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Address: NO-7465 Trondheim, NORWAY
Location: S P Andersens veg 5, NO-7031 Trondheim
Telephone: +47 73 59 03 00
Fax: +47 73 59 03 30

Enterprise No.: NO 948 007 029 MVA

TITLE

ATTRACTIVE MANUFACTURING
Theoretical discussion in IDEELL FABRIKK

AUTHOR(S)

Gaute Knutstad, Marte Pettersen Buvik,
Lars Skjelstad, Torbjørn H. Netland and Johan Ravn

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ABSTRACT

The purpose of this report is to ***highlight theory on operations management and socio-technical system theory that can be input to the conceptual development activities in the research project IDEELL FABRIKK.*** Operations management theory aims at building ***better manufacturing systems that are more productive (efficient) and profitable (effective)*** than what we have today, whereas social research on work practice generally aims at ***building better work places that are more humane, attractive, and educational***. In line with the original ideas behind socio-technical system research, these two paths of research should be integrated to one common concept.

The authors argue that, in order to increase future competitiveness, high-tech companies need to have a ***two-sided focus on value creation***, rather than taking the traditional one-sided economical and technological focus. On one side they need to continue with increased value creation along the track of ***advanced utilisation of technology and operational excellence***. On the other side the companies need to increase value creation by ***improving the Quality of Work life***. The authors propose the ***vision Attractive Manufacturing*** as a potential answer to this need. By “manufacturing” we refer to operational excellence. By “attractive” we encompass the Quality of Work life dimension. In the next years of IDEELL FABRIKK we will develop and describe the conceptual content of the vision Attractive Manufacturing, in order to create a Norwegian manufacturing concept describing the ideal factory for modern high-tech manufacturing.

KEYWORDS	ENGLISH	NORWEGIAN
GROUP 1		
GROUP 2		
SELECTED BY AUTHOR		

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5S - Sorting, Straighten, Shining, Standardise, Sustain
AGV - Automated Guided Vehicles
AIDC - Automatic Identification and Data Capture
AM - Attractive Manufacturing
APICS - American Production and Inventory Control Society
APS - Advanced Planning and Scheduling
AR - Automatic Replenishment
BAM - Business Activity Monitoring
BI - Business Intelligence
BOM - Bill-of-material
CAD - Computer aided design
CAM - Computer aided manufacturing
CNC - Computer Numerical Control
CPFR - Collaborative Planning, Forecasting and Replenishment
ECR - Efficient Consumer Response
EDI – Electronic Data interchange
EPC - Electronic Product Code
ERP - Enterprise Resource Planning systems
FMS - Flexible Manufacturing Systems
GPS - Global Positioning Systems
HR - Human Relations
ICT - Information and communication technologies
IOR - Integrated Organisational Renewal
Jidoka - “working with machines”
JIT - Just-in-time
KDA - Kongsberg Defence & Aerospace
LP - Lean production
MC - Mass customisation
MES - Manufacturing Execution Systems
MPS - master production schedule
MRP - Material Requirement Planning
MRP II - Manufacturing Resource Planning
OM - Operations Management
OPT - Optimised Production Technology
QR - Quick Response
QWL - Quality of Work Life
RAM - Random Access Memory
RFID - Radio Frequency Identification
RFID - Radio Frequency Identification
RLTS - Real time location systems
SCADA - Supervisory Control and Data Acquisition (SCADA
SPC- Statistical Process Control
STS - Socio technical systems
TPM - Total Productive Maintenance
TPS - Toyota Production System
TQM - Total Quality Management
VAN - Volvo Aero Norway
VSM - Value Stream Mapping
XML - Extensible Markup Language

1 Introduction

Production of sophisticated products is foreseen to build the competitiveness of the Western economies' industrial sectors in the future. Increasingly, competitiveness in such industries depends on a complex interaction between social factors such as knowledge sharing, learning and innovation and technical factors such as automation and information systems. However, until now, improvements and developments in these industries have been clearly biased towards the technological side. Now, awareness is strongly needed in regard to social and working conditions if implementation of further advanced technology is to be effective.

Operations management aims at building better manufacturing systems that are more productive (efficient) and profitable (effective) than what we have today, whereas social research on work practice generally aims at building better work places that are more humane, attractive, educational, and that bring along Quality of Work Life for employees. However, in modern high-tech industry we do not need better systems; we need new systems that are better. In order to understand and build new systems that outperform the production systems we have today, the authors see a fruitful synergy of research on operations management and work practice in order to strengthen the socio-technical systems research on modern high-tech industries.

1.1 Research project IDEELL FABRIKK

This report is written as part of the first period of IDEELL FABRIKK. The report is meant as a starting point for the conceptual development in the project.

IDEELL FABRIKK[1] is a four year (2008-2011), €4 million research project funded by the Norwegian Research Council and the two involved industrial partners Kongsberg Defence & Aerospace (KDA) and Volvo Aero Norway (VAN). The project aims at creating the ideal factory for high-tech manufacturing companies in Norway.

KDA develops and produces high-tech products within communication systems, weapon systems, command and control systems and advanced carbon composite materials. VAN is a manufacturer of high-tech aircraft engine components. Both companies are global players and deliver to highly demanding customers including the US Department of Defence, Lockheed Martin, Pratt & Whitney, General Electric, Snecma and Airbus.

[1] More information about the project can be found at www.sintef.no/ideellfabrikk.

1.2 Scope and structure of the report

This report aims at giving an overview of central aspects within the areas of operations management and socio-technical system theory. It is not the intent of this report to cover all aspects of operations management and work research in social sciences[2]. The material covered is a selection within the two research areas, chosen to give an overview and to enlighten the research challenge in the project, which is to combine the best from two areas in order to form a new manufacturing concept for the development and delivery of high-tech products.

The report uses a selection of recent papers to support the idea of strengthening the interaction between new technologies and systems and the human role in modern manufacturing. Changes in demand patterns, competition situation, employees' increasing focus on job satisfaction, and documentation of top quality products almost on an individual product level, causes competitive manufacturers to change in the direction of what we label *attractive manufacturing.*

Figure 1 gives an overview of the scope and structure of the report. In chapter two, industrial trends are highlighted that calls for new knowledge and system development for the type of industry under study. Chapter three and four briefly review theory on operations management and socio-technical systems research respectively. Chapter five merges the two fields of research by discussing nine socio-technical design practices in the light of OM theory on Lean, Mass customisation and ERP. Finally, the vision of Attractive Manufacturing is presented.

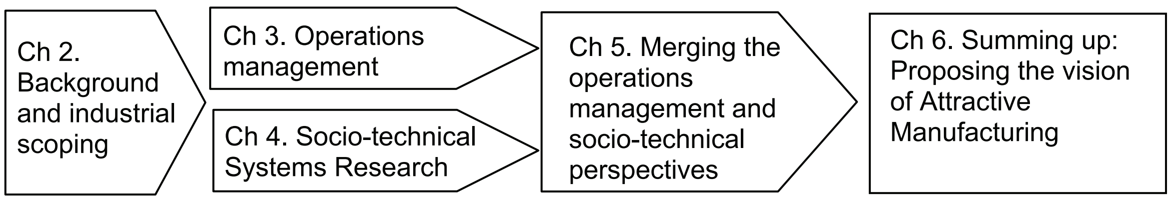


Figure 1 Report scope and structure

[2] For recent State-of-the-art reports on operations management and socio-technical research see respectively Bolseth et al (2007) and Knutstad et al (2009)

2 Background

Organisations are established to coordinate several peoples' effort related to common tasks and objectives. To support such activity, people and organisations use technology. Technology has developed through several decades, and present we speak about production technology, information technology, control systems and coordination technology, amongst many others. All together we talk about this as the technical system of an organisation. And the better the different technologies and systems are able to be integrated, the better an organisation's technological system is.

Organisations arise and grow when a number of people separately accomplish sub tasks that are coordinated into a complete whole, e.g. a product. But these people with their separate sub-tasks are still more than just pieces in a puzzle. People in organisations are not merely a part of the technical system, but exactly people, more precisely individuals who are in social relations with colleagues and management. All together we say that people in organisations constitute an organisation's social system. And the better the people in an organisation work together, the better the organisation's social system is.

The main differences between past and future working conditions which affect modern high-tech production systems can be discussed under the following three headings:

(1) Future competitiveness goes beyond technology
(2) Fully integrated information chain from shop floor to top-floor
(3) Automation alienation, competence gap and attractiveness of work

2.1 Future competitiveness goes beyond technology

Globalisation leads to a shift in sectors, where labour intensive manufacturing of easily exportable products tends to be off-shored and out-sourced from Western economies. At the same time, knowledge-intensive manufacturing of complex, high-tech products is expected to increase the competitiveness of Western manufacturing industries in the future. While technology is simple to copy across both organisational and national borders, work culture and tacit organisation knowledge is hard to imitate and will be a source for sustainable competitive advantage. Nevertheless, technology is still solely driving the innovation in Western high-tech industries.

Organisation and workers add more complexity to a company than technology probably ever will. Moreover, industrial companies are managed by engineers and economists, who tend to look for single-right solutions in order to simplify and justify decisions made. Due to this, decisions on technology are often given priority while decisions on organisation and workers are treated as black boxes which are "fought" with after technology and frame conditions are given.

Fact box 1: New KDA factory

Preparing for increased incoming orders, KDA decided to build a new €100 million factory in Norway in 2008. Strikingly, the need for square meters, machinery and layout as well as the colours of the walls were decided upon before KDA even considered designing the organisation and allocating the people who should actually work in the factory. Even though this shows how complexity traditionally is coped with in engineering organisations, does it secure the best fit between organisation and technology?

