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Production time estimation model for increasing the productivity in SME-s

Author applies for degree of Master of Science in Engineering (M.Sc.)

Tallinn 2015

Author's Declaration

I have written the Master's thesis independently.
All works and major viewpoints of the other authors, data from other sources of literature and elsewhere used for writing this paper have been referenced.

Master's thesis is completed under Jüri Riives supervision

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Master's thesis is in accordance with terms and requirements “.......”....................201….

Supervisor ….. signature.

Accepted for defense

.... chairman of defense commission

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TUT Faculty of Mechanical Engineering

Master's thesis task

2014 /2015 academic year spring semester

Student: Margo Allik 132943MARM

Field of study: Industrial Engineering and Management

Supervisor: Professor, Head of Chair, Jüri Riives

Master's thesis topic (Estonian and English languages):
TOOTMISEGA SEOTUD AEGADE HINDAMISE MUDEL TOOTLIKKUSE TÕSTMISEKS SME-des

PRODUCTION TIME ESTIMATION MODEL FOR INCREASING THE PRODUCTIVITY IN SME-s

Tasks and timeframe for their completion:

Nr	**Task description**	**Completion date**
1	Topic proposal and structure of thesis	01.03.2015
2	Theoretical frame of reference	25.03.2015
3	Case study	20.04.2015
4	Conclusion	15.05.2015
5	Final result	25.05.2015

Engineering and economic problems to be solved:

Increasing productivity is crucial for SME-s due to the increasing global competition. Therefore, it is important to have production time estimation model for increasing the productivity in SME-s.

Defence application submitted to deanery not later than …....… Deadline ……..........

Student ……………………. /signature/ ……….…………. date ….........………

Supervisor……………………… /signature/ …………….……… date ….........………

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Abstract

The work of this thesis was conducted at Tallinn University of Technology. The purpose of the thesis was to investigate the time usage in the production and find the model for increasing the productivity and the value added time.

To achieve the goal of this thesis following steps were made.

At first step, was conducted the research of theoretical background: general view of companies and their strategic decisions regarding business and manufacturing strategy. Both these strategies have impact on the processes at the company and processes have impact on the overall productivity of the company, because time usage for order fulfillment; manufacturing throughput and cycle are depending from these strategies.

At second step, was given overview of throughput and cycle time with components and methodology to calculate it.

A third step was given overview of one practical case study to illustrate the time usage on the assembly process.

End goal of this thesis was adoptions of theory and empirical finding to modulate, time estimation model to increase the productivity and to make a work flow achievable with decreased time usage.

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1. Introduction

Main goal for most of manufacturing companies today, is to be profitable and serve customers. In order to be profitable; company have to achieve high profitability and also have customers, which are paying invoices. In order to win and keep valuable customers; it is important, that products and services have or create value to the customers. Product selling prices should deliver this value to the customers and have to be on correlation with quality and delivery time.

Also in today's competitive marketplace maintaining and achieving manufacturing excellence is one of the keys to success.

A global marketplace for products and services means more customers and more intense competition. In the broadest terms, we speak of competitiveness in reference to other countries rather than to other companies. That's because how effectively a nation competes in the global marketplace, affects the economic success of the nation and the quality of life for its citizens.

The OECD (Organization for Economic Cooperation and Development) defines competitiveness as "the degree to which a nation can produce goods and services that meet the test of international markets while simultaneously maintaining or expanding the real incomes of its citizens." (R.S. and Taylor III, B.W., 14)

The most common measure of competitiveness is productivity. Increases in productivity allow wages to grow without producing inflation, thus raising the standard of living. Productivity growth also represents how quickly an economy can expand its capacity to supply goods and services. (R.S. and Taylor III, B.W., 14)

Productivity is calculated by dividing units of output by units of input. (Russell, R.S. and Taylor III, B.W., 14)

The more efficiently a company uses resources (inputs), the higher productivity it has. It is important to optimize inputs and to ensure that these resources are used efficiently.

One area to find opportunities for improvement is the manufacturing area. Usual activities in manufacturing companies are cutting, grinding, sealing, hardening and assembling. These activities can be the target for optimizations, but it is important to understand which resources and how much are involved in the production.

1.1 Objectives of the Research

1. To study and analyses the performance of selected small medium enterprises.
2. To come out with a proposal for improving the process and increase the productivity in selected small enterprise.

1.2 Scope

This project is focuses on small & medium industry.

In the scope are:

a. Overview of processes important to manufacturing.

b. Proposal of the possible productivity improvements.

1.3 Problem statement

Productivity is one of the keys to financial success of the company. Understanding the time usage in company is important to improve the productivity of the company. Time can be used for value adding activities and non-value adding activities and increasing the time share of value adding activities increases the overall productivity of the company.

So, it is important for small and medium enterprises to understand the benefit and importance of higher productivity, it is crucial to the country's economic growth and play important role to be successful among competitors.

2. Theoretical framework of the thesis

2.1 Order fulfillment process

This chapter is introducing order fulfillment process. Order fulfillment process is defined, with general activities. A summary of the theoretical framework is concluded in this chapter.

