industry.

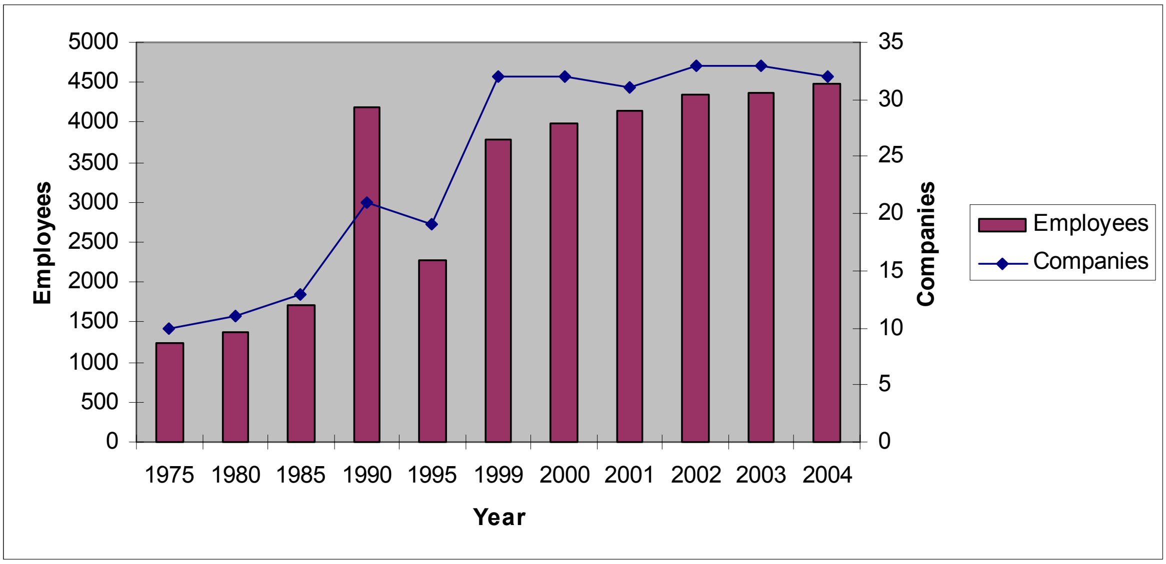

Figure 6 Number of SKOL member companies and their staff (industrial engineering) [95]

The design engineering companies were started as private enterprises, owned by one or several engineers representing the management of the companies. An exception was Ekono, which was owned by the industry.

In the late 1980s, the biggest and most successful companies embarked on a growth policy facilitated by the liberalisation of financial markets, resulting in several acquisitions. The fact that the companies' founders grew older and started thinking about a generation change also promoted this development. At the same time, the companies invested in new office buildings, expecting the value of real estate to continue rising.

When the devaluation and recession in the early 1990s hit the markets, industrial investments plunged, resulting in a heavy restructuring of the Finnish consulting engineering business. Several companies collapsed, and parts of them were combined with other companies, whereas other parts were restructured into new, smaller management owned companies.

In the early 2000s, a new globalisation phase began, with foreign companies acquiring several Finnish design engineering companies [69].

Figure 7 shows the development of personnel numbers in the Jaakko Pöyry Group, which was one of the first Finnish design engineering companies to become truly international. The first foreign subsidiary was founded in Stockholm in 1962 [33].

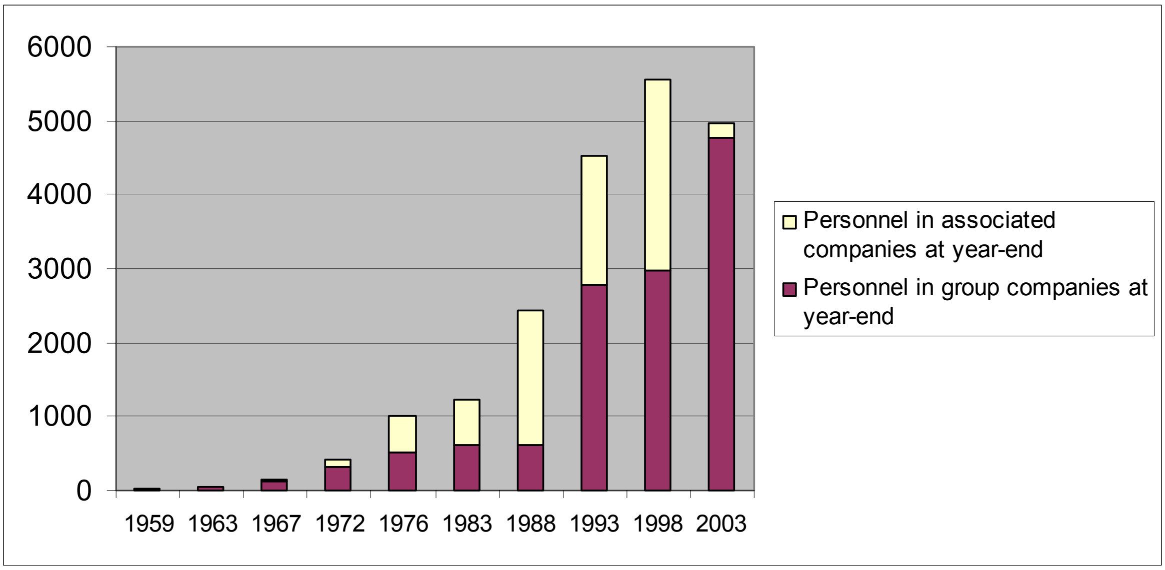

Figure 7 Number of personnel in Jaakko Pöyry Group 1959 – 2003

6.2 Changing Roles of Project Stakeholders

During the past few decades, project stakeholders have had quite different roles in engineering, as has been described previously.

The author's view of this development is illustrated in Figures 8, 9 and 10.

Up to the 1970s, in most projects, the project owner had the engineering resources to carry out process, mechanical and piping engineering without outside assistance. In some cases, the piping installation contractor also did the piping engineering. Electrical and automation engineering were often done by the equipment suppliers and installation companies.

There were many process equipment suppliers at that time, who mostly concentrated their engineering on mechanical engineering for their own equipment.

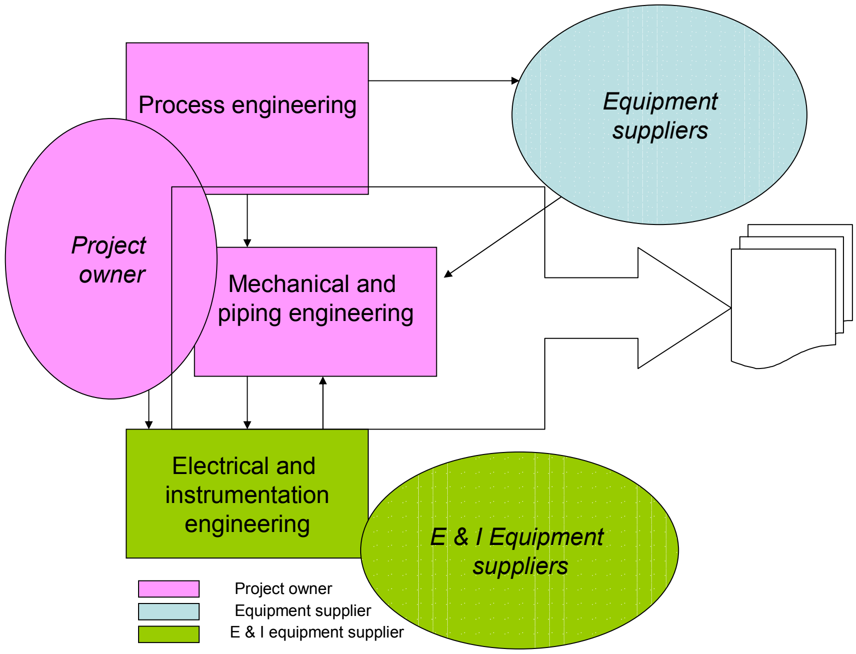

Figure 8 Typical distribution of engineering responsibilities up to the 1970s

In the 1970s, the design engineering companies had become so big that they had the resources for all design disciplines and the capability to propose process designs and solutions for project standards, equipment and systems. Design engineering companies in Finland and in other European countries worked as a partner with the project owner, being responsible for process, mechanical and piping as well as electrical and automation engineering.

The equipment suppliers were still mostly interested in the design of their own equipment, focusing their engineering interests and capabilities on mechanical engineering. They were interested in how their equipment functioned in the process and often gave recommendations for process solutions and instrumentation around the machines.

This situation is described in Figure 9.

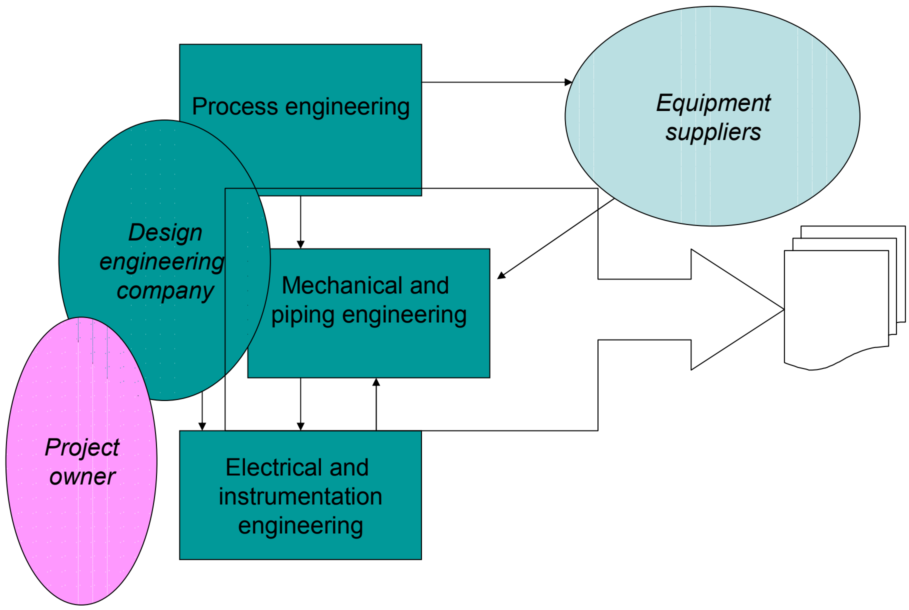

Figure 9 Typical distribution of engineering responsibilities from the 1970s onwards

The author's view of the information flow in process development, corresponding to the situation in Figure 9, is illustrated in Figure 10.

Design engineering companies play a central role in gathering information from equipment suppliers and project owners and in putting this information together into a functional process, thereby acting as a major channel of information from equipment suppliers to pulp and paper mills. New applications of process equipment and connections which later have become industry standards were originally introduced by the design engineering companies.

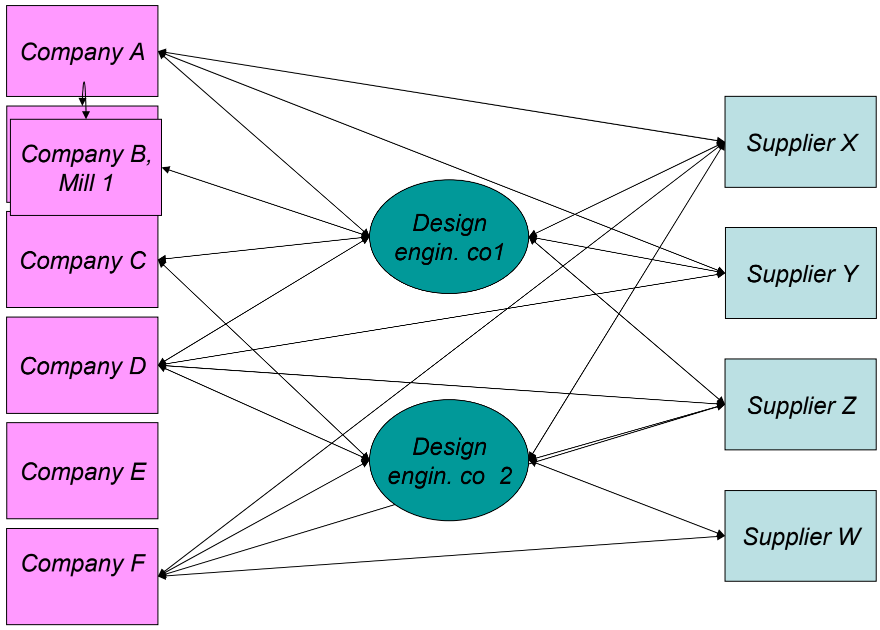

Figure 10 Information flow in process development during the 1970s and 1980s

In the 2000s, the main machine suppliers have become the biggest players in process development. This is due to the consolidation of the industry, with a few vertically integrated companies dominating the market for pulp and paper machinery. Mill engineering, including process engineering, is today often part of their scope of supply.

At the same time, pulp and paper companies have been consolidated into big multinational companies which have several mills in different countries with different types of machinery and process solutions. Therefore, they now have lots of in-house information, which used to be the domain of design engineering companies, whose personnel traditionally participates in several projects around the world. This is one reason why design engineering companies sometimes are considered as mere resource banks, which are hired to handle tasks for which clients do not have time.

The machine suppliers also strive to engage themselves in the whole life-cycle of the production line. They have hired pulp and paper-making professionals for operations improvement tasks and they have automation expertise related to information systems, so they can recommend modifications in operational procedures.

The value of the engineering input in a pulp or paper mill project is only 3-5 % of total project costs. In contrast, the value of main machinery is about 50 % of the total project cost. Consequently, machine suppliers have much greater resources for process system development and better risk-carrying capabilities.

The design engineering companies' existence is justified by the following aspects [85]:

– Pulp and paper companies are being continually streamlined, so they no longer have enough personnel to man a complete project organization.

– This streamlining also affects the administration and management of documents, which are increasingly being handled by systems developed and managed by design engineering companies.

– In principle, all professional consultancies and engineering design firms recognize the very latest technology, providing clients with the most up-to-date proposals and services available.

– The increasing number of turn-key projects results in greater involvement by the suppliers and a greater risk due to the suppliers' lack of experience of 'gluing pieces' together, especially if there is more than one supplier. This is where the mill or equipment supplier will engage an independent consultant/project management company.