Paradoxically, when the technology is given and implemented (e.g. an IT-system, a CNC-machine etc) and workers are allocated to an organisation map, the workers seem to treat the technology as black boxes (Knutstad et al, 2008). This issue only increases in importance as companies evolve into high-tech, mass-customised industries, where technology is considerably more complex than in traditional industries.

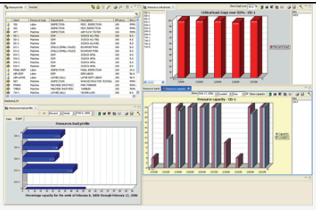
Fact box 2: New FMS at VAN

Preparing for increased production of complex jet engine components, VAN needed to upgrade their machinery park to include a number of highly automated Flexible Manufacturing Systems, and significant investments have been made during the recent years. However, VAN now faces challenges in regard to utilizing the full theoretical exploitation ratio of the FMS due to scarce competence resources and the learning curve. How could VAN prepare for this?

2.2 Closing the information chain from shop floor to top-floor

From a technical point of view, recent developments in ICT and business applications clearly create greater distance between the employees of high-tech manufacturing firms and the production systems. Increasing implementation of Manufacturing Execution Systems (MES) closes the information gap between automatic production systems (e.g. CNC-machines, material handling robots etc), and Enterprise Resource Planning systems (ERP). Moreover, auto-ID technologies such as Radio Frequency Identification (RFID) and sensor-technologies are foreseen to lead to conditions such as Ubiquitous Computing and Internet of Things (Glover and Bhatt, 2006). In parallel, intelligent decision support systems such as Business Intelligence (BI) and Business Activity Monitoring (BAM) systems removes the very last need for top and middle level managers to see operators face-to-face.

Fact box 3: New MES at KONGSBERG Defence & Aerospace



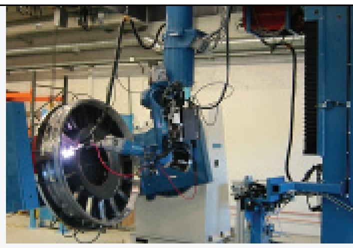
KDA is implementing a MES-system in its production. The MES-system will digitalise all production plans and documentation routines, and hence move KDA towards a paper-less factory. There is no doubt that the MES-system can reduce waste in the organisation by making the production plans and need for track & trace more real-time and effective. However, what the MES-system will introduce of new work processes between operators and managers is much less examined by KDA?

From a social theories point of view, this digitalisation of work places leads towards increased bureaucratisation. All these systems generate and require numerous amounts of routines, procedures, registrations, analyses and detailed reports. There is a trend emerging which suggests that these bureaucratic systems self generate more bureaucracy, since bureaucracy and ICT seem to be interdependent. The bottom line on this is that ICT increases bureaucratic practice, and hyper-bureaucratisation is a result of the increasing use of complex automation and ICT systems (Torvatn et al , 2007). Social science scholars such as Grint and Woolgar (1997) have made considerable contributions on pieces of this puzzle, but the future digitalised working situation where high-tech companies are fully integrated, from auto-ID-labelled materials via automated shop floor machines via MES and ERP systems to top-floor business intelligence, is not much investigated in research and calls for attention.

2.3 Attractiveness of work, competence gap and alienation in regard to automation

In parallel with the development of IT-applications, the focus on automation in Western manufacturing industries continues. However, automation is also moving toward the extreme, and several industries are now experiencing a new wave of alienation[3] in companies related to the man-machine interface. An earlier wave of alienation was experienced when CNC-machines (Computer Numerical Control) and later on FMS (Flexible Manufacturing Systems) replaced the manual turning lathe or the milling machine, with operators simply starting, feeding and emptying the machining centres whilst otherwise passively supervising them. A new wave of alienation is now taking

Fact box 4: Automation at VAN



One of the main goals of VAN related to production is increased automation where machinery can run around the clock also with limited presence of operators. How does VAN cope with alienation related to the man-machine interface?

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[3] "Alienation exists when workers are unable to control their immediate work process, to develop a sense of purpose and function which connects their jobs to the over-all organisation of production,…" (Blauner, 1964, p 15). But alienation is not bound to occur even if new technology is implemented; if workers are properly educated and involved there is per definition no alienation taking place.

place as AGV (Automated Guided Vehicles) and material handling robots are removing the very last of physical operations.

Operators are not operators any more, but still far from redundant; the industry of the future has clearly a growing need for knowledge-intensive jobs in maintenance and in planning and control functions. Irrespective of the automation level in modern industry, there will always be a "man-in-the-circle", meaning that there will always be a need for a responsible human being supervising the production system. Moreover, in high-tech industries, there is clearly a need for increased knowledge also at the shop floor level. Furthermore, the industries are getting more complex due to bureaucratisation that implies for increased need of integrated functions with wide variety of knowledge to be able to understand and capture the wholeness of the complexity, and hence be able to carry out heedful actions and problem-solving. In contrast to this, a decreased focus on attractiveness of work is evident in industry, together with an increased focus on technical and economical value added production systems.

Fact box 5: Man in the circle at VAN

According to VAN's 10-year strategic technology plan, the competence profile of the company will make a considerable switch towards a high-skilled work force in the next years. How can VAN coordinate an optimal mixture of running production and continuous learning and certifications?

3 Operations management theory on high-tech manufacturing

Operations management is truly a broad field of research. Teaching text books on OM often comprise almost 1000 pages (e.g. Chase, 2003; Slack et al, 2004). It is neither the intent nor is it possible in this report to cover the entire field[4]. This chapter gives a brief overview of the history of Operations Management and aims to outline operations management topics that are of particular importance for modern high-tech manufacturers. In this chapter we outline three key areas of operations management that will be discussed in the light of socio-technical systems research in chapter five: (1) Lean manufacturing, (2) Enterprise Resource Planning systems (ERP), and (3) Mass Customisation.

3.1 Origin and theoretical development

The moving assembly line developed by Henry Ford in 1913 was the start of the *mass production* philosophy. The idea was to keep the material flowing and the workers engaged. Standardisation of components and operations paved the way for efficient production. Prerequisites for this system were on time delivery of parts and subassemblies, consistent quality and the ability to schedule the production. Still today mass production is the premium solution for low cost manufacturing.

Fact box 6: Think assembly line

In Aurskog, the Norwegian el-car manufacturer Think aims to build the most modern small-car factory in Europe. With a helping hand from Porsche Consulting an optimised production line is set up planned to have a capacity of 7000 cars annually. Henry Ford's moving assembly line is clearly still in fashion in some industries. (www.think.no)

In the late 1950s and early 1960s, scholars began to deal specifically with *operations management*, as opposed to industrial engineering or operations research. Seeing the production operations as a *system* was encouraged by writers such as Edward Bowman, Robert Fetter and Elwood Buffa (1961) at this time, after having observed that all production systems faced some common challenges in spite of their differences. In this period, many significant topics/tools within operations research was developed (simulation, waiting-line-theory, linear programming etc.). Although the development within operations management is a continuous effort, some important achievements can be identified.

A control concept is the fundamental approach for how to operate, control and coordinate the manufacturing system (Vollmann et al, 2005; Simchi-Levi et al 2007). As shown in Figure 2, there have been developments to both the capacity to handle greater complexity and scope and the orientation to more pull-based production control concepts. Looking fifty years back, simple two-bin systems were sufficient to control the flow of components and products.

However, as the number of products became larger and demand more customer specific, the need for more advanced control concepts arose. Also, the growing competition, and thus the strong cost and price focus, leads to waste elimination and resource and cost minimisation (lean).

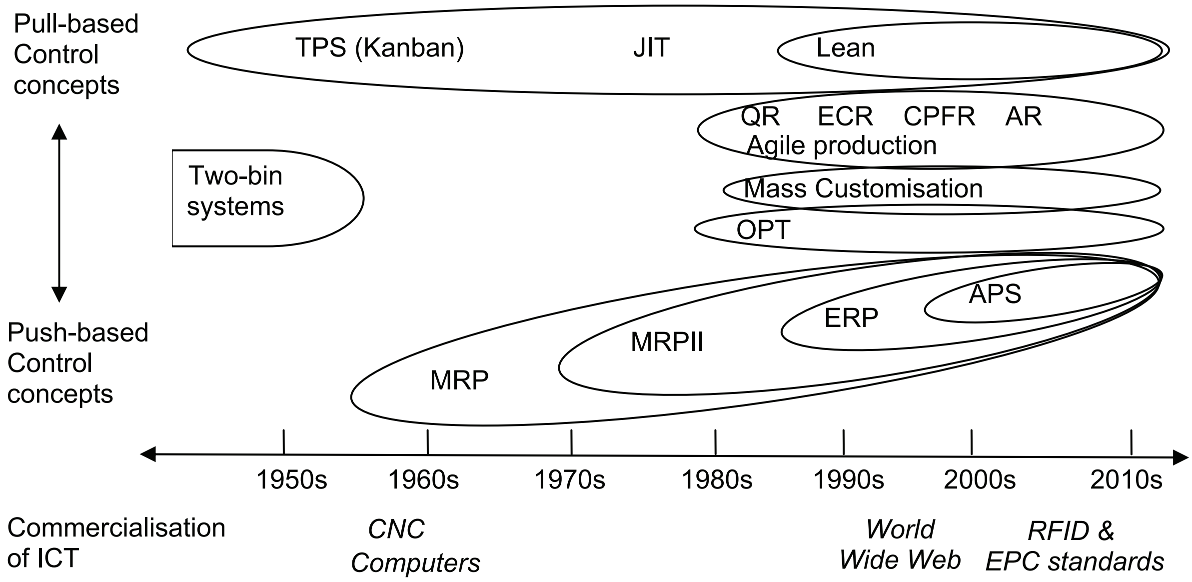


Figure 2: Historical development of control concepts (based on Netland et al 2008)

A new paradigm was introduced around the 1960s when computers made their entry (Manetti, 2001). Simple production management mechanisms based on inventory control and later on *Material Requirement Planning* (MRP) were put to use. The first manufacturing software dates back to the magnetic tape systems in the 1960s, but true MRP software was first made possible in the 1970s, with the introduction of random access memory (RAM). According to Vollmann et al (1997) MRP constructs a time-phased requirement record for any part that adds up to a finished product. A MRP production plan is calculated based on three sources of input: The master production schedule (MPS), a bill-of-materials (BoM) and the inventory status.

