PRODUCTION ACROSS THE NORDICS

INTERNATIONAL PRODUCTION

2022

CONTENTS

OUR THANKS

The participants of the course would like to take the opportunity to thank all the people who made this course possible after two years of pandemic delays. The course has, through the visited companies in Gothenburg and Reykjavik, increased our understanding and broadened our perspectives in a wide arrange of operations; ranging from very large operations in powerplants to the development and production of advanced prosthetics, as well as software and machine learning applications. Thank you to everyone who took the time in accommodating us at the various visits, and passionately sharing with us their operations and experiences of working in their specific fields. Through the visits, a better understanding for challenges in different types of operations could also be achieved.

The course was sponsored by Produktion2030, and by extension Vinnova, Sweden's innovation agency. The goal of Produktion2030 is to strengthen the competitiveness of Swedish industry in order to make Sweden an attractive country for production. Additionally, Produktion2030 runs a research school open for PhD students and actors in industry interested in the issues addressed by Produktion2030, utilizing competencies from academia, companies, research institutes related to product and production development. This course, International Production, is part of the research school run by Dag Bergsjö. Thank you to Produktion2030, Dag, and Vinnova for providing the course and making it possible for us to go to Gothenburg and Reykjavik!

To all of you, thank you!

PhD Participants, 2022

PREFACE

In the uncertain and volatile market that companies are currently facing worldwide, researchers and engineers become a key link to strengthen the industry and universities in order to understand, communicate, and tackle current challenges. In the course, International Production, the goal has been to investigate what makes Sweden and Iceland booming industrial hubs driven by technology. Through the visits to different types of industries, such as fintech, medical, or automotive industry, we as researchers have gained a better understanding of the challenges they are currently facing.

The participants and researchers in this course come from three universities in Sweden: Chalmers University of Technology, KTH Royal Institute of Technology, and the University of Skövde. All researchers are focused on different production areas, therefore, to further investigate present challenging areas, the participants have focused on the six challenge areas highlighted within the Produktion2030 graduate school namely:

- Resource-efficient production,
- Flexible production,
- Virtual production development,
- Humans in the production system,
- Circular production systems and maintenance, and
- Integrated product and production development.

The course aimed to visit a variety of industries from Sweden and Iceland to find out which of the above-mentioned areas constitute a challenge to different companies. We hope that this report provides more details regarding the success and current challenges of the Swedish and Icelandic enterprises.

PhD Participants

November 2022

OVERVIEW FOR THE REPORT

KEY BACKGROUND INFORMATION

LEARNING OUTCOMES

The course aims to create an in depth understanding of product development and production from a global perspective. By visiting regions and discussing problems with fellow PhD students and industrialists from around the globe, the course aims to foster innovative and explorative research in the field. Each year the course has a specific focus on a special region; this year's focus has been on Scandinavia.

More explicitly, the purpose of the Production 2030 course "P02 International Production" is to allow the participants to:

- Identify key differences and similarities regarding product and production development in the studied region in relation to Sweden & Iceland;
- Demonstrate the ability to formulate learnings from the study visits both orally and in written text, and relate the experiences to the research front and industrial practice;
- Be able to present the cultural and historic development of the region we visit;
- Write accessible texts, for a broader non-research audience;
- Describe the regions business system, production and development industry.

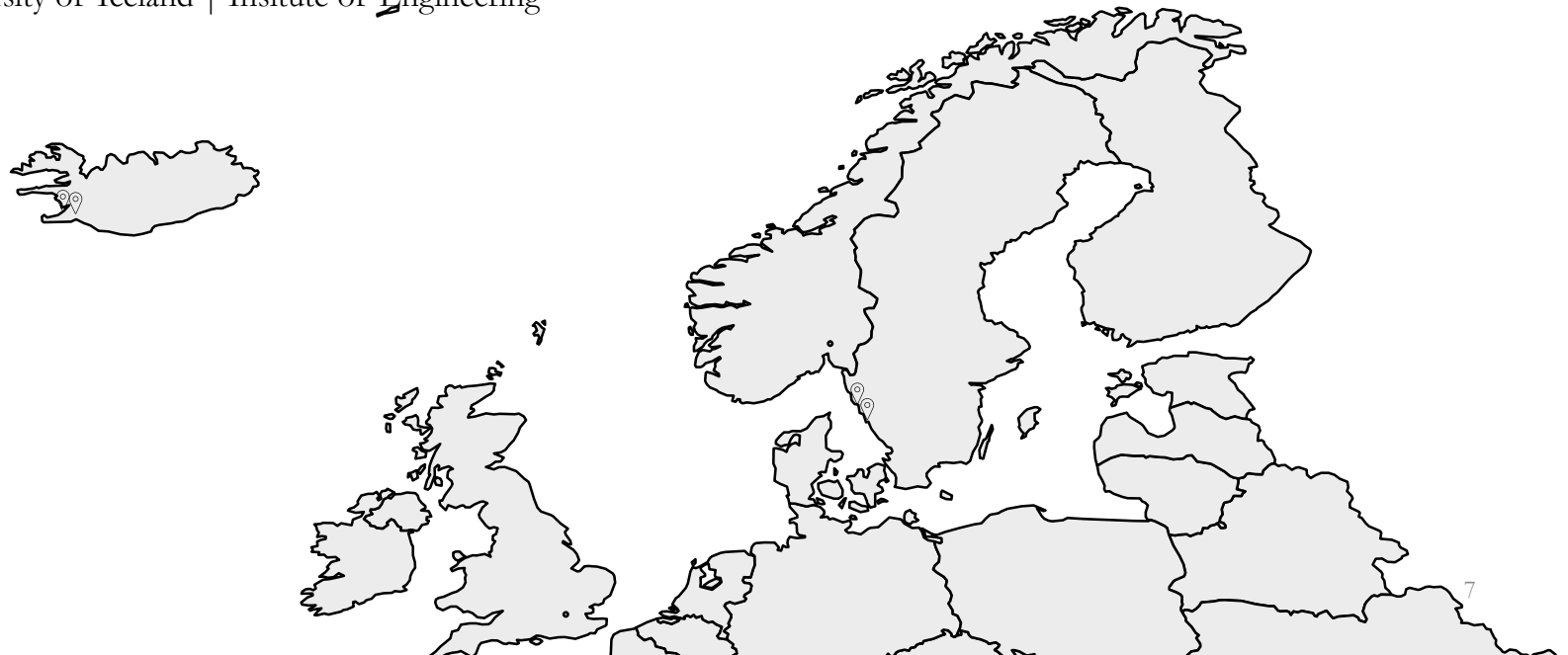
STUDY LOCATIONS

Iceland

- Lucinity | Headquarters
- Nox Medical | Headquarters
- Össur | Production & Assembly Line
- Carbfix | Hellisheiði Power Station
- University of Iceland | Insitute of Engineering

Sweden

- Volvo Group | Volvo Trucks Tuve Assembly Line
- Skanska AB | Vikan Quarry
- Vattenfall | Ringhals Nuclear Energy Plant



COMPANY PROFILES

This chapter provides a description of the companies and the universities that were visited. The universities and companies are presented in a chronological order, starting with the first visit.

Chalmers University of Technology

Chalmers University of Technology is a Swedish university that focuses on research and education in technology, engineering, natural science and architecture. It started out as a school for handicrafts in 1829, and became a university in 1937. The university is located in Gothenburg and is divide into two campuses in the city, one in Johanneberg and one in Lindholmen. There are about 11,000 students enrolled at Chalmers, and approximately 1,000 doctoral students.

Skanska AB – Vikan Quarry

Skanska is mainly known in Sweden as a construction company, involved in the construction of buildings of different sizes, from houses to large office buildings as well as infrastructure, for example roads, bridges and tunnels. The Skanska Vikan site is quarry from where aggregates are extracted, i.e. rocks and gravel used for creating concrete, asphalt and other road-based material. Vikan is Skanska's largest site for extracting aggregates. At the time of the visit there was limited extraction of aggregates from the Vikan site as material from the digging and blasting in the large infrastructure project in Gothenburg, Västlänken, is recycled at Vikan and turned into aggregate products required in the Västlänken project and for other construction projects.

Volvo Group Truck Operations – Tuve plant

Volvo Group consists of several business areas under the brand of Volvo focusing on the production of different vehicles and engines. The main business areas are Volvo; trucks, buses, construction equipment and Volvo Penta which produced marine and industrial engines. There are also other brands that are part of the Volvo group which are not Volvo brands, for example Renault trucks and Mack trucks and these brands focus on different customer segments and/or regions in the world. During the course, a visit was made to the Volvo Tuve plant where the final assembly of Volvo trucks is performed.

Different generations of Volvo trucks

Vattenfall – Ringhals nuclear power plant

Ringhals is a nuclear powerplant located about 60 km south of Gothenburg and is one of three nuclear power plants still in operation in Sweden. The powerplant is owned by the Swedish state-owned power company Vattenfall to about 70 %. The powerplant has four reactors, two of which are still in operation and are planned to remain in operation into the 2040s. The other two reactors were decommissioned in 2019 and 2020 respectively. The reactors that are in operation at Ringhals are pressurized water reactors, and together produces approximately 17 TWh per year, which accounts for almost 20 % of the total electricity demand in Sweden.

Lucinity

Lucinity is a start-up company working with AI and machine learning to facilitate the detection of money laundering cases. Human AI is a term used by the company which entail a collaboration between humans and AI in order to improve identifying money laundering. Through the collaboration between human money laundering investigators and AI, the investigators can work more efficiently and effectively by reducing the time spent on going through large amount of transactional data and focus their attention on cases that are more frequently actually true cases of money laundering. Lucinity works with many different actors and gets to work on these actors' data which means that the company gets experiences from many areas of money laundering and gives a different vantage point compared with for example banks or financial intuitions that work with more restricted data sets.

The slogan of Lucinity greeting visitors to their Reykjavik office

Nox Medical

Nox medical is a company that produces devices for monitoring sleep patterns to facilitate the identification and correct diagnosis of sleep disorders such as sleep apnoea. The device developed and sold by Nox medical allows patients to examine their sleep from the comfort of their own homes instead of having to be examined at hospitals. The main customers of Nox are healthcare providers. The data generated by the device is translated by algorithms developed by Nox and then analysed by physicians to determine if a patient is suffering from a sleep disorder. The company name, Nox, comes from the Greek goddess of night, called Nox in Icelandic (Nyx in English). Through the monitoring device and the AI support, Nox strives to improve diagnostics and by extension help patients sleep better.

The device produced and sold by Nox.