This development, which is described in Figure 11, was strongly referred to in the interviews of Niemi and Alanen (Appendix I), who both stressed the fact that the streamlined organisations of pulp and paper mills no longer include engineers who could concentrate on process development, because the mills' role today is to concentrate purely on production.

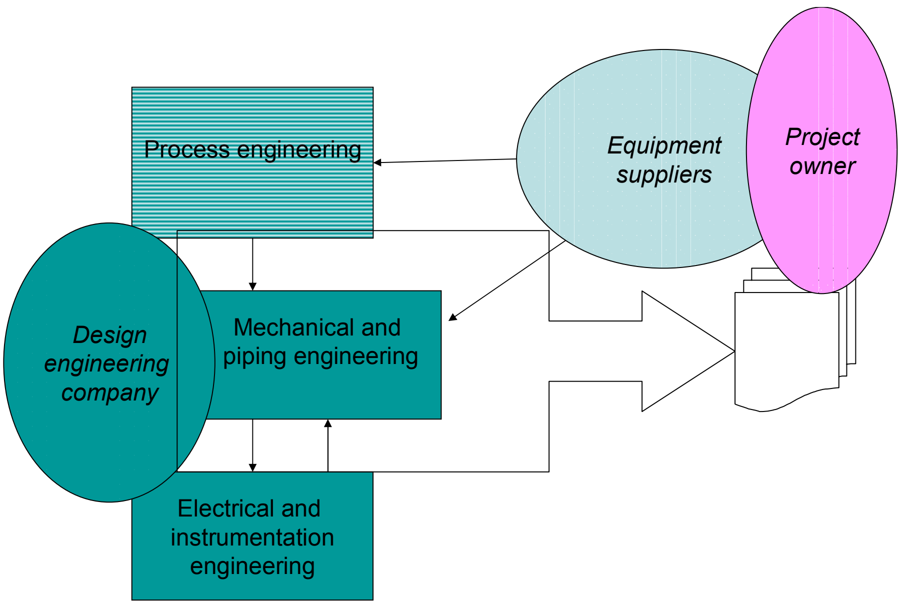

Figure 11 Forecast future distribution of engineering responsibilities

The author's view of the future information flow in process development, which has already largely materialised, is illustrated in Figure 12. The information flow is mainly occurring within the big pulp and paper companies and between them and the major equipment or process suppliers. The role of design engineering companies is moving towards detail engineering, based on process solutions developed by the other stake-holders in the projects.

The development in the pulp and paper industry, which was described earlier, leaves a position for design engineering companies, but directs their role more towards detail engineering as well as information management.

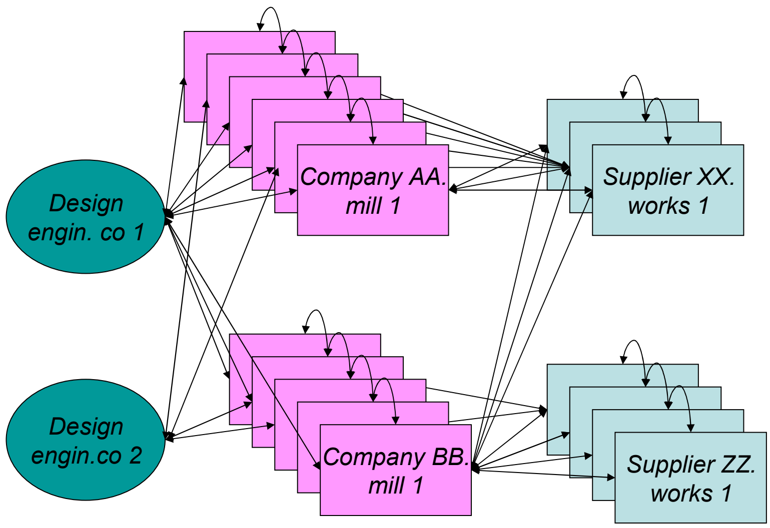

Figure 12 Future information flows in process development

7 TOOLS OF PROCESS ENGINEERING

7.1 General

The world economy is changing continuously, setting new requirements and challenges for plant design. Global competition has increased and the new situation in the market has forced engineering companies to cut costs, tighten time schedules and improve the quality of their design work. One solution to meet these requirements is to use concurrent design and integrate process design into the concurrent plant design [96].

A plant design project is an effort in which a project company delivers a unique product to an external client. Projects are characterised by their product orientation. The objective of the project is to create a physical entity, i.e. a mill [96].

Every new pulp or paper mill project requires individual engineering work. Manufacturing or procurement cannot be done until appropriate engineering work has been completed. On the other hand, detail engineering cannot be completed until final information concerning equipment and piping parts is available.

Nikander defines a construction project's life cycle in terms of the following stages, based on earlier surveys [73]:

- Engineering
- Procurement
- Delivery
- Site

His view of the phasing of these stages is shown in Figure 13.

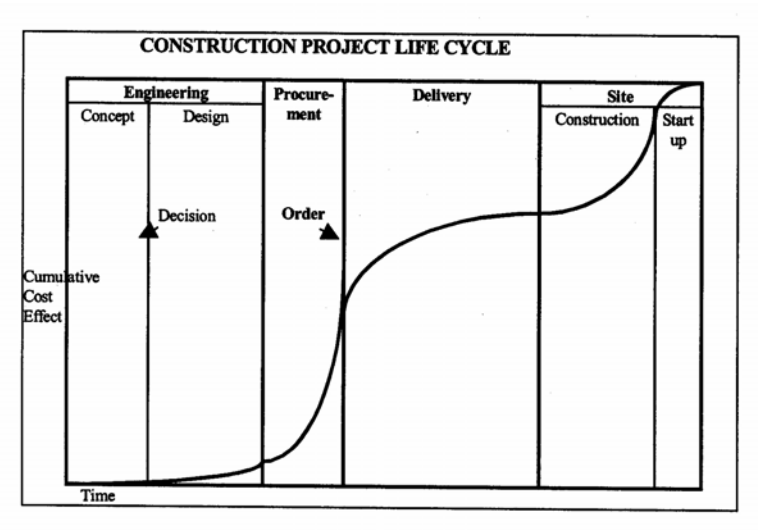

Figure 13 Project life cycle [73]

The same division of project life-cycle activities is also presented in the Guide of Project Management Body of Knowledge, in which the project's life-cycle is divided into the following stages [81]:

- Feasibility
- Planning and design
- Construction
- Turnover and start-up

The approach, according to these sources, is such that the design is completed after the purchases have been made. After that, only concrete work such as construction, installation and start-up are carried out.

The practice in pulp and paper mill projects differs drastically from the project life-cycle presented above. Engineering is ongoing during the whole life-cycle of the project, except for the last stage of construction work and start-up. The project life-cycle of a typical pulp and paper project is shown in Figure 14.

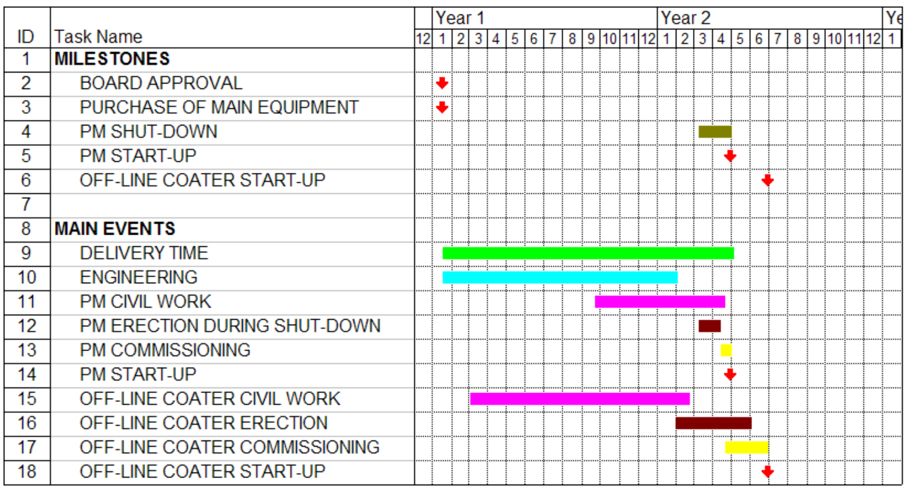

Figure 14 Implementation stage life-cycle of a paper machine rebuild and off-machine coater project

The engineering work in different disciplines must be harmonised to complete the project. The phasing of process engineering work has changed so that a major effort has to be put into process engineering at the beginning of the implementation stage, to guarantee that process flow diagrams and process descriptions are completed in time for mechanical and piping engineering as well as electrical and automation engineering.

Figures 15 and 16 show the phasing of project engineering at present compared to the situation in the 1980s for pulp and paper mill projects.

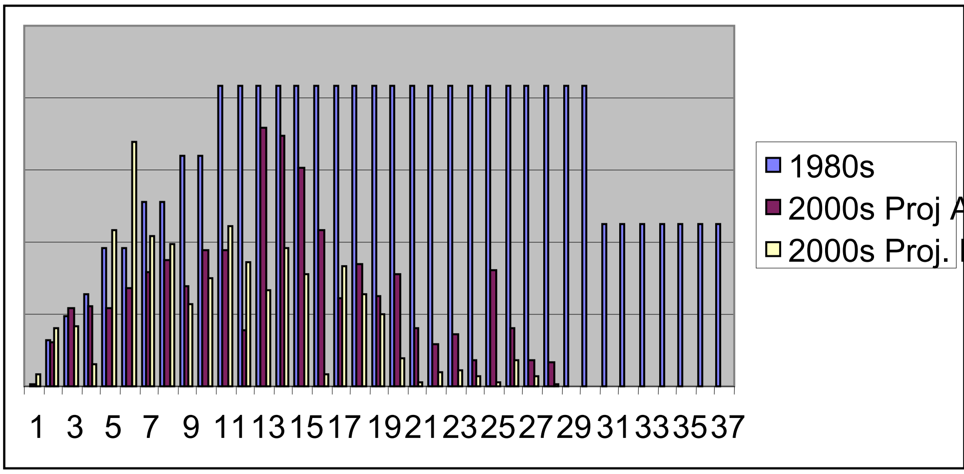

Figure 15 Phasing of process engineering work during a pulp mill project's implementation phase in the 1980s and 2000s

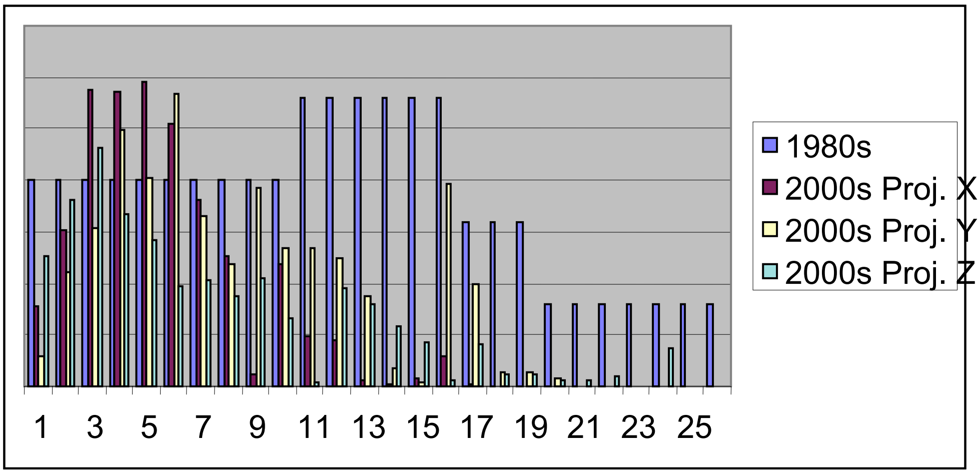

Figure 16 Phasing of process engineering work during a paper mill project's implementation phase in the 1980s and 2000s

7.2 Development of Process Engineering Tools up to the 1960s

The tools used in process engineering have developed along with the development of general office tools.

The tools used up to the 1960s included:

Slide rules and simple table calculators were used for design data and sizing calculations.

In the late 1960s, programmable calculators were developed for simple balance calculations.

Tables and slides were used for heuristic sizing of equipment and piping.

Block and process flow diagrams were drawn using pencil and ruler and stencils. After approval of the diagrams, they were traced on tracing paper by draughtsmen using drawing ink. In the 1970s, plastic became a common drawing base material for approved drawings.

Text documents were hand-written by process engineers and typed out by secretaries or typists.

Interlocking descriptions were dictated to an electrical designer, who drew the interlocking diagrams, and then the draughtsmen traced them.

Figure 17 Process engineering tools in the 1960s

7.3 Development in the 1970s and 1980s

In 1970s, pocket calculators became common, replacing slide rules.

Computers were taken into use in the 1970s and they were first used for automation of piping, electrical and instrument component lists.

From the late 1970s onwards, tracing of process flow diagrams was made using computers and CAD drawing systems.

Advanced type-writers with limited memory capacity started spreading in the 1970s, making it easier to modify text documents.

In 1980s the spreadsheet software was developed and process sizing calculations could be computerised.

As early as 1984, efforts to develop a new type of project database, in which information from all engineering disciplines would be included, were begun in Finland [98].

7.4 Recent Development

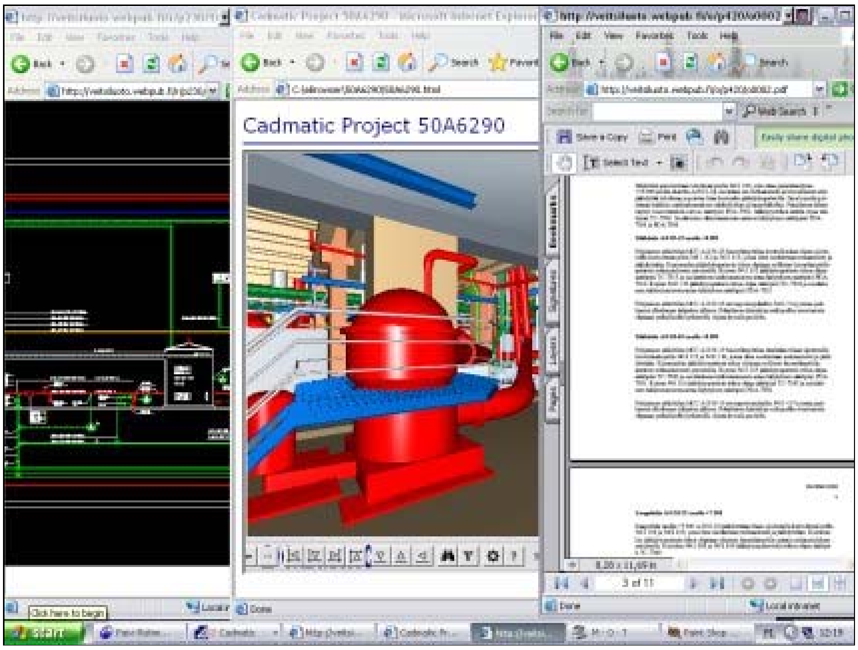

Figure 18 Tools of present-day process engineering

Design criteria and main dimensioning calculations are done with spreadsheet programs.