During the 1980s the term *Manufacturing Resource Planning* (MRP II) was introduced, and has since then been used to identify the capabilities of the newest MRP-systems. In this manner, MRPII can be considered as the heir to MRP. MRP II is defined by APICS as "a method for the effective planning of all resources of a manufacturing company". Manufacturing software was all noted MRP II until the 1990s, when the Gartner Group introduced the term *Enterprise Resource Planning* (ERP), describing software that was integrated both across and within various functional silos in the company. MRP/MRPII is still the most common planning engine for production planning in ERP-systems (Alfnes and

[4] For a recent State-of-the-art report on operations management see Bolseth et al (2007)

Strandhagen, 2000). Today we also see increasing implementation of Advanced Planning and Scheduling (APS) systems in industry.

Customer focus and *Just-in-time* (JIT) manufacturing in particular had its breakthrough in the 1980s. JIT is an integrated set of activities designed to achieve high-volume production using minimal inventories of parts that arrive at the workstation exactly when they are needed. JIT originates from the *Toyota Production System* (TPS) with roots back to the late 1960s (Shingo, 1989). Often combined with *Total Quality Management* (TQM) and focusing on waste elimination, the concept is now a cornerstone in many manufacturers' production practices, although more likely under different appellations (such as lean and agile).

Fact box 7: Hydro Aluminium Raufoss: Hydro Automotive Production Systems

As a premium supplier to the automobile industry Hydro Automotive (www.hydro.com) in Raufoss really knows how to optimise operation effectiveness through Lean Manufacturing. Hydro Aluminium has developed a systematic approach for becoming lean inspired from the original Toyota Production System (TPS); the Hydro Automotive Production System (HAPS) is a well developed step-wise educational, practical and certification-based improvement concept that aims to create a more effective and profitable crash bumper production. Many companies all over the world are developing their tailored production systems inspired from TPS.

With all the alternative concepts for controlling the production available at this time, manufacturing strategy was considered a competitive weapon. Also during this period, computers were introduced in industry at a large scale, inviting further and new developments within as well as between companies. To maximise output of a production system the *Optimised Production Technology* (OPT) (Goldratt, 1984) focused on bottlenecks in design and management of the whole system. The manufacturing strategies *Agile Production* and *Mass Customisation* (Davis, 1987) also appeared in the 1980s-1990s.

Broader control concepts for supply chain management like *Quick Response* (QR), *Collaborative Planning, Forecasting and Replenishment* (CPFR), *Automatic Replenishment* (AR) and *Efficient Consumer Response* (ECR) have evolved since the 1980s in commodity markets. All these concepts are developed on the philosophy of a common responsibility of fulfilling customer demand (agility) though the sharing of order and forecast information and by so improving the information quality used for planning and control (Kollberg & Dreyer, 2006). By making the demand information available earlier, more updated planning and control processes are realised.

Contemporary trends in operations management

There are certain things a company must do well no matter the manufacturing system in use. Time-based competition requires getting rid of waste in the manufacturing and distribution system. Reduced lead times and reduced changeover times serve that purpose by reducing the throughput time and manufacturing costs. Continuous improvement efforts and employee involvement and empowerment help to improve product design, reduce lead times and changeover times, and improve quality (Sahin 2000). According to Strandhagen and Nilssen (2008) trends in operations management today include:

- development of company specific solutions within the scope of the total supply chain
- globalisation of the business, the markets, the workforce, knowledge and technology
- increasing complexity in systems and networks
- real time exploitation of customer and production information (e.g. through data capturing technologies such as RFID, sensors etc)
- increased potential in information and ICT due to increase in information volume, quality, processing capacity and competence
- visualisation of information to stimulate the creative workforce, forming of attractive workplaces and effective processes
- extended and intelligent products

A challenge for many companies is to manage continuous improvement and development within these topics in parallel with demanding operational goals. Participation of all employees is essential in modern complex manufacturing systems.

3.2 Lean manufacturing

Lean manufacturing (Womack et al, 1990) is an enhancement of mass production and puts a focus on value creation, avoiding waste and non-value adding activities and encouraging a higher degree of demand-driven production. Getting the product right-first-time, continuous improvement efforts, quality in products and processes, flexible production, and minimising waste of any kind are the enhancements that produce lean manufacturing (Sahin, 2000). This brings more responsiveness to customer needs, which is also the essence of mass customisation and agility.

Originating in the automobile industry, lean describes in detail practical techniques and methods that promise a higher degree of effectiveness and increased competitiveness for companies. lean manufacturing is popular in manufacturing companies today and a lot of material and support tools such as Value Stream Mapping (VSM), 5S (Sorting, Straighten, Shining, Standardise, Sustain) and Statistical Process Control (SPC) are available to transform a business to be lean. Visual control and Just-In-Time production are the key elements and tools for realising lean manufacturing.

Fact box 8: Visual Management at Nidar AS

Nidar AS (www.nidar.no), a chocolate and sweets manufacturer in Trondheim, has put much emphasis on Visual Management and 5S, that helps streamline and smooth the operations of the popular factory.

Authors of lean have been recognising human factors since its beginning (Womack et al, 1990) and Human Resource Management is just as an important part of lean as Just-In-Time, Total Quality Management (TQM) and Total Productive Maintenance (TPM). Cross-functional training of the work force and employee empowerment have been emphasised as the keys for success in JIT, TQM and TPM (MacDuffie, 1995; White et al., 1999). However, worker empowerment requires increased worker skills, which might not always be apparent. Increased shop floor responsibilities and stress together with strict focus on less waste and faster production has led to the discussion on whether or not lean is actually "mean". Put to the edge, the main aim in lean production is to eliminate all waste in terms of organisational, social and technical waste. This tends to lead to a reduction of resources allocated to organisational learning and development, because their contribution to value creation is often hard to see and define.

Automation within lean manufacturing should, according to Edwards (1996), be minimised unless it is necessary, it introduces machine complexity, reduces flexibility, and is usually a source of downtime if it is not relevant. However, in today's high-tech industry automation is required. Demand for precision, repetition and speed, has made automated machines outperform human workers in many areas. Toyota's concept of Jidoka, which can be defined as "working with machines" (Baudin, 2007) describes in detail the man-machine relationship from a technical point of view. The social view is much less examined.

3.3 Agility and Mass Customisation

Academics and practitioners define agility as the capability of operating profitably in an uncertain, unstable, continuously changing environment. It was first discussed as a manufacturing system in 1991 when an industry group realised that the traditional manufacturing organisations fail to adapt to increasing change in the environment. While flexible manufacturing is the ability to respond to planned changes, agility is the ability to handle unplanned changes by economically producing a variety of products, with quick changeover, in any quantity (Nicholas, 1998). Integration of the value chain in terms of internal and external virtual organisations is one of the key factors in the success of agility (Goldman et al., 1995). Integration includes building partnerships with suppliers, getting significant input from customers, partnering with suppliers or customers in the design process, involving technical people as well as layout people with different aspects of processes etc. While lean manufacturing is involved mostly with the factory floor, agility is involved with the whole enterprise.

The concept and term Mass Customisation (MC) was introduced by Stanley Davis (1987) in his book "Future Perfect". MC is defined as *"the use of technology and management methods to offer product variety and customisation through flexibility and quick responsiveness"* (Pine, 1993). This manufacturing strategy seeks to allow for customer participation in design and specification of their products within a defined solution space. The goal for the company is to supply these products in a large scale without the traditional corresponding increase in production time and cost. Information technology and flexible manufacturing equipment are prerequisites for obtaining MC capability. The product development process has to bring out modular products with enough specification possibilities to satisfy the market, and yet remain rational enough to produce.

Today, *product configurators* (commercial software) are used to outsource the product specification work to the customers themselves, all in order to reduce potential misunderstandings and costs. MC is suitable for markets where the customers find specifying their product a significant advantage. The workforce is challenged both with respect to strategy understanding and daily work flexibility. In high-tech product manufacturing, the demands for documentation and traceability often lead to treating each product as a specific one.

Fact box 9: Mass Customisation at HÅG AS

The chair manufacturer HÅG in Røros (www.hag.no) is able to effectively produce and sell a broad pallet of customised chairs based on a limited set of raw materials.

