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INFORMATION MANAGEMENT OF MATERIAL SUPPLY CHAIN IN ELECTRICITY DISTRIBUTION NETWORK CONSTRUCTION

Master Thesis

Tarkastaja: professori Pertti Järventausta
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Kasvavat investoinnit sähkön jakeluverkkoon kasvattavat myös materiaalitoimituksia. Tiukat projektiaikataulut korostavat materiaalitoimituksen onnistumisen tärkeyttä. Tätä hankaloittaa pitkä ja monimutkainen ketju, jonka läpi materiaalitoimitukset kulkevat. Tämän tyyppiset toimitusketjut ovat alttiita informaation kulun epävarmuuden aiheuttamalle Bullwhip-effektille, jossa pienet ongelmat ketjun toisessa päässä näkyvät suurina ongelmina toisessa. Epävarmuutta voidaan vähentää jakamalla avoimemmin informaatiota toimitusketjussa toimivien yritysten välillä. Bullwhip-effektiltä vältytään, kun paikkansapitävää ja oikea-aikaista informaatiota jaetaan tarvittava määrä kaikille toimitusketjuun osallistuville osapuolille.

Tässä diplomityössä analysoidaan suomalaisen sähköverkkoyhtiö Elenia Oy:n materiaalitoimitusketjun informaationkulun rakennetta. Analyysi on suoritettu vertaamalla kirjallisuudesta löydettyjä hyviä käytäntöjä ja käyttämällä extended Event-driven Process Chains menetelmää. Analyysistä selvisi, että Elenian toimitusketjun informaation kulun ongelmat ovat tiedon läpinäkyvyydessä, tiedon laadun automaattisessa hallinnassa ja informaation ajallisuudessa. Näihin ehdotuksena on kolme tietojärjestelmämuutosta.

Ensimmäinen ehdotus on toimitusketjuportaali. Portaali tarjoaa kaiken materiaalitoimituksiin liittyvät tiedot, kuten tilaukset, toimitukset ja lähetysilmoitukset, kaikille toimitukseen osallistuville tahoille reaaliaikaisesti. Portaali sisältää myös automaation puuttuvien tietojen saamiseen. Läpinäkyvyys ja automaattiset kyselyt vähentävät epävarmuutta tilausten hallinnan sekä kumppanuusjohtamisen tasolla.

Toinen ehdotettu muutos on reaaliaikainen ja informatiivisempi raportointi materiaalin toimitusketjusta. Raportointi sisältää koko toimitusketjun suorituskykyä mittaavia mittareita, jotka luovat ymmärrystä ketjuun. Business Intelligence järjestelmä tarjoaa reaaliaikaisia tietoja useista tietolähteistä Elenian sisällä, jotta jokainen päätös perustuu samaan reaaliaikaiseen dataan. Business Intelligence järjestelmä muodostaa datasta valmiiksi laskettua ja visualisoitua tietoa.

Kolmas ehdotettu järjestelmä ovat älykkäitä tuotteet. Älykkäät tuotteet antavat tuotteille ja toimituksille virtuaalisen identiteetin. Älykkäiden laitteiden kautta voi jakaa tietoa toimitusten etenemistä muille osapuolille toimitusketjussa, tunnistautumalla esimerkiksi tuotteessa olevan QR-koodin kautta älypuhelimen avulla. Älykkäät tuotteet mahdollistavat aikaisemmin mahdottoman tiedon jakamisen. Järjestelmän avulla on myös mahdollista toimittaa sensoritietoja, kuten GPS dataa tiedon jaon yhteydessä.

ABSTRACT

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The increasing electricity distribution investments mean higher amounts of material deliveries. As the construction projects often have tight schedules, successful material deliveries are important. However, the supply chain that the deliveries go through is long and sometimes complex. These characteristics make the supply chain prone to phenomena called the bullwhip effect, which is caused by uncertainties in the information flow of the supply chain. Supply chain uncertainty can be decreased by sharing sufficient amount of high quality information to the different parties taking part in the supply chain.

The information structure of Finnish distribution system operator Elenia's supply chain is analysed in this thesis. The analyse is done by comparing good practices from literature to Elenia and using extended Event-driven process chains method. The findings from the analysis showed that the problems in present information flow are in transparency of the information, lack of automation in information flow control and timeliness of the information. To solve these issues three changes to the ICT-systems are proposed.

The first proposed change is to introduce a supply chain portal. The portal acts as one place for transparent information for all material delivery related information such as orders, deliveries and dispatch notices. The information is available to all parties related to the supply chain. The portal also includes automation for missing information. The transparency and automatic queries for missing information decrease the uncertainty in both order management and supply chain management levels.

The second proposed change is real-time and more informative metrics for the material supply chain. The real-time metering consists of supply chain wide metrics which create better understanding about the chain. The business intelligence system shares real-time data from multiple data sources inside Elenia, so that every decision can be based on the same real-time data. Business Intelligence system provides calculation and meaningful visualisations from the data.

The third proposed system are the intelligent products. The intelligent products are a virtual identity to products and deliveries. By interacting with and identification medium such as a QR-code, with their smartphone the user can share information about the products progression to other parties in the supply chain. The intelligent products allow sharing information that has been unavailable in the past. The system also makes it possible to add sensor data such as GPS information to the communication.

FOREWORD

This thesis was done for Elenia Oy. The topic for this thesis was formed together with the supervisor Henri Hovi and Elenia Oy whom I thank for the interesting topic and environment which the thesis was done in and my colleagues for helping me form the structure of this thesis and the invaluable information and insight you provided.

I would also like to thank Tampere University of Technology for providing interesting and inspiring place to study and especially professor Pertti Järventausta for examining this thesis.

This thesis deepened my knowledge about the subject and I hope it provides valuable information and perspective to the reader as well.

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Arttu Laapotti

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TERMS

3PL	Third party logistics
API	Application Programming Interface
B2B	Business-to-business, Commerce between two companies
BI	Business Intelligence
BOM	Bill of Materials
CAD	Computer Aided Design
CRM	Customer Relations Management, IT-system
DSO	Distribution service operator
EDI	Electronic Data Interchange
eEPC	extended Event-driven Process Chains
EOL	End of Life
ERP	Enterprise Resource Planning, IT-system
FTL	Full Truckload
HTTP	Hypertext transport protocol
ICT	Information and Communication Technology
IoT	Internet of Things
JIT	Just-In-Time. Japanese production philosophy
NFC	Near Field Communication, special kind of RFID
NIS	Network Information System, IT-system
RFID	Radio Frequency Identification
SCM	Supply Chain Management
SME	Small and Medium Enterprise
SOA	Service Oriented Architecture, software architecture
WIP	Work-In-Progress
XML	Extensive Markup Language

1 INTRODUCTION

1.1 Electricity distribution networks in Finland

Distribution network operation in Finland is a governed monopoly controlled by Energy Authority. Energy Authority an agency found for the purpose to supervise distribution network operators (DSO) at 1995 when legislation opened the electricity markets in production and trading for free competition and separated companies that sell and distribute electricity. Before 1995 it was typical that electricity and district heating was distributed and sold by the same, communally owned, company. Energy Authority is operating under the Ministry of Economy and Employment.

Finland is a big and sparsely habited country. This means that the electricity distribution network is wide and distances are long. The combined length of the medium and low voltage distribution networks is around 350 000 km (Lakervi & Partanen, 2008, p. 11) and its replacement value is around 60-70 billion euros. The network was built mostly during the 1970s and is mostly overhead-lines built through forests and fields. Since the 20 kV electricity network is 40 – 50 years old, large parts of the network need to be renovated by the year 2020 (Lakervi & Partanen, 2008, p. 9).

In the beginning of the 2010s whole Finland suffered from several serious autumn storms which wreaked havoc to Finnish infrastructure, especially to rural electricity distribution network. Outages caused by the storms were a wakeup call for the public and authorities on the distribution network's impact to society. Energy Authority made new law which heavily guided companies to invest in their networks in order to avoid long power outages in the future. The new law and regulation principles encourage DSOs to invest in their networks which has led to grand reinvestment plans for some of the biggest Finnish DSOs.

Historically companies' organisation structures were built for operation and maintenance. In time, search for performance improvements led to a grand reorganization which meant outsourcing the network construction in nearly all cases. While outsourcing has proven to have serious benefits, combined with increased investment levels, it also introduced some risks and difficulties. Technical research centre of Finland conducted a research about outsourcing in distribution network operation and construction (Aminoff et al., 2009). One of the main difficulties identified by the research report is information system (IT-system) integration. IT-system integration was considered to be 3rd biggest risk in a poll to DSOs. This was also mentioned as a problem when outsourcing inventories and logistics services.

As the report is already few years old as the time of writing, some of the difficulties considering the IT-systems are already solved or the development is underway. Logistics and inventory management are still pretty much on the same level as they were 2009, IT-systems wise. Even though the need for these systems have much bigger role because of the increased material usage.

1.2 Elenia Oy network investments

Elenia Oy is a Finnish Distribution System Operator (DSO). Elenia Oy was formed to buy the Finnish distribution network services from Vattenfall Oy. The deal was closed in 2012. Vattenfall had formerly formed its Finnish distribution services by acquiring smaller Finnish DSOs. Elenia serves 415 000 customers which makes it the second largest DSO in Finland with a market share of 12 %. Elenia's geographical network area is illustrated in Figure 1.

Figure 1 Elenia's network area in white colour

Elenia has approximately 67 000 km of distribution network of which around 31% is underground cable to the date of writing. In order to meet energy authority's requirements Elenia's strategy is to increase the cabling percentage to 70% by the end of the year 2028. This means around 2000 km underground network cable installed every year in over one hundred construction projects. If all of the cable would be delivered as a standard 500 m drum, 4000 drums would be delivered every year which is over 15 drums delivered every work day and cable deliveries are only one part of the supply chain.

Increased investment levels have forced Elenia to develop its supply chain configuration and partnership leadership and they have evolved with great steps during the last few years. For example Kalliorinne (2014) has developed methods for partnership management, procurement process and forecasting methods for Elenia. Information and Communication systems (ICT-systems) and information sharing processes have not adapted to these changes or the mobile revolution which has brought computers to everyone's pockets during last three years. This thesis takes these changes into account and proposes how the material delivery supply chain's information structure and communication technologies should be developed in order to provide required support for the new and evolved supply chain.

1.3 Research problem

The purpose of this M.Sc. Thesis is to find out and define what information is needed in the different supply chains in distribution network operation and construction to operate efficiently and to determine how this information can be communicated efficiently and on time throughout the whole supply chain.

The research question is:
How information and communication in distribution network construction material supply chains can be improved?

Research question is answered by answering the sub questions:

1. What are the supply chains in distribution network operation and construction?
2. What information is required to ensure efficient operation of the supply chains?
3. What requirements this information sets to the ICT-systems?
4. How to effectively introduce these systems to supply chains?

The research will be concluded to two proposals. First, how to improve existing practices in supply chain in the short time horizon. Second, in what direction the information and communication systems should be developed in the future.

2 SUPPLY CHAINS

This section covers and defines supply chains as they are referred in this thesis. Key characters are listed and key aspects of communication and information in supply chains are defined. This chapter also identifies the key actors in supply chains and defines some metrics for effective supply chains.

Blanchard (2010) defines supply chain as follows. "*a supply chain is the sequence of events that cover a product's entire lifecycle from conception to consumption*." The supply chain consists of all the steps during products life cycle. It reaches from the sub-suppliers to recycling of the product. Supply chain management consists of managing supply and demand in the interfaces of these steps. (Blanchard, 2010 p. 6)

Mentzer, DeWitt, & Keebler (2001) has gathered a definition for supply chain from multiple sources and it is defined as follows. "*Supply chain is a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances and/or information from a source to a customer."*

Handfield (2008) describes supply chain as *"a network of manufacturers and service providers that work together to convert and move goods from raw materials stage through the end user. These manufacturers and service providers are linked together through physical flows, information flows and monetary flows."*

Christopher (2005) defines supply chain as *"a network of connected and interdependent organisations mutually and co-operatively working together to control, manage and improve the flow of materials information from suppliers to the end users"*

Stevenson (2007) defines supply chain as *"a sequence of organizations their facilities, functions and activities – that are involved in producing and delivering a product or service"*

All of the descriptions share some basic similarities. The most distinctive features of a supply chain are listed below

1. Supply chain is considered to be a series or a network of actors. These actors include the end customer, material producers, suppliers, distributors, logistic partners and their facilities.
2. Supply chains actors form partnerships which have common goals.
3. The definitions share an idea of transformation through sequence of actions where materials and other factors of production are converted to final product and customer value.

4. Supply chain is considered to consist of different flows between the actors: materials, information and monetary assets.
5. Supply chain is defined to cover the whole chain from raw materials to end use.

2.1 Supply chain management

Supply chain will become more significant factor in company by every outsourcing decision. With outsourcing you have more actors in your supply chain, more complex interdependencies between actors and less direct control of how the value to the end customer is produced. That is why a supply chain is often called a value chain or a value network. Supply chain management is needed to retain or retake the control on creation of the end-customer value. (Christopher, 2005, p. 14)

Supply chain management originates from the Japanese automotive manufacturing. Toyota invented JIT (Just-In-Time) to minimize the required inventories. JIT included regulation of supplier interaction to production. Japanese industrial leaders also had a vision of improving quality with longer supplier relationships. These two factors led to the development of modern supply chain management. (Vrijhoef & Koskela, 2000)

The basic idea of JIT is that no action should be taken until there is a need for it. On a larger scale this means that JIT is based on a pull-concept: No products are made, no parts ordered until an order from downstream the supply chain is placed. A traditional push method would be to make the products in patches trying to anticipate the demand. (Christopher, 2005, p. 129)

One of the key aspects of JIT production is to eliminate dead stock by reducing the lead and delivery times for parts required in assembly. This however makes the production less robust against demand and supply fluctuations. To combat this issue methods and tools like Kanban were discovered. These tools required a lot of information in order to work correctly. (Sugimori, Kusunoki, Cho, & Uchikawa, 1977)

Modern supply chains are more complex than Toyota's early JIT-warehouse control. And therefore the amount of information required is much higher (Vrijhoef & Koskela, 2000). In supply chains the information flows in both directions inside the supply chain. Coordination of this flow of information is one of the key aspects of the management of the supply chains. The flow affects the whole chain via scheduling, inventory control and delivery. (P. Cachon, Randall, & Schmidt, 2007)

The key issue behind the invention of the modern supply chain management was the so-called bullwhip effect. In bullwhip effect imbalances of supply and demand in the early stages of the supply chain are amplified further down the chain. A problem that might seem small could generate great problems in the other end of the chain. (Blanchard, 2007) A typical example of bullwhip effect is the amplification of variance between sales to the buyer and orders to suppliers. Changes between the order and the forecast produces even bigger variance in orders to a sub-supplier. Bullwhip effect produces problems such as excess material cost, inefficient production, challenges in the schedules and excess inventory costs. (H. Lee, Padmanabhan, & Whang, 2004)

According to Lee et al. (2004) there are four major causes for the bullwhip effect. All of the causes for bullwhip effect are related to the distortion in information flow.

1. Demand signalling. In demand signalling the schedule information distorts from end user to the manufacturer. This can be a result of poor forecasting or multiple forecasts in the supply chain. Signalling is especially strong in supply chains with long lead time. An effective solution to this problem is to increase the transparency in the supply chain.
2. Order batching which means grouping orders in order to gain cost advantages in logistics or via quantity discount. This causes strong seasonality or storage costs to the manufacturer. This cause is common for supply chains with high transport and ordering cost. Some solutions are proposed: FTL (full truckloads) can be achieved with 3rd party logistics partnerships to share high transport costs with other customers or products. Reducing order handling costs is another way to affect this.
3. High price fluctuation. High price fluctuation is especially common in retail. A common solution is long sales agreements.
4. Shortage game which is result of failed capacity planning. Protecting against imaginary shortages with too forward or too large orders is a usual feature of the shortage game. Shortage game can be avoided by trust and visibility through supply chain.