Text documents are written by process engineers using word-processing programs. Secretaries are taking care of their visual appearance, administration and archiving.

The sizing of process systems is done with the help of simulation programs. The simulation programs in use have been analysed by Klemola et al. [45]. Dynamic simulation is a tool that is increasingly being used in training of mill operators.

In the 1990s, the development of databases covering all mill data, together with 3D engineering tools, reached a point where it was justified to launch the virtual mill concept. The data concerning process dimensioning and equipment are fed into the system by process engineers. Equipment lists are generated directly from the virtual mill model.

Process control system displays are programmed into control system programs directly by process engineers.

Loopwise functional descriptions adapted to the control systems are written using JAVA-based programs, and they can be directly linked to the process control software.

Start-up and water-run lists can be generated directly from the database, as the data on equipment, pipe lines, control loops and electrical loops in each water-run loop is identified in the flow diagrams.

3D mill models are being used in training of the mill operators before they can actually see and experience the equipment at site.

The development in recent years has moved towards 4D design in which the fourth dimension, time, is taken into account as an important variable from the beginning of the engineering work. Engineering efforts are directed so that the construction and installation works will be completed according the needs of the commissioning and start-up schedule, and water-run loops are considered from the beginning of process flow diagram work.

The current status of engineering tools in a design engineering company is presented in Figure 19.

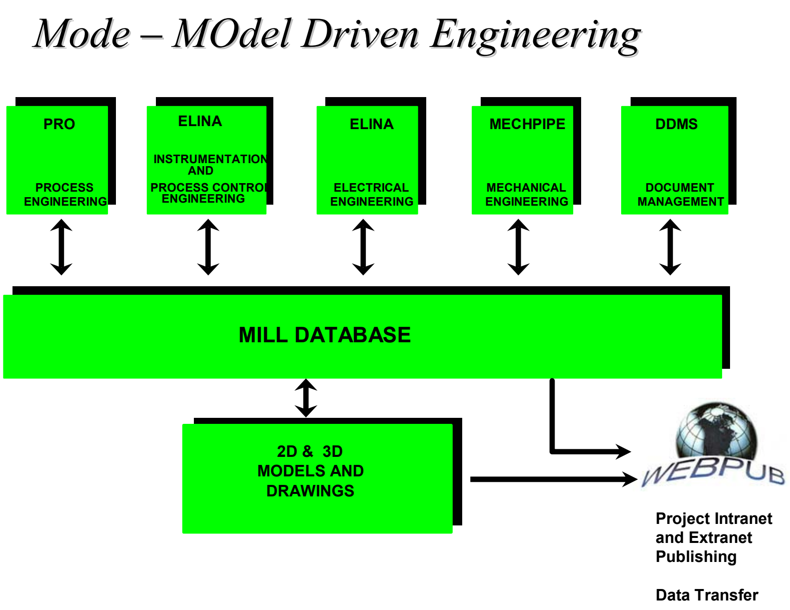

Figure 19 Connections between engineering tools and mill database, present system [97]

In the future, the virtual mill model will become more important as a source of mill data and information, and documents will become less important. The main reasons for this development are document management problems and difficulties caused by different standards and applications used in creating documents.

The objects in the model have interfaces to other mill objects and external objects, and the information that they include is available to the engineering disciplines and also to other project stakeholders as needed. The model can be presented according to different hierarchies, since e.g. the designer's needs differ from those of maintenance staff.

When documents are needed, e.g. for installation contractors, they are created from the mill model.

Depending on the project, designers from different design engineering companies and equipment suppliers can use, add or complement the information in the mill model.

The management of the mill model has to be well organised and open standards available for creating accessible models.

XML standards are one alternative being considered for information exchange. The mill model and its operator interfaces based on XML standards are presented in Figure 20.

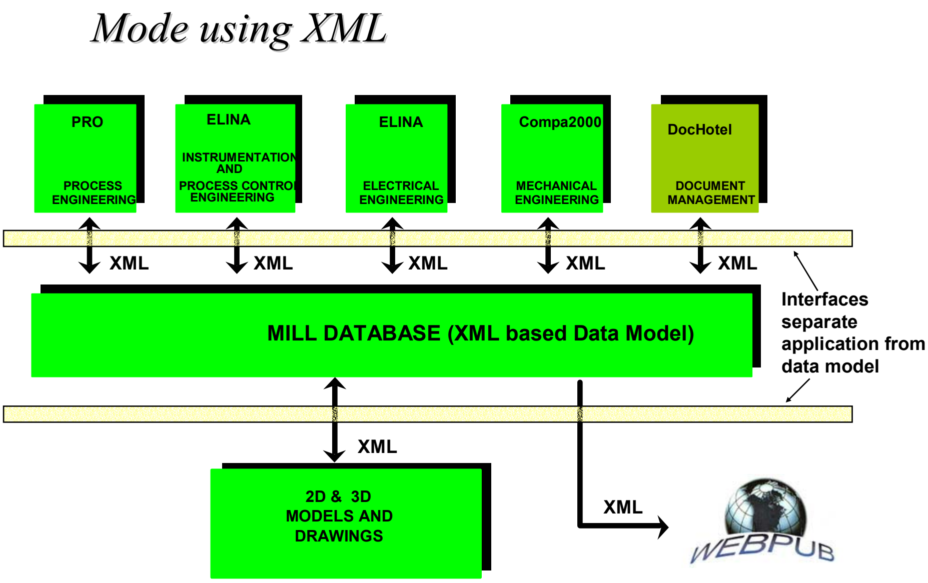

Figure 20 Future connections between engineering tools and mill database using XML [97]

7.5 Current Status of Process Engineering in the Pulp and Paper Industry

The status of process engineering is analysed in the following based on deviations, remarks and risks documented in the auditing reports of a consulting engineering company during the period 1997 – 2003.

The number of auditing reports is summarised in Figure 21.

Figure 21 Number of quality system audits in a design engineering company in 1997-2003

There have been 40 – 50 audits per year. Normally, the number of project audits has been about 30. The year 2002 was an exception with only 15 project audits, because there were fewer projects. The total number of audits in 2002 was 39.

During the audits, the following items are recorded:

- Deviations
- Reclamations
- Noteworthy items
- Risk items
- Development items
- Well kept items

To assess the status of engineering, the deviations, risks and reclamations which can be considered negative items in auditing have been divided between line management, project management and different engineering disciplines. This division was made by the author.

The results are presented in Figure 22.

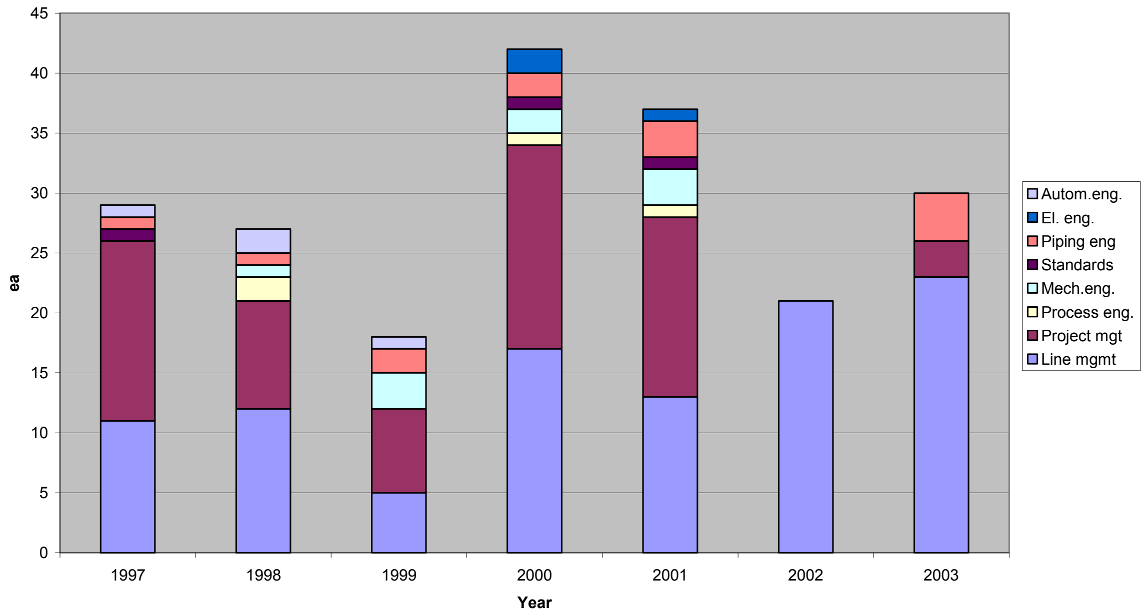

Figure 22 Deviations, risks and reclamations by discipline

The following conclusions can be drawn based on the results:

The largest number of negative mentions is allocated to line management, with most of the negative mentions in line organisation audits referring to line management staff.

In project audits the largest number of negative mentions is allocated to project management, as the project management has a big role in securing timely receipt and delivery of engineering documents.

Although risks are considered as negative aspects in this classification, risks which do not materialise do not cause any harm. The number of negative mentions that can be allocated directly to engineering disciplines is quite small.

Among different engineering disciplines, piping engineering gets the largest number of negative mentions. The number of negative mentions allocated directly to process engineering is small.

The distribution of risks, deviations and reclamations during different years is shown in Figure 23. As the figure shows, risk evaluation was implemented in 1999; before that only deviations and reclamations were noted.

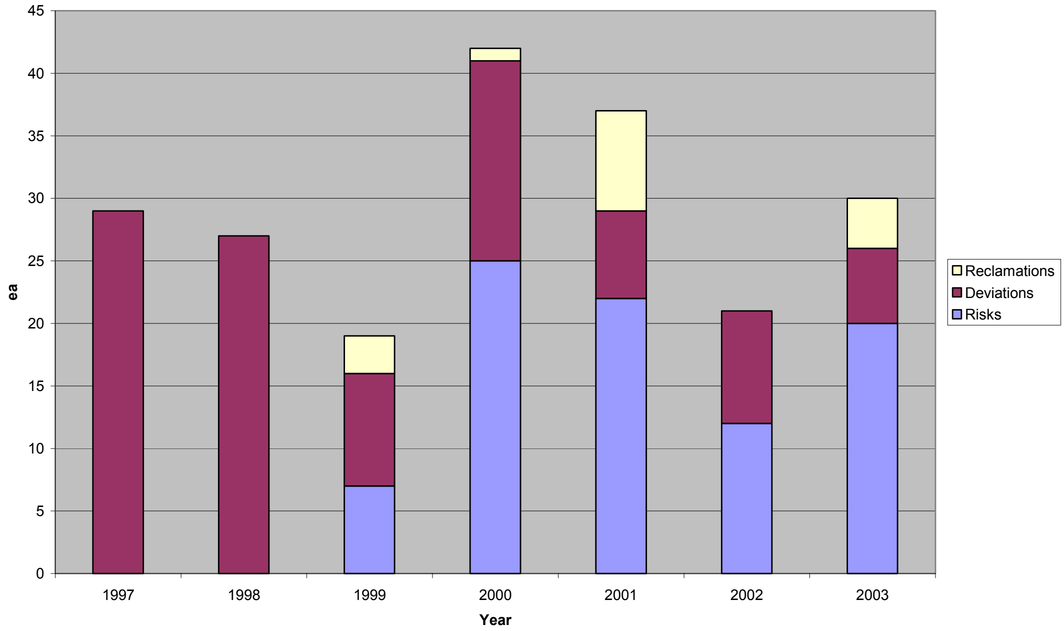

Figure 23 Distribution of risks, deviations and reclamations in 1997 – 2003

7.6 Design Engineer's Dilemma

The author's view of the design engineer's dilemma in a mill project is illustrated in Figure 24.

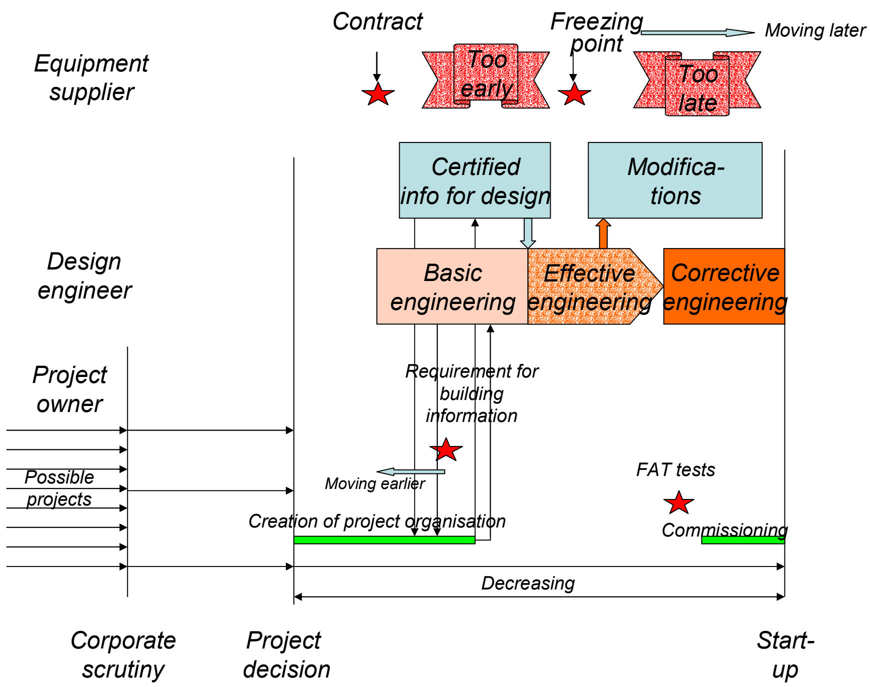

Figure 24 Interaction of project stakeholders in an industrial project

The dilemma is caused by the following facts:

In big companies, several pre-feasibility and feasibility projects are often in progress at the same time. Project teams are often mobilised only after the final project go-ahead decision has been made.