University of Iceland

The University of Iceland is the oldest and largest university on Iceland, founded in 1911.The university is mainly located in Reykjavik but there are facilities located at other areas in Iceland. About 14,000 students are enrolled and the university conducts research and education in law, medicine, social sciences, humanities, engineering and teacher education. The university has Pallas Athena, the Greek goddess of wisdom and learning, as their mascot which is depicted in the logo for the university. In May of 2022, the university had its thousandth doctoral student defend her thesis since the start of the university in 1911. There are currently 700 doctoral students enrolled at the university.

Hellisheiði Power Station

ON Geothermal power plant is located close to Reykjavik and supplies the city and the surrounding towns with hot water and electricity. By drilling down about 2,000 to 3,000 meters into the earth, hot water and steam at approximately 250-300°C is extracted. The steam is used to drive turbines, generating electricity and the output of the plant is about 300 MW of electricity. Fresh ground water is heated by the condensed steam by heat exchange to a temperature at about 83°C which is the supplied to Reykjavik. ON power together with other actors such as the University of Iceland and the Icelandic government have developed a method to reduce the emission of greenhouse gases from the powerplant called Carbfix. The water and steam extracted from the earth have a mix of greenhouse gases that comes along. Instead of releasing these gases into the air, the Carbfix method entail using water to dissolve these compounds into the water before pumping the water back into the earth. When the water is pumped back, the gases react with the bedrock, creating minerals over a couple of years, therefore locking the gases in the form of minerals into the earth.

View at the Hellisheiði plant

Össur

Össur develops and produces bracing and supports as well as prosthetic for arms, knees, legs and feet. The headquarters for the company is located in Reykjavik where approximately 400 employees work. The production of bracing and supports is performed in China, while the prosthetics are mainly produced at the headquarters. Prosthetics are produced to help amputees be safe and mobile regardless of injuries and improve their quality of life. Different prosthetics are produced depending on the needs of the patients, some patients may have a more active lifestyle than others and may then require a more advanced prosthetic. Össur recently launched the power knee which is one of their more advanced prosthetics. The power knee helps people with above knee amputations in many ways, for example by reducing energy cost. People who use some kind of lower limb prosthesis expend about 30-60% more energy in comparison to people with intact limbs, and the power knee can reduce the energy cost when walking. The power knee also assists in sitting down or rising from a chair, and when ascending or descending stairs.

A selection of the products produced by Össur

RESOURCE EFFICIENT PRODUCTION

Industry challenge: *To minimise the resource consumption and environmental impact of production systems and products.*

Resource-efficient production is a prerequisite for manufacturing in a country such as Sweden, with high wages, high quality standards and high material costs. Resources such as materials, people, energy, capital and time must be used efficiently in order for production to remain competitive. Research and innovation aimed at resource-efficient manufacturing requires a holistic approach and affects all the lifecycle phases of products and production systems.

ABOUT THE AUTHORS

Christina comes from a background in the Environmental Sciences and her current research focuses on the integration of environmental management into operational improvements for the aggregate industry. The goal of her research is to aid producers in calculating and improving their environmental performance.

"Coming from a natural science background, I have had few opportunities to dive deeper into different production systems outside of my own research field. This course has given me the opportunity to listen and discuss resource challenges in many different contexts to see where challenges differ or have a lot in common, while learning where opportunities to share knowledge may exist."

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IS DATA THE NEXT FRONTIER IN RESOURCE EFFICIENCY?

Resource Efficiency: An Expanding Domain

Natural resources have been an enabler throughout human history for the emergence of civilizations and are the foundation on which growth and human development have been built. Equally, the mismanagement of natural resources has played a significant role in the collapse of civilizations in the past, with Easter Island's eerie statues of ancient faces with not a tree in sight a stark reminder of what could be if we do not manage natural resources well.

With the beginning of the Industrial Revolution and the widespread use of energy resources derived from fossil fuels, energy came into focus as an important resource for driving development. Considering the non-renewable nature of fossil fuels, depletion was a key concern and focus began to be placed on resource efficiency. Efficiency can be loosely defined as a ratio of inputs to outputs for a given unit with the aim to make gains (i.e. reducing input or increasing output) (Lankford, 2013). Despite the growth in availability of renewable energy sources, energy efficiency is equally important today and still has an intrinsic connection to natural resources considering the necessity of metals and minerals in renewable technologies. On top of material inputs as a driver for energy efficient production, the renewable boom also adds new dimensions to the question of energy efficiency in how we adapt to variable energy sources to utilize over and under production in an effective way (IRENA, 2019).

The Industrial Revolution also raised awareness concerning the importance of labour in production systems. The principle that through supporting workers in their health and lifestyles, greater efficiency could be achieved, eventually led to the establishment of a new discipline for resource management in maintaining and optimizing the efficiency of labour known as Human Resource Management. Nothing highlights this better than by Henry Ford's introduction of an 8-hour workday to improve efficiency (History, 2009).

The need for good management of resources comes from the fact that they are scarce and valuable, and the importance of resources has driven many economies, contributing to resource management becoming a central issue throughout human history, and a key part of modern business management. Out of this reliance on natural resources, efficiency has emerged as a leading management technique. We can see the prevalence of resource efficiency in business management with the rise of methodologies like LEAN and the Circular Economy.

Now, resource efficiency and HR are standard concepts that successful organizations work actively with. However, with the rise of Industry 4.0, our landscape is changing yet again, and data is becoming more and more central for businesses to be successful. With this emerging resource, a question can be raised as to whether data efficiency will be the next front in resource efficiency and how can companies approach this new challenge?

Data As A Resource

Data can be anything and everything, from information used for decision-making to digital information that can be transmitted or processed, according to the Cambridge Business Dictionary. It can be

raw; it can be big; it can be mined; it can be stored; it can be processed; and, as Meta and Google are clear evidence for, it can be valuable. Overall, data has many commonalities with natural resources, so it is no surprise that during the 1980's, a new discipline emerged known as Data Management. The aim of which being to help increase the value gained from data, decrease the cost of processing it, and generally improve efficiency. Despite this, many organizations struggle with managing data effectively, and as more and more data becomes available, common issues often occur leading to problems including poor communication, double-working, and diminished competitive edge to name a few (Gordon, 2013). Managing is not the only challenge surrounding data for organizations though, as issues still persist around collecting, mining, and analyzing data so that it can provide value. Data itself is also not impact free, with growing discussions around the potential future energy demands from data centres making it worthy of consideration for companies wanting to reduce their impact.

Lastly, it is worth considering that data does come with its own unique challenges bearing in mind the human interaction with it, and how to overcome trust issues and knowledge gaps surrounding it is a common problem for businesses (Ugarte, 2021). Considering these challenges, the sites provided insight into how different companies are approaching resource management, and how data fits into that picture.

Observations From The Visits

In Gothenburg, the three companies we visited were in well established industries with long histories. Ringhals nuclear power plant has been producing electricity since 1975 and with that comes a considerable amount of experience in efficiency measures to maximise production. They have also been working with an Environmental Management System (EMS) since 1998 to reduce environmental impact where resource use, particularly for hazardous chemicals, is in focus. Business trips have also been added to the mix in 2022 through a goal to reduce related climate impact by 30% by 2025 (Vattenfall, 2022). With established management systems in place where continuous improvement is a key outcome, Vattenfall has procedures up and running to see that resource efficiency is regularly evaluated and improved. Now they are turning towards the large quantity of data that has been collected over the years and how to preserve, utilize, and share internally the information available from this data. A key challenge discussed by Vattenfall before real value can be taken from the data is addressing digitization with large quantities of data currently in analogue format to be converted into a digital format.

Skanska and Volvo also have long histories, dating back to 1887 and 1928 respectively, with the Vikan quarry dating back to the 1960's and the Tuve plant to the 1980's. Volvo has ambitions to be a fully data driven company and is working actively with digitalization. A key challenge that Volvo is facing discussed by Malin Hane Hagström concerns how to transition into being fully digitalized, and Volvo are putting a focus on change management to address this challenge. For Skanska, the focus lies more in how data can improve material resource efficiency rather than finding value in the data itself (Skanska, 2022).

In Iceland, our first visit was to Lucinity, a company where data is the core of their business, and mismanagement can be the make or break for them as a business. Due to the sheer amount of data that they handle, one concern discussed with Oli Pall Geirsson was the impact of storing this data, as large data centres are becoming huge energy consumers.

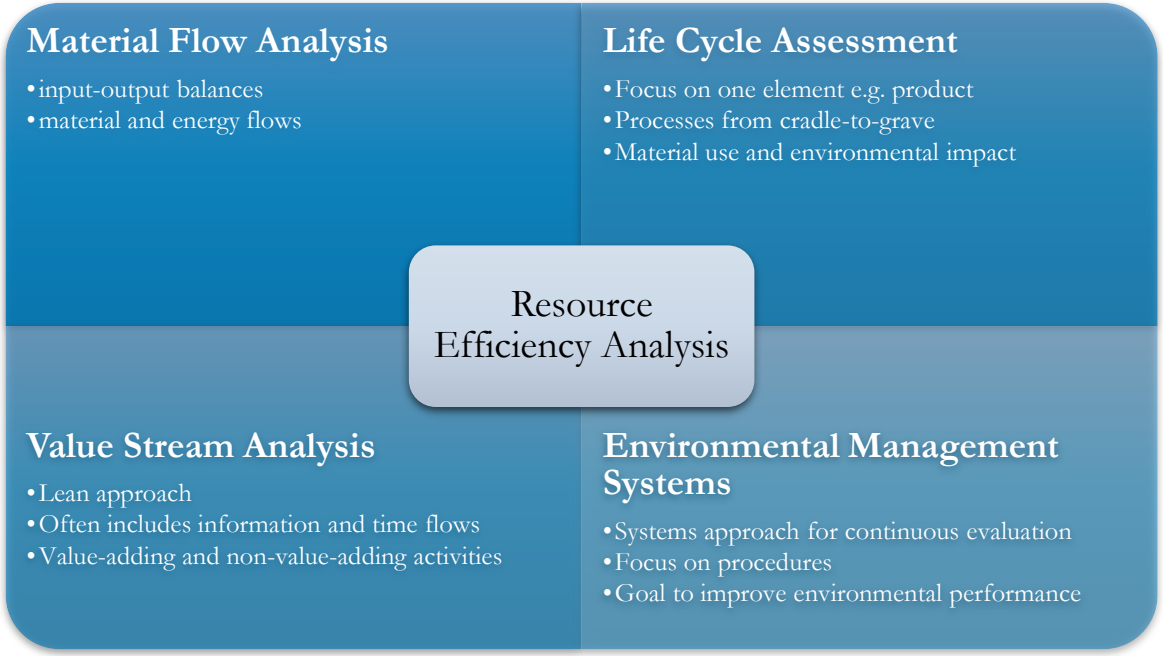
Both Nox Medical and Össur rely on more traditional manufacturing for their products and are implementing resource efficiency measures to reduce waste while utilising innovation to reduce material input. Sleep data is the key output for Nox Medical's products, and efficiently collecting and processing that data is a focus for their R&D presented

by Ingmar Hjalmarsson. A lot of value in data can also be seen for Össur's R&D as more and more data is collected on how the human body works. With the University of Island, where research is being conducted into improvements for those with cochlear implants, alongside both previously mentioned companies being involved in the medical field, growing discussions on the customization of medical solutions considering the variations between individuals are areas to pay close attention to. Data will be essential to achieve higher levels of customization and can contribute to resource efficiency in the manufacturing process as well.