There's no silver bullet for supply chain management. Each market and business environment has its own characteristics to make a successful supply chain. There are however features that all successful supply chains have in common. (Blanchard, 2007)

According to supply chain consultant company Tompkins Associates there are seven key features of supply chain management that make a working supply chain (adapted from Blanchard, 2010, p. 14):

1. Supply chain strategy is based on organizations business strategy
2. Adaptable and agile
3. Transparency. Clear performance expectations and high accountability
4. Continuous improvement in every step of the chain

5. Knowledge of strengths and weaknesses. Benchmarking.
6. End-to-end perspective outlook on the whole chain
7. Global goals.

To ensure that these features are put to practise a dedicated team with skilled personnel is required.

The supply chain can now be considered to have three dimensions which include most of the features mentioned in this section. These are agility, adaptability and common goals. These same dimensions were identified by (H. L. Lee, 2004).

Agility of the supply chain is mentioned as a key feature of a working supply chain. L. Lee (2004) describes agility as an ability to respond quickly to changes in supply and demand. Agile supply chains also handle unexpected external disruptions without high additional costs. Agility is supply chains ability to respond to changes inside the supply chain. Christopher (2005, pp. 130-137) and H. L. Lee (2004) have listed some key aspects in agile supply chains. Three key points are adapted below:

1. Shared information and appropriate metrics. Continuous, shared information reduces lead times and cost of stock. Shared information also helps to respond to demand fluctuation timely
2. Smart design in co-operation. Lead times and other non-value adding tasks can often be eliminated by re-engineering the supply chain, processes and products. Co-operation requires close partnerships and trust between supply chain actors.
3. Reducing complexity. Availability can be improved and costs can be reduced by minimizing the amount of offered products and by late assembly requires creating products with common parts.

Another key aspect is adaptability. Where agility is about changes inside the supply chain, adaptability is the ability to respond changes outside the supply chain. These chances could be, for example, changes in markets, new technologies and legislation. Adaptability depends on how much and how valid market information supply chain actors have. The information can be achieved for example through intermediaries. To be able to benefit from new and more effective partners, products have to be close to industry standard and product mix has to be small. (H. L. Lee, 2004)

Common goals or alignment describes how well and effectively supply chain actors are working towards the finalized product delivery. Alignment is an important, because it will maximize the profits for every actor in the long run. It is important to have clear roles and divide the risks accordingly. To be able to aim to a common goal and overall quality the key metrics and data needs to be shared with all supply chain actors.

Stevenson (2007) also lists some key factors of a successful supply chain. These include:

1. Trust between partners by the use of technology

2. Effective communication inside partnership network
3. Supply chain visibility and transparency
4. Managing unplanned events by notifications
5. Appropriate metrics.

As a conclusion supply chain management is managing the flows of the supply chain: material, information and monetary. These flows go through the whole supply chain and the managerial actions should always take the whole chain in the consideration. Information is in the key role when making decisions and the flow of information should be taken into account when designing the supply chain. JIT philosophy reduces costs but creates even higher requirements for information. Stevenson (2007) sums up the purpose of supply chain management as integrating the management of supply and demand.

The literature review from supply chains and their management shows that information is a key factor in a successful supply chain. It is also seen as the area with most room for improvement in logistics and supply chain management.

2.2 Information flow in supply chains

Last chapter identified distortions in information flow to be one of the most substantial issue behind delivery issues and subliminal supply chain performance. This chapter researches the way information flows in supply chains.

There are three kinds of environmental uncertainties that cause the information distortion in supply chains.

1. Customer uncertainty includes variances in customer's demands in terms of volume, timing and product quality.
2. Supplier uncertainty consists of factors affecting overall quality of the supplier like engineering, lead-times, raw materials and delivery performance.
3. Technology uncertainty is affected by the technological development on the field.

The information to remedy these uncertainties has two attributes that effect the ability to decrease uncertainty in supply chain management. *Information sharing* describes the amount of information and the extent of criticality of the information that is shared throughout the supply chain. Information sharing is proven to improve performance in supply chains. The other attribute is *Information quality* which refers to the timeliness, accuracy and credibility of the information. Even if information sharing is on a high level, but the quality of the information is weak e.g. not timely synchronized the effect to the information distortion that causes bullwhip effect can still be in effect. (Li & Lin, 2006)

Vorst & Beulens (2002) describes another way to categorize sources of uncertainties which have negative effect on supply chain performance:

1. Inherent characteristics are features that cause stochastic fluctuation. These kind of characteristics include weather, seasonality and perishability.
2. Characteristic features of the chain that generates disturbances. These are performance limiting design features in the supply chain. Including insufficient capacity design, ill control structure and limitations of the information system and chain organization structure.
3. External phenomena causing disturbances. These phenomena include legislation, markets and new products.

Information transparency is suggested as a solution to address these problems. Transparency here means sharing real time data of supply, demand, inventory and WIP (Work-in-progress). Simplification of the process is also considered as a performance adding factor together with reducing human interaction which reduces errors in the process. (Vorst & Beulens, 2002)

Event-driven Process Chains (EPC) is a method and notation to visualize business processes such as supply chains. This can be used to analyse the supply chain to identify and eliminate uncertainties (Vorst & Beulens, 2002). EPC is based on mapping events and actions taken in the process and the decisions between them. Actions present the steps of the process and events pre and post conditions which exist between each actions. EPC notation has three kind of decisions: AND, OR and exclusive OR (XOR). EPC has been further developed. This branch is called extended EPC (eEPC) which also includes business units committing the actions, documents and ICT-systems relating to the action. (Van Der Aalst, 1999)

Handfield (2008, pp. 517-518) introduces four levels of supply chain information. The levels are based on the level of decision making the information affects. All of the following steps should be planned in co-operation with actors in supply chain.

1. Strategic decision making ensures that the supply chain strategy is in line with company's strategy and mission. It is the least structured level of the supply chain information needs because of its need to be very flexible.
2. Tactical planning develops plans e.g. inventory planning from supplier side and long-term forecasting from customer side. Tactical plans need to be more formal, because different actors in the supply chain can use them for different needs. Flexibility is still a key.
3. Routine decision making consists of decisions for smaller time horizon, e.g. one month. This can include e.g. master scheduling and supplier evaluation. Routine decisions should be accurate and formal. Some flexibility needs to remain in order to handle exceptions.
4. Execution and transaction processing consists of making orders, controlling physical material and monetary flows. This step is ideally highly automated and standardized. No flexibility is required.

As can be observed from the list above, the lower level of decision making, the higher degree of automation and lower need for flexibility. The first two can be considered to be planning only, no direct physical steps will be taken due to them. The following two will have a direct impact to production, logistics and monetary flows. This leads to 1 and 2 being stationary throughout their time horizon. While 3 and 4 are constantly changing with new orders and changes in schedules.

To achieve control on any of the four levels information is needed by all actors in the supply chain which means sharing information which could be considered private by more traditional partnership management. In addition to traceability of the supply chain data is needed to find common goals, to timely synchronize the supply chain, to improve profitability and to find new technical innovations. (Christopher, 2005, p. 132 ; Fawcett, 2014, pp 387-388).

In addition to inter-organizational partnerships the supply chain strategy needs to be backed up by intra-organizational enablers. Since well performing supply chain is in line with the organizations strategy *Top management support* and intra-organizational culture of information sharing are requirements for a high performing supply chain. To effectively put an information sharing strategy in use organization has to have proper IT-enablers. (Li & Lin, 2006)

The most critical data that needs to be shared in supply chain according to (Fawcett, 2014, p. 388-393) is listed below:

1. Sales and forecast data is vital for preventing bullwhip effect. All of the major bullwhip causes mentioned in section 2.1 can be mitigated by providing the real demand data and accurate demand forecast for the supplier.
2. Inventory levels are one profound concepts of supply chain management. Available inventory data provides visibility throughout the chain reducing the need for multiple safety stocks.
3. Order status data sharing allows tracking shipments and helps actors down the chain to organize and plan their work/production accordingly.
4. Capacity and capability information from other actors in the chain is important for capacity planning. When peak demands, production stoppages and disruptions are informed early enough and in co-operation delivery errors and chain wide stoppages can be avoided.
5. Performance metrics help to pinpoint strengths and weaknesses of the chain.

Fawcett (2014) suggests the two ways of sharing information between supply chain actors. Traditional method is so called *bow-tie approach* where sales and purchasing relay the information from inside the company to each other. As presented in Figure 2.

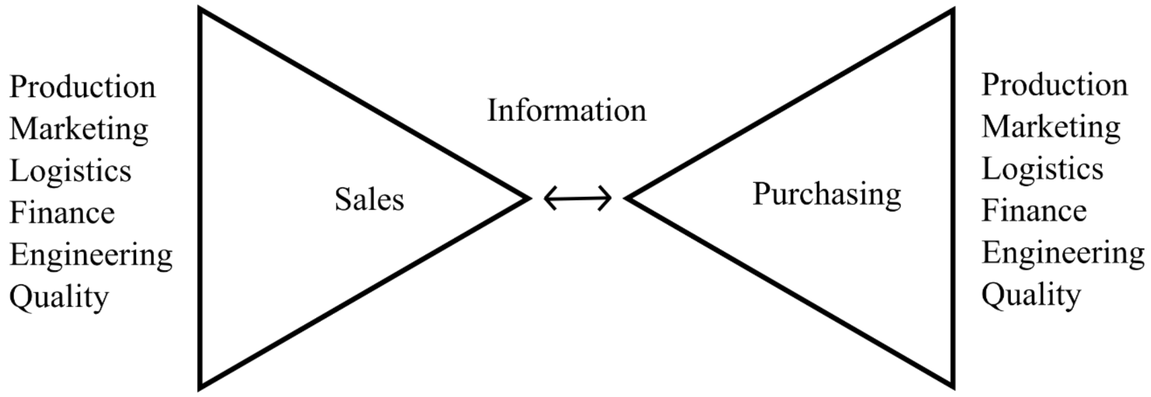

Figure 2 Bow-tie approach to information sharing (Fawcett, 2014)

The other way of sharing information is considered to be the *diamond approach*, where information is not relayed through sales and purchasing, but instead the information flows directly between the organizational functions as presented in Figure 3.

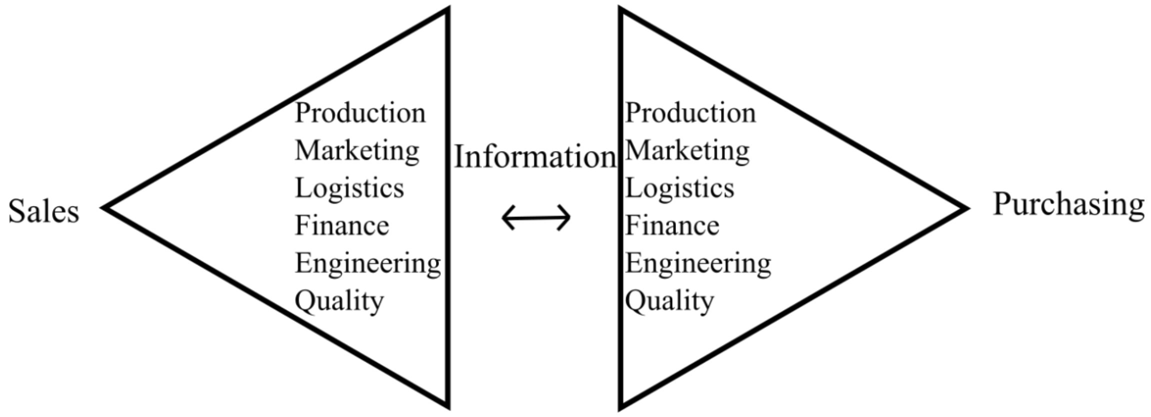

Figure 3 Diamond approach to information sharing (Fawcett, 2014)

From the two approaches above diamond approach enables closer contact between right functions and creates more contact points between organizations. This makes diamond approach align better with good SCM practices. (Fawcett, 2014)

Bow-tie and diamond models describe the interfaces actors have in supply chain. On a larger scale information can flow in three different ways according to Christiaanse & Kumar (2000). In first model information flows upstream and downstream the same path and in same time with the physical flow, for example a package list delivered with the associated package. In model 1 actor next in the chain is not notified in advance. As mentioned in section 2.1 this is one of the major causes for bullwhip effect. Figure 4 illustrates the information flow in first model.

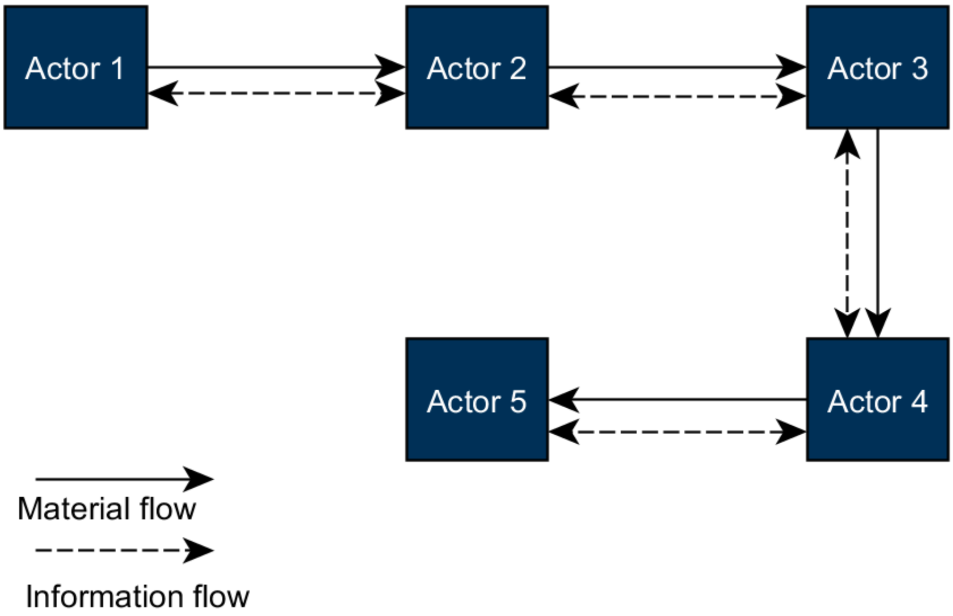

Figure 4 Supply chain information flow in model 1

The second model is similar to model 1. The difference is the timing of the information. Information still flows the same path as material flow. Information flow precedes material flow and is not delivered with the delivery but via information carrier. Information carrier can be for example telephone, email or EDI. In model 2 there is still lag in information as only the next actor in the chain gets notified in advance. Same data also has to be duplicated for next actor in the chain which can cause quality distortion in the information. Model 2 is illustrated in Figure 5.

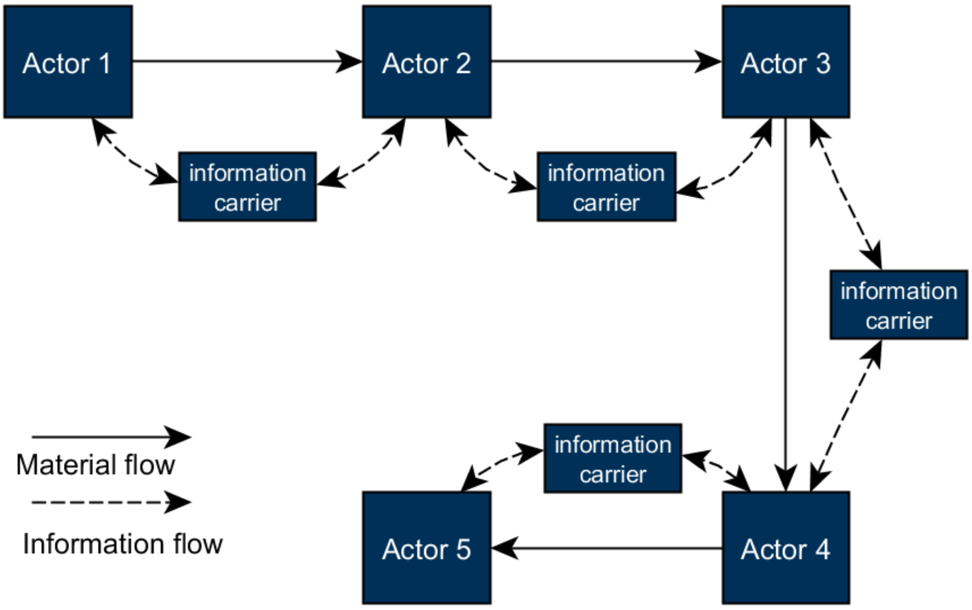

Figure 5 Supply chain information flow in model 2

The third model is the most open as presented in Figure 6. Information carrier as well as path can differ from material flow. Information is centralized and both ends of the chain will receive the data simultaneously. There is also no need to duplicate data, because all actors receive the data from the actor who produced it. As the data is centralized more in-depth analysis of the supply chain can be made.