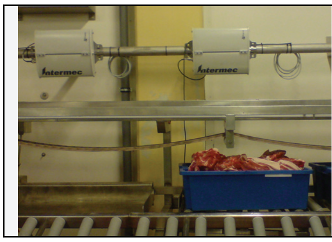
Even though the definitions of agility and, in particular mass customisation describe them as offering anything, anywhere and at anytime, there are still limitations on the variety that can be offered. The two systems can produce high variety, customised products as long as they belong to the same family and use similar components and the same processes in different sequences. Technology still needs changeover time, and thus serial effects are present and modular products are preferred. The promising metal printing technology[5] may in future represent true one-of-a-kind production. The challenge now is on production capacity and availability of materials.

3.4 ERP-systems, information sharing and visibility

Perhaps more than any other single factor, ICT has changed the basis of production economics by automating many clerical tasks and increased manufacturing accuracy, reliability, and predictability (Jelinek and Goldhar, 1984; Rondeau and Litteral, 2001). To utilise information, we need to collect it, access it, analyse it and have the ability to share it for collaboration purposes.

A wide range of ICT systems exist (e.g. ERP, APS, MES, EDI, XML, RFID, CAD/CAM etc), covering various functions and processes in and between companies. ERP is present in most companies today, in different levels of integration and complexity. The systems normally have a given functionality in the kernel of the system (Christensen, 2008) and have the possibility to communicate with other business systems in addition. The architecture of the total system is an important decision for all companies as it influences future developments and costs. Feedback from the manufacturing process into business systems has been the focus of recent years, and Manufacturing Execution Systems (MES) as well as Supervisory Control and Data Acquisition (SCADA) functionality has been developed. MES has evolved to fill the communication gap between the manufacturing planning system (ERP) and the control systems used to run equipment on the floor. SCADA software is used to make information visually available to plant operators. These are software systems supporting control and monitoring of individual machines or a set of machines on the shopfloor. Standards are introduced to enable a centralised infrastructure, data sharing and plug-and-play functionality.

Fact box 10: Nortura BA – A Norwegian RFID pioneer



The meat cooperative Nortura BA (www.nortura.no) has been a pioneer in using RFID for material control and track & trace purposes in Norway. Nortura has since the mid-1990s used RFID-tags on grazing sheep, and is continuously involved in RFID pilot projects. Nortura has decided to integrate a RFID-tag in all their ca 2-3 million carrying crates. Moreover Nortura looks to adjacent technologies such as temperature sensors, GPS and mobile technologies in their aim to improve.

Since the 1980s there have been great developments in the field of Automatic Identification and Data Capture (AIDC). By combining Global Positioning Systems (GPS) and Radio Frequency Identification (RFID), possibilities exist which will automate the collection of data in order to track material flow in real time, allowing greater visibility of both product and production requirements in the supply chain. It is these real time location systems (RTLS) that will be key to complimenting the lean production methods of the future (Powell, 2008). RFID uses low priced *tags* (a small antenna and a chip used to communicate using radio waves) that are attached to products, cases or pallets. The tags are small and can be embedded in stick-on-labels or permanently attached to the object in focus. This relatively cheap yet extremely accurate method of data collection opens new possibilities in production planning and control as well as for improvement initiatives. The technology is ready and industry is working on introducing it into its value chains. Combining RFID-technology with sensor technology further enhances the intelligence of such data-capturing technologies. As RFID tags are getting better and cheaper and Electronic Product Code (EPC) standards are evolving, new possibilities in the use of RFID for controlling operations arise. Today we are at the beginning of integrating RFID into business workflows and cross company supply chains (Chao & Yang, 2007).

[5] Metal printing: www.sintef.no/Home/Technology-and-Society/Production-Engineering/Metal-Printing-Process

4 Socio-technical systems research

This chapter gives an overview of the most central aspects of socio-technical systems research[6]. Revolutionary with socio-technical systems thinking is that it postulates mutual dependency between an organisation's technical and social systems. More precisely, if your intention is to optimise the technical system, you need to relate it to the social system (Vice-versa if your objective is to develop the social system, you need relate it to the technical system). We might assume this important knowledge to be obvious or taken for granted, but in reality it is not. Examples of great socio-technical practice in organisational design or development are as rarely present today as it was 50 or 60 years ago.

4.1 Socio-technical concept and theoretical development

The socio-technical concept has its origin in the coal-mining industry and is developed through the analysis of several mine studies in England in the early 1950s. One of the most famous and vital important studies were performed by Trist and Bamforth (1951). These studies revealed that the use of self-managed work teams improved both the performance and the psychological well-being of the workers. In one of his further analyses, Trist (1981, p. 9) put forward seven significant aspects of which he speaks of as "a first glimpse of the emergence of a new paradigm of work in which the best match would be sought between the requirements of the social and technical system":

1. from single jobs focus to work system
2. from individual job-holder to work group
3. from redundancy of parts to redundancy of functions
4. from considering individuals as an extension of the machines to seeing them as complementary to the machines
5. from variety decreasing to variety-increasing
6. from external to internal regulation of individuals
7. from prescribed part of work to discretionary part of work

STS grew as a result of apparent short-comings in the previous eras of work organisation and management. Taylor's Scientific Management focused on the mechanics of management and organisation and tended to ignore the human side of manufacturing. The next landmark era of management, the Human Relations movement, focused more on the human side, omitting, for the most part, the technical considerations of manufacturing.

[6] For a recent State-of-the-art report on socio-technical system research see Knutstad et al (2009)

The objective of socio-technical systems was to define a structure that responded to the requirements of the job tasks and the technologies, as well as the psychological needs of the people involved. Furthermore, given the interdependence of systems and the environment, the socio-technical approach attempted to structure the system of work so that it could respond to environmental changes and demands in a rapid and flexible manner.

The challenge is to organise individuals and technology in such a way that tasks and work is performed to everyone's satisfaction. Design of work must contain a conscious choice between technological requirements and the demand and essential needs defined by the human system. An efficient and effective manufacturing enterprise is a result of mutual adjustments of demands from both systems. But there is no simple procedure to achieve mutual adjustment since the social and technological reality is based in two widely different logics, the social sciences and (natural) sciences. Since a socio-technical system consists of both a social and technological part it will also produce two different kinds of results: products such as commodities and services, and social and psychological aspects such as motivation, commitment and job satisfaction. This kind of results is what we later on will define as the vision of "Attractive Manufacturing".

4.2 The Norwegian industrial relations system

Shaped by dialogue between key actors in Government and the industrial partners in the post-war period, the industrial system of Norway was launched and structured as to rebuild industrial capacity after wartime. Starting already in the 1930s, after a long period of economic crisis, mass unemployment and industrial conflicts, *The Basic Agreement* between the social partners in industry were first signed in 1935[7]. This agreement[8] between the employers' organisation, NHO (former NAF), and the Confederation of Trade Unions, LO, is often referred to as "The Constitution" of Norwegian working life, and regulates the social partners' collaboration and actions both on macro- and micro level along with supplementary labour legislation.

The Norwegian IR system both on micro- and macro level is marked by a high level of trust, low conflict, predictability and dialogue (Øyum & Ravn, 2008; Ravn, Øyum, Håpnes & Nilssen, 2009). Scholars conceptualising what has become "The Norwegian model" (cf. Gustavsen 2007) emphasize characteristics like universal welfare arrangement and large public sector, high employment (both men and women), small wage differences and a large

[7] The predecessor Verkstedoverenskomsten was signed in 1907.
[8] The Basic Agreement is an agreement between the Confederation of Norwegian Enterprise (NHO) including all its national and local associations and individual enterprises, and LO Norway including all its unions and associations (divisions).

degree of social mobility, strong collective actors, both centrally coordinated wage formation and local bargaining at company level, and tripartite cooperation (Løken and Barbosa, 2008). Within this context the cooperation between the employers and employees has always served a dual purpose. Employees have contributed to industrial growth and moderation of wage and in return, workers were granted legitimate rights for secure working conditions and benefits from growth. This duality is in line with Grimshaw and Rubery's (2003) perspective of mutual interests between economists and industrial relations, underlining that "trade unions can even act as a positive factor in achieving high productivity levels as they can act as a source of 'voice' for the workers (…) (Freeman and Medoff, 1984; Grimshaw and Rubery 2003:53).

The Industrial Democracy Project (Emery and Thorsrud 1969, Gustavsen 1992) launched in the 1960s, supported by the Confederation of Norwegian Enterprises, the Norwegian Confederation of Trade Unions and the Social Democratic Government, became the back-bone of a practice of collaboration between shopfloor workers' unions and management as to institutionalise industrial democracy in the workplace. Over the recent five decades a tradition for close cooperation between industry and work research has gradually emerged in Norway. In 1982, a passage was included in the Basic Agreement where the partners bind themselves to collaboration on enterprise development. A tradition emerged for cooperation on concrete enterprise development projects between local management and local shop stewards, the national agreements being the foundation. Within this practice, the social partners also developed thorough experience in working with action researchers, and our research institution has been a part of this (Levin 2002, Levin et al 2002, Greenwood and Levin 1998, Ravn, 2004, Elvemo et al 2001a/b).

Fact box 11: Siemens: Management-union cooperation

Siemens in Trondheim has roots from the Norwegian Industrial Democracy Project in the sixties and they still provide a good example of how operators, the union and managers uniquely cooperate to create value and attractive work.

4.3 Nine socio-technical design principles

The key question is how can the relationship between the two parts, the social and the technical, best be designed in terms of creating attractive manufacturing and positive results for both parts? One attempt to an answer is a set of principles that will improve the way work is organised, that fulfil the ideal on joint optimisation. Based on Hertzberg's Two Factor Theory (in Elden et al., 1986) and psychological job demands, socio-technical practitioners and theorists have developed such a set of principles for work design (Cherns, 1976, 1987).