ON's geothermal plant at Hellisheidi has a strong focus on energy efficiency in providing hot water and electricity to residents in Iceland with minimal losses, and also has a long history in the area. Now focus is much more on environmental concerns, particularly carbon capture and storage to make the plant carbon-neutral by 2025. Considering their close work with nature, monitoring is an important aspect of their work to ensure sustainable and safe energy production, and where data can add a lot of value for the business.

Trend Analysis And Discussion

Considering resource management in general, there was a stronger emphasis on human resources with notable investments into creating desirable work environments in Iceland compared to Sweden. The benefits of investing in desirable physical working environments can include a better retention of top talent, as well as contributing to being an attractive employer (Earle, 2003). These points were noted as contributing reasons for implementing voluntary employee benefits by



Key methods for approaching resource efficiency in organizations based on methodologies listed by Scmidt et al. 2019.

Lucinity and Nox Medical to retain staff on the sparsely populated island. Companies in both Iceland and Sweden involved in manufacturing noted efforts of keeping manufacturing within the Nordics where economically feasible, with Össur, Volvo, Skanska, and Nox Medical having assembly lines and/ or some manufacturing on site at the locations visited. This allows easier monitoring, communication, and implementation for material resource efficiency measures for the businesses. Material resource management was an area most companies were active in and, therefore, making it difficult for resource efficiency to be forgotten in daily operations while giving the companies more opportunity to identify improvement areas. That said, there is still much that can be achieved within the realm of resource efficiency, in human, material and energy domains (Schmidt et al., 2019). Data can play a key role in unlocking these opportunities.

Turning toward data as a resource, the value to be gained from data varies considerably between the different companies and industries visited during the course; from being the main value generator for Lucinity to more supportive roles at Skanska and Össur. That said, data is now a universal resource and is creating value to some degree in all the companies visited in both Sweden and Iceland. Considering the similarities between data and traditional resources, none of the companies visited noted using resource efficiency techniques in their data management yet. Lucinity noted that energy costs do drive efficiency measures at data centres for data storage, however, this is an aspect that few companies have a direct influence over. It also does not consider the data itself and risks data becoming a victim of the Jevons paradox that we see in resource management; namely that increasing efficiency does not lead to reduced consumption overall, rather an increase like that we have seen over the 20th century with resource consumption increasing from around 1 tonne per person to over 11 tonnes per person (Schmidt et al. 2019 & Polimeni et al., 2009).

As data is not impact free and can provide value, its characteristics have a lot in common with traditional resources. Insight into whether resource efficiency analysis techniques like those listed in Figure 1 could be adapted to data resources as a way of tackling current and future challenges with data management could be valuable for companies across the Nordics. Traditional resource efficiency tools that could be applicable include: waste management of data at Lucinity considering the large amounts of data processed; value identification for data at Ringhals Power Plant; and product life cycle perspectives for Nox Medical considering the key output for their products is valuable data.

Considering the commonality among companies in their interest in data and the similarity in characteristics between data and traditional resources, I do think data could be the next frontier in resource management and worth the attention of future research.

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Heated groundwater released as steam at Reykjadalur Thermal River illustrating the vast amount of geothermal energy present on Iceland. One of many inspirational places visited during the trip.

FLEXIBLE PRODUCTION

Industry challenge: *To strengthen organizations by enabling production systems capabilities to be flexible when it comes to facing market variations.*

Flexible production is essential to cost-efficiently achieve high flexibility and provide better responsiveness.

Flexible production research constitutes a mainstream topic and a major drive toward the future of the manufacturing industry.

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FLEXIBLE PRODUCTION

Introduction

Production organizations currently face a fiercely competitive market that combined with an increasingly shortened product lifecycles, increased product tailoring and customization, frequent volume changes while being pressured to maintain a high degree of cost efficiency and quality, make flexible production an industry challenge to investigate.

What is Flexible Production

Flexible production is a significant challenge in today's manufacturing industry (Produktion 2030). In order for the manufacturing industry to cope with nowadays production challenges, manufacturing systems setups need to incorporate flexible production considerations enabling the systems with the capability of changing it function and capacity according to product and production changes. New knowledge and innovative manufacturing methods can be supported by novel simulation techniques, automation, and digitalization, to achieve flexible production systems (Produktion 2030).

Industrial needs

Globalization has contributed to bringing the world closer. People around the world are more connected than ever before, information data and financial flows are more agile than ever and goods that are manufactured in other parts of the world are seamlessly available to end-users as local products. However, this transformation has also contributed to creating a volatile and sometimes unknown landscape for the manufacturing industry. Manufacturing companies nowadays are facing an intense global competition, increasingly shortened product lifecycles and increased product customization and tailoring while being pressured to maintain a high degree of cost-efficiency (Koren, 2010).

The previous steady lifecycles of development and introduction of new products were marked by a smooth ramp-up with a steady volume increase which usually was followed by a maturity phase with stable demands and then a smooth ramp-down. In today's volatile and unknown market, these lifecycles are becoming shorter and shorter,

(Future Technologies That Will Drive Industry 4.0. Axiomegroupe, World economic forum, june 2019)

where to a large extent, the results of the end user's requirements of increased customization and personalization of products which is forcing manufacturing industry into a new manufacturing paradigm shift from today's mass customization to mass personalization or individualization (Koren., et al 2018). As a result of the shorter product lifecycles and customization, production systems are required to manufacture an increasing number of product types and variants (Wiendahl., et al 2007). It is estimated that product lifecycles have been reduced by 25%, leading to that product variety has more doubled in the last two decades (Roland Berger, 2019).

With the above-mentioned trend, production organizations in the future are most likely needed to introduce more new product types into existing production systems, leading to more frequent ramp-up and ramp-down scenarios when transitioning from an outgoing product to a new one. Consequently, the more flexible production systems are, the more efficiently they can transition from one product to another, making flexibility one of the key enablers for the future of the manufacturing industry.

Relevance of flexible production to some of the visited companies

Ringhals nuclear power plant & ON Power Geothermal power plant

From the energy production perspective, it is vital to think about flexibility, from both the demand side and the supply side. The Ringhals nuclear power plant is located in the south of Gothenburg. It provides about 20% of the total electricity consumption of Sweden. However, the electricity demand varies a lot in different seasons. The company has to apply both management and technological approaches to predict the future demand and generate the adequate electricity from the nuclear energy in a flexible manner. However, for the ON Power Hellisheiði Geothermal power plant we visited in Iceland, the energy source is from geothermal. The energy source itself is unstable. Multiple technologies are applied to acquire stable energy output in the forms of electricity or warm water. Compared with the nuclear power plant, the geothermal power plant cares more about how to flexibly use the available energy sources in a more efficient way.

Volvo Group Trucks Operations: Tuve plant

Based on the course industrial visits, we can confirm that the flexible production challenge area is very relevant especially when it comes to Volvo Group (Tuve plant). Volvo Tuve plant located in Gothenburg produces several heavy-duty trucks such as Volvo FH, Volvo FH16, Volvo FM, and Volvo FMX. Additionally, it produces frame members not only for the Tuve plant but also for other assembly plants. Today's volatile market has suffered disruptions and shortages of raw materials and components (e.g. semiconductors). Some of these disruptions have been caused by events such as a pandemic or war, highlighting the need for companies such as Volvo Group to ensure that their production plants are flexible enough to cope with the arisen challenges. Furthermore, due to the different production truck variants produced at the Tuve plant and considering the intense global competition that forces the manufacturing industry to ramp up and ramp down products more often requiring production volume adjustments, we can conclude that flexible production is a challenging research area to be strengthened and considered for manufacturing companies such as Volvo Group.

Össur

Össur is a great company dedicate in helping disabled people and people who needs auxiliary in mobility. They are not only the technological company in research and yet the main producer for their various products in prosthetics, bracing and supports. It requires a considerable flexibility in production. First, the production plan had already been considered during the design phase. The long-time accumulated experience and the internal collaboration enable them to be more efficient and flexible in the production. Besides, the external collaboration is also an effective tool for them, which is the close relationship with the machine manufacturers. A close relationship with the machine manufacturer enables the maximize the flexibility and quality in production. Most of the machines were customized dedicated to their demands and the machines usually replaced and updated in every 6 years. Moreover, automation in the production also facilitate the flexibility as it can help the operator to switch the product in a short period. Overall, Össur is a traditional manufacturer who embrace the new technology and have the quick update with fast pace of the development of the world.

Our conclusion

We found this course very relevant and inspiring . It was great since it provided us the opportunity to visit in person several production systems and compare their similarities and differences when it comes to reconfigurability and flexibility. We could see different production sites in different Scandinavian countries comprising wide variety industries.

The course is also very interesting especially noticing that the AI and robotic technologies are more and more applied in industry to improve productivity and decision-making. We also noticed that flexible production is emphasized more than ever due to the requirement of customized products and services. This great experience motivates us to think more in our research.

We also found this course very inspiring especially when we noticed that additive manufacturing was found to be applied in the industry to improve flexibility in production. For instance, to make mold. And we found there are more opportunities that additive manufacturing can be applied to enable the flexible production. It motivates us that additive manufacturing is a game-changer when it has been used in the right domain and our task is to seek an efficient way to adopt the technology while saving the cost.

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VIRTUAL PRODUCTION DEVELOPMENT

Industry Challenge: *To convert information and data into knowledge and input for decision-making in virtual and physical production systems.*

Resource-efficient production is a prerequisite for manufacturing in a country such as Sweden, with high wages, high quality standards and high material costs. Resources such as materials, people, energy, capital and time must be used efficiently in order for production to remain competitive. Research and innovation aimed at resource-efficient manufacturing requires a holistic approach and affects all the lifecycle phases of products and production systems.