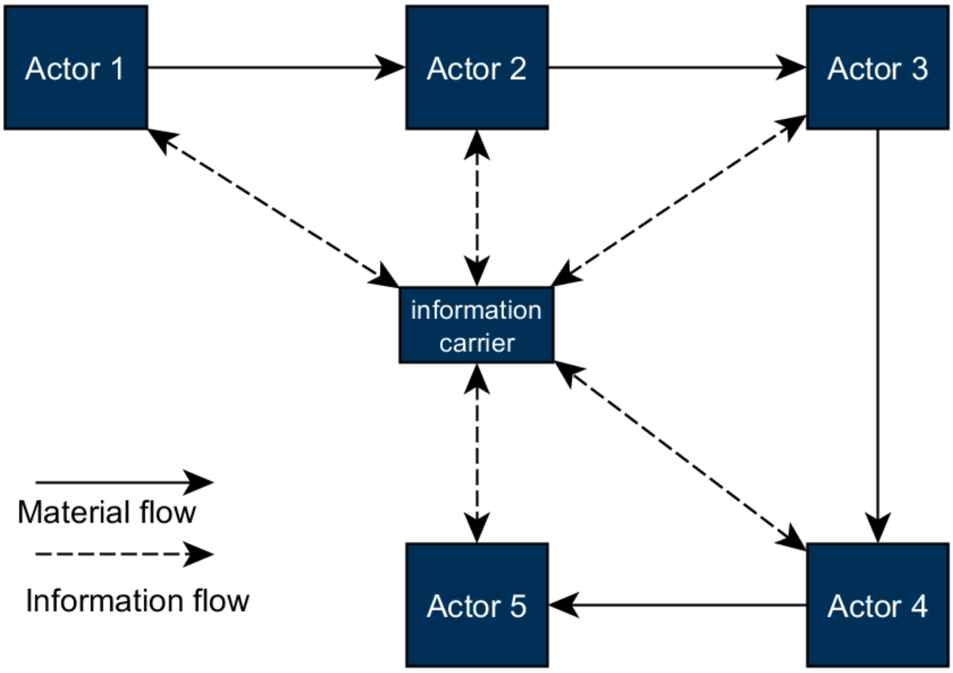

Figure 6 Supply chain information flow in model 3

Comparison of the pictures shows the differences of the models. Even though the amount of information available for each actor is highest in the model three, there is only five information connections (illustrated as arrows in the pictures) in model 3 compared to eight connections in models 1 and 2.

In this section it was discovered that information needs to both accurate and timely to ensure the correct operations throughout the supply chain and to avoid the bullwhip effect. This can be ensured, for example, by centralizing the data. Centralized data in this context doesn't necessarily mean that the data is available from one place, but that it is available for all supply chain actors. This is also known as transparency of a supply chain. It's also acknowledged that information is required on different levels of operation and the information needs for each levels differ in flexibility and formality. The needs of different levels need to be taken account when designing the information structure of the supply chain.

2.3 Supply chain metrics

This section covers the most common supply chain metrics found from literature and their effects on the supply chain.

True insight of a system is next to impossible to have without proper metrics. Measurements are perhaps to most powerful tool of managing especially large systems like supply chains. Three key aspects to measuring are:

1. Creating understanding
2. Driving human behaviour
3. Getting results.

Without measurements there are little to none real information about the performance of the supply chains and no possibility to control the process with feedback loops. Since people have tendency to adjust their work according to the measurements, the control over both supply chain strategy and supply chain execution are highly dependent on the measured things. (Fawcett, 2014)

As measurements control the actions taken in the supply chain, it is important to measure the right things. Measuring incorrect things can lead to poor understanding of the system and poor partnerships. In addition to measuring correct things measurements have to be timely and accurate. Fawcett (2014) mentions three questions to ensure correct measuring.

1. Do measurements help managers to understand critical value-added process?
2. Do measurements system communicate expectations and promote correct behaviour?
3. Does measurement system deliver high levels of targeted results?

In earlier sections supply chain was defined as an entity with a common goal. Success of the common goals need to be measured with common metrics to find out if these goals are met. Metering should be on different levels of the decision making in supply chain management, described in section *2.2 Information flow in supply chains*. There should be a balance between the levels. These metrics should consist of both, financial and non-financial metrics. (Gunasekaran, Patel, & Tirtiroglu, 2001)

Gunasekaran et al. (2001) categories metrics for supply chain performance.

1. *Order lead time* describes the time it takes for an order to turn in to a delivery.
2. *Customer order path* describes the effort the process needs to go through and the complexity of the chain. JIT and process re-engineering aim to improve supply chain performance in this category.
3. *Range of products/service* as a supply chain metric is based on the idea that companies with narrow range of products will be more likely to innovate which has a serious impact on the supply chain.

4. *Capacity utilization* includes all planning decisions. By measuring how effectively the whole supply chain is utilized. Ability to respond to customer's demand quickly correlates highly with capacity utilization.
5. *Scheduling efficiency* measure how effective the planning the actions in supply chain. Failures in scheduling and/or poorly designed actions will lead to high inventory levels.
6. *Inventory levels* measure how effectively scheduling is done and how effective the process is in different phases. Common inventories are Raw materials, WIP, Inventory of ready products
7. *Supply chain partnership metrics* measure actors' willingness to develop the cooperation between each other.
8. *Delivery performance metrics* measure the supply chains ability to make the deliveries on-time and with high quality. These metrics include OTD (on time delivery) metrics such as delivery-to-request, delivery-to-commitment, order-fill-lead time. Also quality factors such as number of faultless deliveries.
9. *Flexibility* describes how efficiently the supply chain can meet individual customer needs.
10. *Customer service metrics* such as customer-query-time which describes the delay between making the order and first contact back to customer.
11. *Total distribution cost* measures the total cost inside the whole supply chain.

These metrics take into account the all the four critical links in supply chain presented by Gunasekaran et al. (2001): plan, source, make, deliver. Fawcett (2014) divides these metrics in three categories source, operations and logistics.

In addition to more traditional metrics listed above. Fawcett (2014, p. 417) introduces some metrics intended especially for measuring supply chain performance rather than how single companies perform as part of the supply chain.

- *Supply chain inventory days* represents the total number of days of inventory time from raw materials to delivery to end-customer
- *Source/make cycle time* presents the time it takes to build a product from scratch without inventories.
- *Supply chain response time* how long does it take adjust production to 20 % increase in market demand
- *On-shelf/In-stock percentage* measures at which rate customer needs can be fulfilled instantly. Measures ultimate supply chain customer satisfaction
- *Customer inquiry response time* represents time from customer inquiry to first response back to customer
- *Cash-to-cash cycle time* measures how long does it take to convert raw materials in a sale.

Some of these metrics can also be used to measure performance of one actor in the supply chain, for example cash-to-cash cycle time.

SCOR (Supply Chain Operations Reference) is a model which is created to standardize the measures for supply chains. SCOR is maintained by APICS Supply Chain Council. Table 1 proposes the metrics have as presented by APICS.

Table 1 SCOR supply chain metrics (APICS, 2015)

Performance Attribute	Level-1 Strategic Metric
Reliability	Perfect order fulfilment
Responsiveness	Order fulfilment cycle time
Agility	Upside supply chain flexibility Upside supply chain adaptability Downside supply chain adaptability Overall value at risk
Costs	Total cost to serve
Asset Management Efficiency (Assets)	Cash-to-Cash cycle time Return on supply chain fixed assets Return on working capital

The rate of change in business has soared during the last decade. As a solution to this companies have started to use more and more a metric driven approach to decision making. This is made possible by the wide adaptation of information technologies and real time data they introduce. Systems like ERP (Enterprise resource planning) and the CRM (Customer relations management) produce vast amounts of data which can provide competitive advantage. This data is however not often presented in quickly accessible manner but requires analysing and interpretation. As the complexity in business grows, grows the number of data sources and analysing data quickly and thoroughly gets harder. Forming quickly accessible and visual metrics and analyses from this multi-source data is called business intelligence (BI). (Sahay & Ranjan, 2008)

One of the most important features of BI is to connect enterprise systems to production information. BI is especially effective when searching for new patterns from enterprise data. A selection of statistical analyses can be utilized to find out the causalities between different data sources. This is called *data mining*. Data Mining tools include regression analysis, Bayesian statistics, clustering and other data machine learning tools. Discovered patterns and models can be used to create better forecasts and alarms to react to changes in the supply chain before serious disturbances are created. Understanding of the patterns and models in the supply chain enables a proactive response to delivery errors and disturbances. (Duan & Xu, 2012)

2.4 Roles in supply chains

Slack, Chambers, & Johnston (2010, pp. 140-142) divides supplier and customers to tiers. These tiers represent the distance from the observed party. For example, first tier supplier supplies directly observed party and second tier is the supplier’s supplier. First tier suppliers and customers together with observed party in supply chain form the immediate supply chain. Co-operations between these parties is called materials management. In contrast all of the actors are often called supply network.

According to Stevenson (2007) supply chain material flow consists of suppliers, production, logistics, customers, and reverse logistics (returning the goods from the customers). With each step adding value to the next step which is why supply chains are often called value chains.

Logistics is moving incoming and outgoing shipments, services, cash and information. In addition to traditional traffic management approach to logistics, companies have started to consider information more and more important aspect of logistics. Already today 3PL (3rd party logistics partner) has a big role in creating and delivering information for the supply chain. So the information capabilities of the logistics partner should be one of the key factors when choosing a 3PL. (Stevenson, 2007, p. 513)

Reverse logistics is a function in supply chain, which returns already shipped goods to their origin. This can be due to faulty orders, faulty goods or recycling. Reverse logistics also includes actions needed to sort the goods, verify their condition, make repairs and dispose of the unusable goods. (Stevenson, 2007, p. 513)

Virtual operations is a term which describes a party in the network who produces little value to the physical flow, but governs other parties in the chain to produce the value. The advantage is the economic and technical flexibility and the low risks because no production investments are done. The downside is, that it is hard to develop and maintain high technical skillset. Also the developed competencies will easily be available to the competitors through common partners. Therefore, success of virtual operations depends only its ability to manage and govern its supply network. (Slack et al., 2010, p 389)

Inventories and stocks are used to compensate the delay between supply and demand. Inventory can be used to even out several types of fluctuations between supply and demand. For example, buffer inventories protect the supply chain from unexpected variations in either supply or demand, anticipation inventory copes with planned or known fluctuations and pipeline inventory solves the transportation delays in the chain. The supply chain actor who manages inventory depend on the return of the capital and therefore aim for the shortest possible inventory turn time. This is even more important in supply chains with products that deteriorate or otherwise lose their value over time. In the end the actor tries to balance the equation between availability and costs of inventory. (Slack et al., 2010, pp. 352-369)

3 ICT-INTEGRATION IN SUPPLY CHAIN

This section covers the theory behind the ICT-integration in supply chains and proposes solutions to issues which are presented in section *2 Supply chains*.

In Chapter 2 the importance of information flow in supply chains was acknowledged. Recent rapid development in information technology enables nearly limitless amount of information to be transferred with minimal human intervention. This enables information sharing in supply chains in real time. However, the information technology should be seen as an enabler instead of a straight solution to bad supply chain performance. Automating a supply without consistency or without linkage to business strategy will only make it easier to do mistakes and adds no value nor make the supply chain management easier. (Fawcett, 2014)

ICT-integration is a solution to information flow management and can't affect concrete material flow. Because of this, information flow needs to be decoupled from the material flow as presented in the section 2.2. This enables the usage of electrical information and communication technologies to be used as an information carrier. Electrical information carrier and automatic handling reduces possibilities of error and therefore improves the quality of service. (Christiaanse & Kumar, 2000)

Sharing information requires technical and managerial capabilities which smaller parties of the supply chain may lack. The cost of the required capabilities can be reduced with standardization. The lack of market wide information sharing standards has led to low adoption rate of EDI (Electronic Data Interchange, system to system -integration) technologies on certain markets. Smaller parties simply can't afford to invest to multiple EDI-interfaces. (Fawcett, 2014)

The greatest challenges in adopting internet and ICT-technologies in B2B (business-to-business) integration is the complexity. Complexity of the operational environment, complexity of the ICT-systems in companies and the complexity of the cost structure of supply chains. The complexity of the operational environment is a result of multiple actors with different business processes and operating in different areas of expertise. In Chapter 2 aligned and shared goals in supply chain was mentioned as one of the key features of a successful supply chain. If the goals inside the supply chain differ too much, the information flow is distorted and becomes hard or impossible to be shared with ICT-technologies that require a certain amount of formality and quality of the data in order to work efficiently. The complexity of ICT-systems is partially a consequence of complexity of the environment. Different business processes require different ICT-systems and therefor the information they produce is inherently different. ICT-systems also lack standardization in communication protocols. Since no standardized solutions are available for example for EDI (Electronic Data Interchange), each solution is made for a specific purpose and at a specific time. These kind of solutions are usually costly to implement and maintain and are usually build between two big companies with long lasting partnership. Complexity of the cost structure is also inherited from complexity of the environment. As stated in the chapter 2 bullwhip effect has more severe effects the further away from the customer the actor is. Because of this the costs of the information distortion and the ROI (return of investment) of the ICT-integration are hard to calculate for one actor in the supply chain, even though the gains of quality information are fairly easy to observe on operational level. (Ahn, Childerhouse, Vossen, & Lee, 2012)

3.1 ICT-systems in supply chains

This section explains the different computer and communication systems affect the supply chains, presented in section *2 Supply chains*.