Table 1 Cherns' (1976, 1987) 9 STS design principles

Principle 1: Compatibility
Everyone can assent readily to the notion that means should fit ends, that the way in which design is done should be compatible with the design's objective. The statement that a design should be "participative" is for instance either too readily accepted which suggests that its meaning has not been fully understood, or it has been dismissed as impractical. From the beginning we must recognise that design is an arena for conflict, it has to satisfy an array of objectives, each represented by an organisational element. Design members must reveal their assumptions and reach decision by consensus. Joint "optimisation" of technical and social systems is often wrongly interpreted as modification of a technical design for social considerations. It is a joint design in which the decision is reached for both technical and social reasons. The principle of compatibility is truly the first principle, how well it is adhered to determines how well the reminder can be followed.
Principle 2: Minimal critical specification
This principle has two aspects, negative and positive. The negative simply states that no more should be specified than absolutely essential; the positive requires that we identify what is essential. It is of wide application and implies the minimal critical specification of tasks, the minimal allocation of tasks to jobs or of jobs to roles, and the specification of objectives with minimal critical specification of methods of obtaining them. While it may be necessary to be quite precise about what has to be done, it is rarely necessary to be precise about how it is done. In most organisations, there is far too much specificity about how and indeed about what. And a careful observer of people in their work situation will learn how people contrive to get the job done in spite of the rules. Many of the rules are there to provide protection when things go wrong for the man who imposed them; strictly applied, they totally inhibit adaptation or even effective action. In any case, it is a mistake to specify more than is needed because by doing so, one closes options that could be kept open.
Principle 3: Variance control
This principle states that if variation cannot be eliminated it must be controlled as near to the point of origin as possible. We need here to define variance, a word much used in the socio-technical literature. Variance is any un-programmed event; a key variance is one which critically affects the outcome. This might be a deviation in quality of raw material, the failure to take action at a critical time, a machine failure and so on. Much of the elaboration of supervision, inspection, and management is the effort to control variance, typically by action which does less to prevent variance than try to correct its consequences. The most obvious example is the inspection function. Inspecting a product, the outcome of any activity, does not make right what is wrong. And if this inspection is carried out in a separate department some time after the event, the correction of the variance becomes a long loop which is a poor design for learning. The socio-technical criteria require that inspection be incorporated with production where possible, thus allowing people to inspect their own work and learn from their mistakes. This also reduces the number of communication links across departmental boundaries.
Principle 4: The Multifunctional principle
The traditional form of organisation relies heavily on the redundancy of parts. It requires people to perform highly specialised, fractionated tasks. Each is treated as a replaceable part. Simple mechanisms are constructed on the same principle. Disadvantages arise when a range of responses is required, that is, when a large repertoire of performances is required from the organisation. Usually organisations need to adapt to their environment and elements of organisations need to adapt to their individual environments, of which the most important are usually other organisational elements. There are two ways of doing so, either by adding new roles or by modifying old ones (the mechanism

adds another specifically designed gadget, the organism learns a new trick). Hiring specialists or experts is the mechanical response; training to enlarge the repertoire is the organic.	

Principle 5: Boundary location
Its essential feature is that boundaries should not be drawn so as to impede the sharing of information, knowledge, and learning. The traditional organisation relies heavily on the redundancy of parts. It requires people to perform highly specialised, fractionated tasks. In STS designed organisations people with closely related tasks are organised so they easily can exchange and coordinate their effort.
Principle 6: Information flow
The principle of boundary location counsels against, if it cannot absolutely prohibit, the interruption of information or the insertion of information loops by misplaced organisational boundaries. However, this alone will not ensure that information is provided to those who require it, when they require it. Obstacles are vertical as well as horizontal. Information in an organisation has three uses: for control, for record, and for action. Its use for control of behaviour is pernicious, with its associated power games. Its use for record is essential but abused. Information systems that provide management with comprehensive and detailed information of the operations constitute a virtually irresistible temptation to intervene, to harass, and to usurp subordinate control and authority. Information required for record should be readily available for call only when needed. Information for action should be directed first to those whose task it is to act. This holds for action to control variances; it holds equally for action to discharge all actors' responsibilities: for safety, waste control, planning cost control etc.
Principle 7: Power and authority
Davis (1982) has coined the term "work authority" to describe two linked concepts. Those who need equipment, materials, or other resources to carry out their responsibilities should have access to them and authority to command them. In return, they accept responsibility for them and for their prudent and economical use. They exercise the power and authority needed to accept responsibility for their performance. But there is also the power and authority that accompanies knowledge and expertise.
Principle 8: Support congruence
The implications of socio-technical analysis and design are comparatively readily accepted for production, maintenance, and quality control. But the support of production teams implies significant and far-reaching changes in reward and information systems, in financial control, and in marketing, sales, purchasing, and planning. How much control can be exercised by production teams over purchasing, and how much influence they should exert on marketing and sales policy are questions which raise major design issues.
Principle 9: Incompletion
Go back to the drawing board. Although the myth of stability is essential to enable us to cope with demands of change, we all know that present period of transition is not between past and a future stable state but really between one period of transition and another. Redesign is not a task of a special design team; it is the function of self-regulated operating teams provided with techniques for analysis, the appropriate criteria and principle of design.

In essence, these principles form the underlying fundamental platform for the design of socio-technical systems. The study of Trist and Bamforth (1951) revealed an alternative way of organising work and utilising technology. Since this actually contradicted British thinking at the time, industries goal of increased efficiency and productivity through mechanisations and strong political forces put a lid on the study. But the principles and their embedded values of democratisation, participation, empowerment and self-regulating teams was, due to close relations between British and Norwegian researchers and the Norwegian political context, brought into further development through the Norwegian Industrial Democracy project.

4.4 Teamwork in flexible organisations

De Sitter et al. (1997) stress the need to build simple and flexible organisations with complex knowledge-intensive jobs, instead of building complex organisations with simple and specialised jobs. An important and essential feature or result of socio-technical systems design is teamwork. The end of working through the design principles described above will most likely be one or another way of team organising. The Norwegian Industrial Democracy project from 1962-1969 resulted in several field experiments where self-managed work groups where implemented as alternative forms of organisation to increase participation and reduce alienation of work (Emery & Thorsrud, 1976). The insights from these studies diffused to the Swedish motor industry, in particular Saab-Scania and Volvo, where group-based production systems were adapted with great success.

The socio-technical systems theory and subsequent experiments had a profound impact on work redesign for many years and more recently we experienced a re-emergence of these principles for work team design (Wilson & Whittington, 2001). Such teams have many labels: self-regulating, autonomous, semi-autonomous, self-directing and so on. In part, the numbers of terms and distinctions have evolved to describe and distinguish varying levels of autonomy and different types of internal or external leadership and supervision. However, all of the definitions embrace the notion of a workgroup that has the opportunity for greater independence of decision making than is conventionally available.

Self-managed work teams may be defined as teams that are able to regulate their behaviour on relatively whole tasks for which they have been established, including making decisions about work assignments, work methods, and scheduling of activities (Cohen, Ledford & Spreitzer, 1996). A self-managed work team consist of employees who are responsible for managing and performing the tasks that result in a product or a service being delivered. Tasks are typically rotated among team members, as are management responsibilities. Self-managed work teams are intended as a tool for achieving the best match between the technical and the social system (Yeatts & Hyten, 1998). Team members are given the authority to make all or most decisions related to their work and they consider both the technical needs and social concerns prior to making decisions. They are believed to be in the best position to identify the relevant technical and social factors because they have firsthand of the work and the employees involved (Manz & Simms, 1987). With decisions being taken within the group itself, continuous improvements are more likely to become part of the team's operation so that defects are reduced and product quality enhanced (Dunphy & Bryant, 1996).

Fact box 12: Teeness: Self-managed work teams

Teeness AS, manufacturer of silent tools in Trondheim is characterised by a flat organisation and a successful implementation of self-managed groups in the production. (www.teeness.no).

Self-managed work teams can be thought of as providing an "enriched" work environment because it provides team members with the opportunity to use different skills, complete a meaningful piece of work, perform tasks that affect other team members, make important work-related decisions, and learn how well they are doing (Cummings, 1978). The combination of these is likely to meet the psychological demands at work including job variety, ability to learn, decision-making power, social support (Trist, 1981), resulting in increased employee satisfaction.

4.5 Newer socio-technical trends

In the 1970s and 1980s, an extensive number of researchers were focused on socio-technical systems thinking and extended this concept from the Norwegian Industrial Democracy project, with its principles, values and experience. Around the world at least four different tracks and perspectives are identified:

Track 1 Participatory design (Australian track)

Emery (in Eijnatten, F. M. et al., 1993), gained a lot of experience from the participating into the Norwegian Industrial Democracy Project, especially the lack of diffusion of the concept in the participating companies. According to Emery, this was mainly caused by the researcher's expert approach in the project and by that insufficient internal support from the people in the involved companies. Bringing this knowledge back to Australia, Emery developed what he called "Participatory Design" based on the method known as "the deep-slice approach". This method made it possible for employees, middle management and union representatives jointly, from the beginning of a project, to take responsibility for the task of organisational design. Later on this technique was exported to India, the Netherlands and (back to) Norway. And the long awaited diffusion took place in Norway in 1972 when the companies by them self took control of the development, but not until disappointed researchers had withdrawn. Presently this non-expert approach has very little practical impact and theoretical influence.