ABOUT THE AUTHORS

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"Digital Transformation has been playing a critical and indispensable role in resource-efficient production in the Nordic countries. This course gave us deeper insight to study which digitalization level each company is currently at and how it concerns them, as well as estimate their digitalization transformation development opportunities and challenges simultaneously to investigate current and future digitalization policies in each Nordic country. "

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EFFICIENT-RESOURCE PRODUCTION VIA DIGITAL TRANSFORMATION

Digitalization Transformation

In recent decades, for production & manufacturing companies, how to achieve sustainable development into their products and processes are the hot and everlasting topic with different purpose behind of it. Some companies consider it as the critical method on increasing or securing their core competitiveness and creating the better image and marketing while others believe the sustainable development can support their companies to reach out innovative solution to implement sustainability. However, as the change of operating environment and high cost of materials, labor market and energy, how to effectively design the market success factors such as cost, quality, time, and adaptability for long term successful production needs to be taken into consideration. The key solution to achieve this goal is to increase the efficiency of all production factors via industry 4.0, especially in which the digital transformation can provide a sustainable increase in recourse efficiency, reduce the negative impact on environment simultaneously reduce the cost.

The closer interlink between the physical and digital worlds made and advanced development of the Internet of Things (IoT) and Cyber-physical Systems (CPS) technology simulated by digital transformation offers the chance to qualitative growth and enable to continuously evaluate the process and machine state, to take countermeasures at the right time to keep the process constantly at its optimal state, to make the intelligent self-decision based on big data, to avoid any unwanted outlier or falsifications, to simulate and predict process impacts and to establish smart factories.

Through digital transformation provide many potentials on the implement of resource-efficient production and initiate the new era of industrial revolution – digital revolution accompanied by more advanced technology innovation and changes, the several challenges still exist and wait to be tackled. Those challenges are clarified in form of questions below(Topic and Biedermann 2020).

- How to implement digitalization in the process of development and production of goods and services?
- How importance of digital transformation for increasing resource efficiency?
- Which core elements of the digital transformation are related to the increase in recourse efficiency?
- How to know if each company is ready to achieve the digitalization?
- What are the amply measures to increase the resource efficiency through digitalization?

Digitalization Level Measurements: Methodology

Once goal to implement digital transformation is set, how to analysis, measure and estimate which digitalization level the company is in naturally becomes the urgent issue. M. Topic and H. Biedermann defined the eleven concrete and practical measures for digital transformation in practice, which enable to apply into different

companies with scales from small, medium to large(Topic and Biedermann 2020). Besides, these measures can be utilized collectively or separately based on each company's individual practical application in digital transformation to save recourses and achieve sustainable development. The eleven measures are further elaborated from one to another below.

- Cross-linking of sensors & actuators

The connection between sensors and actuators which is regarded as the fundamental element on digital value creation allowing data captured from different sensors and actuators to be monitored and efficiently utilized during manufacturing and production process.

- Utilization of digital object memories

Relevant data needs to be further stored into the memory which is equipped and integrated with physical objects including products and machines.

- Decentralized control

Making workpiece or components intelligent plays important role in decentralize production and value-added network. With knowledge of properties, the workpiece or component itself provides information on how it can be designed, manufactured, inspected and shipped and further control its own production process during the lifecycle.

- Measures for worker support and assistance

With the development of AI technology, the workers working in the board range of manufacturing and assembly tasks urgently get intelligent supports and assistances with mobile terminals. And the application of VR based digital twin into the assistance to intelligent assembly process or assembly training process is one of typical examples.

- Dynamically cooperating systems and modularization

Modularization enables to add or modified production components to production plant which can better support to achieve creation and modification of interoperation between two or more parties with less effort.

- Introduction and use of positioning and localization systems

Intelligent tracking and locating system provides the great supports on machines, plant component and finished products searching.

- Condition monitoring

The condition monitoring offers the access to continuously capture, analyze and estimate the in-time state in production process on the basis of sensor data acquisition, processing and AI based analysis and decision-making.

- Predictive maintenance

Through the predictive maintenance system, ongoing malfunctions and machine failures enable to be predicted and prevented before they occur with help of proactive inspection and repairing and maintenance plan.

- Consistent data integration

The integrated consideration of production and order planning need supports from consistent data integration and uniform and universal access to data structure.

- Virtual product development

In the process of the product development, the digital 3D model of a product is designed on the computer, which as the virtual model can be further modified, tested, and optimized by simulation system or produced and assembled using Industry 4.0 based technology – 3D printing, virtual reality, and digital twin.

- Cloud computing

The individual workspace such as program, storage space and computing capacity are not provided on the hard disk of PC but via the Internet or the cloud.

Digitalization Level Estimation in Each Company

Several companies coming from different sectors such as production & manufacturing, energy, digital software, digital consulting, medical equipment in two countries to which we paid the visit are all in the process of implementing digital transformation. However, each of them are facing distinct challenges and at the different development stages. Through the eleven measures clarified above, the digitalization level of each companies enables to be estimated and visualized. The digitalization level of each company is further analyzed and compared with each other based on the combination of eleven measures, our practical visiting experiences, detailed communication with working staffs and management team during the visits and literature reviews after the visit. The credit given in each measure applied by each company is the range from 1 to 5. The higher credit each measure has, the more frequently and maturely the company is utilizing that measure for its digital transformation process estimation.

Digitalization Policy in Nordic Countries

Undoubtedly, the digitalization policy raised by each country's government including in which extent they recognize the current state and future development of their countries' digitalization, which method are most suitable on each country's digital development, how to find these best and most adaptable methods, how to increase the investment on relevant financial, energy and human resources to stimulate the companies potential on digital transformation based

Table 1: Overall digitalization level estimation

Company	Measures				
	Cross-linking of sensors & actuators	Utilization of digital object memories	Decentralized control	Measures for worker support and assistance	Cloud computing
Skanska Vikan	3	4	3	3	2
Volvo Tuve	4	4	4	4	4
Ringhals	3	3	4	4	2
Nox medical	3	4	3	4	5
Össur	3	4	4	4	5
Hellisheidi	3	3	3	3	2
Lucinity	NA	NA	4	4	5
Company	Measures				
	Introduction and use of positioning and localization systems	Condition monitoring	Predictive maintenance	Consistent data integration	Virtual product development
Skanska Vikan	4	3	3	2	3
Volvo Tuve	4	5	4	4	5
Ringhals	3	5	5	3	2
Nox medical	3	3	2	5	5
Össur	3	3	2	5	4
Hellisheidi	3	5	4	3	2
Lucinity	NA	NA	NA	5	5

innovation has the indispensable and significant impacts on each company's digitalization future and efficient-resource production strategy. Hence, to study on and understand the strategical development guidance of digitalization from each government is highly necessary. The overall review on digitalization policy in all Nordic countries firstly presented based on their magnitude of efforts, focus and use of means, then detailed policy in our visiting countries – Sweden & Iceland from different aspects including priority areas, key policies/strategies and key actors (steering groups/committees).

When it comes to the magnitude of economic efforts, Finland plays the leading role following by Denmark and Sweden. Finland has invested most in programmes and initiatives driving automation and digitalization. The three most critical initiatives in Finland are DIGILE,

Industrial Internet and 5th Gear with total financial support around EUR 200 mill meanwhile Denmark invests EUR 15 mill from the public sector including EU funds. Due to the different economic efforts made by each Nordic country, they apparently differ in the focus of the policies. Denmark is the only one country that supply programmes specific geared toward digital follower and the main target group in Denmark are the wide range of companies that prefer to invest the new technology at the mature stage. Finland pays more attention on applied research within digitalization and automation by getting innovators involved as participants. However, in the other Nordic countries has a board focus on manufacturing with different projects focusing on the IoT and industrial strongholds. Be the digital follower as Denmark's focus, it needs more supports from advisory services and diagnostic tools while the competitive methods for applied research are applied by other Nordic countries through the more investments in temporary projects which is not good for the instant knowledge accumulation(Nordic Council of Ministers 2015).

The glance at the beautiful scenery in Iceland

Digitalization Policy in Nordic Countries

In Sweden, Digitalization initiates with priority areas such as digital skills, digital security, digital innovation, digital management and digital infrastructure with policies containing Digital Agenda for Sweden 'For a sustainable digitalized Sweden (2017)', National Programme Digitalt Först(2015-2018), National digitalization strategy for schools and Digital Agenda for Sweden 'ICT for everyone' and challenge-driven innovation project STREAM funded by VINNOVA(Randall L, Berlina A, Teräs, J & Rinne T 2018) through the collaboration between Digitalization Authority, Digitalization Council and Swedish Association of Local Authorities and Regions(SKL)

Compared with Sweden, Iceland mainly focuses on the implementation of National Cyber Security and the development of smooth digital public services towards better efficiency, transparency and democracy and knowledge building in IT in order to be the top 10 nations on the e-government development index. The steering committee driving the digital transformation in Iceland are Ministry of Transport and Local Government, Information Society Taskforce, Information Society Taskforce and Cyber Security Council.

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HUMANS IN THE PRODUCTION SYSTEM

Industry Challenge: *To strengthen cooperation between humans and automation in order to enhance people's performance and increase productivity and flexibility.*

There are challenges in industry regarding the cooperation between humans and automation technology. Automation is becoming increasingly common and the cooperation between humans and automation is important in order to enhance the performance and increase both productivity and flexibility. Manufacturing is becoming increasingly digital, but humans are still vital in the manufacturing. This is in line with the recent report published by the European Commission regarding the new Industry 5.0 concept wherein humans are seen as integral part of the industry in the future, and the importance of human centric design is emphasised (European Commission, 2021).

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HUMANS IN THE PRODUCTION SYSTEM

Introduction

The Production 2030 challenge of humans in the production system is addressed in this chapter wherein safety, automation and collaboration between humans and technology are analysed in the visited companies. Last year, the European commission released a report regarding Industry 5.0 which is a complementary approach to Industry 4.0 in which the wellbeing of the worker is placed at the centre of the production process and new technologies are used to provide prosperity beyond jobs and growth while respecting the production limits of the planet (European Commission, 2021). The Industry 5.0 connects to the industrial challenge presented by Produktion 2030 regarding humans in the production system.

One of the most important paradigmatic transitions characterising Industry 5.0 is the shift of focus from technology-driven progress to a thoroughly human-centric approach. This means that industry needs to consider societal constraints, aiming not to leave anyone behind. This has a number of implications, pertaining to a safe and beneficial working environment, to the respect of human rights, and to the skills requirements for workers. A human-centric approach in industry puts core human needs and interests at the heart of the production process. Rather than asking what we can do with new technology, we ask what the technology can do for us. Rather than asking the industry worker to adapt his or her skills to the needs of rapidly evolving technology, we want to use technology to adapt the production process to the needs of the worker, e.g. to guide and train him/her. It also means making sure the use of new technologies does not impinge on workers' fundamental rights, such as the right to privacy, autonomy and human dignity (European Commission, 2021). Current research in Industry 4.0 pays limited attention to the human operators (Neumann et al., 2021). Not considering humans in the design and implementation of technologies related to Industry 4.0 risk creating phantom profits where expected profits from the technology are lost due negative consequences for the operators such as fatigue, injuries, and increased errors (Sgarbossa et al., 2020). In this chapter, the visited companies are presented connected to the challenge presented by Production 2030 regarding humans in the production system as well as the related Industry 5.0 concept as introduced by the European Commission. This is followed by a section on analysis and reflections on the visits.