ERP (Enterprise Resource Planning) systems were developed on the basis of MRP (Material Requirements Planning) which is a computer system made to transform product requirements in the master schedule to schedules for assembly, raw materials, subassemblies and final assemblies. MRP optimizes a solution to problems: what is needed, how much is needed and when it is needed. From these the system can output a planned order schedule, various reports and control the inventory levels. ERP continued to develop the idea of MRP not only to take into account the material and capacity information but also financial and human resources information. ERP is becoming more and more about integrating different applications inside an enterprise rather than just a support system for manufacturing resource planning. (Stevenson, 2007, pp. 635-661)

The next state of ERP system is proposed to be ERP II that will have more supply chain oriented focus, bringing trading partners and customers as part of the system instead of large, uniform and standard system. The next iteration of ERP-systems is proposed to consist of more or less independent modules which can be unique to certain business sector or business process. (Fawcett, 2014)

CRM (Customer Relationship Management) is a system to keep track and analyse customer behaviour. It focuses on brining the highest possible value to the customer, trying to automate customer transactions. (Fawcett, 2014)

One of the new supply chain information systems made possible with the introduction of internet are the e-marketplaces. E-marketplaces can have different solutions in different supply chains. In addition to providing catalogues and handling order execution these market places can include for example procuring for products from multiple vendors and help planners by providing information about products and terms of delivery. (Fawcett, 2014)

The evolution of the e-marketplace systems has led to supply chain portals. Portal is a system which shares data between all the actors in the supply chain. There are separate functions for suppliers and customers, but the delivery dates and other information is available for all the parties concerned. The aim of the supply chain portal is to provide real-time and transparent information to ensure changes in supply or demand are being taken into account. Supply portal also allows alerts and notifications to control the process. (Boyson, Corsi, & Verbraeck, 2003)

Business intelligence is becoming more and more important for metrics and data based decision making. BI software combines data from different sources so data availability from different systems is important for real time BI systems. BI systems are usually a combination of data sources, data storage, logic and BI tools as illustrated in Figure 7. (Sahay & Ranjan, 2008)

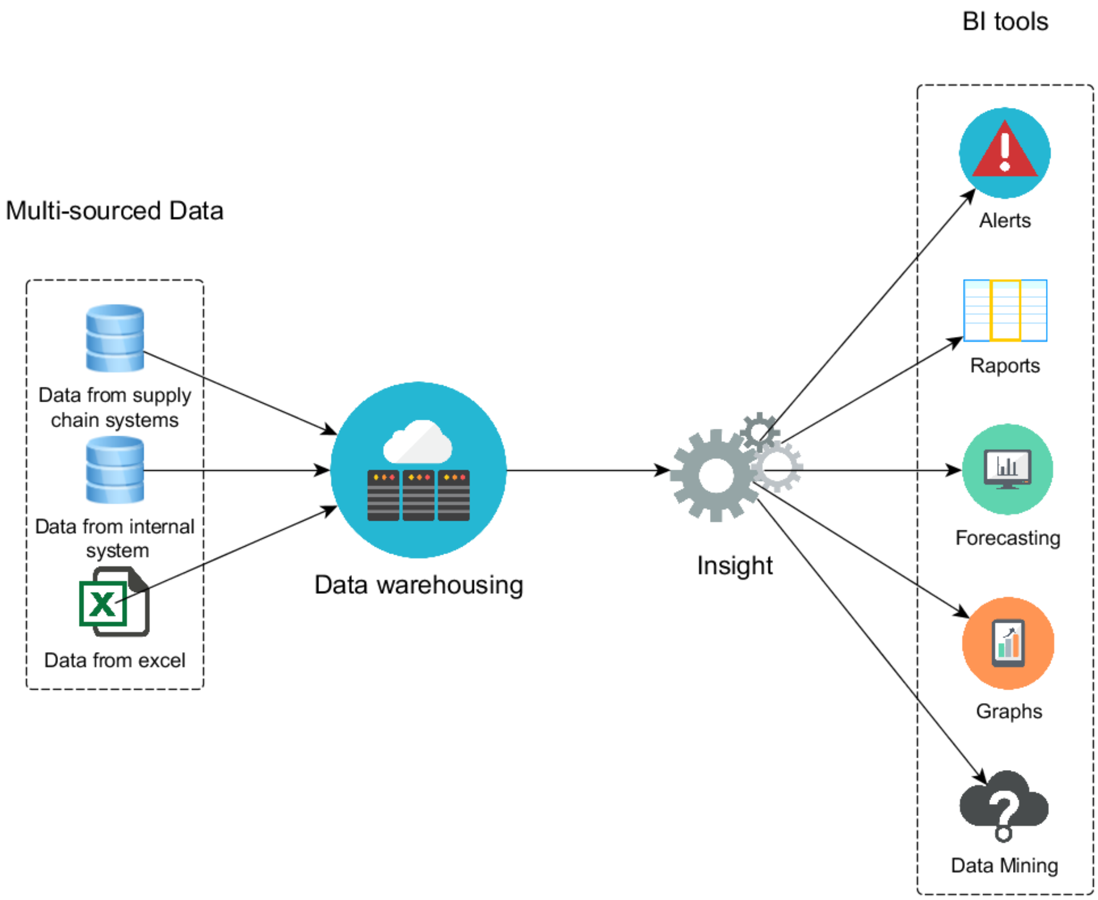

Figure 7 Basic structure of a BI-system. Adapted from Sahay & Ranjan (2008)

Market has some widely adopted tools for BI with different price points and functionalities for example SAS and Qlik Sense. There are also some upcoming products such as the Microsoft Power BI.

3.2 ICT-technologies

Since there is a lack of standardization in inter organization communication, there are nearly as many solutions as there are problems. This section introduces the most well-known technologies to exchange and produce information inside supply chain. The most apparent use of ICT systems is to relay transactions such as orders and order confirmation.

Electronic data interchange (EDI) was introduced during 1960 and is used to deliver B2B communication such as financial, manufacturing, logistics and other data. First attempt to make a universal EDI standard was made during the 1970s by ANSI X12 committee. Even though X12-standard is a cross-industry standard it didn't satisfy companies needs internationally. United Nations Economic Commission for Europe (UN/CEFACT) defined their own standard UN/EDIFACT. Both X12 and UN/EDIFACT are e-business framework standards. Business framework standards describe how transactions should be carried and what kind of information should be transferred. Business framework standards create alignment on both companies' business processes which is required in order to have formal communication. (Nurmilaakso, 2008)

In addition to framework standardization, which is considered as high-level standardization, EDI transactions need a technical specification for data formats and structures. Standards which specify how data is presented are considered to be low-level EDI standards. The most popular data format standard is widely adopted XML (Extensive Markup Language) developed by W3 consortium. However, even though UN/EDIFACT and X12 are considered as high-level standards they include low levels elements comparable to the XML standard. (Nurmilaakso, 2008)

Most of the popular EDI business frameworks are forks of either UN/EDIFACT or X12 but use XML as data format. Cross industry utilized electronic business XML and electronics focused RosettaNet are good examples of the typical development routes of standardized EDI business frameworks. (Ahn et al., 2012; Nurmilaakso, 2008)

EDI and XML have historically been a tools for B2B commerce between two large corporations. EDI implementations are considered to be expensive and slow to adapt and hence EDI hasn't really found its way to SMEs (small and medium enterprises). In addition to high cost of implementing the EDI connection itself, EDI connection require systems to support them which produces even more costs. SMEs can also have more variability and lower lifespans in their partnerships, in comparison to large corporations, which not only makes the ROI for single EDI connection lower but also increases the need for flexibility and quick adaptability. According to a survey by Nurmilaakso in 2008 only 12 % of European companies used XML or EDI based transactions. This number is surprisingly low compared to the huge role internet has in business nowadays and raises concerns whether XML or EDI are the right ways to implement electronic transactions in supply chains. (Nurmilaakso, 2008)

In contrast to the implementation heavy EDI/XML protocols are web applications and web services. Web application run on the web and are more agile to develop since resources are easier to scale and deploy as only the cloud side needs to be updated and no programs need to be installed when the applications are accessed through a web browser. This makes web applications less platform dependant since every device with a web browser can access the service. Web applications are also natively connected to the web and they can easily be implemented to use external data from other web applications and services. This is done through APIs (application programming interface). A good example of an API is using Facebook to login, implementing Google maps application in other internet services or implementing weather data from 3rd party service provider to a web application. (Marston, Li, Bandyopadhyay, Zhang, & Ghalsasi, 2011)

HTTP (Hypertext transport protocol) is the most used web technology. Next to every website uses HTTP in some way. HTTP communication is based on requests and responses. Sent message is always responded and the sender has the information whether the message is delivered or not. In comparison to EDI and XML mostly use ftp connection which provides no real response whether the message is actually recorded in the system and is intact.

One of popular paradigms to create web applications is to divide the system to services. Services are elements which serve a certain purpose and is connected to other services in the application. This practise ensures low cost, rapid deployment and rapid updatability of the services. The services are linked by web standards and together form the application. (Papazoglou, 2003)

This kind of approach is called SOA (service oriented architecture). SOA has a few major characteristics. Maybe the most important feature is *technology neutrality*. Today mobile devices have become more and more the most used devices in world-wide internet usage. The amount of different devices and platforms using the services has rapidly increased with the mobile revolution and will increase even more with wider adoption of the Internet of Things. Technology neutrality is hard or impossible to achieve without *loose coupling.* Loose coupling means that in order to add or remove a device or client, no changes to the rest of the system is required. If changes to the system would be required, every time a new type of device or platform is added the system would be under a constant change. With loose coupling services should have a way to find each other so that the idea behind loose coupling is not lost when service provider joins, changes or leaves the system. The loosely coupled systems are tied together with *location transparency,* which is often implemented with a registry containing the locations of each service providers in the system, analogous to an address book in physical world. All three characteristics above are required from a service which is easily integrated according to SOA. (Papazoglou, 2003)

Typical SOA implementation consists of three entities:

- Service provider
- Service requester
- Service registry

Figure 8 illustrates the dependencies and actions between the entities. The difference between service provider and requester is not distinct and the roles can chance depending on the use case. In some cases, service 1 can be the requester and service 2 the provider, but in other cases the roles can swap.

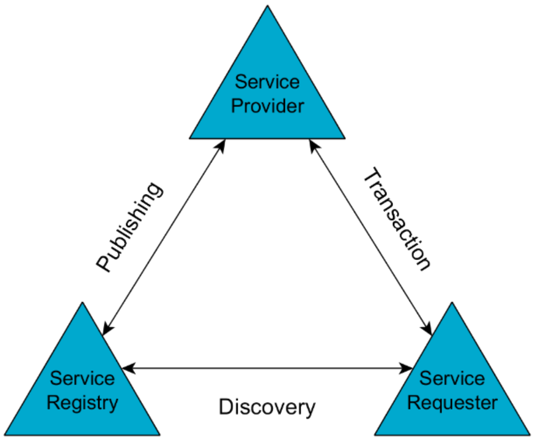

Figure 8 Relations between parties in SOA adopted from (Papazoglou, 2003)

Service provider publishes its location to the registry and service requester discovers the provider from the registry. After the requester knows where to send the request the request for the required information is sent and the provider responds to request.

One of the most popular open web API-standards used to communicate between services in SOA is called RESTful. RESTful communicates through HTTP-protocol. RESTful is stateless which means no information is stored in the services, but all information is required in real time from the data sources. RESTful is often used with JSON (JavaScript Object Notation) for data-exchange. JSON is native to web-browsers and requires no interpretation to be displayed on a webpage.

Compared to typical paper catalogue and fax approach, which EDI is built on and is strongly inherited by the newer XML standards. HTTP based web technologies allow more dynamic approach to displaying catalogue data. Since the exchange of data is real time available products and their information can be shared easier than they are in a static

XML approach where data is only sent during making an order. (Fujii, Nakayama, Tanaka, & Nagamura, 2010)

Internet of Things (IoT) is a term introduced in the 1990s by MIT and refers to devices that produce information independently. IoT-devices and service include sensors and devices which communicate independently with ICT systems and other IoT devices. Internet of Things closes the gap between physical objects and internet and is argued to have great impact on accuracy and timeliness of information in the supply chain since material flow can report its own status semi-automatic or fully automatic.
(Zhou, Chong, & Ngai, 2015)

Maybe the best examples of IoT in electricity distribution network operations, and in general, are remotely operated AMR- energy meters and remote controlled switches and circuit breakers in distribution substations. However, IoT devices don’t have to be always connected or static. In logistics and supply chain management the most widely adapted technology is RFID (Radio frequency identification). RFID is based on tags equipped with an antenna. A RFID-reader can read these tags from a distance and identify the tags it has in its range. This data can be used to determine tagged items in a warehouse without any human interaction. A typical solution with RFID in supply chains is inventory management where inventory management can be handled by placing tags in products. This also makes the inventory management virtually lag free. By leaving the inventory or terminal the product tells the system to adjust the inventory management system and inform the next step in the supply chain about the delivery. This reduces the work required by both, the warehouse worker and the truck driver, and decreases the possibility of human error in the process. (Fan, Tao, Deng, & Li, 2015)

As technologies like RFID don’t require human actions, vast amounts of data can be collected effortlessly. Data, such as single product shelf-life which was nearly impossible to obtain by hand becomes possible with automatic data collection methods such as RFID. This data can be used to minimize inventory inaccuracies and to decrease overall shelf inventory levels. (Fan et al., 2015)

RFID can also be used to track the product down the supply chain. When locations of warehouses and moving trucks are known via GPS or other location system, the location of the object is known as the warehouses and trucks are aware what is being transported with the help of RFID tags. Smart tags can also share other viable information such temperature and whether the shipped product has been agitated or not. With information about the physical material flow in deliveries logistics can be evaluated with much higher precision and when the information is shared to all supply chain actors, supply chains can be planned more efficiently. (He, Tan, Lee, & Li, 2009)

RFID has some competition in intelligent identification of goods. The predecessor of RFID was optical scanning of barcodes. In the past, the barcodes just identified to product type, but with the introduction of the 2D barcodes and internet services scanning the barcode with for example smartphone can create information that includes data such as location information. 2D barcodes are also very affordable solution since just stickers and a fairly simple web application is required. The more advanced technology competing RFID is Bluetooth identification. Bluetooth is widely used in mobile computing applications and the most recent iteration, Bluetooth 4.0, introduced low energy mode which is often used in identification and interaction in low powered devices.

Kiritsis (2011) broadens the idea of identification of the products and defines them as intelligent products which not only know where they are going by an identification method but can also have information about their BOM (bill of materials), service records, environmental data and other lifecycle information which can be utilized in PLM (Product Lifecycle Management). With information way closed information loops can be created all the way back to the manufacturer of the products who can improve their designs and material choices according to the data. Kiritsis (2011) has defined three stages of information loops in product life cycle:

1. BOL, beginning of life. Design, manufacturing and logistics of the product.
2. MOL, middle of life. Use, service and maintenance of the product.
3. EOL, end of life. Recycle and disposal of the products.

All of these stages produce useful and even vital information to the all of the supply chain actors. In addition to helping in making the design choices the manufacturer of the intelligent product has information to help with for example logistics coordination. Customer benefits greatly from installation and maintenance data which improve asset management of said products. When the EOL has been reached, recycling partner and the customer have a clear indication of how much and what materials the intelligent product contains, and whether there are wholly reusable parts in the system. This also helps in coordination of the reverse logistics. Steps and flows of intelligent products are illustrated in Figure 9.

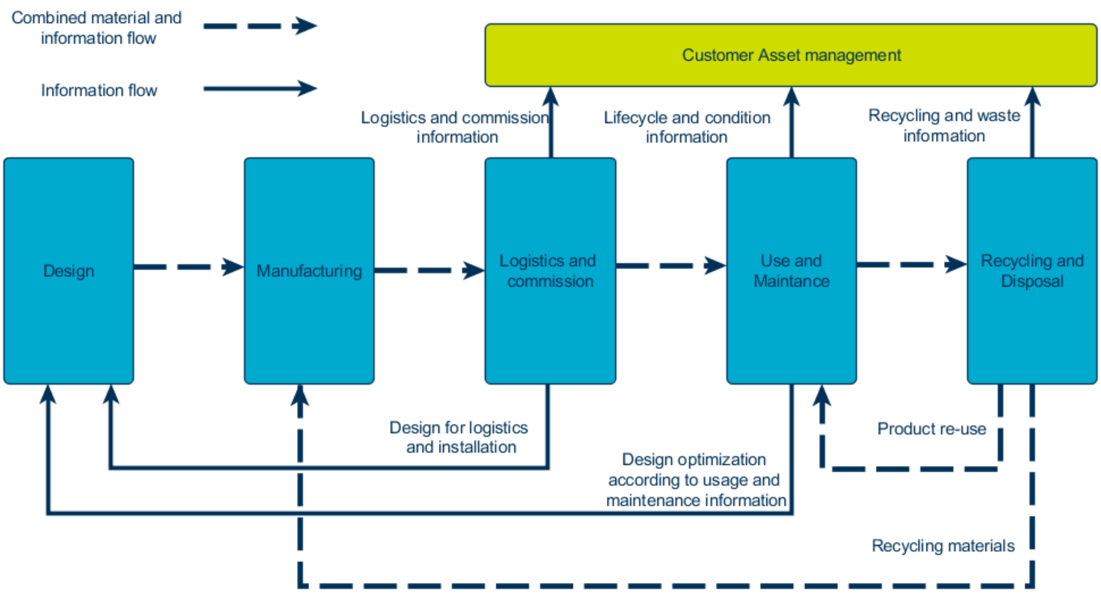

Figure 9 Information flow from intelligent devices in different lifecycle stages. Adapted from Kiritsis (2011)

When moving out of a phase the intelligent product triggers all of the needed outgoing flows. The intelligence in the physical product can be achieved with various technologies. It can range from simple identification tags such as 2D barcode or RFID to computers with sensor technology and internet connection capabilities. With different technologies come different connections. ID tags connect to their intelligence by a reader device and more intelligent products connect to the internet by cellular networks, mesh networks, wired network or a hybrid between them. Sensors can even communicate directly with each other. Information is processed by a middleware and delivered to the cloud or directly to companies' ICT-systems such ERP. Middleware also makes the information from various devices and technologies unified to be usable in ICT-systems and its users and thus ensuring the *loose coupling* which was discussed earlier as a characteristic of SOA. (Kiritsis, 2011)

Loose coupling becomes more important with the intelligent products the longer the life cycle is. The middleware needs to be able to communicate with various types of devices as the technology evolves. This ensures the system and the old devices won't become obsolete and won't obstruct introduction of new technologies.