Project time schedules are shortening due to shorter equipment delivery times, and the freezing points of equipment suppliers for final decisions of equipment selection are postponed because of the shorter delivery times.

Civil engineering, however, requires finalised information at an early stage because of the increasing use of prefabricated elements.

The client's project organization's comments and approval of design engineers' plans and equipment suppliers' plans tend to be delayed by the project team's and operators' late commitment.

The information from equipment suppliers cannot be considered final until the freezing point has been reached. In many cases, information from some sub-supplier is non-existent until very late in the project.

The design engineer's work is ineffective before the final information is available.

Equipment modifications due to the design engineer's design solutions made after the freezing point usually result in discussions and financial claims.

According to the author's experience, these factors have become even more critical because of a number of recent developments:

Pulp and paper companies may have several feasibility studies going on at the same time and costs must be minimised before the project go-ahead decision. For this reason, the mills cannot recruit project personnel until the decision has been made. This might have been easier earlier, when the company management was closer to the mills.

Equipment suppliers' engineering and production are divided between several different units. Internal discussions about delivery limits, standards and other solutions used in the project may not be completed until the contract is made, as the equipment suppliers also want to save costs until they have secured the contract.

Equipment suppliers are nowadays subcontracting part of the equipment that they earlier used to manufacture themselves. This means that there may be several alternative solutions until the decision to purchase the equipment in question has been made, and the decision is made as late as possible to avoid early commitment of capital.

8 FUTURE DEVELOPMENT

8.1 General

In the following, an attempt is made to predict the future development of process engineering methodology.

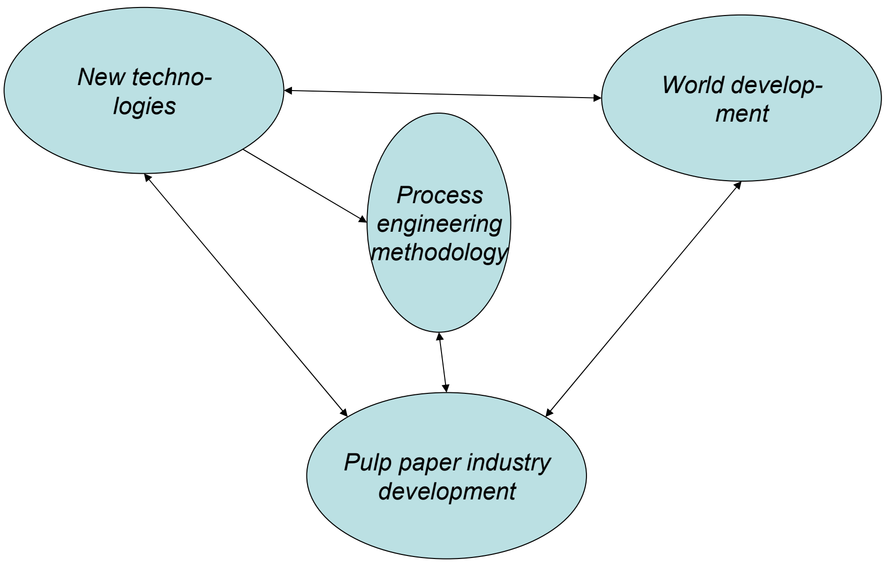

Figure 25 Development of process engineering methodology

The development of methodology is dependent on the development of (1) pulp and paper industry, (2) new technologies and (3) general world development.

On the other hand, the development of process engineering methodology may affect the pulp and paper industry's development. Most certainly, it does not have any noticeable impact on the development of new technologies, much less on the world development in general.

8.2 World Development

There is increased uncertainty in the world after the big political changes of 1989 – 1991. Since that time, several regional wars have been fought; also in Europe, which during the status quo of the cold war was a relatively tranquil area. The development in Europe was strongly affected by the enlargement of the European Union, when ten new members joined the Union in 2004, and more nations are negotiating future membership. The enlargement will have effects both inside the European Union and outside it.

The heterogeneity of the Union will increase considerably, and decision-making will be even more difficult than today. The movement of people from less wealthy countries to wealthier ones is expected to increase, which will influence development on both sides of this divide.

Uncertainty in the European countries which do not enter the European Union can be expected to increase, as the economic gap is most probably widening between them and the EU countries.

The aging of the peoples in the Western world will have a considerable impact on the population structure and labour markets.

An increase in terrorism seems inevitable, as in open societies terrorist acts are impossible to eliminate completely.

The anti-globalisation movement gathers both demonstrators, who are sincerely concerned about the concentration of economic power, and criminals, who just want to cause disorder. It remains to be seen how terrorist groups will exploit the demonstrations of the anti-globalisationists.

According to Jakobson, globalisation has its limits: the dissimilarity of values and constructs stays, and the economic inequality between and within the nations comes to a head [38].

A factor that will most probably have a big impact on all industry in the European Union is the Kyoto protocol, which the EU countries have signed, but competing nations have not.

The new chemical directives of the European Union will have an influence on the usage of chemicals in the industry [74].

8.3 New Technology Development

The development of new uses for wood is continuing. In the future, more wood is expected to be used in composite materials and in the chemical industry. This usage is expected to rely on raw materials that are different from those used by the pulp and paper industry, though new industries may also compete for the same raw material with the pulp and paper industry [101].

According to Tekes, chemical and machinery suppliers serving the pulp and paper industry are searching for new customers in other industries. This represents a threat to the pulp and paper industry, as research and process know-how is very much in the hands of equipment suppliers [101].

The media industry is growing rapidly at the moment, mainly in the field of electronic communications, which also represents a threat to the pulp and paper industry.

Development of biotechnology opens up opportunities for improvement of the pulp and paper industry's manufacturing processes and the properties of its end products.

The development of information technology facilitates creation of intelligent processes which consume less water and energy than the present ones [101].

On the other hand, the average growth of productivity based on existing machinery has been 1 – 2 % p.a., with the change to lighter products equalling 1 – 2 % p.a., so the average growth of consumption can be satisfied with the existing equipment, without any major new projects [61].

When examining the future prospects for paper and board products, the potential for new intelligent products seems to be improving [22]. Intelligent products have the following functional properties:

- Perceptual ability, helping to define the place and condition of the product
- Power of deduction, helping the product to adjust itself to changes in environmental and other conditions and ability of response, making it possible to carry out the transition. This guarantees the optimal action in all conditions.
- Ability to communicate with other systems, a core feature of intelligent products

Electronic paper is a product that positions itself between traditional paper and electronic screens. The production of electronic paper for commercial applications started in 2004. The product will be launched in the consumer market during 2004, first in Japan [82]. The first generation models will be black and white, in which the formation of text and pictures is based on an even layer of microcapsules containing coal and titanium dioxide, which change colour when the electronic charge changes. The pages can be loaded using e.g. mobile phones. The colour of the microcapsules remains even after the charge has been removed. Four-colour electronic paper displays are believed to be a long way off [51].

Electronic newspapers are being developed in several projects, and are expected to reach the market within the next few years [27].

On the other hand, the advantages of paper as a reading interface are also emphasised: paper is inexpensive, it is easy to convert and transport and the contrast between paper and printing ink is high. According to Ström the electronic newspaper is a product for a small and narrow target group, especially business people and students, but most probably the big audience is not willing to bear the inconvenience and pay the costs involved in this new technology [72]. In a study by Schilit, summarised by Leskelä, paper is considered a better interface in passive reading than electronic media, whereas electronic media are considered better for active reading [53].

The paper producer’s view is that readers trust printed media and that newspapers should offer more interactive feature to attract young readers. Magazines have been more active in transforming themselves according to young people’s wishes. The competition between printed and electronic media is considered good, as it makes the media industry more dynamic [68].

The electronic book has been on stage for several years, with controversial results [3]. The e-book was expected to make its final break-through in 2003. It is forecast to enjoy a great future, although in some quarters it is already seen as a flop [4].

In packaging materials intelligent products give many advantages in monitoring the status or position of the packed product. A good example are intelligent medicine packages which register when the patient has taken the medicine and gather data on how the medicine has worked. This technology is based on an RFID (radio frequency identification) chip which is integrated during the printing process to produce a computerized paper with a 35 kB memory [71].

For food products, intelligent packages can indicate the approach of the ‘best before’ date. They can also warn of leaks. A packaging system for meat products has already been developed, which absorbs the gases that cause the product to go bad [16].

Intelligent packages offer advantages in the logistics chain by indicating the locations and freshness of the product and when to replenish supplies [16]. According to the Technical Research Centre of Finland, VTT, from 2008 onwards electronic, updatable codes and tags will be available, which will be traceable and updatable with a mobile device [55].

Biotechnology is foreseen to offer great potential in the future development of the pulp and paper industry.

8.4 Development of Process Engineering Tools

Until recently, owner-operators were mostly interested in building, operating and maintaining their physical mill. The information collected during the different phases of the mill’s life-cycle was not sufficiently integrated. The new information technology standards open up new possibilities to build a virtual mill, integrating all the information from different stakeholders. The virtual mill can be viewed and maintained with various tools and it consists of all the data that defines the mill [93].

The purpose of the mill model is to keep mill data management as simple as possible, enabling easy implementation and use of the model by different stakeholders. Consequently, the model is static and excludes any dynamic nature and other behavioural aspects. The model is best suited for data transfer and static operations [93].

The roles of process models have also been studied by Virkki-Hatakka et al. [48].

The development of new tools for process engineering was widely presented in the ESCAPE-13 conference in 2003, including several papers on applications in the pulp and paper industry. The topics of most interest were pulp cooking, the recovery boiler and energy savings in process integration [48].

Simulation programs will be developed further and will find new uses especially in training applications. The use of dynamic simulation for engineering purposes is not considered to be significant because of the inaccuracy of the models, especially related to chemical pulping reactions, and also because of the huge amount of work that is required to prepare them. The information needed for sizing a plant can be produced with static balance and sizing calculations.

On the other hand, for standard processes such as pulp refining, dynamic simulation offers a powerful tool for designers and suppliers in analysing the operation of the plant.

Computational fluid dynamics is a method in which the material flows in a system are mathematically modelled and the behaviour of the system can be shown as a coloured picture. This method gives a very illuminating picture of the areas that need to be inspected, and it will most certainly find growing use in process engineering and process development.

8.5 Development of Paper Quality

According to Gädda, paper quality continues to develop in an evolutionary way. Surface quality is improving, lower grammages can be used and stiffness is better than it used to be [105].

In packing materials the changes are particularly visible:

- The appearance of the package is becoming ever more important
- Active materials can be used to identify the circumstances of the material packed: temperature, conservation time etc.
- Packages can include identifiers to make stealing or falsification more difficult
- Identifiers to enable location can be printed on paper

According to Gädda [105], micro-processors can be printed on paper, but according to Ström [71] it will take several years before micro-processors on paper can be commercialised profitably.

8.6 Development of Pulp and Paper Industry

In the 20th century, several inventions were made in electronic data transfer, which all were forecast to put an end to or reduce printing paper consumption growth: the introduction of broadcast radio in the 1920s and of television in the 1960s and the “paperless office” expected to result from improvements in automatic data transfer in the 1980s. These inventions did not put an end to paper consumption growth.

The development of the Internet and wireless communication in the 1990s is also seen as a threat to paper as a communication material, and it remains to be seen what the consequences are.

The development of newsprint and printing/writing paper consumption in Western Europe and the main events in electronic media development are shown in Figure 26.

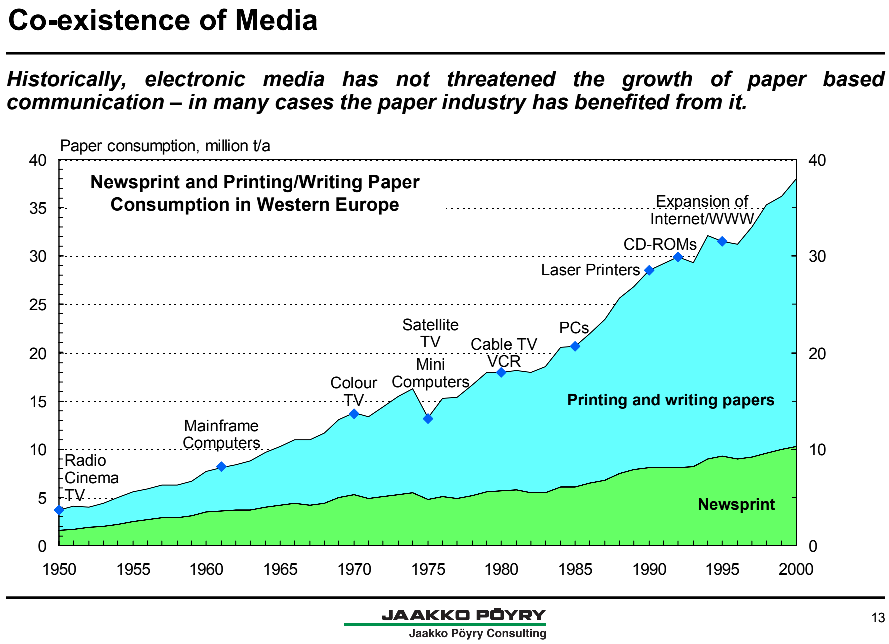

Figure 26 Newsprint and printing/writing paper consumption in Western Europe between 1950 and 2000 [35]

Oil-based raw materials were expected to assume a leading role as the packaging material and to replace fibre-based materials. However, the oil crisis in the 1970s and the requirements for sustainability changed this development. So far, fibre-based packaging materials have competed successfully against other materials, as the consumption growth shows, Figure 27.