Experiences from visits

A wide range of different industries were visited during the course, some of the companies did not have a production system in the sense of producing physical items. The visits have been grouped into three categories in this section, first companies having a physical output, including Skanska Vikan, Volvo Group, Nox medical, and Össur. The second section includes the two power plants, Ringhals nuclear power plant and Hellisheidi goethermal plant. Finally, the last section includes Lucinity and Nox medical (Nox is part of two categories) which both focus more on software and algorithms rather than physical artefacts.

Industries with a physical output

This subsection deals with the visits that actually have a physical output in some way i.e. Skanska, Volvo Group, Nox Medical, and Össur. Both Volvo and Össur are manufacturing companies while the output from Skanska is aggregates, and Nox Medical producing a device for monitoring sleep patterns as well as algorithms to facilitate analysis of collected data.

Skanska Vikan see large potential for automation in the operations in the quarry. A pilot project was conducted in collaboration with Volvo Group regarding automating and electrifying equipment in the quarry. One target for the project was automated dump trucks. In the Vikan site, a fleet of dump trucks is used to move aggregate products from the crushers at the blasting sites to the right storage point in the quarry. The dump trucks are manually operated and work in hazardous areas with cliffs, uneven and rough roads, high noise levels as well as interactions with other large vehicles and machinery. In the project, Volvo introduced automated dump trucks, a kind of outdoor automated guided vehicle (AGV). AGVs are becoming increasingly common in many application areas, such as in production and logistics, container ports, and hospitals for their possibilities to improve productivity while still being flexible to manage changes (Bechtsis et al., 2017).

These automated dump truck had no operator and moved between different positions in the quarry to either pick up or delivery rocks and gravel automatically. Several potential benefits were identified by using automated dump trucks for the humans working in the quarry. By automating the dump trucks, operators would no longer need to work in the dangerous areas mentioned earlier and instead could work in other operations with less exposure to risks. For instance, some operators could work with supervising the fleet of automated dump trucks, to make sure that they function as they should. This supervision could be conducted from the safety of an office rather than in the quarry. Furthermore, the automated dump trucks were electrical reducing the emissions of greenhouse gases in the quarry. The use of automated dump trucks at Vikan is a good example of where automation technology can improve the situation for the humans in the production system with improved safety for operators and other employees working in the quarry. The collaboration between Volvo and Vikan worked well, however, when the pilot project was over, the usage of automated dump trucks was not continued. The automated dump trucks were still at a prototype stage and required further development.

Volvo's Tuve production plant has a modern production line that produces consistent and reliable trucks for the world. In addition to trucks, they also export assembly kits for trucks, and these are shipped out and sent all over the world. Most of the assembly processes are carried out manually, in the assembly line, and in the materials handling. The materials handling is a crucial process in assembly and can account for a large portion of the manufacturing cost for a product (Esmaeilian et al., 2016). From the beginning, the assembly objects are transported by AGVs, which automatically move the assembly objects between assembly stations at each takt. As the human operator is crucial in production, it is important to ensure that the workstations are carefully designed from an ergonomic point of view. During the visit at Volvo, parts of the assembly line were observed where several operators worked on assembling different parts to the assembly objects. For example, the different functional parts are bolted to the frame by the human operators. Even with the use of air pump assistance, human workers take on the core assembly work.

A fixed takt of each process in the Volvo production plant, encouraging humans to work continuously on the parts around them for the limited time available. This means that if the focus is on the human dimension, the workers in each part must work as part of a complete team to get the job done correctly and efficiently. Several tools are available to the operators to assist when for example lifting heavy objects. The assembly object is also tilted to allow the operators to more ergonomically perform their assembly tasks.

The realization of human-centered design is an important topic in Industry 5.0. Monitoring sleep problems is crucial, as sleep affects many normal daytime activities, and Nox products make it easier to correctly identify sleep disorders, and the tests can be performed at home, rather than having to go to hospital. A simplified portable sleep device minimizes the cost to the client, translates the data into something the doctors can understand and assists in determining if there is a sleep problem. Take sleep apnea for example, in which a person stops breathing for a period during sleep. Most sleep studies are conducted in hospitals and require the use of many sensors on the patient. Nox products use embedded sensors for capturing, analysing and processing biomedical signals from humans, then these signals are associated with the patterns and diseases of sleeping for humans. Finally, the designed solutions are provided to help humans with better sleeping state. In collaboration with world-renowned universities such as Stanford and Harvard, pharmaceutical companies and hospitals, Nox provides technology to assist doctors in determining the presence or absence of sleep problems. Nox products are also used in several research studies on sleep, for example (Yoon et al., 2019). Ultimately, Nox is a business-to-business company, and they have for example worked with Coca-Cola in Atlanta to perform sleep checks on employees. They are constantly working with different international manufacturing technology to update their products in several iterations in a five-year product cycle. During the visit, the quality assurance processes were shown wherein multiple generations of products are being tested, and Nox's employees play a vital role in the production of the products by undertaking some functions including design, shipping, testing, and quality control.

Össur is a global leader in non-invasive orthopaedics that help people live a life without limitations. The company is focused on improving people's mobility through the delivery of innovative technologies in the fields of Prosthetics and Bracing & Supports and has a successful track record in the development, production, and sale of non-invasive orthopaedics. An example of a product produced by Össur is the Power knee and an updated version of the Power knee had recently been released at the time of the visit to Össur.

Evolution of Össur's Power knee product

Humans in the Össur production system play an important role in the product design, development, production, and assembly. Since many assembly components have complex structure and also the precision and quality are critical to the final use of products. Within the manufacturing factory in Iceland, it was observed that the production system at the Össur's shopfloor involves a lot of human manual work, especially in the assembly system. The human-centric assembly system mainly focuses on the assembly operations and production of some of components such as assembling motor components and producing the fibric materials used for holding component production. In the assembly line, humans use their knowledge to assemble one or more components at his/her workstation. When the current assembly process is finished, the assembly object is moved to the following assembly operations in the sequence. During the assembly, humans also need to collaborate with other workers for the correct assembly and perform the quality check of each product. In addition, to have better ergonomic and lightweight design, the production of the lower and upper limb prosthetic components involves the wide use of fibric component. Within this process, humans stack the thin fibric material on top of each other and forms a fibric component with meeting specific requirements. Finally, these fibric components are cut to produce the components of limb prosthetic products. In the manufacturing and machining section, humans take the responsibility of programming and computer-aided design of the motor.

Energy production

Two power plants were visited in the course. Electricity is the main output of the powerplants and in the case of the geothermal power plant hot water is also an important output.

Safety is always important when humans are involved in a production system and measures should be taken to ensure that the work performed by humans is safe, limiting risks for injuries and accidents as much as possible. Safety is especially vital in the operation of a nuclear power plant as was experienced during the visit to Ringhals. One aspect of safety is for the operators working there. As a nuclear powerplant involves fission and handling of radioactive material, all employees are required to wear a dosimeter at all times in order to detect if there are elevated levels of radiation in the area. The figure shows a replica of the main control unit of one of the reactors.

Replica of the control unit for one of the reactors

Another aspect relates to safety on a societal level, e.g. that no unauthorized people gain access to the power plant. During the visit, a tour of the turbine building for one of the reactors was performed. A security checkpoint had to be passed before being allowed into the power plant area and during the tour, armed guards escorted the group at all times. Cooling the reactors is always vital in a nuclear power plant. Since the Fukushima nuclear disaster in 2011, stricter regulations for independent cooling of the nuclear reactors were developed.

Independent core cooling systems were installed for the reactors at Ringhals which are able to keep the reactor cool for 72 hours in the event of, for example, a natural disaster, loss of power at the plant, or failures of the water pumps used in the daily operations. Furthermore, safety in nuclear power is not only of importance in the operations, spent fuel is radioactive for a very long time and must be safely stored to not harm humans or the environment for many years into the future. In addition to spent fuel, decommissioned reactor tanks and other radioactive material must be stored away from humans as well. It was recently decided (decided in 2022) in the Swedish parliament that a final repository for radioactive material shall be built in Forsmark, the site of another operational nuclear power plant in Sweden. The final storage will be located 500 meters below ground in the bedrock. When the final radioactive material from the different nuclear power plants has been moved to the storage, the plan is to seal the storage facility so that no one can access it.

The geothermal power plant in Hellisheidi is highly environmentally friendly compared to powerplants using oil or coal. Compared with other renewable energy sources, the geothermal power is also very reliable. Solar power relies on that it is daytime with sunlight and wind power relies on windy days, and when these are not present very little electricity will be produced from these two sources (Ellabban et al., 2014). The geothermal power is, as mentioned, reliable and independent of time of day and weather conditions. The Carbfix method mentioned previously further improves the environmental performance of the power plant by capturing and storing CO2 and other geothermal gases in the bedrock. However, the goal of the Carbfix method is not to capture 100 % of the gases since for example CO2 is used in greenhouses for growing different crops in the surrounding area. CO2 is needed in the greenhouses, and it is therefore not desirable to capture all the CO2 as CO2 for the greenhouses would then have to be collected from elsewhere. The production of electricity and hot water at the geothermal powerplant is human-centric from the environmental perspective. Similar to the nuclear powerplant the safety of the employees is important. At the geothermal plant, radiation is not something that employees needs to be kept safe from, but there are occasionally gases from the ground that could be harmful to humans. Employees working at the power plant are required to wear a device that monitors the levels of harmful gases in the air when they are working outdoors, for example at the drill sites.

Water, wherein greenhouses gases have been dissolved through the Carbfix method is led back into the ground

Digital offerings

Lucinity main offering is not in physical products (or energy) but relates to digital offerings. Lucinity has no physical product offering at all. Nox medical produces and sells products, but an important aspect of their offering is to assist physicians in diagnosing sleeping disorders with algorithms to analyse the collected data.

As stated in the chapter on Nox Medical, their device allows for performing tests for sleeping problems at home. The collected data from using the device during sleep needs to be analysed, and another part of the offering of Nox is the algorithms they have developed. The algorithms perform the necessary analysis in order to present the data in an understandable way for physicians. The physicians are thus assisted by the algorithms and data analysis performed by Nox's device in the process of arriving at the right diagnosis and by extension the right treatment.