3.3 Information flow and communication in integrated supply chains

This sub section explains how the key issues of communication in supply chains can be solved with the help of ICT-integration.

As mentioned in chapter 2 a lot of the performance aspects of supply chains depend on fast communication to all of the actors in the chain. Rapid changes in supply or demand require a lot of information to be delivered to multiple actors in supply chain. In addition to this information needs to be able to be measured, supervised and controlled.

Fast peer-to-peer information exchange can be achieved through traditional technologies such as phone calls and e-mail, but they have next to no traceability and work effectively only in peer to peer communications. It is also hard or impossible to sum up or form a big picture from information produced by mail or phone call. Even though these communication technologies lack fundamental capabilities required in supply chains, their implementation cost, speed and adaptability are hard to match, which is the reason why these technologies are still widely used.

As more sophisticated, but traditional methods such as EDI or XML-messaging systems are expensive to implement, hard to change and lack the adaptability of phone and e-mail, there is a need for a system which can effectively both relay and combine data, serve both automatic and manual communication to multiple actors in the supply chain. Traditional methods are based on peer-to-peer communication which creates long chains presented in *Figure 5 Supply chain information flow in model 2*. Communication in supply chains is rarely this linear, but more like presented in *Figure 6 Supply chain information flow in model 3.*

SOA principles and cloud based web applications is often proposed as a solution to this web like structure, because it is designed to be changed easily and be platform independent which makes it easier to ensure mobile compatibility via SOAs *platform independency*. Since networked supply chains have multiple kind of actors producing and receiving information in different places ensuring mobile compatibility is vital for satisfactory *information quality*. Platform independency also enables unified data from sources ranging from manual web form to fully automated ERP order. As SOA is also designed to be under change it can, in combination with different ways to input data, shorten the adaptation time for new actor in the supply chain. The cloud application must be built so that it can also handle changes in the system, easily delivering the information to all relevant actors. So that all parties acknowledge the changes and they reflect in real time to the decision making on a larger scale.

SOA principles and easy ways to input data do still not remove all the lag between the moment information is created and when it is inputted to system via web forms or computer systems. Also some of the data such as physical location of the product can be hard to determine accurately or require too much work to input. Human input also leaves room for errors and inaccuracies. These problems can be solved with intelligent products introduced in section *3.2 ICT-technologies*. Intelligent products also can provide more *data sharing* since they can produce variety of data and with help of web based communication all of the required data on product during its lifetime is uniquely pointed to that product and available.

In addition to real time data about the deliveries and orders, information is also needed in strategic, tactical and real time decision making. This data includes meters and analyses about the supply chain as mentioned in section *2.2 Information flow in supply chains*. This can be achieved with BI solutions which analyses data from companies own systems such as ERP and CRM in addition to the supply portal.

4 SUPPLY CHAINS IN ELECTRICITY DISTRIBUTION NETWORK CONSTRUCTION

This chapter explains the special characteristics of the network construction material supply chains and fits the supply chain theory target company's environment. The chapter also describes the challenges in the target company's material supply chain and information sharing processes. Research and findings in this thesis focus on the material delivery supply chain and not on the construction work done by the contractor.

As described in the Introduction the amount of investments in electricity network construction is soaring. Electricity network construction shares similarities with more traditional construction. It is heavily project centric and include heavy machinery which sets high requirements to on-time delivery because machine down time generates expenses.

Supply chains in construction in general have special characteristics compared to those of factory manufacturing. All materials are being delivered to single location and are used to build a single fixed location product unlike in factories where multiple products pass through the factory and are being distributed to the clients. The construction site is also different for different products unlike in factory environment. This makes managing logistics harder in construction. Also different types of project have little to no repetitiveness in the bill of materials. (Vrijhoef & Koskela, 2000)

According to Vrijhoef & Koskela (2000) there are four roles of supply chain in construction.

1. To reduce the cost and duration of onsite activities by manage the flow of materials to the site.
2. To reduce the cost of supply chain activities such as logistics, inventories and lead time.
3. To transfer activities from side to earlier stages of the supply chain with for example prefabrication.
4. To improve the integration of the site and the supply chain by planning and developing the site actions so that they work as a part of the supply chain.

The electricity distribution network construction has its own special characteristics which affect the supply chain. The products between different projects are more similar than in traditional construction. This makes the bill of material a lot less complex. With only few items in bill of materials making the most of the material expenses of the projects, there's high repetition in materials of cable network construction projects. These projects are also not fixed in one location but constantly moving. Which makes logistics even harder than in traditional construction. This means that network construction shares some extremes with construction, such as unfixed logistics routes, but also shares characteristics with more lean factory production, such as simple and repeatable bill of materials and high degree of prefabrication. All of the roles mentioned above are already taken into consideration in today's DSO supply chain. This leads to the conclusion that the problems arise from the information flow rather than the flow of materials.

4.1 Materials and material flows in network construction

This section describes the structure of medium voltage distribution cable network, explain some dependencies between network construction materials and introduces the product mix.

As all of the new network built by Elenia Oy is underground cable network this section mostly describes the components and material flows of underground cable networks. The underground cable network consists of medium and low voltage underground cable systems.

The network consists of nodes and cables between them. On medium voltage side the node is the secondary substation. Inside medium voltage substation there is medium voltage switchgear, distribution transformer and low voltage switchgear. Secondary substation transforms the 20 kV medium voltage to 0,4 kV low voltage which can be distributed to residential customers. Secondary substations are connected to each other via medium voltage underground cables which consist of the cable itself and cable accessories such as joints and terminations. 20 kV cable also connects the medium voltage system to 110/20 kV high voltage primary substations.

On low voltage side the nodes are distribution cabinets which house low voltage switchgear. Distribution cabinets are connected via 0,4 kV low voltage cables which consist of low voltage cable and low voltage cable joints. Low voltage cables also connect distribution cabinets to secondary substations and to customer connection points. Figure 10 illustrates the distribution network.

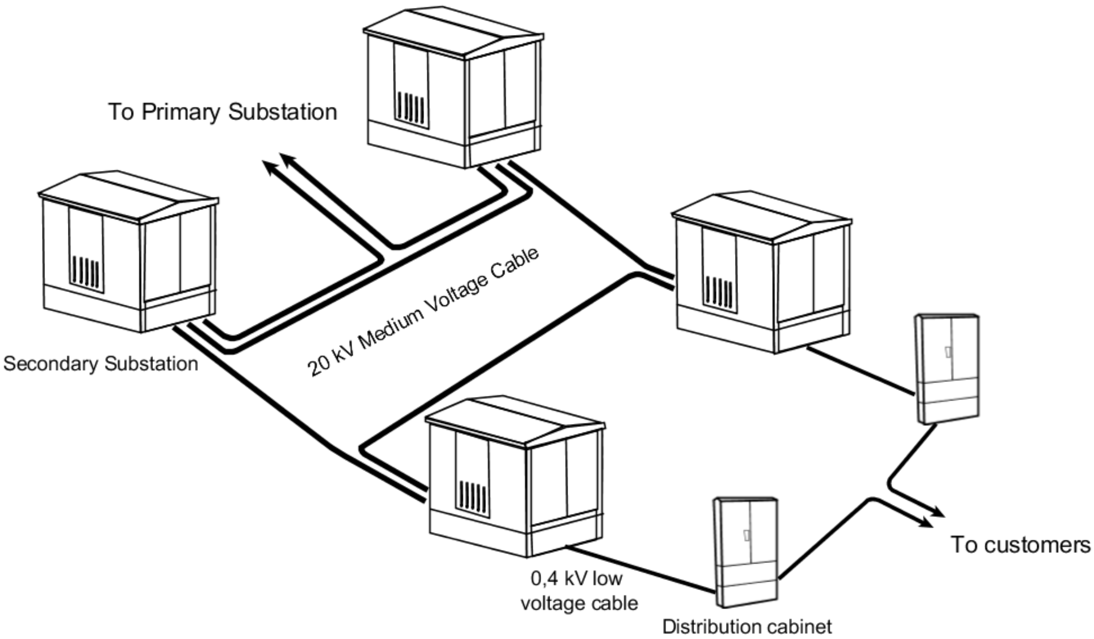

Figure 10 Simplification of 20 kV and 0,4 kV electricity distribution network

Since a big portion of the network construction is excavating cables which requires heavy machinery, the most critical component are the cables, especially medium voltage. Because of the nature of the cable excavating prefabrication is not possible. Prefabrication can however be done in other components, mainly substations and distribution cabinets, in order to transfer activities to earlier states of supply chain as mentioned above.

The construction in the network can be roughly split to three categories in supply chain wise. The categorization is made based on two factor, the product mix required and the design horizon of the projects. The design horizon also affects the required supply chain lead time and also the forecasting horizon. These three categories are listed as follows:

1. Grand long term reinvestment programs, for example, Elenia weather proof investment plan. These project plans originate from internal strategies. It is characterized by designing the projects up to one year ahead and the projects have a schedule that extends to the full year. With the help of design system, the bill of materials is known half a year in advance. This enables a long forecasting horizon and enables really long lead times for the supply chain. In addition to long time horizons all of the projects have very similar product mix. These plans add up to major share of the materials, so the project have high volume and low product mix. Long lead times, high volume and low product mix makes this category ideal for JIT deliveries without stocking the products.
2. Short term investments, reinvestments and maintenance. These project plans originate usually from external demand. They consist mostly of building network for new customers, but can also include repairing of existing network to prevent failures or safety incidents. These projects have shorter design horizon and because

of it, require much shorter lead time from the supply chain. Since the lead time is shorter, JIT-deliveries without stock are not always possible, since some of the projects have short design times. The product mix is also wider since some of the work focuses on the old overhead lines.

3. Fault repairing. Fault repair work originates from a failure in the network. There is no design horizon and longest possible delivery times are minimal. These deliveries are impossible with JIT deliveries and all the material needed in these has to be stocked near the faulted network component. The product mix in this type of work is really broad, because every network component could need to be replaced.

4.2 Network construction supply chains

This section introduces the supply chains in different logistics solutions in distribution network and introduces all actors in the chain.

Electricity distribution network construction has very distinct types of actors.

1. Elenia acts mainly in governing role in the supply chain since it can’t effect the material flow in the supply chain as all of the construction work is nowadays done by a contractor. This makes DSO essentially a *virtual operation* in the supply chain. On the other hand, DSO has the biggest interest in completion of the projects, which also makes them the most interested in effectiveness of the supply chain and the information flow affecting it.
2. Contractor either buys or receives the materials from DSOs supplier, installs them and finalizes the network. Contractor is dependent on supply chains ability to deliver materials on time since next to no work can be done without materials. Network construction requires heavy machinery such as excavators and contractors also use subcontractors. This makes the contractor interested in the information flow and when the materials arrive to the site.
3. Wholesaler is often used for warehousing and logistics. Wholesaler also manages its partnership network. Both material flow and information flow go through wholesaler which makes it important that the wholesaler can communicate required information downwards and upwards the chain.
4. Supplier is the actor who produces the materials. Supplier has the biggest impact on the information flow because the bullwhip effect amplifies any of the information mistakes made by the supplier.

There are multiple types of supply chains viable for electricity distribution network construction. The main differences between supply chain configurations is the actor with the biggest responsibility in the chain. This also affects the way the risks are divided between actors in the chain.

For DSO the simplest supply chain configuration is the model where the contractor does all the material procurement for network construction materials. In this model, there is next to no procurement or material specialists working for the DSO. This doesn't however remove the need of having in house knowledge about the products installed in to the network. It doesn't make the supply chain immune against delivery errors either and not having the information about the material deliveries can also weaken DSOs ability to forecast delays in the construction projects. With this solution costs other than the procurement price affecting the overall costs, such as ease of installation can be taken into account easier, when the contractor decides what materials to use. (Arola & Laapotti, 2015)

A typical solution in the past has been to use a retailer to deliver all the construction materials. This has allowed agility for the supply chain, since a retailers keep stock to even the demand fluctuations and offer shorter order lead times. Retailers also have knowledge from various areas of expertise. This model somewhat limits the material choices to those that the retailers offer and can also add uncertainty to the supply chain since there is no partnership between the supplier and the customer. If the retailer fails to communicate the problems to all of the customers, which can prove difficulty some problems such as the bullwhip effect can cause delivery errors. The product mix is considerably smaller in underground cabling network projects than it is when building overhead lines. It is not necessary to keep everything in stock and it would only create excess costs to supply chain. With small product mix it is easier to adapt JIT deliveries and minimize costs throughout the supply chain. JIT deliveries without stocking works only with *high volume low mix* products and with demand which is forecastable. (Arola & Laapotti, 2015)

The other extreme is to procure all of the materials either from the contractor or directly from the suppliers depending whether the materials are *low volume, high mix* or *high volume low mix products*. This results to simple supply chain while still maintaining control over the most important materials, having simple information structure in the supply chain and eliminating excess costs. Here the problem is the agility of the supply chain. To ensure shorter enough delivery times to satisfy the needs of short term investments some of the materials need to be warehoused either at the manufacturers or by the contractor. (Arola & Laapotti, 2015)

The model used at Elenia today is a hybrid between the last two. Some of the materials are delivered straight from the supplier whereas other are delivered through a wholesaler to enable shorter delivery times in order to satisfy the delivery time requirements of the short term investments and enable smaller suppliers and suppliers who have longer delivery times due to geographical distance to supply to Elenia's supply chain. The main problem with this arrangement is its complexity. Complex chains need more information in order to keep the process working. At the moment the information comes from multiple suppliers and the wholesaler. The information is also often structured differently in each case. (Arola & Laapotti, 2015)

As mentioned in chapter *2 Supply chains*, one of the key characteristics of a successful supply chain are adaptability and agility, or in short, supply chains ability to react to changes in demand and changes in the market. To some extent this problem can be solved with light product mix and high degree of late customization. These are issues which are taken into consideration today in design of network construction supply chains. However, it has been observed that these are not the only sources of complexity and therefore are not the complete solution to this problem.

Earlier it was stated that supply chains have three kinds of uncertainties. Decreasing the size of product mix and adding late customization addresses the characteristic uncertainty, but does not address the inherent or external uncertainty. As inherent uncertainty is the natural stochastic characteristics of the process it is hard to decrease. Inherent uncertainty is especially a problem in forecasting. With long forecast horizons the uncertainty grows (Vorst & Beulens, 2002). Inaccuracies in forecasting resulting from stochastic variances can still be taken into account so that every actor acknowledges the uncertainty. When the uncertainty is acknowledged, no overreactions are made and hence no bullwhip effect is present. This can be achieved for example by adding error margins to the forecast. Uncertainty can also be minimized by real-time forecasting. In short the bullwhip effect is caused by lack of trust to supply sides ability to hold the promised delivery dates and demand sides short order lead times.