Track 2 Integrated Organisational Renewal (Dutch track)

A second track developed in the Netherlands (de Sitter et al., 1997) where researchers answer to the diffusion challenge was labelled Integrated Organisational Renewal (IOR). The IOR approach is based on four basic concepts. Firstly all organisational elements (individuals, tools, systems and machines) are tied together in time as a function of the systems structure. The second concept is controllability, and is defined as the system's ability to reach a wide range of objectives regarding efficiency and performance. The third concept is the combination of production structure and control structure, which are defined as the two organisational action systems. And the fourth concept is structural parameters. In essence, an enterprise's complexity is dependent upon the number of structural elements. Traditional bureaucratic manufacturing systems tend to maximise the number of structural elements, and hence they are complex. Increased complexity is caused by increased process variability, increased probability of interference, and increased sensitivity to interference. Thus the aim of IOR is to reduce the probability of interference by decreasing variability and by reducing sensitivity to interference by increasing control capacity. To accomplish this aim, IOR has developed a strategy to implement a successful redesign process. The IOR approach is an attempt to change focus away from the old functional oriented production thinking to more of a flow and process oriented production thinking. But this is mainly theory development and the process description is characterised by detailed control and expert solutions.

Track 3 Empowerment (North American track)

In North America we find a third track. The efforts in this area are an evident continuance of the classical socio-technical thinking and the experience from England. Probably the most influential contribution stemming from this work in the 1970s and 1980s is the concept of empowerment. Empowerment appears when power is transferred to employees and they experience ownership and control over their tasks and work. This is a concept that has made some impact, but its essence is similar to what is already embedded in self-regulating groups.

Track 4 Democratic dialogue (Scandinavian track)

In Scandinavia, which is the fourth track, the main focus has been to solve the problems of distribution that become evident through the Norwegian Industrial Democracy project. Scandinavian researchers have focused their research on designing development networks between companies from communication theories based on dialogue methods labelled as democratic dialogue. Opposing the classical and participatory design approach, where the focus is on the content of the design, democratic dialogue is focused on the process itself as the point of departure. The main tool within this tradition is a conference, called dialogue conference, where the participants by thirteen criteria of good communication are guided through the conference. Even though this tradition has some foothold, we will argue that its main focus is basically on the social dimension. However, the industrial project with Volvo's factory in Kalmar is more likely the one that has made the Scandinavian model famous (Lindø, P., 1992). Several of the intrinsic aspects of group work as involvement, participation and quality of work life diffused to the USA. In the end of the 1970s we find these elements in the "Quality of Work Life" project with General Motors and "Employee Involvement" with Ford (Durand, J-P. et al., 1999). Presumably, "consultants" such as Deming and Juran, brought these concepts and values with them to Japan and in their work with Japanese automotive industries. And in recent time's Japanese automotive industries have brought the concepts and values back to Europe and the USA, rebranding these concepts as "teamwork" and "lean production".

4.6 The contemporary STS has lost it's original roots

Even though the term socio-technical was introduced in a production system context, there has been a shift away from the technical towards the social aspects of socio-technical systems thinking in the latest decades. Today, socio-technical system theory typically deals with topics such as motivation, process improvement, job satisfaction, self-managing teams, job design and enrichment, job rotation, and empowerment through communication, participation and so on. These are all important aspects of work, but along this line we argue that present STS thinking has lost its original and important perspective which deals with integration. Hence it is crucial to bring a modernised STS thinking into focus again, not by itself, but as a vital part of the two-sided value creation process that will strengthen a company's competitive edge.

In this chapter we have pointed out the origin and the development of the STS perspective. We argue that the contemporary STS literature has some deficiencies in regard to the original thoughts:

- Little focus on management
- Little focus on white-collar workers
- Mostly focus on developing the social dimension of work
- Relatively little concern with technology itself

5 Merging the operations management and socio-technical perspectives

As outlined in chapter four, Cherns (1976, 1987) formulated nine STS work-design principles that provide a systematic overview of STS thinking on work-design issues. These principles have been successfully applied to the analysis of work-design issues in relevant operational management research. In the next sections, some of this research is presented. First, an outline of the research conducted by Benders, Hoeken, Batenburg and Schouteten (2006) is presented. This deals with ERP systems conflicting with socio-technical design principles. Then findings from Liu, Shah and Schroeder (2006), which use the STS-principles to relate work design to mass customisation, are discussed. Finally the work of Niepce and Molleman (1998) is described, applying the principles to the comparison of lean production and STS thinking in terms of the design of work systems.

5.1 Modern socio-technical versus ERP system design

Enterprise Resource Planning (ERP) is a method of using computer technology to link various functions, such as accounting, inventory control, and human resources, across an entire company. ERP is intended to facilitate information sharing, business planning, and decision making on an enterprise-wide basis. Previous research has demonstrated that ERP systems and self-managed work teams, which both are at the core of socio-technical system (STS) design, are difficult to combine in practice (Koch & Buhl, 2001 in Benders, Hoeken, Batenburg & Schouteten, 2006). Benders et al. (2006) argue that the deployment of ERP systems in organisations may result in a potential loss of effectiveness and flexibility of organisations, and losses in job decision latitude, motivation and quality of working life. The basis for this is that ERP implementation conflicts with three design principles of the STS.

Firstly, ERP implementation conflicts with the design order principle of STS in which the information structure is derived from the production and control structure. In the case of ERP however, the information structure is the starting point which does not necessarily fit pre-existing organisational structures and processes. Secondly, ERP systems are at odds with the principle of minimum critical specification. The design of the systems leads to a tendency to create tasks that are functionally decomposed. This segregation of control aspects contradicts the fulfilling of the social-technical requirement of integrating primary and supporting functions. This leads to maintenance of complexity instead of simplifying the situation to be controlled. Thirdly, ERP systems are at odds with the principle of task completeness. The implementation of ERP directly affects job decision latitude in various ways. Predefined user groups and role structures tend to be used leading to a 'segregation of duties'. In addition, authorisation is also often concentrated with a limited number of users, generally those at higher, hierarchical levels. This may cause problems at the shopfloor, as work cannot proceed in the absence of those who are authorised to access or enter data. And obviously, data entry jobs within ERP systems consisting of monotonous and short cyclical tasks are, in socio-technical terms, seen as 'passive jobs' (Karasek, 1979). In a socio-technical design, data entry task would be integrated with other tasks into complete jobs. Tasks assigned to a member of the group should be complex enough to provide motivating and challenging assignments that give meaning to a person's working life. This implies a balance of job demands and decision latitude. A 'good job' consists of complete tasks and sufficient control capacity to deal with control needs and offers sufficient challenges to job holders. In these kind of jobs, workers are motivated and report better health conditions, resulting in less absenteeism and higher productivity (Karasek, 1979).

As we have seen, especially in terms of quality of working life, ERP appears to be at odds with the concept of team working. Whereas ERP strives for standardisation and centralisation, teamwork is aimed at the empowerment, decentralisation and enhancement of team autonomy (Benders et al., 2006). The focus of ERP upon standardisation, authorisation schemes and central control limits the decision latitude (control capacity) at individual and team level, thus disturbing the balance between the need of control and control capacity. This may lead to increased stress levels and organisational inefficiency. But if team members have the opportunity to participate in the configuration of the ERP system, this may enhance the mutual understanding between groups in the organisation and lead to an improvement of the system's productivity and the worker's enactment of the technology. It also does justice to the teams' autonomy and decision latitude. This approach is in line with STS design which aims at balancing organisational requirements and workers' needs (quality of working life). Benders et al. (2006) conclude that socio-technical reasoning may assist managers and end-users in seeing that ERP systems are meant as tools to support primary processes, and should use primary processes as a starting point rather than working exclusively according to ERP logics.

5.2 Linking work design to mass customisation: a socio-technical systems perspective

As we have seen, mass customisation is the ability to use technology and management methods to offer product variety and customisation through flexibility and quick responsiveness (Pine, 1993). It is the capacity to manufacture a relatively high volume of product options for a relatively large market that demands customisation, without substantial trade-offs in cost, delivery and quality (Liu et al., 2006). It combines the cost-saving effectiveness of mass production with the value-added process associated with product customisation (Berman, 2002 in Liu et al., 2006).

Mass customisation has gained increasingly importance in recent years due to its ability to provide customised products efficiently and effectively, and manufacturing companies are continuously searching for ways to develop their mass customisation ability. The literature implies that one of the key factors that facilitate mass customisation is the way work is organised within a company (Pine, Victor, & Boynton, 1993). Work design is defined as the system of arrangements and procedures for organising work, including the set of activities that are undertaken to develop, produce, and deliver a product. Liu et al. (2006) use the nine design principles in socio-technical systems (STS) theory (Cherns, 1976, 1987) to identify 10 work-design practices that are relevant to the mass-customisation context. These are 1) employee empowerment, 2) feedback to shop floor employees, 3) autonomous maintenance, 4) cellular-manufacturing setup, 5) multifunctional employees, 6) high standards for recruiting, 7) task-related training for employees, 8) differentiated reward and incentive systems, 9) employee-contribution willingness and 10) continuous improvement and learning. They focus on the social system, as the organisation's social system can play a critical role in responding to the technical innovations and the external environmental changes though its human-resource management, especially the design of the work system. They tested the assumption that these 10 work-design practices would positively predict mass customisation ability by collecting survey data from manufacturing plants across three industries in six countries.