Lucinity has no production in the sense of assembling components to a finished product but work with algorithms and AI for anti-money laundering. They have developed the concept of they call human AI: "empowering humans to do what humans are uniquely good at". The aim of the human AI is to facilitate the identification of suspicious money laundering cases. Current systems at banks and other financial institutes are not always that helpful in identifying money laundering cases according to Olí Pall Geirsson at Lucinity. A lot of time is spent by employees in these banks and financial institutions in order to identify potential money laundering cases, but it is very difficult to find true money laundering cases in the large amounts of transactional data that is available. The collaboration between AI and humans improves the detection of money laundering. The AI scans large amounts of transactional data and if the algorithms find suspicious activities a human investigator is notified and can look into the data in detail. Here it can be said that Lucinity automates the initial scanning of the transactional data reducing the need for humans in this stage, and the humans can focus their effort on real money laundering cases. This allows the investigators to work on cases that are true money laundering cases more often, making their work more efficient and effective, as well as increasing the number of cases brought to and convicted in courts.

Money that goes through money laundering come from criminal activities and are, according to Olí Páll Geirsson, often used for purposes such as for funding wars and further criminal activities. Improving the detection of money laundering cases can reduce the amount of money that ends up for these purposes, again improving the lives of humans through the collaboration between AI and humans. The human AI concept allocates the work between humans and the AI in a good way, humans are assigned to tasks which are well suited for humans while the AI is assigned to tasks that are well suited for AI like quickly going through a large amount of transactional data. Even though Lucinity does not have a production system, the human is central in many ways in the services they provide, improving the work of anti-money laundering investigators and stopping criminals from feeding illicit money into the financial system.

Analysis

Aspects relating to the manufacturing companies and fruitful collaborations between several actors to improve different parts of the production relating to humans are analysed in this section.

Manufacturing and automation

Both Össur and Volvo involves a lot of assembly operations during the production of Volvo trucks and assistive products for Össur. Human operators are included in the loop of the production assembly lines, and take responsibility of manufacturing products, component assembly and quality check. In both of production assembly lines, there are still much manual work needed to be performed by human operators. They play an important role in the production and assembly systems. For example, human operators in the production systems of Össur starts with manufacturing model of the assistive products made by the fabric and plastic materials, cutting the raw materials into the predefined models with polishing and forming, together with machining of the mechanical devices such as metal components and motors. When all the necessary components for assistive components are ready, they are sent to the assembly production assembly line. All of the assembly operations there are almost finished by manual work because this process often involves precise assembly of small and precise components and frequent testing. This also requires the skillful and well-trained experience of human operators. In the assembly lines of the Volvo trucks, especially in the final assembly of the truck, human operators often need to perform the assembly of heavy components although the assembly objects are moved by AGVs at Volvo.

In order to improve the working conditions and repeatable quality of the manual work, human-robot collaboration (HRC) has become popular in the last decade. HRC combines the strength, repeatability and accuracy of robots with the high-level cognition, flexibility and adaptability of humans to achieve ergonomic working environment with better overall productivity (Wang et al., 2019). Within the context, human operators can use assistive robots/machines to ease their work with better ergonomic effects. In addition, human-human, robot-robot, and human-robot can be possible solutions to reach the target of efficient human-centric production systems. To reflect the mission of Industry 5.0, human operators' skills, rights, benefits, and working environments would be a core point in the production assembly lines. HRC could become increasingly important in production systems in the future when it is likely that more aspects of the processes are automated in line with both Industry 4.0 and Industry 5.0. For example, more automated assembly in the cases of Volvo and Össur but also in the logistics side of the processes like automated internal transportations with AGVs and automated picking in the materials handling when preparing kits and when sequencing parts for the assembly line.

Collaborations

Actors from different sectors can come together to improve the production processes and for the humans involved. Two examples of fruitful collaboration projects were identified during the visits. Skanska Vikan and Volvo collaborated on automation technology and through the project it could be seen that the automated dump trucks had potential to improve the work environment for the people in the quarry where the dump truck drivers could be assigned to work in less hazardous environment.

Volvo received input to their product development process for the automated dump trucks while Skanska Vikan learned about potential benefits and areas of application of automation in their processes. The second example of collaboration refers to the Carbfix method. Through the collaboration between the university of Iceland, the Icelandic government, geothermal plant, and other actors the already highly environmentally friendly geothermal power plant could reduce the emissions even more which helps in reducing global warming.

Combining expertise and resources from industrial actors, academia, and governmental institutions could make production systems more human-centric with the use of automation technology in the Skanska-Volvo example and to create a better environmental situation as in the Carbfix and geothermal plant. The assembly and material handling processes at for example Volvo or Össur could potentially utilise further technologies for automation to facilitate the work of the human operators, which could improve the well-being and performance of the production.

Reflections

The visit to the industrial companies and the universities in Sweden and Iceland enabled investigation and observation about the research topic of humans in production systems, from the settings of the production and manufacturing of Volvo trucks, assistive devices, power plants for electricity and heating, to conversion of CO2 into stones. The visits provided insights into several companies. It can be observed that humans in the production system of Össur not only have an important role in the product design, assembly operations, manufacturing components of the assistive devices, but also control the quality check of the products and global supply services. In parallel, the humans take main responsibility of control, management, and maintenance of runtime of the power plant. The human operators are deeply involved in these production activities, especially in the final assembly of trucks and assistive devices. This has a number of implications, pertaining to a safe and beneficial working environment, to the respect of human rights, and to the skills requirements for workers. Safety is a key in the power plants, especially for the nuclear power plant both in the operations and when dealing with spent fuel. For Lucinity, improving the work of money laundering investigators and increasing the detection of money laundering cases is vital. For Skanska Vikan, there are potential benefits of using automation technology, to improve the work situation for operators in the quarry.

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Thingvellir national park

CIRCULAR PRODUCTION SYSTEMS & MAINTENANCE

Industry Challenge: *To develop competence and service-based products.*

A circular production strategy, such as re-manufacturing, is a way to enable smart and resource-efficient products and production systems.

The shift towards a circular economy and circular production requires new design at the product and production level.

The service life of products and production systems can be extended through smart maintenance, new combinations of materials and components and data analysis. To achieve this, we need to develop competence and find new types of service-based products.

ABOUT THE AUTHORS

Darya is a PhD student at the department of Production Engineering at KTH Royal Institute of Technology. Her research focuses on information management, design and development of an information model for closed-loop feedback, as well as digital twin technology.

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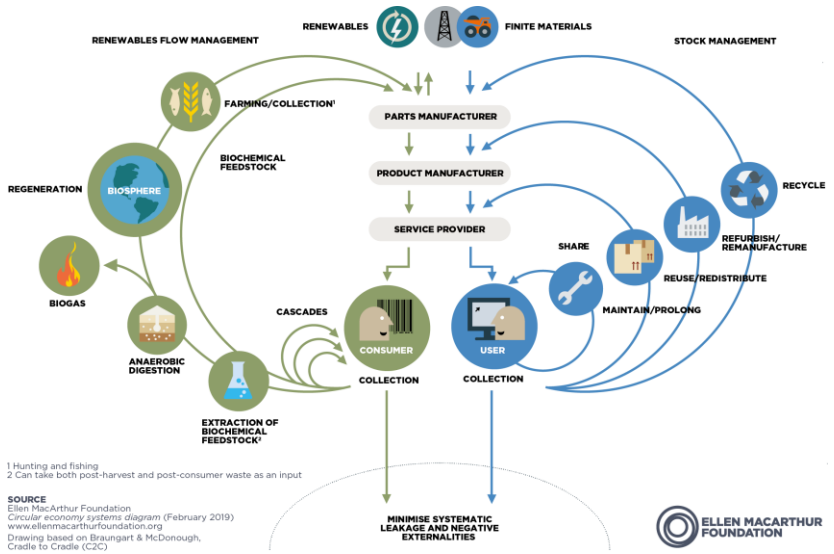
CIRCULAR PRODUCTION SYSTEMS & MAINTENANCE

Introduction

The traditional linear approach of take-make-use-dispose assumes that the planet's natural resources and its capacity to waste and pollution are unlimited (Murray et al., 2017); thus, it is not feasible in the long term and has made a series of challenges for our societies such as waste generation, resource scarcity, and sustaining economic benefits (Lieder et al., 2017).

To cope with these challenges, it is essential to decouple the economic growth from the consumption of finite resources by designing a restorative and regenerative industrial economy that designs out the waste and pollution, keeps the products and materials in use, and regenerates natural resources (Ellen MacArthur Foundation, 2013a). Circular Economy has been recommended as an alternative solution to overcome the limitations of the linear approach (Korhonen, Nuur, et al., 2018) by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017).

Transition to the circular economy advocates innovative changes in production and consumption paradigms, requires rethinking and redesigning business models, product design and supply chains (Kouhizadeh et al., 2020), and a systemic approach to integrating business model, product design, and supply chain with the help of Information and Communication Technology (ICT) to enable the dynamic interconnection among these three functions (Lieder & Rashid, 2016; Rashid et al., 2013, 2020).

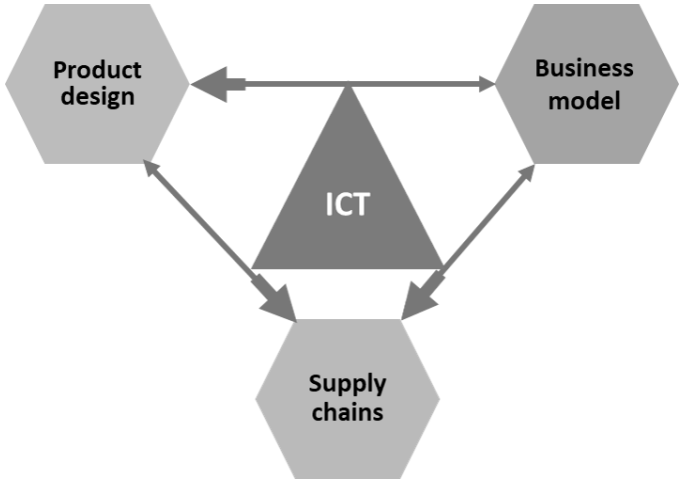


Butterfly Diagram (EMF)

Circular Production / Manufacturing System

Circular Production / Manufacturing System refers to a system that is designed intentionally to close the loop of components or products preferably in their original form through multiple lifecycle products (Rashid et al., 2020). This system is in line with the definition of Circular

Economy as "an industrial system that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013b). CMS is considered as a systemic value chain management approach that consists of three main pillars, i.e., business model, product design, and supply chain. These three pillars interact with each other dynamically and need to be coordinated with the ICT infrastructure (Figure 2). Therefore, the decision-makers need to ensure that the right information is available at the right time and in the right format.