As regulatory model governing the Finnish DSOs calculates the value of the assets in the end of every year, the construction projects must be finished by the end of the year. This fixes the forecasting horizon to one year, so the forecast must be updated constantly according the progressing orders and changing plans. This also drives towards the need of real-time forecasting.

In addition to qualities of the products the characteristic uncertainty can result from bad information structure of the chain. As supply chains in network construction are typically rather short which makes mapping the supply chain information simpler. In this study eEPC method and notation are used to map the information structure, its points of uncertainties and risks associated. Even with simple supply chains the steps which the information takes in each company quickly adds up. In extra organizational studies it was noted that potential causes for disturbances in supply chain information structure are hard to understand without a detailed review of the process. eEPC was found out to be a good way to review the information structure.

The eEPC method and process analysis identified some points of uncertainty. The most common point of uncertainty was handling the communication in case fluctuations at supply or demand. At this point changes are communicated via updated order confirmation by e-mail. This however leaves the demand end of the supply chain, which is mainly the contractor, without the whole picture of how the fluctuations affect their project schedule. The E-mail also only reaches the person who made the order, but who wasn't necessary the same person who needs the information later on. These steps add up to long information chain which causes the information quality to decay in two ways. It causes delay to the information flow and can distort the message. There's also no way to create a consensus about the dates and metrics between actors in the chain because everyone has their own data and own perspective. This reduces transparency and because of it reduces the flexibility of the chain. eEPC also revealed that without centralized information, the information delay can be too long.

Elenia's order handling process was formed with eEPC notation and is illustrated in Figure 11. Green boxes are activities, which describe actions taken in the chain, the orange boxes are events which are states between activities. X marks an *XOR (exclusive or)* decision which means that either of the paths will be followed. Extended notation also covers things such as documents and actors taking part in the activities. The process chart below is created with ARIS express software which is free to use and offers community support for the usage and practises of creating eEPC charts. (Software AG, 2015)

The grey boxes in this notation describe documents produced by the process. These documents represent the formal data which is exchanged between systems and is a required for the process to work. The red boxes visualize risks involved in activities. The yellow boxes indicate the party or person responsible for the action, depending what process is modelled. Light blue boxes describe the ICT-system related to the activity.

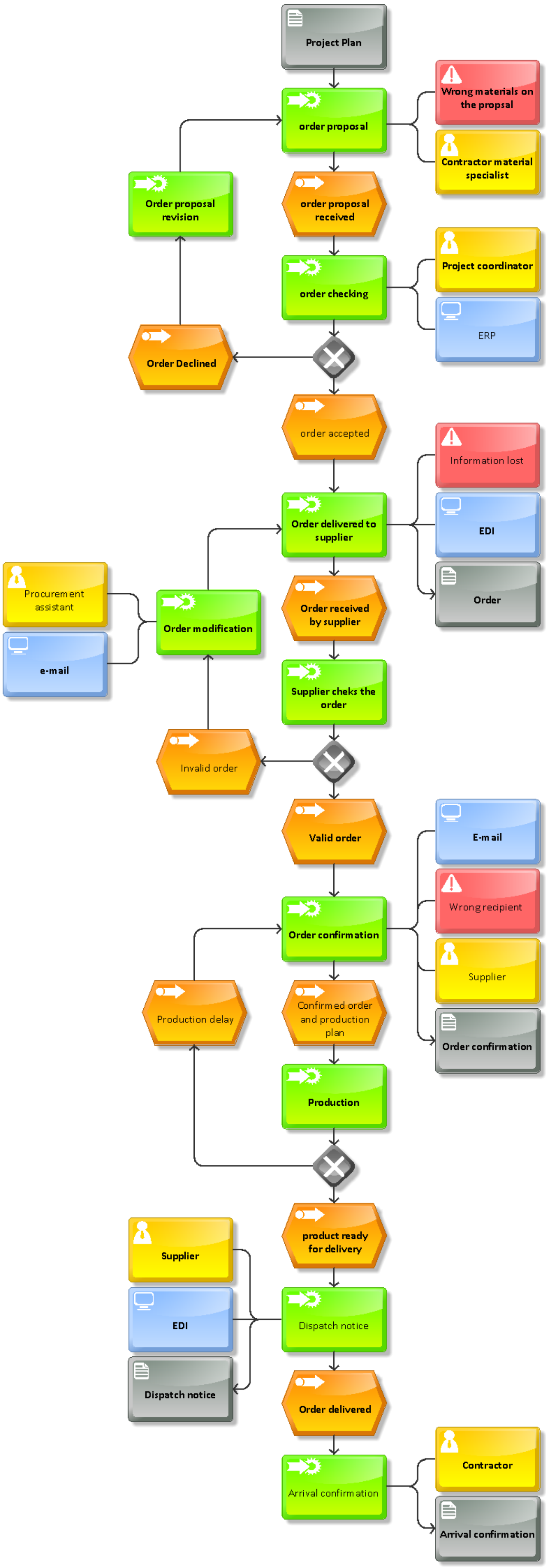

Figure 11 Elenia order handling process in eEPC notation for direct JIT-deliveries

The overall state of the order handling process is good. Every step has a feedback loop to govern the process to the right output and the process can be modelled with eEPC without big exceptions. This process has also not been commented to be hard or impossible to follow. The problems arise when the process is not followed. At the moment following the process is based on the responsibility of people in different companies and there is little or no governance to the human actions because of the lack of time overseeing the process. Overseeing is a task which should be automatized by introducing queries about missing information such as order confirmation, dispatch notices and delivery confirmations.

Throughput times for this chain can be up to one year. Typical time for reinvestments is from three months to half a year. This can also be problematic since the time between order confirmation and delivery is nearly as long. After that, contractor only receives a phone call with the dispatch notice at the time of delivery. The uncertainty raises as no information about the delivery is received in up to half a year. Solution to this would be to remind both parties about the delivery inquiring whether the latest dates for demand and deliveries still hold or to deliver data from earlier stages of the manufacturing process, before logistics.

During internal review of the supply chain metrics described in section 2.3 Supply chain metrics the following metrics were found to be the best fit for Elenia’s supply chains. The focus on the review was to find metrics to detect delivery performance decrease as early as possible and to predict delivery errors. When considering these metrics, the findings of the section *2.3 Supply chain metrics*, metrics currently in use and preliminary thoughts for good metrics for Elenia’s supply chain were used. The following metrics were considered to be the best fit for Elenia’s supply chain:

1) OTD. Delivery date compared to project schedule. On time delivery is a one of the most important supplier partnership metrics in Elenia’s scorecard describing delivery performance. (Kalliorinne, 2014) The problem is that delivery errors are detected with a significant delay with OTD which makes it subpar in anticipating delivery errors.
2) Order lead time. Measures the time between order and delivery. Order lead time is usually better the shorter it is and describes supply chains agility. However, as network construction is heavily project based, it has fixed material listing and schedule. The earlier the orders are made the more time supplier has time to adjust capacity. Long order lead time reduces the need for the agility in the supply chain.
3) Confirmed delivery date progression. The difference between confirmed delivery and required delivery date indicates the same problems than OTD with less precision, but before the deliveries are made. With this metric, problems can be addressed as soon as possible.

4) Order confirmation lag. Lag in order confirmation is found out to be a symptom to ill information structure or problems in a well-structured process. It causes uncertainty in supply chain, inaccuracies in metrics above and risk of bullwhip effect. Long lag time has been found out to have an effect to the delivery delays later on.
5) Capacity information. Available capacity can be compared to the forecasted demand. This information free capacity information can be used to optimize the schedules and inform about potential delivery delays before orders are even made.
6) Buffer stock balance. Buffer stock is used to even some of the fluctuations in demand. Critical observation the balance of the stock helps in anticipating future delivery problems.
7) Cash-to-cash time is the time it takes for material delivery to convert in to network value. The metric describes how in time the deliveries are requested. Product that is delivered but not installed generates risk of thievery or vandalism and ties up capita.

It was also noted that some statistical analysis on these metrics is required to determine whether the variances are a result of inherent features or characteristic features of the supply chain. Or in other words whether the variance in the metric means normal stochastic variance or if it means a disturbance in the supply chain. As some of these metrics were examined for supply chain performance errors in past, it was noted, that the alerts from the abnormalities should be real-time or near real-time and not from monthly reports. This is due to the fact that when the potential upcoming delivery errors could be spotted, the time left to act according to the alarm is very short.

4.3 ICT-integrated supply chains in network construction

This section introduces network construction covering the present state of the supply chain ICT-integration in cable distribution network construction and evaluates the compatibility of the integration aspects described in chapter *3 ICT-integration* to the target environment.

Today Elenia's the network construction projects are mostly handled in two systems. These are the Network Information System (NIS) and Enterprise Resource Planning system (ERP).

NIS handles the documentation and network designing. Bill of materials for a project can be formed according to the network design. There are two phases in network design: initial design forms a coarse plan to determine the electrical integrity of the network and the final design, which takes account the restrictions in terrain and ownership of land, determining where the cables, substations and distribution cabinets are placed. Materials are then ordered according to the bill of materials. BOM can be also be used for example to forecast demand for the next year. Managing BOMs of the several hundred project plans has proven to be difficult, since the plans are constantly evolving and at the moment there is no way to form a summary of the BOMs from all of the ongoing works which causes severe issues in forecasting.

ERP handles project supervisory, procurement, purchase orders and financial transactions. Purchase orders are managed in ERP which makes it a critical system when it comes to tracking deliveries, handling logistics and forecasting the demand. ERP also houses the product catalogue. At the moment only limited amount of information in ERP can be accessed by the contractor.

There is also an eMarketplace portal where the contractor can make orders, make changes to delivery times and addresses and confirm arrival of the materials. This updates the information in ERP system. The biggest problems with the portal now is the lack of updated information about the deliveries. Order confirmations arrive by email. And since the order lead time can be up to six months, the information of the confirmed or delayed delivery time can be hard to find, especially with a mobile device. This makes forming a whole picture of the deliveries of a particular project really hard. Without the big picture it is hard to know whether the material deliveries line up with the progression of the project. The problem with email is also not being able to verify that all orders have been verified. As it was noted in the metrics, long delay in confirming orders is a sign of problems in the supply chain. This can’t be measured effectively from emails.

This model doesn’t support the model prosed in section *2.2 Information flow in supply chains* where the centralized and transparent information was found out to be the best model to avoid the bullwhip effect. On top of the problems with email based communication mentioned above, some of the information is not received at all at the moment. To centralize and make the delivery information transparent, one system has to house all of the required information. This system combines the data from several sources and is linked to multiple different information systems which could range anything from supplier’s ERP systems to manually added data from contractor mobile device. This means the system needs to be both *loosely coupled* and *technology independent.*

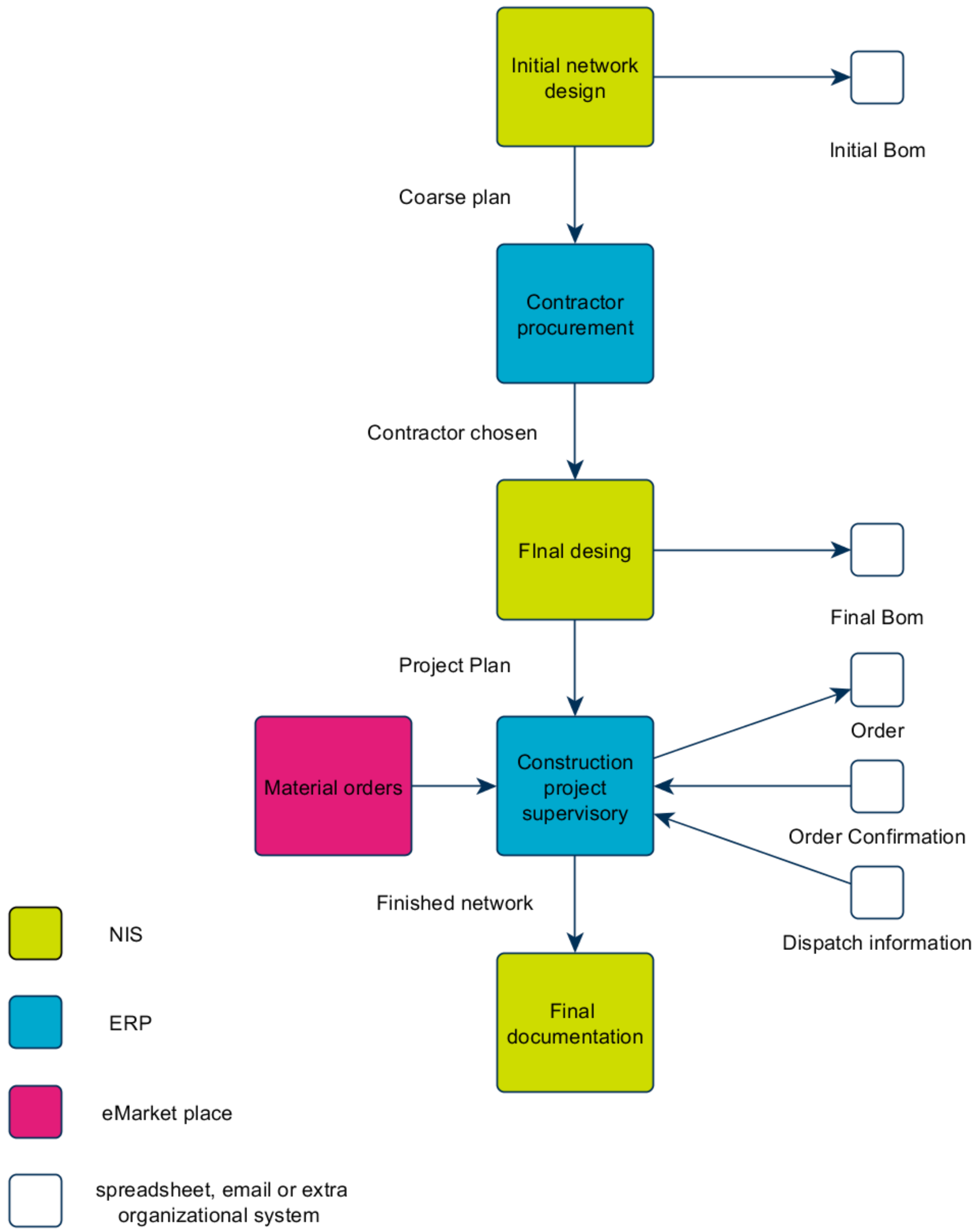

Figure 12 Reinvestment project flow through different ICT-systems

Introducing new suppliers has also proven to be slow and problematic. Integration via EDI or XML requires the information to match perfectly on both Elenia's and supplier's systems. If direct integration cannot be formed all of the communication is done via email. Email communication is peer-to-peer and is impossible to make centralized and transparent. On the other hand, easily adaptable solution which requires no special ICT-systems from the supplier is required. Smaller suppliers who do not have the required ICT-systems for system wide integration will be excluded from the supply chain if there is no replacement for email. Replacement for email is also needed since integration takes time because some of the integration features is hard or not viable to implement in each integration. Same information should be able to be provided to the DSO whether the supplier has a EDI or XML integration or the supplier is using a less integrated way such as email to communicate.

A proposed solution to this problem is a supply chain portal. The purpose of this portal is to create transparency and ensure the quality of the information in the ICT-systems. The system will have distinct user roles as described in section *2.2 Information flow in supply chains*. On the execution and routine decision level (levels 3 and 4 mentioned earlier includes: contractor project coordination, supplier and wholesaler order handling and DSO order handling) the portal fulfils following use cases:

1) Allow contractor to create material orders according to the BOM, delivery times, stock balances and request changes to delivery.
2) Allow contractor to review the delivery schedule from the latest and most up to date delivery date.
3) Allow supplier to confirm orders, change delivery date because of delays in production, confirm change request to delivery date and send dispatch notices.
4) Automatic queries for orders without confirmation, orders without arrival confirmation and orders without dispatch notice. Automatic notifications about changes in delivery dates and pre-delivery notification.