The STS principle of *compatibility* states that system design must be compatible with the organisation's long term objectives, and this is achieved by involving employees in the planning process. The principle of *minimal critical specification* states that as little as possible should be specified about how jobs are to be performed, so that employees can contribute with their creative options. These two principles highlight the importance of *empowering employees* which features flat hierarchies with widely dispersed decision-making authority, increased mutuality of interests between employees and employers, and support for group work (Pasmore, 1988 in Liu et al., 2006). In mass customisation, production tasks are no longer narrowly defined and repetitive as in mass production, but rather become complex and flexible (Pine et al., 1993). Organisational flexibility must be an inherent feature of mass customisation in order for the organisation to effectively adapt to the turbulent environment and employee empowerment is an important enabler of organisational flexibility in turbulent environments. Liu et al. (2006) predicted that employee empowerment would enhance the company's mass-customisation ability by providing organisational flexibility, but the results did not confirm this. This is in sharp contrast to other operational management research and research in other areas which shows that employee empowerment is strongly linked to successful implementation of innovative production programs as well as superior operational and organisational performance (Liu et al., 2006). One explanation for these conflicting findings is that the effectiveness of employee empowerment is contingent upon other factors such as business strategy, leader characteristics and environment.

The principle of *variance control* states that variance should be controlled as closely as possible to the point of origin. Operators should be able to detect and correct variance at its origin, before it causes further difficulties for downstream operations (Pasmore, 1988 in Liu et al., 2006). Variance control is especially favourable in a mass-customisation context because high variety in products and high flexibility in processes introduce more channels for variance to occur than in a mass-production environment, so the ability to control variances has added significance for mass customisation. The principle of *information flow* states that organisation should provide workers with the right feedback so that they are able to control variance that occurs within the scope of their responsibility. Liu et al. (2006) identify two relevant work design practices based on the two STS principles discussed above: ***feedback to shop floor employees*** and ***autonomous maintenance by shop floor employees***. Feedback about their performance is critical to adequately fulfil their responsibilities and is also a prerequisite to learning and self-calibration (Pasmore, 1988 in Liu et al., 2006). Immediate feedback enables fast variance detection and correction. Because shop floor employees have the best knowledge about possible operating problems, having them autonomously maintain the equipment helps reduce risk of operations failure and helps control variance at the origin. These two work design practices is shown to facilitate a company to achieve mass-customisation ability.

The principle of *boundary location* states that organisation boundaries should be drawn so as to facilitate the sharing of information, knowledge, and learning. Interdependent units should be included in the same department for better variance control. Instead of being put into segregated functional groups, employees should be organised into work cells that combine interdependent jobs and employees from several specialised skill areas. How technology is laid out is as important as what technology to use. This is because the layout of technology affects employees' feelings about their work and, consequently, their work performance (Pasmore, 1988 in Liu et al., 2006). The authors identify ***cellular-manufacturing setup*** as the work-design that corresponds to this STS principle. In this setup dissimilar but sequentially related machines are located in physical proximity to one another and are dedicated to the manufacture of a specific family of component parts (Huber & Brown, 1991 in Liu et al., 2006). In this case, the work of one individual is directly tied to the next and group tasks are defines to encompass critical interdependencies in the work, which enhances group cohesiveness and performance. Liu et al. (2006) found that cellular-manufacturing setup was positively related to mass customisation.

The principle of *multifunctionality* states that workers should be capable of performing a diverse range of jobs. In mass customisation, increased uncertainty in the environment and complexity in the production system make the manufacturing tasks more complex, flexible, and interdependent. Workers within a manufacturing cell are required to be multiskilled, flexible, and adaptive. Multifunctional skills are necessary for employees to appropriately respond to the increased uncertainty and complexity. The work design practice of ***multifunctional employees*** was found to be positively related to mass customisation ability.

The STS principle of *support congruence* states that the system of social support should be designed in a way to reinforce the behaviours that the organisation structure is designed to elicit. There is a wide range of support mechanisms and three of the most prominent are identified here. ***High standards for recruiting*** ensures that shop floor employees have the ability efficiently perform the complex and flexible manufacturing tasks in a mass-customisation environment. ***Task-related training*** provides employees with the technical skills, trouble shooting capabilities, and appropriate knowledge about equipment and processes**. *Differentiated reward and incentive systems*** can be used to greatly motivate shop floor employees to grasp multiple skills and perform challenging tasks**.** These practices can be employed to screen, enrich, or motivate shop floor employees with an intention to enhance their capability to effectively control variance, grasp multiple skills, and work in multifunctional cells. Liu et al. (2006) found that all of these three work design practices increased the mass-customisation ability.

The principle of *human values* states that, in organisational design, the needs of the employees should not be neglected and the quality of working life should be an important consideration. This includes worker responsibility, variety, growth, involvement, security, labour relations, and so on. Satisfied employees are committed to using their full capacities to solve problems, adapt to new circumstances, and take advantage of new opportunities, leading to higher performance (Pasmore, 1988 in Liu et al., 2006). Companies with employees that are committed and ***willing to contribute*** to the organisation are more likely to achieve mass-customisation ability.

The STS principle of *incompletion* states that organisation design is a continuous process and there is no such thing as a final design. There is limitless potential to increase human knowledge and creativity and to advance technological capabilities. In the era of mass customisation we need learning organisations which adapt that can adapt quickly to new customer demands and marketplace changes (Hirschhorn, Noble, & Rankin, 2001). ***Continuous improvement and learning*** is necessary and vital to further improve the technical and the social system and is positively related to mass-customisation ability.

The results show a strong relationship between work-design practices and mass customisation, indicating that designing work systems has significant implications for mass customisation. Increasing demand uncertainty and the resulting product customisation has increased the level of organisational complexity in terms of task diversity and employee interdependence. Under this scenario, STS theory may be a more appropriate work-design philosophy than in the mass-production environment (Hirschorn et al., 2001). As a production paradigm, mass customisation is mainly an operations issue. This study, however, shows that successful pursuit of mass customisation requires efficient human resource management as well. The integration of human and technological factors is a prerequisite for successful mass-customisation implementation.

5.3 Work design issues in lean production from a socio-technical systems perspective

Niepce and Molleman (1998) evaluate the similarities and differences between lean production (LP) and socio-technical systems (STS) with respect to work design issues. Both paradigms are concerned with many aspects of the company, but this evaluation and comparison concentrates on the role of the worker in the labour process. In STS as well as in LP, the worker plays a central role. STS clearly views people as a resource to be developed (Trist, 1981) and even though LP shares this approach and acknowledges the importance of the human being in the labour process (Cheng & Podolsky, 1993 in Niepce & Molleman, 1998) opponents of LP state that LP is simply the perfection of something they consider to be an inhumane system.

In order to contrast the two concepts, Niepce and Molleman (1998) use the nine design principles (re)-defined by Cherns (1987) as their theoretical framework. The principles may be described and denoted somewhat differently from the overview given in the previous section, since Niepce and Molleman based their work on Cherns' principles from the revisited version from 1987. For each of Chern's design principle, they examine whether LP matches this principle or whether LP endorses a different approach. We realize that Niepce and Molleman's (1998) article is not a recent contribution and some of the elements in the lean production thinking may be somewhat different today. But at the same time, we believe that the core aspects of this paradigm is the same as it was 10 years ago and therefore will be relevant today as well.

As we have seen, the principle of ***minimal critical specification*** states that as little as possible should be specified about how jobs are to be performed and as much autonomy as possible should be given to employees to perform tasks according to their knowledge and experience. In STS, by setting production targets for the self-managing working group as a whole in order to ensure freedom of choice, standardisation of output as well as decentralisation of control become important coordination mechanisms. STS tries to maximise individual or work group autonomy and regulatory tasks are an integrated part of the job. STS strives towards job enrichment in which workers gain control over activities that used to fall under the domain of the management. In LP, the leading coordination mechanism is the standardisation of the work process and LP tries to achieve a perfectly balanced production system, with the absence of buffers and the goal of zero defects. Teams are not autonomous but are built around the supervisor, a strong hierarchical leader who directs the team. Participation seems to be limited not only to certain areas of decision making but also to certain mechanisms of involvement. This shows that LP and STS differs in the way they coordinate activities. STS strives to resolve shop floor problems through mutual adjustments and decentralisation of control which entails an enlargement of problem-solving capacities. LP, in order to "deproblemise" the production process, seeks to reduce the level of uncertainty by favouring the improvement of the standardisation of work processes and direct supervision.

The principle of ***boundaries*** says that departmental boundaries should be drawn to encompass tasks that are sequentially related to one another as opposed to technically similar to one another. Organising work around the product flow facilitates information and experience sharing and encourages ownership and responsibility for within-group tasks. STS emphasizes boundaries between groups and the autonomy of teams by minimising the number of inter-group relations. LP on the other hand enhances dependencies by minimising buffers and for this the most significant boundary is the entire organisation and not the team.

According to the principle of ***multifunctionality***, workers should be capable of performing a diverse range of jobs. In STS, having multiskilled workers means that team members can assist each other and each member possesses a variety of skills relevant to the group task. Multiskilled workers are regarded as reserve capacity so if one of the members is absent, the team as a whole can accommodate this temporary loss. STS tries to extend multifunctionality beyond the boundaries of the individual task, but within the boundaries of the team. Similarly, in LP workers are supposed to carry out a wide range of duties. However, multifunctionality is not limited to the tasks of the work group and the integration of sequential tasks within the job is not intended. This makes it possible to move workers and their skills in and out of several groups and thus builds a flexible workforce that is very adaptable. The downside of this is that it may contribute to the de-skilling of workers as they perform simple and narrow tasks.