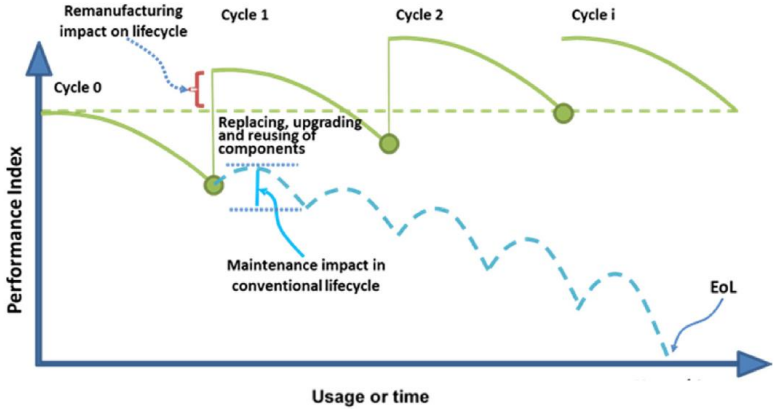
Circular Manufacturing System main pillars and their interactions (Rashid et al., 2020)

Pillar 1: Circular Business Model

The concept of circular manufacturing system calls for innovative circular business models to close the loop by design and intention (Rashid et al., 2020). As shown in Figure 1, business model has the dominant strength among other pillars. Moving from sale-oriented business models to service-oriented business models approaches the full loop closure in the production systems, nevertheless, adds complexity (Rashid et al., 2020). Product design and supply chain will be heavily affected by the chosen circular business model, e.g., in Product Service Systems the OEMs keep the ownership of the products and therefore, are motivated to design their products for long lasting; moreover, they need to have a robust circular supply chain to return their products when needed.

Pillar 2: Product Design

Successful implementation of Circular Economy will result in material savings and avoiding negative environmental impacts. This potential can be unlocked by designing the products for multiple life cycles and long lasting. Multiple lifecycle product design prolongs the functional life of the product. After each designed cycle the product needs to be taken back to bring to as new condition (Figure 3). Therefore, Product design has a crucial role in circular manufacturing systems implementation (Asif et al., 2021).

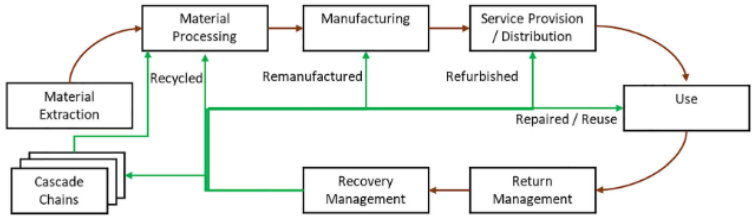


Multiple Lifecycle Products (green) vs. Linear Products (blue) (Rashid et al., 2013)

Pillar 3: Circular Supply Chain

Circular Supply Chain is considered as a crucial enabler of Circular Economy implementation where its design and performance are significantly influenced by business model and product design.

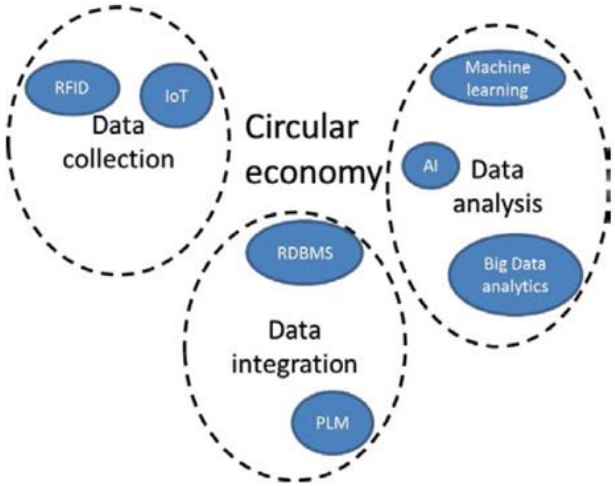
Amir et al. (2022) defined Circular Supply Chain (CSC) as "closing the loop by intention and design with a zero-waste vision where the forward and reverse flows are integrated and optimized for multiple lifecycle products to enable restoration and regeneration of technical cycles." (Figure 4).



Circular Supply Chain structure (Amir et al., 2022)

Pillar 4: Information & Communication Technologies (ICT)

ICT enables the mutual interaction of business model, product design and supply chain and supporting their activities by collecting data, analyzing and transforming it into knowledge and disseminating this knowledge among relative stakeholders through the product lifecycle. These technologies can be divided into three main categories of Data Collection, Data Integration, and Data Analysis. ICT has an important role in implementing CE by dealing with reverse flow uncertainties and filling the information gap in lifecycle stages and among different stakeholders.



CE enabling digital technologies (Pagoropoulos et al., 2017)

Visits

Skanska, Gothenburg, Sweden

We visited Skanska, one of the world's leading construction and project development companies in the Nordics and Europe in Gothenburg. This company has a vision of being climate-neutral by 2045 as part of Sweden's acts on its carbon emissions.

The construction and civil engineering sector generates approximately one-third of Sweden's annual waste and accounts for a quarter of the hazardous waste.

This sector can minimize the waste generation and move towards circularity by improving their resource usage efficiency, increasing reuse

of materials and recycling. One of the challenges mentioned by Skanska is waste classification regulations that makes prevent development of circular business models and limit recycling.

Form the product design perspective, Skanska and other pioneers in the construction sector emphasize on the need for circular material flows with net-zero waste production and suggest standardized and modular construction that enables more functions over time. This advocates for design for reusability and multiple lifecycles before returning the material flows to the natural systems.

Volvo Group Trucks, Tuve Plant, Gothenburg, Sweden

Volvo group is adopting a strategic approach on Circular Economy to capture its value and accelerate towards sustainability.

Design phase is one of their area of focus to influence their products lifecycles sustainability portfolio. Reducing material usage, extending the products lifecycle through repair and maintenance, and end of life material recycling are among the topics that Volvo tries to consider in the design stage where new business models are required to enable all these processes.

Remanufacturing is another focus area in their journey towards circularity. Volvo has a target of increasing their remanufacturing activities by 60% by 2025.

Reaching to the level of zero waste to landfill by 2025 is another circularity target for Volvo that needs to be done via minimizing the residuals and increasing the reuse and recycle share of materials.

Hellisheiði Power Station, Carbfix technology, Iceland

Iceland has a unique geographical location on the ridge between two tectonic plates. In addition to that, it is located over magmatic plumes, which means disposition of magma close to the surface. Thanks to these factors, Iceland is a country with high volcanic and geothermal activity.

Hellisheiði Power Station is the largest geothermal power plant in the country, and a supplier of electricity and hot water for Reykjavik area. The plant is an example of clean energy, since resources are renewable, temperature losses are low, and excess heat is reused for heating of water and internal needs.

From a circularity point of view Carbfix technology is of the greatest interest of the shift of business model. Carbfix technology is based on chemical reactions between carbon dioxide and basalt, to "turn CO_2 into stone" by getting insoluble non-volatile compounds. Thanks to volcanic activity, Iceland is literally made of basalt and it has a potential to store a vast of carbon dioxide. During the visit it has been mentioned, that the storage of CO_2, as well as other greenhouse gases, could be a new business model.

Import of gases from other countries, dissolved in water, could be an option, as well as an internal use of the technology on the production sites to reduce carbon footprint. The adoption of Carbfix technology is not a panacea for global climate change and reduction of greenhouse gases in the atmosphere, however, this might be a makeshift solution.

Hellisheiði plant

Conclusions

Transition to the circular production systems is important, especially in connection with the upcoming energy and resources crisis. However, it requires a systematic approach, throughout whole value chain. Companies are facing the challenge to rethink their business model and product design, as well as supply chains.

Data is a hidden resource for the transition towards circularity. Nowadays companies collect a vast amount of data, however, it is used insufficiently. Data management, analysis and prediction of trends and quality could be an enabler for the development of circular approach.

There are limitations due to the current legislation on the use of medical supplies. For example, it has been mentioned by Nox Medical and Össur, that they cannot reuse most of component parts due to hygiene and safety restrictions.

Geysir area, Strokkur eruption

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INTEGRATED PRODUCT & PRODUCTION DEVELOPMENT

Industry challenge: *To strengthen product development processes and tools for innovative product development.*

- A product must create value for all the parties in the supply chain.
- Development of products and production systems needs to take place more rapidly, in parallel and in an integrated way in order to meet market demand for speed and flexibility.
- Strengthening the integration of product and production development is crucial for competitive manufacturing companies.

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Vilhelm in an industrial PhD student at Volvo Group Trucks Operations, affiliated with the department of production engineering at KTH. He has a master's degree in engineering physics from Uppsala Universitet. After graduation he stayed at Uppsala Universitet working as a research engineer at the division for Solid state Physics. In 2007 Vilhelm left academia and started his career in the industry. He has worked for both SMEs and large global companies, but all the time close to production. In 2021 Vilhelm took the next step and started his PhD studies.

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INTEGRATED PRODUCT AND PRODUCTION DEVELOPMENT

Introduction

- We are living in an era that is rapidly changing, information, technology and society is evolving at a speed that has not previously been seen in history. This reality introduces new complexity to products and services that need to be dealt with.
- There are many driving forces currently taking place that radically impact industry. These forces include the strong drive to go from fossil-fuelled to electrified products, the impact that digitalisation will have on production systems, as well as the impact of digitalisation on traditional ways of working in engineering. (Hane Hagström, 2021)
- "Integrated Product and Production development" is one of the challenges, identified by Produktion2030, that Swedish industry need to strengthen to reach the ambition of have the role as global leader in Production.
- From the Produktion2030 home page the industry challenge is defined as: "To strengthen product development processes and tools for innovative product development", which is interprets as "To strengthen product and production development processes and tools for innovative development" as the definition of the challenge for the industry.

What is Integrated Product and Production development?

- To further explore the theme the first step is to define what Integrated Product and Production development means through a literature study. The term was entered into established search engines for scientific papers such as Science Direct and Web of Science.
- The term "Product development" describes the process from a business idea or customer inquiry to a product ready for the market. Various disciplines work together to create and realize an effective and efficient system with the product in focus (Graessler & Hentze, 2019) and "Production development" is the same concept but with the production system in focus.
- The two processes are often interlinked and dependent on each other and there is a wide variety of approaches to the development of production through the creation of a product. The differences between them are predetermined by the chosen focus, the technologies used, the production capacity and the existing hierarchy of systems and subsystems, enterprise processes (Garina et al., 2018).
- It is worth noticing that within academia there is a higher focus on the product development compared to production development, especially methodologies and process models dedicated to production equipment has a lower scientific coverage compared to their product-oriented counterparts (Vielhaber & Stoffels, 2014).