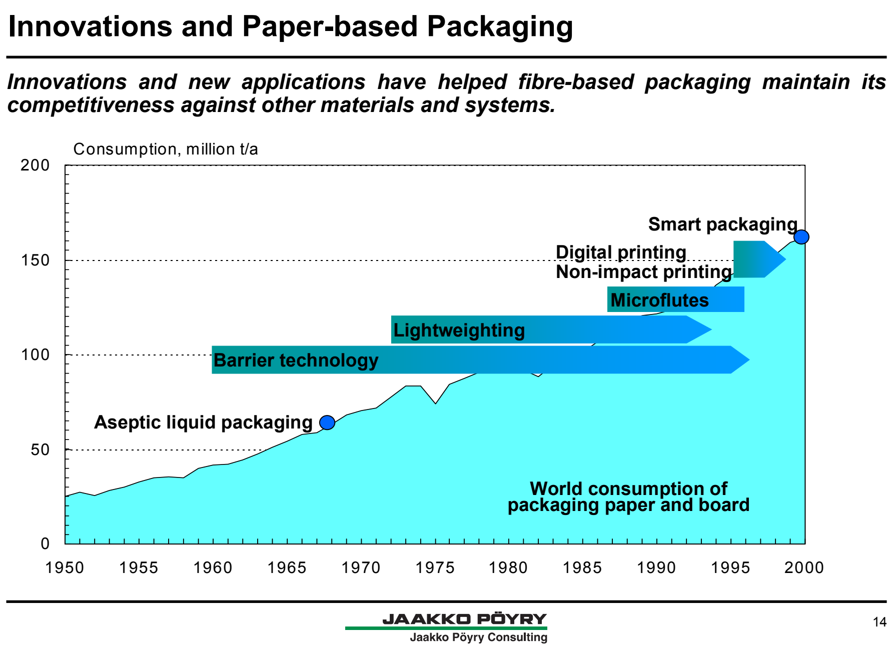

Figure 27 World consumption of packaging paper and board between 1950 and 2000 [35]

So far, the growth of paper and board consumption has followed the growth of GDP in the world, and the growth is expected to continue at an average rate of 2.2 % up to 2015, Figure 28.

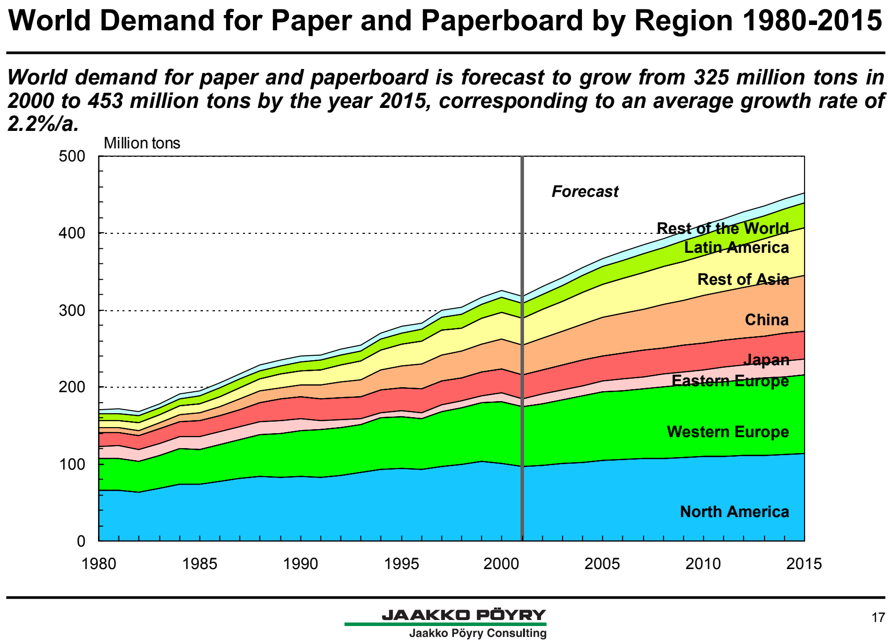

Figure 28 World demand for paper and paperboard by region 1980 – 2015 [34]

Future growth expectations vary considerably between different paper grades. Some examples are shown in Figures 29 and 30.

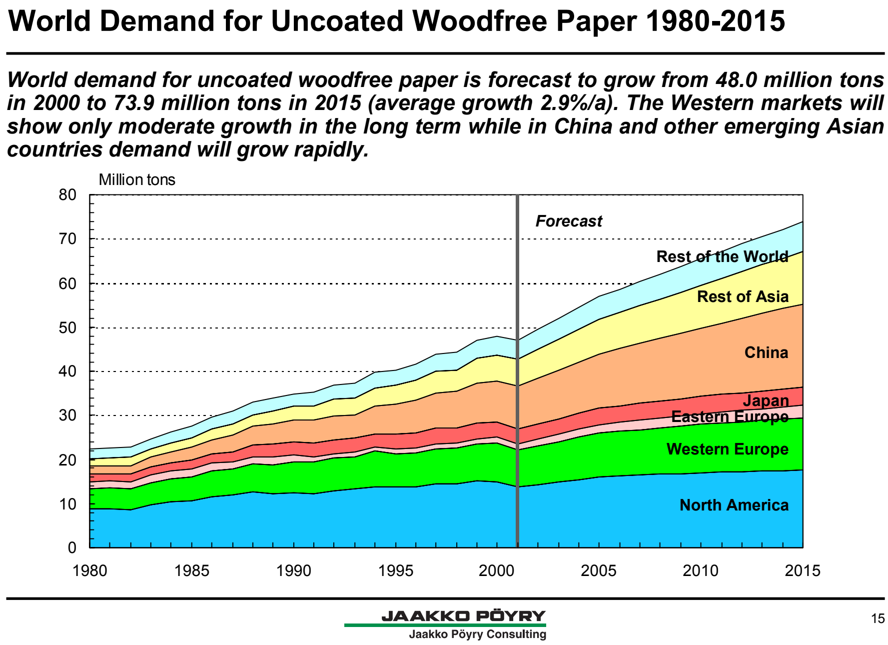

Figure 29 World demand for uncoated woodfree paper 1980 – 2015 [35]

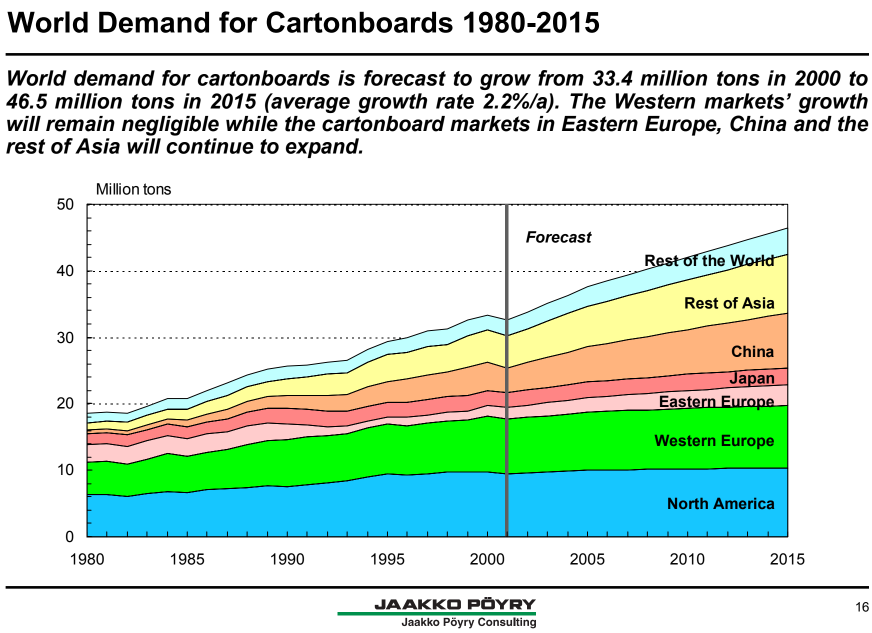

Figure 30 World demand for cartonboard 1980 – 2015 [35]

Significant growth is also forecast for pulp in the near future, to meet the needs of increased paper production.

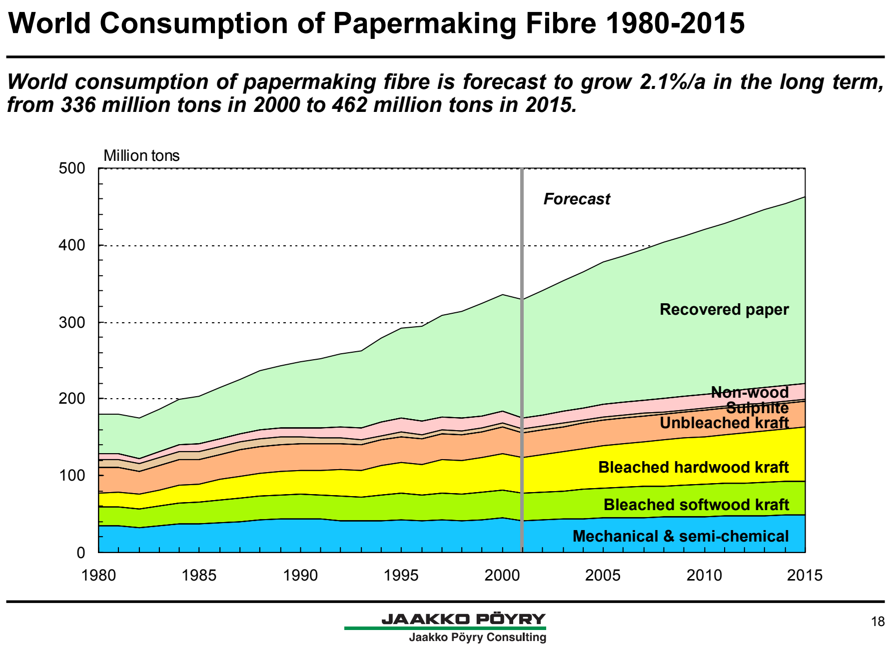

Figure 31 World pulp consumption in 1980 – 2015 [35]

These projections are questioned by some researchers, who say that the link between GDP growth and paper consumption has been broken by the growing importance of electronic media. According to these researchers, the decline in demand for some printing paper grades in the past few years is no longer cyclical. As younger generations spend more time on electronic media, the importance of printed media is decreasing, which is bound to affect paper demand [26] [65].

8.7 Sizes of pulp and paper mills

The sizes of pulp and paper mills have continuously grown. The production capacities of single line chemical pulp mills have grown from 400 000 t/a to 900 000 t/a during the last 30 years as shown in Figure 32.

There are views, that the sizes of continuous digesters have already exceeded the optimal limits as the fibres are treated unevenly in the different locations of the digesters as the diameters grow. The development work still aims for bigger production capacity for the chemical pulp lines.

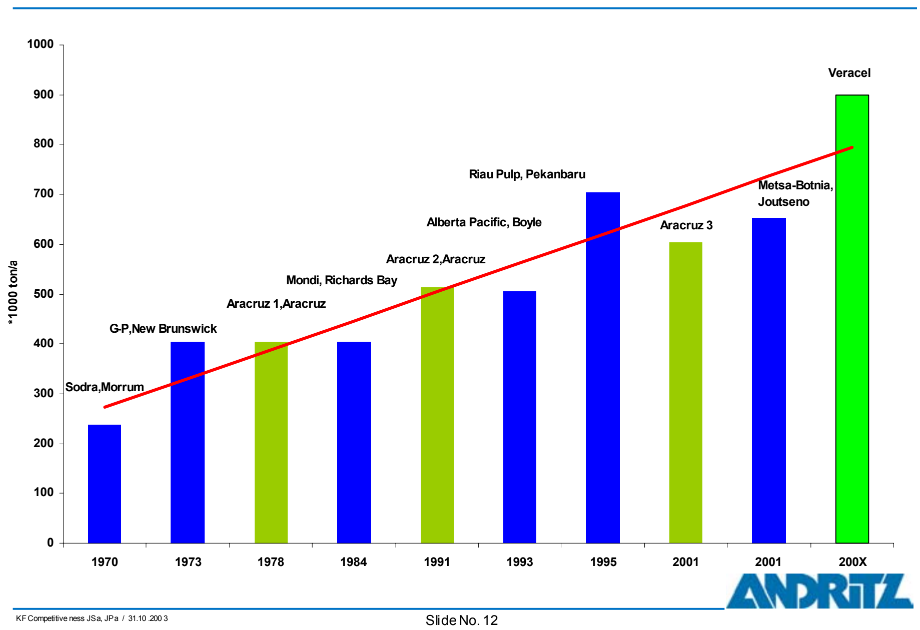

Figure 32. Development of chemical pulp mill design capacity, 1970 – 2004 [83]

At the moment there are mills with the design capacity of 3 000 t/d under construction, and according to the equipment suppliers all the elements to build a chemical pulping line of 4 000 t/d already exist [84].

The view of Andritz Oy of the production capacity development in chemical pulping is shown in Figure 33.

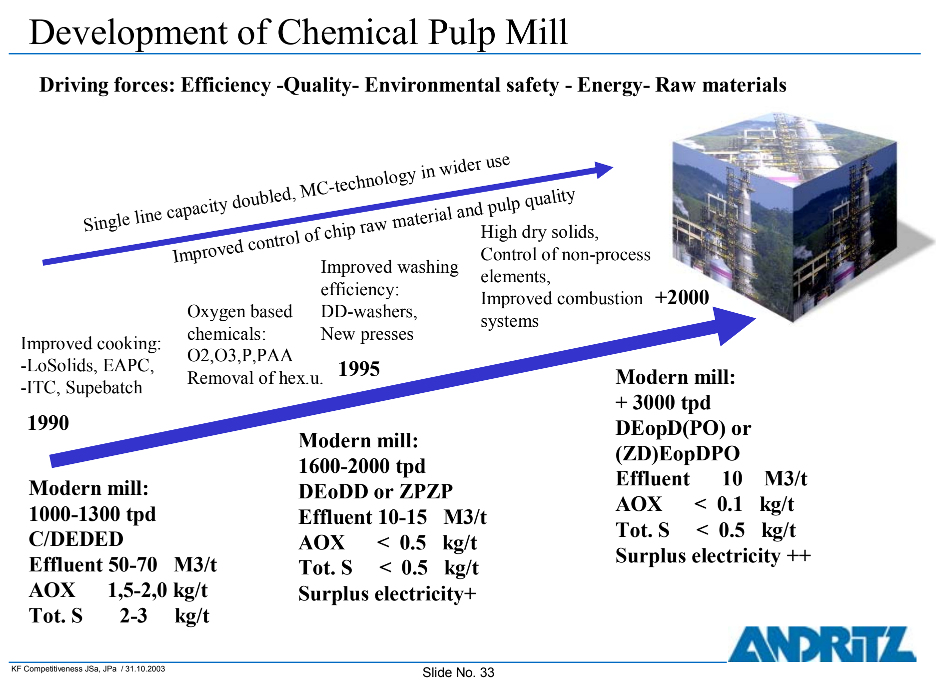

Figure 33 Development of chemical pulp mill [83]

Development of the sizes of paper machines is shown Figures 34 and 35.