On the tactical and strategical decision level (levels 1 and 2 mentioned earlier includes: DSO supply chain management, DSO demand forecasting, supplier production planning, supplier supply chain management, wholesaler supply chain management)

1) Displays summary of the BOMs for demand forecasting
2) Displays the most up to date demand forecast for all parties
3) Displays the most up to date production schedule and capacity forecast for all parties
4) Displays buffer stock balance for all parties
5) Displays the basic supply chain metrics required for partnership management
6) Provides the API for Business Intelligence tools for advanced data analysis

After these changes the process that was introduced in *Figure 12 Reinvestment project flow through different ICT-systems),* will transform to what is presented in Figure 13 below. Now every party in the supply chain now has only one place to go where all of the information is available and presented in a meaningful way.

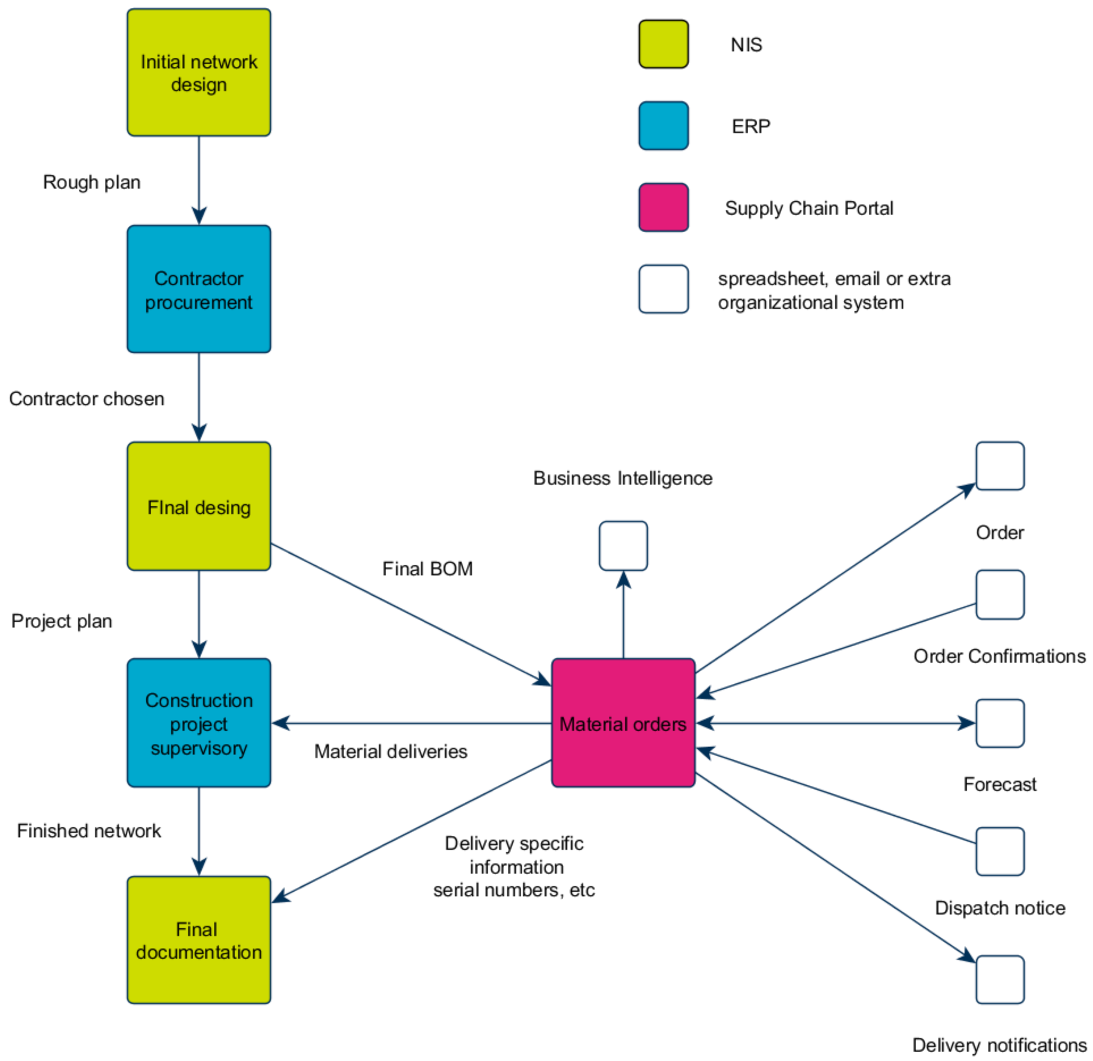

Figure 13 Investment project flow with Supply Chain portal

As mentioned in section *4.2 Network construction supply chains* network it was noted that supply chain metrics require long term statistical observation and on the other hand, changes have to be spotted in real time. Neither of these is possible with monthly spreadsheet reports. The information to support all decision levels is now in either ERP system or monthly and quarterly spreadsheet reports. Internally it has also been discovered that in order for the data to support decision making it has to be reliable, always available and visualized properly.

In the past Microsoft Excel has been utilized since most of the metrics require calculation and spreadsheets offer an easy way for simple visualisations. Spreadsheets however require constant updating and can't deliver real time information. Performance becomes also an issue when data is combined from multiple systems, for example metrics which require information from NIS and ERP. Spreadsheets are also hard to read with mobile devices.

Business Intelligence system is proposed as a solution to above mentioned problems. The system combines data from NIS, ERP, Supply Chain Portal and less structured sources, including spreadsheets. Adding new data sources to the system has to be relatively easy to ensure, that the system retains its integrity after new systems are introduced and it does not obstruct introducing new systems. The insight calculation has to be easy to change as well. If reports are hard to change or difficult to make, people will either fall back to spreadsheet reporting or keep using metrics which are found out to be not adding any understanding of the process or govern the process to a wrong direction. The ultimate goal for the system is to be as reliable and repeatable as an automatic ERP report and as customizable as spreadsheet reports while being transparent to all parties who make decisions based on same data.

BI-system satisfies the following use cases:

1) Allows users to explore data with interactive visualisations. Data has to be viewable from all available dimensions such as products projects, suppliers, contractors and time.
2) Allows user to display data such as material orders, BOM and commissioned materials.
3) Allows user to display dashboard of the metrics mentioned in section *4.2 Network construction supply chains* and alert the user when predefined limits are exceeded.
4) Allows easily to create new reports and metrics and make them available to all parties.
5) Allows easily to add data sources to the system.
6) Allows data mining in the future.

Since data warehousing would be out of scope of this thesis simpler solution as structure of BI system is proposed. This structure doesn't have distinct parts for data warehousing and insight, but combines a local database and computation engine as one. This structure can be found from BI solutions like Qlik view and Microsoft Power BI. Both of the example systems were researched and found out to suit current needs proposed in this research. Figure 14 Structure proposal of Business Intelligence system describes the system structure.

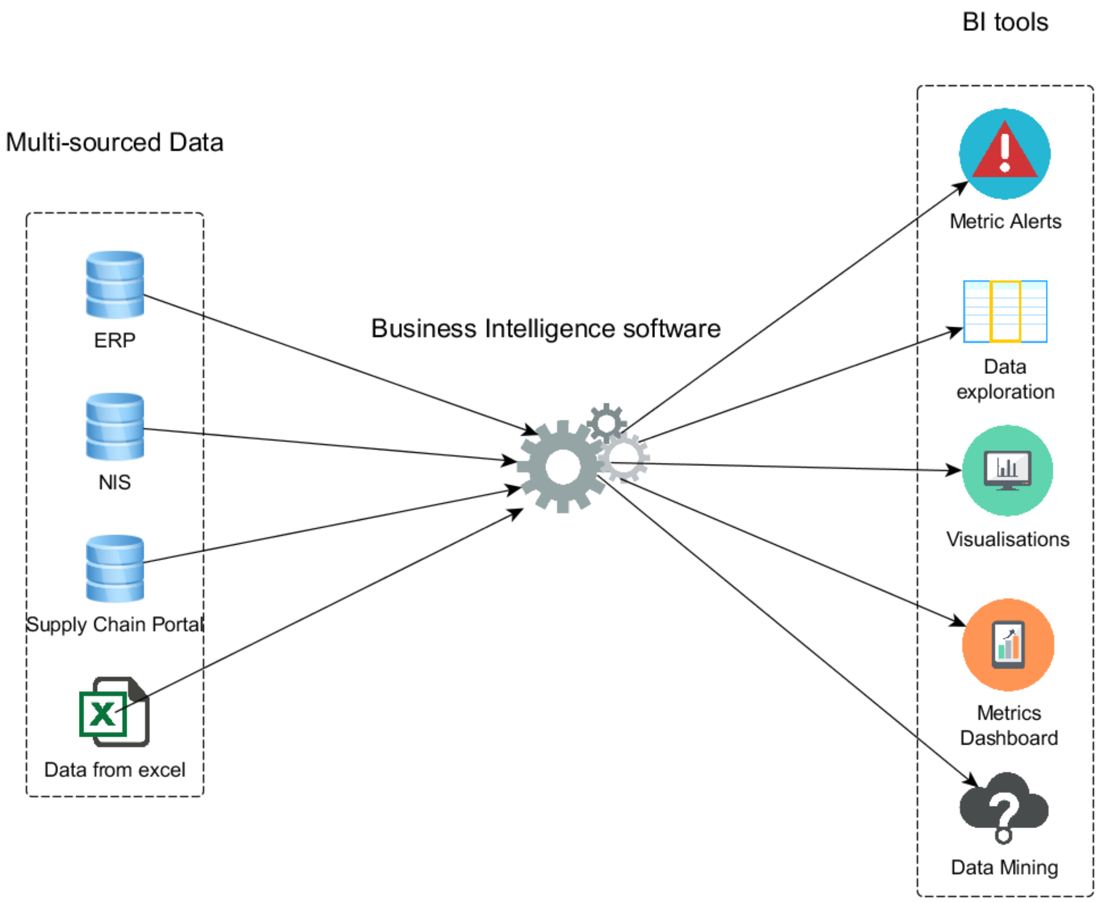

Figure 14 Structure proposal of Business Intelligence system

Supply chain portal and BI systems are both focusing mainly on *information sharing* perspective of the supply chain information flow. As mentioned inn chapter 2.2 Information flow in supply chains, another perspective is the *information quality*. Information quality is taken into account in supply chain portal, but inputting data to a web portal still causes time lag which causes deterioration to the information quality.

The special characteristics of network construction supply chains amplify this problem. Materials are not delivered to a fixed location but the sites can be tens of kilometres wide. Because of this, the person who receives the delivery could be someone with no connections to the supply chain portal. Since most of the work is done on the field, mobile capability of the systems is essential.

To produce high quality information an intelligent product system is proposed. This system allows users to input to state information of the products life cycle, straight from the construction site with, for example, a smart phone. The system gathers information and relays it to the right information system. Some of the information such pictures, manuals and other product specific information can also be stored in the intelligent product system.

The main idea is that every physical delivery and product has a virtual counterpart which holds information about the products lifecycle such as logistics information, measurements and network information. The virtual counterpart can be used to input information and provide sensory data such as GPS information to the information systems in the supply chain.

Because the distribution network consists of nodes (secondary substations, distribution cabinets) and underground cables, the virtual counterparts can't be similar for every product type. For example, interacting with underground cables when they are commissioned is both really hard and serves no real purpose and the delivery information seldom matches the final product, since cable line between two substations can be installed from multiple cable drums from several deliveries. However, substations are physically interacted with in network operation and maintenance situations which makes them accessible and optional place for identification medium. Some smaller articles in the delivery are also used to create bigger wholes, for example fuse switch disconnectors are used to construct a distribution cabinet and do not hold any interesting information after commissioning. The structure of the system is illustrated in Figure 15.

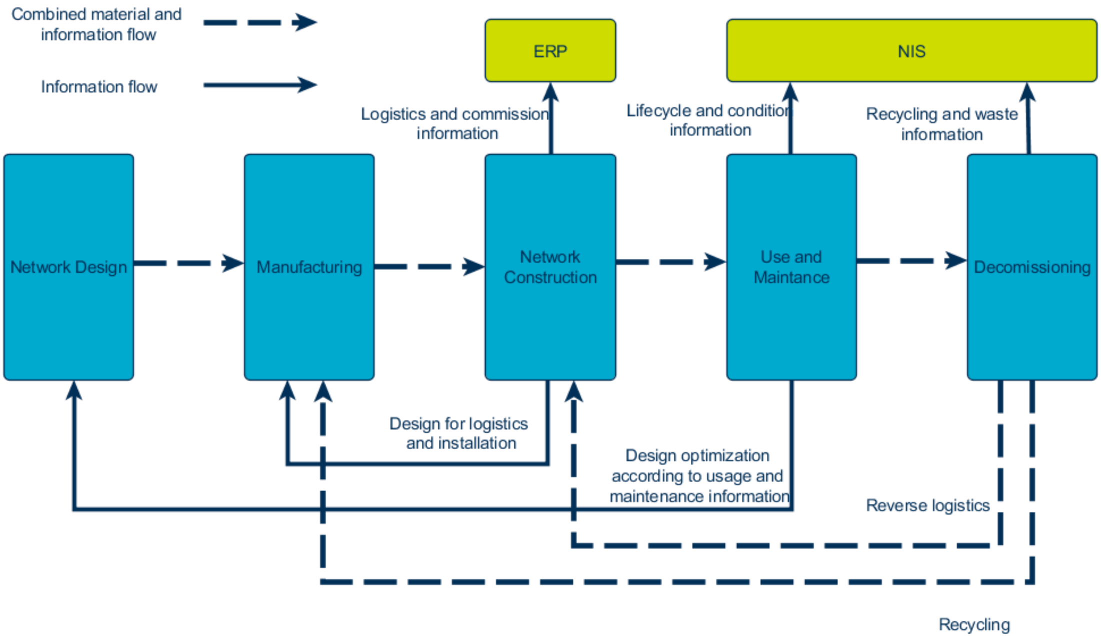

Figure 15 Material and information flow of intelligent product system material and information flow

The following use cases are proposed to be available for every delivery:

1) Dispatch notice
2) Logistics state information
3) Confirmation of arrival
4) Claim about incomplete delivery or defect product

The special need for different product categories and their use cases are proposed as following:

1) Substations and distribution cabinets
    - Inputting state information about commissioning
    - Inputting cable measurement information
    - Inputting serial number information for components used such as the transformer
    - Viewing network topology for the substation
    - Notifying about defects or deterioration
2) Cable drums
    - Order reverse logistics for the cable drums
    - Order reverse logistics for excessive cable which was left over from a construction site
3) Recycled products
    - Order reverse logistics to repair, disposal or reuse
    - Mark repair complete and order logistics back to field or warehouse

Interactions with intelligent products are made with generic mobile devices such as smart phones. The communication is initiated via a physical identifier. The system has to be *loosely coupled* so that it won't obstruct introducing new identifying technologies to the system. Easiest to implement and most available identifier technology is 2D barcodes such as QR code which can be scanned with every modern smartphone. QR codes can be used to store web addresses to the intelligent product user interface. Other technologies widely available today are for example RFID/NFC tags. Figure 16 illustrates the intelligent product interaction with QR code as a physical identifier.