The principle of ***support congruence*** states that human systems such as reward, assessment, training, and promotion policies should support the activities of the team members. Niepce and Molleman (1998) focus on training and reward systems in order to illustrate some of the possible differences and similarities between the two concepts. Training is considered a critical element in both systems as only skilled and knowledgeable workers are able to meet the needs of the organisation. Training is an important consideration in LP as workers need training to engage in improvement activities. They need to understand the process as a whole and should be trained, among other things, in the use of problem-solving techniques. The need for training is more broadly oriented in STS. Because responsibilities are delegated and the workers are expected to manage a broad range of skills, they need training in subjects such as supervision, communication skills, conflict resolution, and management of suppliers and customers. When it comes to reward systems, STS recommends pay for team performance while LP uses a rather individual reward system.

This principle states that ***feedback*** about production should be available to the employees who perform the task. STS use feedback to enable the group to make corrections if needed and to enhance their autonomy. In this way, feedback can be used to improve the way work is designed as well as to refine the process of work itself, thus supporting double-loop learning

(Argyris & Schön, 1978). Feedback under LP is predominantly used for the surveillance and monitoring of the worker's activities. The often-used display boards (Andon system) in LP plants, for example, make any discrepancy between the production target and actual performance immediately apparent to everybody. Information helps to make the organisation more transparent and focuses on the reduction of deviation from fixed standards.

The design process is an ongoing process according to the STS principle of ***incompletion***. According to STS, if workers get the opportunity to engage in improving their own jobs, they will be motivated by an internal drive because it leads to more "enriched jobs" which fulfil their growth needs. The principle of continuous improvement, or Kaizen, in LP corresponds to this STS principle. But there are also some differences. In LP, continuous improvement means the continual rationalisation of production since it aims at a reduction in activities by reducing manning and working-time buffers and thus an improvement in performance. Whereas continuous redesign in STS leads to more enriched jobs, Kaizen has no such objectives. In STS, improvement activities are rather unstructured and are an integrated part of daily work, whereas in LP, improvements are regulated by standardised procedures.

The principle of ***compatibility*** refers not only to the internal fit between work systems and the technical systems but also to the design process itself. In STS, technology must be used in a way that supports rather than minimises the role of human resources. It is supposed to support the reduction of the division of labour and induce an improvement of work content. In this tradition, the technical system should facilitate the process of "enrichment" while in LP, the technical systems help to standardise work processes and their use is principally directed toward the necessity of being efficient even if this leads to the substitution of labour by technical equipment. Regarding the design process, STS requires a fit between the approach used and the outcome desired. In the view of STS, it is unlikely that design by experts or design presented in an authoritative way will lead to participation and ownership of the work processes. In LP, experts play a crucial role in the design process. Shopfloor workers often join specialists in working out improvement programs. Nonetheless, workers' involvement in decision making is limited to consultation and the gathering of information. Workers are not allowed to make decisions themselves.

The principle of ***socio-technical criterion***, or variance control, prescribes that variations from what is planned or expected should be controlled as closely as possible to their point of origin, as workers are in the best position to act on them. Correcting one's own errors is one of the basic principles of Total Quality Control (Shingo, 1986, in Niepce & Molleman, 1998) which is used in LP. Removing quality control from the sole responsibility of the quality control department and its separate quality control inspectors and assigning it to all disciplines in an organisation as both concepts do, is a major departure from classic mass production. However, there are differences between the two concepts concerning the areas which workers are allowed to make changes in. STS integrates double-loop learning activities in daily work allowing workers to change procedures, norms and targets, to a certain extent. In LP the workers are supposed to solve the underlying problem immediately and can only suggest improvements in work standards, work processes or targets.

The principle of ***'human values'*** states that the organisation has to be sincerely concerned with the human needs of the employees and that Quality of Working Life (QWL) must become an important consideration for the organisation. QWL focuses on four different aspects: work content, labour relations, conditions of employment (such as reward systems), and working environment. The aspect has become a point of interest to almost all employers, is part of modern management and is not restricted or exclusive to STS or LP. Niepce and Molleman (1998) focus on the work content and labour relations in the discussion on QWL. In STS, obtaining challenging work has been centred on the content and redesign of work. The substantial attention paid by STS to such elements as regulatory tasks, autonomy, and wholeness of tasks illustrates its focus on work content when designing jobs. LP, on the other hand, does not emphasise a fundamental redesigning of jobs to make them more appealing (Hoerr et. al, 1986, in Niepce & Molleman, 1998). Instead, a regime of standardised work performed in short cycles gives it a Taylorist image. The work is characterised by a relative lack of regulatory tasks and the loss of a degree of freedom as workers are not really authorised to decide how work should be performed. Still, LP claims that respect for the human system is important and beneficial for both the production and the human side. But LP clearly breaks away from the notion of Scientific Management by treating employees personally and encouraging them to participate by utilising their skills and seeing workers as capable employees rather than impersonal means of achieving organisational goals. Close relationships between managers and workers are a goal in LP, and it may seem that LP chose to invest in better labour relations as a counterbalance to a somewhat strict work regime as a result of a systemised control mode. Whereas in STS, the improvement of QWL focuses largely around work content, in LP, QWL is primarily aimed at improving labour relations. Irrespective of this difference, both concepts acknowledge the importance of paying due attention to issues concerning QWL.

From this evaluation, it becomes clear that with respect to some principles LP and STS seem to differ only moderately, with respect to others they differ moderately, and with respect to a third group of principles, they differ more fundamentally. What both frameworks have in common is that they promote the information flow, the socio-technical criteria, the principle of incompletion, and the congruence of support. However, they differ somewhat in the manner in which they give substance to these elements. LP and STS seem to diverge more in the application of technical concepts and in the way they operationalise the principle of multifunctionality. LP seems to calibrate multifunctionality to the task whereas in STS it is calibrated to the group and directed to higher level of task identity. The two models seem to differ more fundamentally with respect to four elements: their definition of boundaries, the extent of the specification of work processes, the design process itself, and the human values they consider. It seems that the two systems differ most fundamentally with respect to the control systems they advocate and the extent to which they give room to local autonomy and decision making. Behind this however, lies a more profound distinction, namely their different value bases and assumptions about work and the nature of human beings: STS insists that the ownership of the production process belongs to the worker themselves, LP vests its control in experts and procedures. Given this perspective, it is comprehensive why the mail coordination mechanism favoured by STS is the decentralisation of control and mutual adjustment, whereas in LP it is the standardisation of work processes.

6 Summing up: Proposing the vision of Attractive Manufacturing

In order to increase future competitiveness, companies need to have a two-sided focus on value creation, rather than taking the traditional one-sided view based on economical and technological issues. Companies need to continue with increased value creation both along the track of advanced utilisation of technology and operational excellence whilst simultaneously increasing value creation along the line of Quality of Work Life. This double-focus vision we label ***Attractive Manufacturing***.

Advanced technology asks for advanced organisations

Production of sophisticated products is foreseen to build the competitiveness of the Western economies' industrial sectors in the future. Increasingly, competitiveness in such industries depends on a complex interaction between social factors such as knowledge sharing, learning and innovation and technical factors such as automation and information systems. However, until now, improvements and developments in these industries have been clearly biased towards technology. Now, a joint awareness programme is strongly needed in regard to the social and technical aspects of work to reach sustainable competitiveness in the future. The challenge is to ***match people and technology***.

The concern is two-sided. On the technological side, the modern production systems are potentially extremely vulnerable where everything is dependent on everything. Not if but when a failure occurs, potentially the whole system stops. And detecting the problem somewhere inside the complexity of the integrated production system requires a highly competent engineer, knowledgeable in both manufacturing and information technology. On the social side the concern is on increased alienation, reduced control over work and reduced Quality of Work Life of the work by reducing operators to "button-pushers".

Today companies, such as Volvo Aero Norway and KONGSBERG Defence & Aerospace, are building ***state-of-the-art integrated production systems*** by implementing more and more advanced technology (FMS, robots, MES etc). The goal is ***operational excellence***. But at the same time the companies strive with building ***advanced organisations*** that can utilise and release the potential embedded in the technology. While technology is easier to copy across organisational and national borders, work culture and tacit organisation knowledge is much harder to imitate, and can be a source for sustainable competitive advantage.

Attractive Manufacturing - a proposed vision

In our conceptual perspective we argue that in order to increase future competitiveness, high-tech companies, such as Volvo Aero Norway and KONGSBERG Defence & Aerospace, need to have a ***two-sided focus on the value creation***, rather than the one-sided traditional economical and technological focus. On one side they need to continue with increased value creation along the track of advanced utilisation of technology and operations management. On the other side the companies need to increase value creation along the line of Quality of Work Life. This we label ***Attractive Manufacturing***.

By “***manufacturing***” we mean industrial value creation, that through humans and technology creates wealth (jobs and products) in an environmentally and economically sound way – i.e. retains the operations management perspective. ***Operational excellence*** is a key to manufacturing competitiveness. By “***attractive***” we mean work places that create satisfied, productive and loyal employees driven by a desire to create value for the company along with stimulating attractive workplaces for all colleagues – i.e. retains the STS perspective. ***Quality of Work Life*** is a key to attractiveness.

Attractive Manufacturing can be achieved with an ***integrated operations management and socio-technical approach***. Much research remains in order to describe and realise this vision. This we will address in the following years of the research project IDEELL FABRIKK.

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