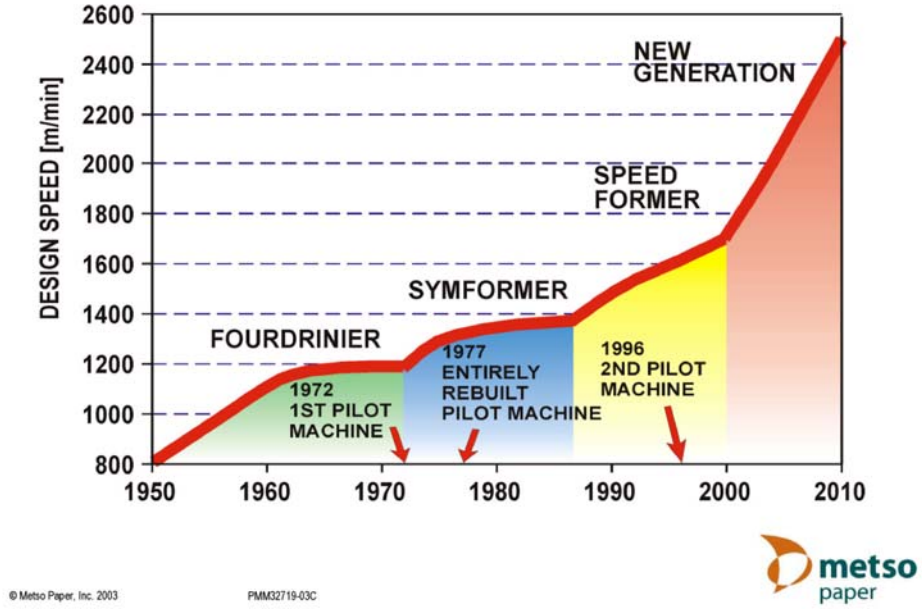

Figure 34 Past and forecast paper machine speed development [63]

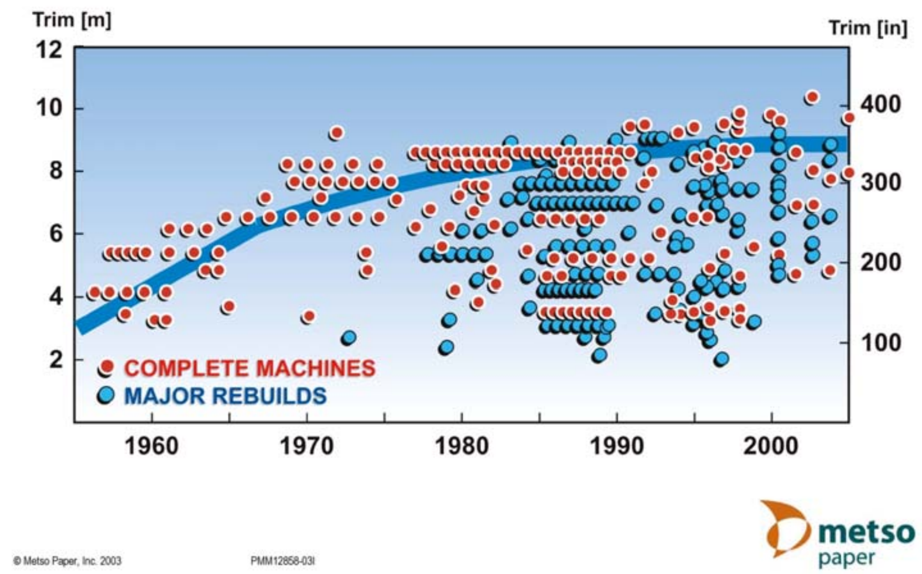

Figure 35 Trim development of Metso paper machines [63]

The common view of the big paper machine suppliers is that the maximum widths of the paper machines have reached a level that is difficult to exceed because of structural reasons. New development in the paper web threading from the press section to the dryer section is happening at the moment, and design speeds as well as production speeds of the paper machines will rise clearly.

Thoughts have been presented, that one should make narrower paper machines and locate them so that two machines could be operated by one crew. This way the production increase could be staggered so that there would be less new production for the markets to absorb at one time. The economies of scale and the difficulties of operation several machines by one crew are at least at present pushing the development of the paper machines towards the maximum possible sizes.

8.8 Pira's Factors

Pira International has identified seven factors that will influence and affect the pulp and paper industry [66]. These are:

Globalisation and competitiveness

Now the trend in the industry is towards concentrating on specific product sectors. The structure of the industry will be built around a small number of large players and a large number of small niche players; medium-sized companies will disappear.

Siitonen has studied the globalisation and regionalisation strategies of the pulp and paper companies in her dissertation. Her conclusion is that the companies which have been active in globalisation process have become the best performers. Other good performers are the companies that remain intra-regional, if they are able to maintain good competitiveness and high asset quality. Those companies that are aiming to become inter-regional have the biggest difficulties [92].

Market positioning

The paper industry has to change its focus from that of a process industry driven by 'tonnes out of the door' to an industry that will become an integral part of supply chains delivering to end users and consumers.

End users expect the product to perform consistently and develop in line with changing technologies. Such expectations can only be met by the paper industry becoming truly customer-focused and being sufficiently flexible and agile to be able to develop and deliver to the market a stream of new and improved products [66].

Technology

Technology manifests itself in a number of ways: as new high-speed paper-making technology delivering large-scale, high-efficiency capacity, via on-line rebuilds for new levels of efficiency, through to more sensitive process upgrades to restore competitiveness of older assets. It is also radically changing and improving sensing and control in the paper-making process from the wet end through to the product. Perhaps the greatest challenge is the effective use of the new technology [66].

Innovation and R & D

For many years, the machine suppliers have been the main source of process technology innovation. The question is how long the suppliers will continue to invest in process technology innovation on behalf of the industry in the face of decreasing potential returns.

Some pulp and paper companies do not directly invest in R&D but rely entirely on external sources for their technological development. In pulp and paper industry, R&D efforts should be increased, not reduced. There needs to be a willingness to develop strong multidisciplinary teams, drawn from relevant parties within the supply chain [66].

Raw materials

Overall, there is sufficient raw material to service the needs of the paper industry. The industry will, however, be affected by competition for the land, alternative uses of the fibre/cellulose derived from the forests and alternative routes for maximising the yield and extraction of fibres [66].

Environment

The pulp and paper industry has responded to the environmental demands placed upon it. The new challenges facing the pulp and paper industry include:

- IPPC Directive
- the Post-Kyoto Strategy

Economic issues

The creation of shareholder value can no longer be dependent on improvements made through incremental production or cost reduction. Into the equation comes the achievement of building long term relationships with the 'right' customers. This is in line with the overall shift in focus from 'production-oriented' industry to 'customer-focused' industry [66].

8.9 R & D Challenges in the Pulp and Paper Industry

The research council of the Finnish Pulp and Paper Research Institute (KCL) carried out a study in 2003 of the challenges of pulp and paper industry. Its purpose was to analyse the whole forest products cluster and the customer challenges facing the forest products industries, especially the paper and packaging products [80].

In this study, major challenges were seen in the following areas:

Changes in information technology and new media for information sharing and communication represent a challenge for paper industry. Paper consumption is expected to decrease because of these new media, but the technologies also create new possibilities for paper and packaging industries.

Alternative packaging materials represent a challenge for wood fibre-based packaging industries. In this area, sustainability and composite materials create new possibilities for wood-based materials.

Important matters to safeguard the future of the pulp and paper industry in Finland are, according to the study:

- To guarantee the development of the know-how and make sure that there will be enough skilful people also in the future

- To secure continuous development of production processes in co-operation with forest cluster industries. Special emphasis must be given to process, product and service innovations, which traditionally have had a big role in research institutions.

The role of paper in the media industry, especially in printed media, has changed considerably and is expected to continue to do so. Unlike in the past, all stages of an information distribution process can be digitalised, and electronic distribution today complements printing and physical distribution. The paper industry is not considered as one of the core processes of the media industry, only as a raw material supplier to printing houses. The paperboard industry is also seen as a raw material supplier to the packaging industry [80].

Print on paper is expected to retain its key role in traditional applications like newspapers, magazines and books due to its availability and economy. New possibilities are probably opened by integration with the energy cluster and IT cluster, and by the promotion of sustainability.

In the packaging industry, the competition between various materials will continue, and fibre-based materials have safeguarded their position in hard packages due to their excellent visual properties and cost-effectiveness. In soft packages, plastic has superb properties, such as flexibility, transparency and resistance to moisture or oxygen.

At present, several technology investments by foreign companies in forest cluster industries have strengthened Finland's position as a leading nation in the forest product industries [75].

8.10 Forecast for the Next 25 Years

The Ministry of Trade and Industry of Finland commissioned Jaakko Pöyry Consulting Oy to carry out a study in 2003 to review the development of the pulp and paper industry in Finland from now up to the year 2030 [79].

The technological trends foreseen in this study are the following:

8.10.1 New Technologies for Paper Manufacturing [79]

The following new technologies in paper and pulp manufacturing are either in the early stages of production or expected to evolve during the study period into technologies that are commonly used in commercial production:

High-consistency forming

This technology means that the stock consistency in the paper machine's headbox is raised from today's normal consistencies of 0.5 – 1.2 %. Consistencies of up to 20 % have been considered and a laboratory-scale former has been tested with consistencies of 5 – 12 % [18].

High-consistency forming technology is nowadays in use in liquid packaging board manufacturing, with a consistency of 3 %.

The advantages of high-consistency forming are economy-related: higher consistency means less pumping of liquid, less dewatering and less need for storage capacity.

The effect on paper quality is two-fold: bulk and thus stiffness improve, whereas formation and thus optical and strength properties are impaired, which is why high-consistency forming has not become a standard method.

Higher consistency than 3 % requires a new kind of forming technology with higher shear forces and turbulence.

A lot of development work has been done during the past few years, which may lead to commercial solutions in the future. Board manufacturing will be the primary target.

Multi-layer forming

Multi-layer forming is commonly used in board and tissue manufacture, but in printing and writing paper grades it has not yet made a commercial break-through.

Multi-layer forming can be either complete layering, in which the stock components may consist of different types of pulp, or chemical layering, in which the basic stock is the same for all layers but filler and chemicals can be proportioned into different layers in desired proportions. Complete layering aims for better raw material economy, decreased basis weight and increased stiffness, whereas chemical layering aims for better control of filler distribution and thus better printing properties.

Complete multi-layer forming requires separate stock preparation systems for different layers. Chemical layering just requires separate headbox feed systems and separate filler and chemical proportioning systems, as the stock is the same for all layers.

Dry forming

Dry forming technology is used in the production of hygiene products and napkins. In this method the fibre content of the raw material is 85 %, the remaining 15 % being latex.

A new method in which the paper web is formed from pre-treated fibres with air is being developed for the manufacture of various paper grades.

Dry forming is being studied in the Helsinki University of Technology, and the findings look promising [46].

Fibre filling

Studies have been going on for several years on the filling of voids in cellulose fibres with chemicals, such as precipitated calcium carbonate and titanium oxide. This method is meant to improve the retention of filler in paper and to optimise the share of fillers. With this method paper strength properties improve as the share of filler flocculating on the surface of fibres is smaller than in conventional proportioning. An advantage that this method is expected to bring is improved opacity at lower grammages.

POM technology

This technology has been developed to simplify the paper machine's short circulation. The aim has been to facilitate grade changes, reduce investment costs and minimise energy and water consumption.

Some systems are already in use, but this technology still remains to be introduced for big and modern machines.

Impulse technology

Impulse technology combines wet pressing and contact drying. The paper web is directed through a hot press nip, in which the temperature is 150 – 500 °C and the pressure 0.3 – 7 MPa and retention time up to 100 ms. More water is removed from the web than in any other pressing method, making it possible to increase the production or reduce the size of a paper machine. It also offers possibilities for improving paper quality. A negative aspect is the tendency of the web to split after the nip.

The impulse technology has been developed in STFI in Sweden and is today considered technically viable [70].

This technology is not expected to be applied at commercial scale in the near future.

Condebelt technology

The Condebelt technology was patented in 1975. In this technology, the paper web is dried between two smooth steel belts: an upper belt heated with steam and a lower belt cooled with water. The paper web is transported between two wires and dried in contact with the hot steel belt under pressing. The pressing force is determined by the steam pressure. The evaporated moisture migrates through the wires and is condensed on the cooled steel belt, where the latent heat of the steam is transferred into the cooling water.

The method was developed to make drying more effective. About 80% of the primary heat energy used is recovered, but it is important to find a sensible use for the warm water generated in the process.

The Condebelt technology was found to have a positive effect on the quality of board. Two units are in production at the moment.

Combined with other drying methods, the Condebelt technology makes it possible to increase the efficiency of board production and to create new properties for the product.

So far, operating speeds have been much lower than for modern printing paper machines, and the pronounced two-sidedness of the product makes it difficult to use this technology on paper machines.

Impingement drying

In this method hot air (300 – 400 °C) is blown in high speed (90 m/s) on the paper web. This increases evaporation and thus the drying section of the paper machine can be shortened up to 25 % compared with the cylinder drying.

This method consumes more energy than cylinder drying.

With this method the paper web threading from press section to dryer section is improved so that the highest paper machine speeds for certain paper grades (newsprint, SC-offset) will raise about 200 m/min [39].

Spray coating

Spray coating is a new coating technology using high-pressure spray nozzles for coating and surface sizing. In this method, the paper web can be coated simultaneously on both sides without touching the paper surface. The coating layer is evenly thick.

Spray coating technology makes it possible to raise the speed of coating machines, and develop new coated grades.

The spray coating method is suitable for wood-containing and wood-free paper grades as well as board grades. The operating costs of spray coating are lower than those of other coating methods, as there are only a few parts that wear or require maintenance; also paper web strength requirements are smaller than in conventional coating. The efficiency improvement is said to be 5 - 6 % compared to blade coating and 2 % compared to film coating.

Dry coating

In dry coating the paper is coated with dry pigment, which is a low-water precipitated calcium carbonate, called nano-PCC. This method combines particle transfer based on ion blasting and a new method to prepare PCC. The particles manufactured with this method have better optical properties than particles produced with the conventional method.