Why is this important?

- The speed at which our society is progressing is increasing and by that also technology and product development. The life cycle of products is getting shorter with time and new product generations, or completely new products are introduced at a higher pace. The time from an idea to market introduction is shrinking and at the same time competition between companies is increasing. due to globalization and the increasing ability for fast and easy distribution of both goods and information.
- For the industry this means that, in order to stay competitive, activities that previously had happened in serial and with a higher level of independence now need to be interlinked and in parallel, integrated. By this approach both time and cost can be reduced by designing your system correctly from the beginning since the cost for changes increases by a factor of ten for each stage. (Stürmlinger et al., 2020)
- One other important reason for observing the complete product and production process as an integrated process is that optimization of the complete system, for example Lifecycle cost or environmental impact, is easier to perform (Vielhaber & Stoffels, 2014)

Which are the challenges?

- Previously the product and production process were two separate processes with only some interaction. This means that, still in most companies, both domains' processes are owned by independent organizational units, they use different terminology, methods and tools (Vielhaber & Stoffels, 2014), and often located in geographically different locations.
- Since the development of product and production is complex and requires cooperation between different domains, knowledge is identified as a crucial resource in the integrated process (Klippert et al., 2022).
- A supportive knowledge management infrastructure together with a well-working process is what creates knowledge value for businesses, which is important for their competitiveness in today's market (Lee, 2016).
- There are several barriers that makes knowledge transfer and re-use difficult. Riege (2005) has identified 28 barriers, categorized in individual, organisation and technological aspects. One barrier mentioned is the geographical distance between teams, which is often the case in industry.

Experience from the visits

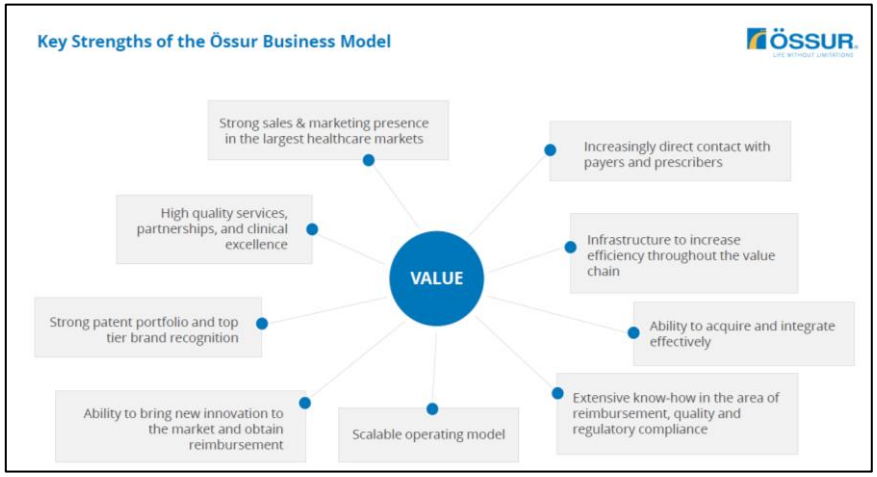
- During the course a wide variety of companies were visited spanning from companies working with software for money laundry detection to a nuclear powerplant, that knew their lifecycle and was planning to close the operation.

Visiting Carbfix, Hellisheiði geothermal power plant

- Skanska Vikan was also visited who produces rock aggregates and asphalt. The products need to fulfill external standards and there is no product development, but a lot of development activities on the production side. So, no link between product and production development was found.
- In Iceland we visited the Hellisheiði Power Station and Carbfix, where the latter is a spin-off of a business opportunity identified in the production process, but no link between the product and production processes were presented.
- However, two companies presented clear connections between product and production development, Volvo and Össur, which are presented below

Össur, Head Quarter, Reyjkavik, Iceland

- Össur's product development is located in Iceland. Production is distributed over the globe with low-tech products, in high volume, produced abroad. Their high-tech, flagship products are produced in production facilities located close to the product development departments.

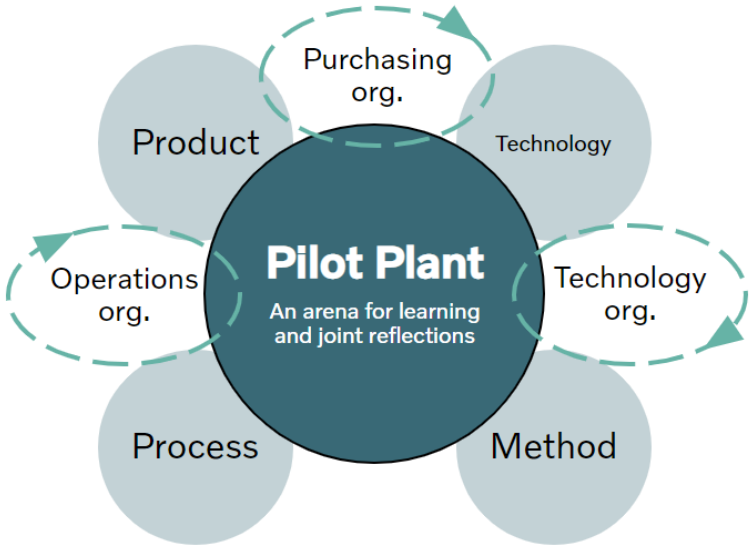


From Össur Annual Report 2022

- Össur presented how collaboration with product development and production had led to changes in the design of the product. The changes improved producibility and had been implemented with a new generation of the product.
- Össur highlighted the proximity to the production facilities, making it easy to meet regularly to discuss and find consensus as one key success factor for the implementation of the changes in the new generation of product.

Volvo Group Trucks Operations – Tuve Plant, Gothenburg

- Volvo Group presented an increase in the product portfolio with new products currently been developed.
- They confirmed the findings from literature with new products, shorter lifecycles leading to quicker product introductions and the need for higher efficiency in the production system.
- The Tuve factory had introduced the concept of Pilot Plant, a physical arena where all needed functions in the product and production development process met and developed the processes together.
- Volvo is working consciously with integrating product and production development. There are organisations and structures in place to enable this knowledge.
- As new products drives new business models (or the other way around), parameters such as cycle time, part life length and circularity will likely change and need new ways to do safe and effective production with quality



Volvo Pilot Plant Concept (pic from Volvo Tuve presentation)

Conclusions

INTEGRATION AS A KEY BUSINESS FACTOR

Only two companies expressed connections between product and production development. But of these companies expressed the connection as a key business factor

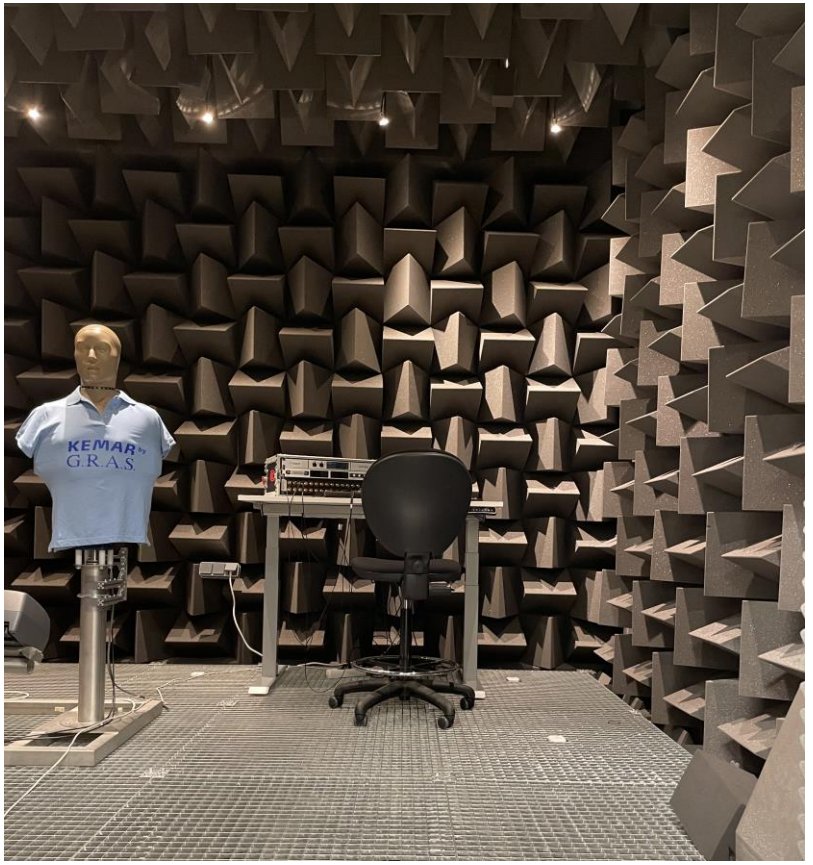
GEOGRAPHICAL PROXIMITY

Össur stated that proximity between Product and Production development was a key business factor

Volvo stated the use of Pilot Plant closely located to the product development department a key business factor

KNOWLEDGE MANAGEMENT

The authors see a large potential in increasing the focus on systematic knowledge management as a key factor in integration of product and production development



Soundlab, University of Iceland | Insitute of Engineering

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OVERVIEW

THEME 1:

RESOURCE EFFICIENT PRODUCTION

Data as a resource is becoming increasingly important for the majority of companies in the Nordics and the application of traditional resource management tools on data is a suggested area for future research.

THEME 2:

FLEXIBLE PRODUCTION

To strengthen organizations by enabling production systems to be flexible to address market variations is a key challenge to consider in the manufacturing industry.

THEME 3:

VIRTUAL PRODUCTION DEVELOPMENT

Digitalization level is distinct in each Nodic country with the reason that each country has its own digitalization transformation policy and different measures on digitalization level.

THEME 4:

HUMANS IN THE PRODUCTION SYSTEM

Humans are central in the production systems of the visited companies. Use of automation technology and AI to support humans in their work may become more common in the future.

THEME 5:

CIRCULAR PRODUCTION SYSTEMS & MAINTENANCE

Circular production systems require a complex approach through the whole value chain. Industry in the Nordics has started the adoption of a circularity approach.

THEME 6:

INTEGRATED PRODUCT & PRODUCTION DEVELOPMENT

Integration of product and production development is a key business factor for the Nordic countries, and geographical proximity between the two departments can have a beneficial effect.