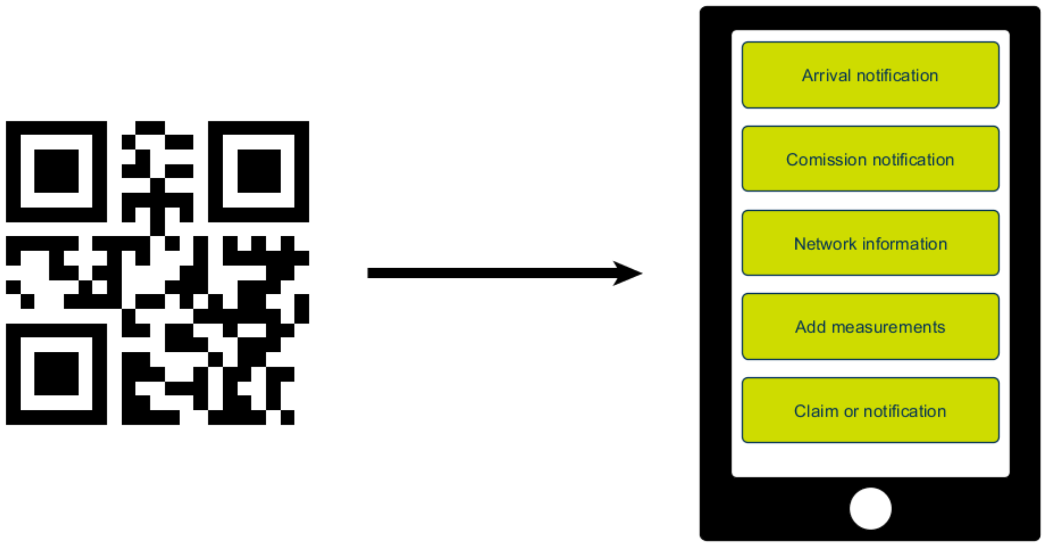

Figure 16 Intelligent product interaction with QR code

5 CASE STUDIES

This chapter presents case studies of integrated supply chain systems. Case studies are chosen to find out if the solutions proposed above are in the line with services which are commonly used on other markets

5.1 Liaison Technologies

Liaison technologies is a global integration and data management company which provides cloud and on-premise services. Liaison has over 7000 customers all over the world including some of the biggest companies in the world. Liaison has offices in both US and Europe.

On top of EDI/XML transactions and invoice handling, Liaison provides integration for forecasting and inventory management systems, collaboration processes such as claim handling and document sharing, metrics and user management.

In the centre of the services Liaison provides the integration service which integrates different sources of information to uniform data which can be interpreted by customer's ICT systems. The suppliers can integrate to the system via direct EDI connection to their own systems or via less formal communication such as email, telephone or fax. On top of the ways mentioned before Liaison also provides a supplier portal called SupplierWeb. In SupplierWeb the supplier can input the required data and the customer can use functionalities which are not available at customer's own ICT-systems. The suppliers are also not bound to one kind of integration, but have a possibility to use, for example, direct integration to the degree they can and input the remaining data via email and the SupplierWeb.

One of the integration cases handled by Liaison is Metso Automation. Metso Automation wanted to improve its supplier network in order to cut costs and improve efficiency by introducing more integrated supplier network. In addition to cost related goals Metso Automation wanted to add visibility to tools used by the supplier but owned by Metso and allow supplier to see CAD-drawings related to the products to be delivered.

The goal was to reach the goals by integrating the suppliers more effectively to Metso Automation's ERP system. Some direct EDI connections were established but rest of the suppliers didn't have big enough volumes to make a EDI integration cost effective. Metso wanted a solution which would guarantee same level of integration for suppliers who were not viable for EDI integration.

Metso divided its suppliers to three categories depending on the volumes and the degree of speciality in the product. This led to three categories. Only the supplier supplying standard products with high volume were found out to be viable for direct EDI integration. For the more specialized suppliers a Liaison SupplierWeb was found out to be the best solution. This solution made automated order handling with exception handling possible also for suppliers who were not viable to integrate via EDI. This also allowed Metso to integrate more informal information such as sharing the CAD drawings for Metso specific products, asset management of Metso owned tools and Vendor-managed Inventories (VMI) balances. Liaison has also integrated Metso's third-party RFID system via its integration technology.

This integration has lowered the operating costs of purchasing via automation. Integration and VMI have created visibility and reduced the tied capital of the inventory items. Same information is now also received from supplier that are not viable for EDI integration. From technical point of view Metso's ERP system only has to communicate with the integration platform. This means there are no changes required to the internal system of Metso when new suppliers are introduced. On the supplier side, suppliers with small volumes can now also take use of the VMIs and transparency information. Smaller suppliers can now also be integrated to Metso's system via easy-to-use web portal.

It was noted that a development project like this requires both well-defined business processes and the right technical solutions to support them.

In discussions between Elenia and Liaison it was found out that ideas presented in this thesis lined up with Liaison's product catalogue pretty well regarding the supply chain portal.

5.2 Microsoft Power BI

Microsoft Power BI is a business intelligence suite. It allows users to import data from various sources such as data bases, excel files and internet services like Google Analytics. When a data model is established users can create reports and dashboards from the data. Reports can contain various visualisations from the data model. All of the visualisations are interactive which means changing filters or clicking bars on the visualisations also change the values of other visualisations accorindgly. Power BI uses DAX programing language to create insight and calculations. DAX is really close to Microsoft Excel syntax which is extremely familiar to most people.

The Power BI has two main components: a desktop application for creating the data model and the reports and a cloud service for sharing the reports. In this case study the desktop application was used to create a report of some of the supply chain metrics proposed in section *4.2 Network construction supply chains*. The process was swift and quite straight forward and requires no extra skills in addition to good knowledge in Microsoft Excel. A proof of concept (POC) of Elenia's Supplier report is presented in Figure 17. The report is made with Power BI desktop and with random data which does not represent Elenia's figures, but this POC would work also with real data, out of the box.

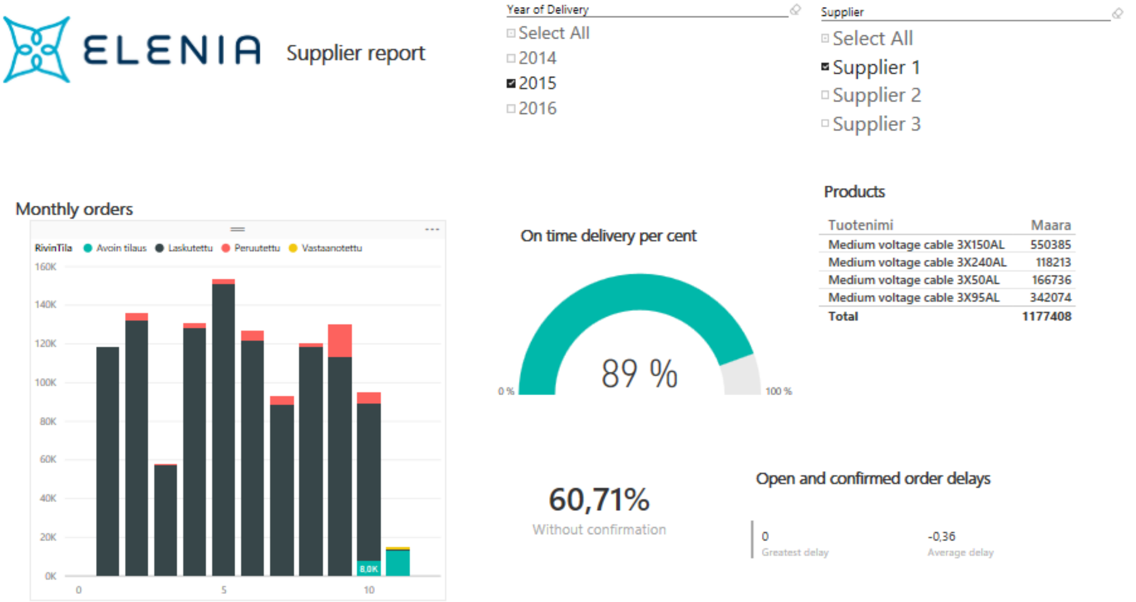

Figure 17 Proof of concept of Elenia supplier report made with Microsoft Power BI

The idea of the report is to have a picture of supplier's performance with one glance. All of the visualisations in this report are interactive. For example, clicking one of the bars in the bar chart provides information for that specific month in all other metrics.

This report can be uploaded to Microsoft Power BI cloud server and distributed to all Elenia's personnel with one click. The desktop version of the software is free to use. The cloud service has free and paid options. The free option allows user to have reports and data models up to 1 Gb and share them inside organization. Microsoft has also implemented mobile apps for the most used mobile platforms.

Since Microsoft Power BI can do most of the features proposed in this thesis for free and implementing it would only take few days, it is ideal for at least for a transition period to a more integrated solution.

6 CONCLUSIONS

As it was stated earlier in this thesis, Elenia Oy is a *virtual operation* in its material delivery supply chain, since it has no effect to the physical flow of materials. This makes Elenia's role in the supply chain purely governing. Governance can be done via affecting information flow and material flow.

The main threat in disturbances of the supply chain information flow is the bullwhip effect. The bullwhip effect is caused information distort which amplifies towards the ends of the chains. In electricity distribution this means mainly contractors losing trust to the delivery capability of the suppliers. This leads to ordering materials much earlier than they are really needed according the project plan. This leads to distortion in demand which causes problems in supplier's production planning and causes new disturbances to delivery performance. This decreases contractors trust to delivery performance even more, causing a vicious circle. The same phenomena can be observed when supplier loses trust to demand forecast and is not prepared to meet the demand if it raises within a small time horizon. In both scenarios the supply and demand are distorted from the real need of supply and demand. This kind of progress generates risks to all parties in the supply chain and hence the risks stacks up quickly.

The distortion also keeps the parties from operating at the maximum efficiency, generating excess costs to the chain. If the construction projects progress at steady pace during the year, the material demand should be consistent, too. The supplier could then produce materials at a constant output throughout the year, which means less over time work, less idle time for machines and less inventory keeping which means cost savings to the supplier.

As mentioned above the bullwhip effect is a product of uncertainty. The uncertainty can be divided to three categories:

1. Characteristic uncertainty which can have multiple sources. The most important are the characteristic faults in the information sharing process. The area of business also introduces uncertainties such as the early weather caused seasonality, early seasonality caused by the project schedules which are fixed to end in the end of the year and other uncertainties which depend on the way the information flow is conducted.
2. Inherent uncertainty is the statistical variance or noise present in the system. Not all of the failed deliveries signal larger problems in the supply chain. Separating the noise from actual delivery errors has to be done via statistical interpretation.

3. External uncertainty is the uncertainty presented by factors outside the supply chain such as weather changes, political atmosphere and new laws. External factors can transform to *characteristic uncertainty.*

The structural uncertainty can be affected by re-engineering the information sharing process. The eEPC notation was found out to be good way to map the process. The current bottlenecks can be found by auditing information sharing processes with suppliers and contractors. Auditing the processes with eEPC is beneficial especially with new suppliers and contractors, when changes to information or material flow are made and with suppliers with issues with delivery performance and providing required information. Unknown bottlenecks can be found via extensive metering of the supply chain and by exploring the delivery data. Reducing complexity in the material flow, such as decreasing the size of the product mix, helps also by reducing the need for information in the first place. Transparency in supply chain also help detect issues such as orders exceeding the production capacity. The main purpose of transparency is discovered to be ensuring that supply and demand are balanced all the time and neither is distorted.

The effect of the other two categories can be decreased by transparent information sharing. When an order is delayed because of an unforeseeable reason, the earlier contractor receives the information the more time it has to adjust the project schedule. This gives the contractor a possibility the rearrange the work and avoid excess cost. This also builds trust towards the supplier and avoids things like *demand signalling* and *shortage game*, which were mentioned to be among the main reasons for the bullwhip effect in section *2.1 Supply chain management.*

Information sharing and *information quality* were found out to be the two main features of information in supply chains. Information sharing is the amount of information is shared on the supply chain. When there is not enough sharing in the chain, different parties have to anticipate and forecast the actions by themselves, which creates multiple forecasts for the supply chain and effects such as the *demand signalling.* The degree of information sharing also depends on the complexity of the chain. The more complex the chain is the more information is required by different parties in the supply chain. Information sharing also consists of accessibility of the data. The second feature is *information quality*. Even if *information sharing* is on high level the chain can still have information related performance issues and misunderstandings if quality of the data is low. Quality depends on how true the information is and how real-time it is. Unreliable information doesn't decrease the uncertainty. Information that is not available as soon as it is created, decreases the time the contractor has time to react to changes in delivery times.

This thesis proposes three changes to ICT-systems to improve *information sharing* and *information quality*. These systems compliment the exciting systems by either viewing the information in more accessible manner, making inputting information easier or creating information automatically. Easy and fast integration is vital for systems like this since have multiple users and it combines data from multiple systems and from multiple parties in the supply chain. The system should not obstruct changes in supply chain information structure or changes in the material flow.

The first is supply chain portal which brings all of the relevant supply chain information to all parties of the chain. It improves transparency and availability of information by creating an easy to use environment to create orders and track deliveries for all parties on the supply chain. By adding bill of materials information to support ordering and material usage monitoring, the system reduces waste and helps to eliminate faulty orders. This helps to decrease cost generated by waste and unnecessary logistics. Automatic queries for missing information also adds automatic governing to the information process and improve information quality. The portal has two roles: order handling and supplier relations management. Order handling focuses on single orders and projects, supplier relations management focuses on demand and supply forecasts and order portfolio. Both roles have distinct views to the system. As it was discovered during the case studies solutions like this have been implemented a lot on other areas business.

In order to ensure that the information flow is efficient it needs to be monitored and critically examined. This requires metrics. A good metric describes the state of the process or creates understanding of the supply chain. *4.2 Section Network construction supply chains* describes suitable supply chains metrics for Elenia at the moment. Metrics should be reviewed constantly in order to have metrics which describe the process at its present state. New bottlenecks and threats can be found by exploring the data and by data mining. Information quality is important also in metrics and monitoring. The most important aspects of information quality are the timeliness, the accuracy and that everyone makes decisions based on the same data.

The second ICT-system improvement proposed in this thesis was the Business Intelligence system, which creates a data model from multiple data sources and allows users to create value adding visualisations and alerts to the metrics. This can be done with multiple cost effective or even free software solutions as presented in the case studies.

Third proposed change are the intelligent products. Intelligent products allow contractor, supplier, Elenia or logistics company can interact with the physical product or delivery and provide information about the products progression throughout the supply chain. The interaction is done via an identification medium such as a QR code or a RFID tag with a general purpose electronic device such as a smartphone. Since information is now created without delay as the physical event in the material flow happens, the timeliness of the information improves which improves *information quality*. This system also enables sharing real-time information which was impossible in the past, such as ordering reverse logistics for empty drum rolls, tracking the real commission date and tracking recycled products needing repair. This improves *information sharing.*

To implement these system changes two strategies in different time horizons are proposed. The first proposal is for short time horizon. These changes are possible to implement immediately or within a year of time of writing.

1. Monitoring the balance of supply and demand and to avoid disturbances is to watch for the overall demand forecast and orders and compare them to capacity forecasts from the supplier. This way crude imbalances can be spotted early on. This can be done immediately and without any changes to the ICT-systems.
2. Introducing the supply chain portal as proposed above with current data for EDI integrated partners and integration with Elenia's ERP system. Also introducing automatic notifications to improve information quality.
3. Introducing a business intelligence system with ERP integration via available connections and data manually from other systems. Updating the data daily or on-demand. Introducing a manually updated Microsoft Power BI model as a first step, as proposed in case studies.
4. Test and pilot intelligent products to track selected deliveries using QR code as identification media. Emphasis in piloting has to be on usability and improving information quality.

The second proposal has longer time horizon. These changes can be implemented in next 3 to 5 years.

1. Introducing the supply chain fully with all suppliers, wholesalers and contractors. Integrating the system with BOM information from NIS and data from logistics companies. Integrating material supply chain portal to project management and construction state tracking.
2. Integrating all the relevant systems to business intelligence, such as NIS. Improving the data to be real-time. Data mining by hand and with machine learning algorithms.
3. Introducing intelligent products fully with technology independent identification. Integrating construction state tracking, installation manuals, network information and multi state production delivery or tracking. Researching possibilities of GPS and other sensory data to help improving the supply chain.

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