This method makes it possible to improve many paper properties, because the web is not re-wetted and re-dried. It also decreases the water consumption. Energy-savings in coating are expected to be up to 90 %. Investment costs are also expected to be considerably lower.

This technology is being tested at pilot scale, but it is not expected be commercialised until spray coating has stabilised its position.

Long-nip calendering

Long-nip calendaring is based on shoe press technology and soft roll covers. The small elastic modulus of the roll covers minimises the pressing of the web. Thus, good bulk is achieved and the uniformity of printing properties and gloss are improved. For this reason, the grammage of the paper can be reduced and production efficiency improved.

8.10.2 New Technologies for Chemical Pulping

New and revolutionary technologies that would replace sulphate pulping are not expected to emerge within the next few decades. The sulphate pulping technology is being continuously developed to increase yield and energy efficiency and to reduce discharges [79].

The most interesting new technology that has been studied for several years is gasification of black liquor. This would lead to a substantial increase in the power production of pulp mills, from 500 kWh/t to 1000 – 2000 kWh/t. This technology is being studied and major pilot plants are being built in Sweden and the USA [79].

8.10.3 New Technologies for Mechanical Pulping

Thermomechanical Pulp

The development of pulp refining processes aims at reducing the power consumption in refining, which is in the range of 2400 – 3300 kWh/t, depending on the quality of the pulp [79].

RTS technology is an example of new refining technology. In this technology, the pressure and temperature as well as refiner speed are increased, allowing a decrease of 10 – 20 % in energy consumption [79].

Groundwood Pulp

In groundwood pulping the main emphasis is expected to be on developing grinders from batch operation into continuous grinding machines. The continuous-feed grinder capacity is expected to be 60 – 70 % higher than the highest capacity of today's grinders [8].

8.10.4 Development of Printing and Writing Papers

In a recent study [79], the following main trends are forecast for different printing paper grades:

The need for pulp refining is expected to decrease, which reduces power consumption of paper making process.

Cleaner plants will be developed to reduce power consumption. Paper machine wet-end chemicals and wet-end chemistry control will be developed to improve the paper properties and to improve the evenness of the paper web. Process monitoring systems will be improved, which allows more effective use of raw materials and chemicals.

Paper machine production speeds will be increased, especially for woodfree grades. This development is due to following improvements in paper machine construction: New types of headbox design will facilitate controlled fibre orientation. New types of wire and press design will be developed. Press section with no suction roll will improve paper quality, because suction roll marking decreases and less air is emitted in the paper web. New drying methods are being developed. Calendering equipment will be developed.

Spray coating will be used for surface sizing, allowing higher production speeds. Spray and curtain coating will be used for coating, and special fillers and coating pigments will be developed. Drying equipment after coating will be developed to improve efficiency.

New technology allows more efficient grade changes.

Newsprint

The trend is towards surface-sized or coated (5 – 8 g/m^2) newsprint. The coating will be done in the film coating units, and new types of coating pigments are being developed. New calendering methods will be developed.

In the coated grades the share of long-fibred pulp will increase to ensure greater strength. New types of lower-freeness mechanical pulp will be developed for newsprint pulp.

Paper machine speeds will increase, and a press section with two shoe presses will become common practice, although today there are controversial opinions about the right press section type.

Wood-containing grades

Filler contents of the wood containing printing papers will be increased and the share of fibres decreased.

In Finland, only high quality SC-A grades will be produced; lower-quality SC papers will be made in areas where recycled paper is available.

Ever better multi-nip calendering concepts for SC paper grades will be developed to improve the gloss and smoothness of the paper web. Minimum two-sidedness of the web is the goal of the paper producer, as the all the pages of the magazines are printed with four colour printing.

The share of coating in LWC paper will increase, and the whiteness and gloss of the paper will be improved. New coating methods for LWC paper will be developed, and tailor-made PCC pigments for coating and filler will be developed.

The use of long-fibred kraft pulp as reinforcement pulp for LWC grades will be reduced and the quality of mechanical pulp improved.

Woodfree grades

The share of fibres will decrease and the share of filler and coating will increase. Methods to fill fibres with fillers will be developed to improve opacity. The share of short-fibred chemical pulp will increase and that of long-fibred pulp will decrease. The share of recycled pulp and also CTMP pulp will increase

Multi-layer forming will be introduced to make the best possible use of different raw material components in different layers of paper.

Surface sizing technology will be improved to facilitate paper machine speed increases.

Coating methods will be developed to improve printability. Drying equipment will become more efficient. Tailor-made fillers and coating pigments will be introduced.

New calendering methods will be developed.

8.10.5 Tissue

The following main trends are forecast for tissue production:

The TAD (through air drying) method will be developed to replace the press section on tissue paper machines for the heavy, bulky and absorbent grades. This method is already in use in the USA, but not yet in Europe.

Shoe presses will become more common in the tissue paper machine press sections. This will increase the bulk and softness of the product. Higher-temperature hoods will be developed to raise the production capacity of paper machines.

8.10.6 Board grades

Board production is expected to be characterised by the following main developments [79]:

Raw material components will be specifically selected to increase the bulk of the product. Refining of fibres will be more energy-intensive and fractionation of fibre components will become more common.

Improved stock screening will make cleaner plants obsolete. New chemicals will be used in the wet end of board machines.

Production speeds of board machines will be increased, especially for grades with a high share of long-fibred pulp. Higher headbox consistencies will lead to easier dewatering and reduced energy consumption. Gap formers will become more common on board machines.

Press sections with no suction rolls will be introduced to improve board quality; press sections will be equipped with two shoe presses.

Film transfer coating will be used for surface sizing and pre-coating. Spray coating will become more common, and also new coating technology and tailored coating pigments will be developed.

Long-nip calendering will become more widely accepted. Also multi-nip calendaring is increasing in board production.

Process control systems and quality control systems will be improved. Board machine control technology will improve.

9 CONCLUSIONS

9.1 Factors in World Development Affecting Process Engineering

The world's development will continue to be driven by the accelerating globalisation. Regional conflicts and widening differences in wealth bring uncertainty and unrest.

A factor causing uncertainty is the effect of environmental and energy aspects, which at present are in a phase of transition period because of the Kyoto protocol. The protocol's requirements are respected in the European Union, whereas some major competing countries have announced that they do not intend to comply with its requirements. Emission trading is starting, creating a clear disadvantage for the companies or production units which have improved their operations gradually by adopting the latest technology.

9.2 Factors Affecting Paper Industry

The pulp and paper industry is expected to retain its status as an important branch of industry in the foreseeable future. Its products have many advantages, and so far paper and board consumption has continued to grow despite the introduction of competing technologies that have been forecast to make paper obsolete.

Paper consumption growth has traditionally followed the growth of GDP. At the moment, this link seems to have been broken, with paper consumption growth in developed countries being clearly slower than GDP growth. However, in developing countries paper consumption growth is clearly higher than the growth of GDP.

The latest developments in electronic media have changed the consumption patterns of some major paper grades, causing their consumption to go down, at least regionally. An example of this development is the newsprint consumption in the United States, where the consumption has gone down since 1987.

Paper is in many respects a good reader interface, both from the readability and availability point of view. So far it has not been matched by electronic media. Electronic paper has been under development for years. Some developers of electronic paper have announced that they intend to start commercial production during this year.

Bulk products will be produced on paper and board machines which are as wide as the widest paper machines today. Paper machine operating speeds will continue to rise.

The present trend towards bigger companies and higher investment capital returns has clearly reduced the number of capital investments. Another factor that limits the number of projects is the huge production capacity of the new mills, which creates a big problem for marketing the products.

No major change in paper mill processes for bulk products is foreseen, but the process development will continue in an evolutionary way. Of the new developments referred to in Chapter 8.10, a clear majority is based on the development of main machinery; only a few improvements in process systems are listed.

Mills making bulk products will be increasingly standardised and the processes simplified. The pressure to reduce investment and engineering costs will result in simpler processes. This requirement is also valid for engineering work; standardised processes and mill layouts require only a minimum amount of engineering.

On the other hand, the increasing requirements for uniform product quality and the development of sensors for measuring the chemical status of the stock in critical places cause a need for more automation. This also increases the amount of process design work.

9.3 Development of Process Design

Traditionally, process design in the pulp and paper industry has been more focused on the mechanical aspects of paper manufacturing than on its chemical aspects. This is because mechanical aspects are more concrete, though also the process designers' educational background has played a role.

In the future, there will be a stronger focus on chemical aspects. New sensors allow better definition of the chemical status of pulp and paper mill processes, which has to be taken into account when the processes are designed. The importance of understanding organic and inorganic chemistry will grow in process design.

The rapid development of process control systems and other automation systems is one factor that also process designers must be aware of. The signal traffic between different automation systems complicates engineering work in some respects, and the process designer must be aware of the type and requirements of information exchange. In many cases, the best operator interface is specified by the process designer.

The importance of process integration will grow with the rising costs of energy and raw materials and growing environmental requirements.

New technology is developed at a rapid pace and the tools for engineering work are quickly outdated. This results in continuous change and time-consuming learning to use new tools which makes the work inefficient and also causes the reference information to be quickly outdated.

As project time schedules become shorter, less time is available for engineering, which means that process design decisions must be made quickly to enable other engineering disciplines get their initial data in good time. This is in contradiction with the development described in Chapter 7.6, which tends to lead to a very difficult situation from the point of view of detail engineering. For this reason, the process engineers must have a clear vision of the preferred design solutions and the professional ability to convince the project stakeholders that these solutions are correct.

Pulp and paper mills have expressed their clear desire to standardise mill design solutions and to reduce engineering costs in mill projects. This attitude can only lead to design solutions that are similar to the best ones of today, but major innovations cannot be created.

During the 1970s and 1980s, the engineering work done by design engineering companies, which included process development and design, gave clients new technological solutions by combining the best of different suppliers' solutions. Since then, process development has lost its status in design engineering companies, who have concentrated on developing integrated design systems and project management tools, while leaving the process development work to the equipment suppliers. The process design in design engineering companies has lost its creativity, and its main task today is to convey information from equipment suppliers to the detail design disciplines. This is done by feeding the required data into the database of the virtual mill model, increasing the share of routine work in process design.

The equipment suppliers have willingly increased their commitment to process design, as their supply packages include complete mill departments, and as they also wish to participate in the whole life-cycle of their clients' mills. The supplier's commitment to and responsibility for the process can indeed be seen as a positive development, at least from the industry's point of view.

9.4 Summary

The author's view of the future development of process engineering can be summarised as follows:

Process development will be largely driven by the main equipment suppliers. The reason for this development is their ambition to supply complete plants or process systems instead of single pieces of equipment. This leads to complicated processes, as the operation of the machinery is often improved by adding more controls around it.

The pulp and paper companies' interest lies in product development, as their main goal is to create winning brands and effective brand management. They willingly cede responsibility for process development and project management to major equipment suppliers. This development will spread to the pre-engineering phase, during which the main process solutions are developed. Ultimately, this will lead to fewer alternatives for pulp and paper mills.

Design engineering companies will find their niche in detail engineering based on approved process solutions. Their development work will focus on increasing the efficiency of engineering work.

Process design is a content-producing profession, which requires certain special characteristics: creativity, carefulness, the ability to work as a member of a design team according to time schedules and fluency in oral as well as written presentation. In the future, process engineers will increasingly need knowledge of chemistry as well as information and automation technology.

Process engineering tools are developing rapidly. At the moment, these tools are good enough for static sizing and balancing, but dynamic simulation tools are not yet good enough for the complicated chemical reactions of pulp and paper chemistry. Dynamic simulation and virtual mill models are used as tools for training the operators.

Computational fluid dynamics will certainly gain ground in process design.

10 RECOMMENDATIONS FOR FUTURE RESEARCH

Pulp and paper industry can be considered a mature industry branch, in which the present major processes are well established. In this type of industry, careful process design is essential in order to compete successfully.

The profitability of the plants is based on economies of scale, and at least from the point of view of design engineering, a totally new technology is unlikely to make a break-through in bulk grades, so that it would be able to compete with existing technologies in meeting the ever-increasing demands for short- and medium-term profitability. A totally new technology involves risks that are hard to contain.

A pulp and paper industry leader once noted that paper engineers are so simple-minded that based on similar sources of information they make similar decisions. As the education of pulp and paper engineers is very concentrated, this statement is most probably more truthful in the pulp and paper industry than for instance in the chemical industry. This could be examined in more detail by comparing the education and innovativeness of engineers and the development of the chemical industry with those of the pulp and paper industry.

Product development research is growing in importance, as paper, as an information carrier, is facing increasing competition from electronic media. As a packaging material, paper and board are competing with oil-based materials. In this competition, paper and board have advantages as well as disadvantages, which lead to development of composite packages combining different materials. Intelligent packaging applications are the subject of intensive development work.

According to sources studied by the author, process integration is relatively well taken into account in the pulp and paper industry. It is a natural part of process engineering during the early phases of project development when the mill design concepts are developed. This is why it is not an issue in the everyday working life of process engineers. However, because of the trend towards sustainability in terms of raw materials, energy and the environment, extensive publicly funded research is being done in this area.

Process intensification has become an issue in the pulp and paper industry. The Marcus Wallenberg award winner P-O. Meinander has strongly criticised many design solutions that have served as cornerstones of the paper-making process without explaining the theoretical background for his criticism [59] [60]. He and the big equipment suppliers have developed paper mill wet-end designs, in which the water volumes are considerably smaller than in traditional systems. The smaller volumes make grade changes faster and thus improve the efficiency of operation. This subject merits continued research.

The research concerning the development of process engineering could be continued by comparing the design of pulp and paper industry processes with processes in the chemical commodity industry and by analyzing the similarities and differences of the process engineering methodologies. Differences worth analysing can be sought for instance in:

- Sources of initial data
    - importance of main equipment suppliers
    - exactness of natural sciences (physics, chemistry)
    - significance of laboratory tests and trial runs
- Process engineering methods and tools
- Education and career backgrounds of process designers

11 LITERATURE

1. A Jaakko Pöyry Review, *Future of Paper in the Telematic World,* Helsinki 1984

2. Aarikka, A, Interview of Eino Mäkilä on 4.1.1981, 10.12.1982, archives of Metsä-Botnia Oy, Joutseno Mills

3. Ahti, J., *eBooks and WSOY,* Lecture in AEL/INSKO Seminar "Älykkäät paperit", 22.11.2001, Espoo

4. Almegård, A., *Välkommen till framtiden!,* Nordisk Papperstidning Nr 2 2004, p. 41

5. Aro, Eino J. , Joutseno-Pulp Osakeyhtiö, 24.11.1981, manuscript, archives of Metsä-Botnia Oy, Joutseno Mills

6. Baasel, W, D, *Preliminary Chemical Engineering Plant Design*, American Elsevier Publishing Company, Inc., 1976

7. Backhurst, J.R., Harker, J.H., *Process Plant Design*, Heinemann Educational Books, London, 1979

8. Barnet, A.J., *The 24th Leask Survey: Equipment sales tailed off but there has been a rebound in 2001,* Pulp & Paper Canada, 102(2001):4, pp. 10 - 17

9. Concidine, D.M., *Chemical and Process Technology Encyclopedia*, McGraw-Hill Book Company, 1974

10. Douglas, J. M., *Conceptual Design of Chemical Processes*, McGraw-Hill, 1989

11. Edgar, T.F., Himmelblau, D.M., *Optimization of Chemical Processes*, McGraw-Hill International Editions, 1989

12. Euzen, J.P., Trambouze, P., Wauquier, J.P., *Scale-up Methodology for Chemical Processes,* Editions Technip, 1993

13. Finnish Forest Industries Federation, internet pages 20.3.2003.

14. Finnish Society of Automation (Suomen Automaatioseura), *Teollisuusautomaation vuosikymmeniltä, 1960- ja 1970-luvut,* SAS julkaisusarja nro 23, Saarijärvi, 2001

15. Finnish Society of Automation (Suomen Automaatioseura), *Teollisuusautomaation vuosikymmeniltä, osa 2 –vuoteen 1990,* SAS julkaisusarja nro 25, Saarijärvi, 2003

16. *Forest, environment and industry; a story of new ways forward,* Finnish Forest Industries Federation, Helsinki, 2004

17. Franck, P-Å, Åsblad, A, Berntsson, T, *Process Integration Applications in the Pulp and Paper Industry,* International Conference on Process Integration, Copenhagen, Denmark, 7 – 10 March, 1999

18. Gichoracki, T.J., Gullichsen, J.E., Paulapuro, H., *High Consistency Forming – A New Concept,* Tappi Journal 84(2001):3, p. 61

19. Group discussions, Group 4, Process *Integration as a Tool for Strategic Planning in Industry,* International Conference on Process Integration, Copenhagen, Denmark, 7 – 10 March, 1999, Volume III, Summary

20. Gundersen, T, *From Gothenburg '92 to Copenhagen '99 – Major Trends and Developments in Process Integration*, International Conference on Process Integration, Copenhagen, Denmark, 7 – 10 March, 1999

21. *Hannes Jansson on Joutseno-Pulp Oy on 25.11.1981*, 12.1.1982, archives of Metsä-Botnia Oy, Joutseno Mills

22. Heilman, J., Juhola, H., *Intelligent printed products secure paper-based communication,* Nordisk Papperstidning Nr 2 2004, pp. 42..44

23. Heinonen, P., oral presentation and manuscript, 2.9.2003

24. Herder, P., *Process Design in a Changing Environment,* Delft University Press, 1999

25. Herder, P.M., Weijnen, M.P.C., *Concurrent engineering approach to chemical process design: practical implications and case-studies,* Proceedings of the International Conference on Industrial Engineering and Production Management, Lyon, October 20-24, pp. 524-533, 1997

26. Hetemäki, L., *The Outlook for Global Communication Paper Consumption,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

27. Holmström, A., *Morgondagens dagstidning behöver inget papper,* Nordisk Papperstidning Nr 2 2004, pp. 50..51

28. Honeywell Corporation, internet home page, 19.8.2004

29. Hougen, O.A.Watson, K.M., Ragatz, R.A. *Chemical Process Principles, Part I, Material and Energy Balances*, 2nd Ed., John Wiley & Sons, Ltd, 1967

30. Hämynen, T, *Karjalan yhteiskunta ja talous 1800-luvun lopulta toiseen maailmansotaan,* Karjala – historia, kansa, kulttuuri, toim. P. Nevalainen ja H. Sihvo, Suomalaisen Kirjallisuuden Seuran toimituksia 705, Pieksämäki, 1998, pp. 153 – 206

31. ISO 10006, *Quality management – Guidelines to quality in project management,* First edition, 1976-12-15

32. J.R. Fair, AiChE Monogr. Ser.**76**(13), (1980)

33. Jaakko Pöyry 1958 – 1983, Art-Print Oy, Helsinki, 1984

34. Jaakko Pöyry Consulting Research Report, *World Fibre Outlook up to 2015, Volume I, Executive Report,* Vantaa, May 2003

35. Jaakko Pöyry Consulting Research Report, *World Paper Markets up to 2015, Volume I, Executive Report,* Vantaa, October 2002

36. Jaakko Pöyry Oy, Operational Procedure A20

37. Jaakko Pöyry Oy, Operational Procedure PA1

38. Jakobson, M., *Tilinpäätös,* Otavan kirjapaino Oy, Keuruu, 2003

39. Jokinen, J., telephone conversation, 13.10.2004

40. Juva, Einar W., *Rudolf Walden 1878 – 1946,* Werner Söderström Oy:n kirjapaino, Porvoo 1957

41. Karlsson Kurt K., *Paperinvalmistuksen historiaa, Paperin valmistus osa I*, SPIY:n oppi- ja käsikirja, 2. painos, Turku 1983

42. Kaunonen, A., *Future of Pulp and Paper Mill; Automation Visions,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

43. KCL, internet home page, 19.8.2004

44. Kirk-Othmer, *Encyclopedia of Chemical Technology*, Third Edition, Volume 19, John Wiley & Sons, 1982

45. Klemola, K., Turunen, I., *State of Mathematical modelling and Simulation in the Finnish Process Industry, Universities and Research Centres,* Technology Review **107** (2001), Tekes

46. Kononov, A., Paulapuro, H., *Dry Forming, a Future Method of Papermaking,* Paperi 2003, AEL/Insko Seminar, Helsinki, 20.11.2003

47. Koskinen, J., *Neles, Nelimarkan oivalluksista maailmanmaineeseen,* Ajatus Kirjat, Helsinki, 2003

48. Krazlawski, A., Turunen, I. (editors*), European Symposium on Computer Aided Process Engineering – 13,* Elsevier Science B.V., 2003

49. Kōnönen, T.A., *60 vuotta selluloosan valmistusta Joutsenossa*, Joensuu, 1967

50. Lempinen, K., *Joutseno-Pulp Osakeyhtiö 1909-1959*, Karjalan Kirjapaino Oy, 1959

51. Leppänen, J., *UPM positiva till den elektroniska utvecklingen,* Nordisk Papperstidning Nr 2 2004, pp. 56..57

52. Leppänen, V., oral presentation, 21.3.2004

53. Leskelä, M., *Informaatiopaperin tulevaisuuden vaatimukset,* Lecture in AEL/INSKO Seminar "Massat 2000", 17.11.1999, Espoo

54. Linderborg, Stig, *Kymin tekninen historia 1938 - 1991*, 1997

55. Linna, H., *Intelligent Paper and Packaging,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

56. Ludwig, E.E., *Applied Process Design for Chemical and Petrochemical Plants, Volume I*, Gulf Publishing Company, Houston Texas, 1977

57. Lukkari, J., *Piuhat katoavat antureista,* Tekniikka & Talous nro 34, 14.10.2004, p. 21

58. Lund, A., *Förteckning över pappersmaskiner i Finland 1842 – 1998*, Åbo Akademis Tryckeri, Åbo, 1999

59. Meinander, P.O, *Understanding the Papermaking Process,* www.pom.fi/latest updates/new articles, 10/-04

60. Meinander, P.O., *Misunderstandings about the Papermaking Process*, www.pom.fi/latest updates/new articles, 10/-04

61. Meristö, T., Kettunen, J., Hagström-Näsi, C., *Metsäklusterin tulevaisuusskenaariot,* Tekes, Teknologiakatsaus 95/2000, Helsinki, 2000

62. Metso Automation Oy, internet home page 19.8.2004

63. Metso Paper Oy, presentation material, 2003

64. Michelsen, K-E, *Viides sääty, Insinöörit suomalaisessa yhteiskunnassa*, Vammala, 1999

65. Moore, G., *Factors Influencing the Pulp and Paper Industry,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

66. Moore, G., *The Challenges ahead,* Pulp & Paper International, 45(2003)6, pp. 32..34

67. Moulijn, J.A., Makkee, M., van Diepen A., *Chemical Process Technology*, John Wiley Sons, Chichester, 2001

68. Munter, S., *Kohtalonkysymys – nuorten lukijoiden metsästys,* Staffin Stora Enso, Nr 2, 2004, pp. 16..23

69. Myllys, T., *Osaamiselle on kysyntää*, SKOL Visio, Helmikuu 2004, p. 3

70. Myrsten, C., *Högprisprojekt på tröskeln till verkligheten,* Nordisk Papperstidning, nr 8, 2003

71. Myrsten, C., *Tidning genom mackapär lär dröja,* Nordisk Papperstidning Nr 2 2004, pp. 54..55

72. Myrsten, C., *Papper kombinerat med microchips blir oslagbart,* Nordisk Papperstidning Nr 2 2004, pp. 46..48

73. Nikander, I.O., *Early Warnings – A Phenomenon in Project Management,* Helsinki University of Technology and Project Management Association of Finland, 2002

74. Nurmi, K., *EU:n uusi kemikaalistrategia – Muutosvoimat,* Lecture given in AEL-Insko Seminar ”Sellu 2003 & Paperi 2003”, 20.11.2003, Helsinki

75. Ojanperä, K., *Ulkomaiset yhtiöt lisäävät paperikehitystä Suomessa,* Tekniikka & talous, 5.2.2004, p. 6

76. Oy Metsä-Botnia Ab, internet home page, 15.2.2004

77. Paavola, A., *Future Visions of Paper Sensor Technology,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

78. Palmen, K.E., Ramsay, A., Solitander, A., *Paperiteollisuus ,* Oma maa, tietokirja Suomen kodeille, IV osa, 2. painos, Werner Söderström Oy, Porvoo, 1928, pp. 127 – 142

79. Paperi 2030, Kauppa- ja teollisuusministeriön tutkimuksia ja raportteja 6/2003

80. Paperi- ja selluteollisuuden T&K-haasteita painetun viestinnän ja pakkausteollisuuden arvoketjussa, KCL 2003

81. PMBOK Guide, *A Guide to the Project Management Body of Knowledge,* Project Management Institute, 2000 Edition v 1.2

82. Puustinen, T., *Sähköinen paperi on valmis,* Talouselämä numero 10/2004, 12.3.2004, pp. 54..56

83. Rahkila, P., *Future Visions of Chemical Pulping,* a Lecture Given in The Future of Pulp and Paper Seminar, Lappeenranta, 24-26.8.2004

84. Rodden, G., *A 4,000 Tonne/Day Kraft Mill May Be Reality,* Pulp & Paper International 46(2004)2, pp 25..26

85. Rodden, G., *From Cradle to Grave,* Pulp & Paper International, 45(2003)5, pp. 33..35

86. Rooks, A, *Finishing Strong: How Finland Stays on Top*, SOLUTIONS! for People, Processes and Paper, December 2003, pp 27 – 30

87. SCAN M3:65 Drainability of Pulp by the Schopper-Riegler-method

88. SCAN M4:65 Drainability of Pulp by the Canadian Freeness Method

89. Seppälä, R., *Korvessa karjui se karvainen karhu, Jaakko Pöyryn pitkä tie Sodankylästä kuuteen maanosaan*, Otava, Keuruu, 2004

90. SFS-EN ISO 9000-1, *Guidelines for selection and use,* 1994-12-05

91. SFS-EN ISO 9004-01, *Quality management and quality system elements. Part 1: Guidelines,* 1994-12-05

92. Siitonen, S., *Impact of Globalisation and Regionalisation on the Performance of the World's Pulp and Paper Companies,* Acta Universitatis Oeconomicae Helsingiensis A-225, Helsinki, 2003

93. Siltanen, P., Syrjänen, T.L., *Mill Model Concept for Paper Mill Life Cycle Management,* ICE 2004

94. Stora Enso Oyj, internet home page,14.3.2004

95. Suomen Konsulttitoimistojen liitto SKOL ry, statistics, 2004

96. Syrjänen, T. L., *Process Design as Part of a Concurrent Plant Design Project,* European Symposium on Computer Aided Process Engineering – 13, A. Krazlawski and I. Turunen (editors), Elsevier Science B.V., 2003

97. Syrjänen, T., *XML suunnittelujärjestelmien integroinnissa, case Jaakko Pöyry*, Presentation held on 25.2.2004 at Palace Gourmet, Helsinki

98. Talvio, P., *Today's Design Systems Keep All Parties Involved on a Daily Basis*, Pulp & Paper September 1987, pp 60..62

99. Tekniikan Sanastokeskus, definitions of terms, Internet 16.5.2003

100. Teräs, Timo, *Puumassan valmistuksen ja käytön kehitys Suomessa ja ulkomailla, Puumassan valmistus, osa 1,* SPIY:n oppi- ja käsikirja, 2. painos, Turku 1983

101. *Tulevaisuus on osaamisessa: teknologiastrategia – näkemys valinnoista*, Tekes, Helsinki, 2002

102. Tuuri, Antti, *UPM-Kymmene Metsän jättiläisen synty*, Kustannusosakeyhtiö Otava, Keuruu 1999

103. *Webster's Third New International Dictionary*, Merriam-Webster, Inc., Springfield, MA, 1986

104. Vilbrandt, F.C., Dryden, C.E., *Chemical Engineering Plant Design*, McGraw-Hill Kogakusha, Ltd Tokyo, 1959

105. Virolainen P., *Paperi korvaa niin piitä kuin polttopuuta*, Tekniikka & talous, 15.1.2004, p. 14

106. Yang, J., Koiranen, T, Kraslawski, A, Nyström L., *Object-oriented Knowledge Based Systems for Process Equipment Selection*, Lappeenranta University of Technology, Department of Chemical Technology, Publication 32, 1992