Order fulfillment process and definitions is widely explored by various authors. One of the most common definitions is made by Keely L. Croxton.

Order fulfillment is a key process in managing the supply chain. It is the customers' orders that put the supply chain in motion, and filling them efficiently and effectively is the first step in providing customer service. However, the order fulfillment process involves more than just filling orders. Order fulfillment involves generating, filing, delivering and servicing customer orders. The order fulfillment process involves designing a network and a process that a firm to meet customer requests while minimizing the total delivered cost and maximizing the firm's profit. It needs to be implemented cross-functionally and with the coordination of key suppliers and customers. (Keely L. Croxton, 19)

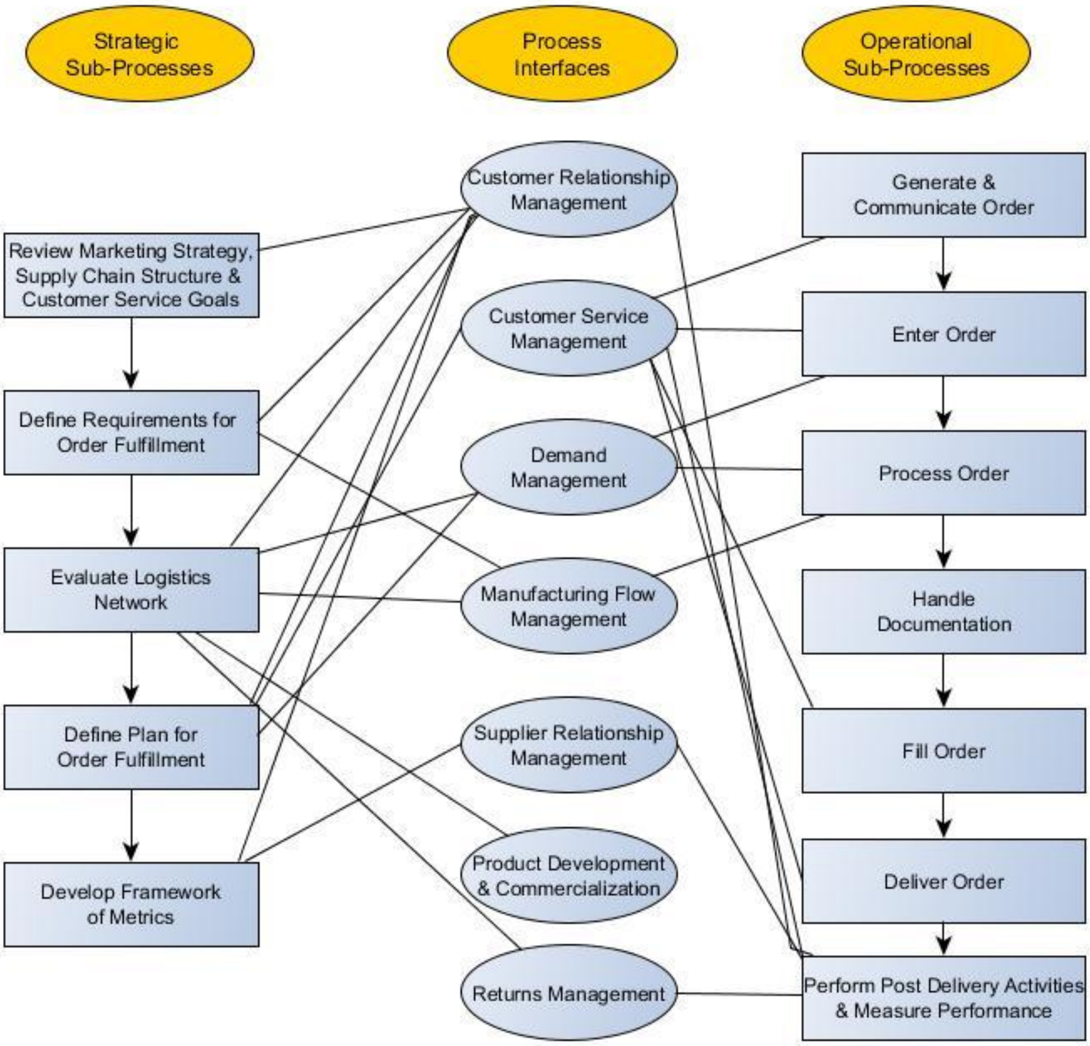

Figure 1. Order fulfillment. (Keely L. Croxton, 21)

The order fulfillment process has both strategic and operational elements, as shown in Figure 1. Therefore, the process has been divided into two parts, the strategic process in which management establishes the structure for managing the process, and the operational process that is the execution of the process once it has been established. Implementation of the strategic process within the firm is a necessary first step in integrating the firm with other members of the supply chain, and it is at the operational level that the day-to-day activities take place. Figure 1 also shows the interface between each sub-process and the other seven supply chain processes. These interfaces might take the form of a transfer of some data that the other process requires, or might involve a sharing of information of ideas with another process team. (Keely L. Croxton, 21)

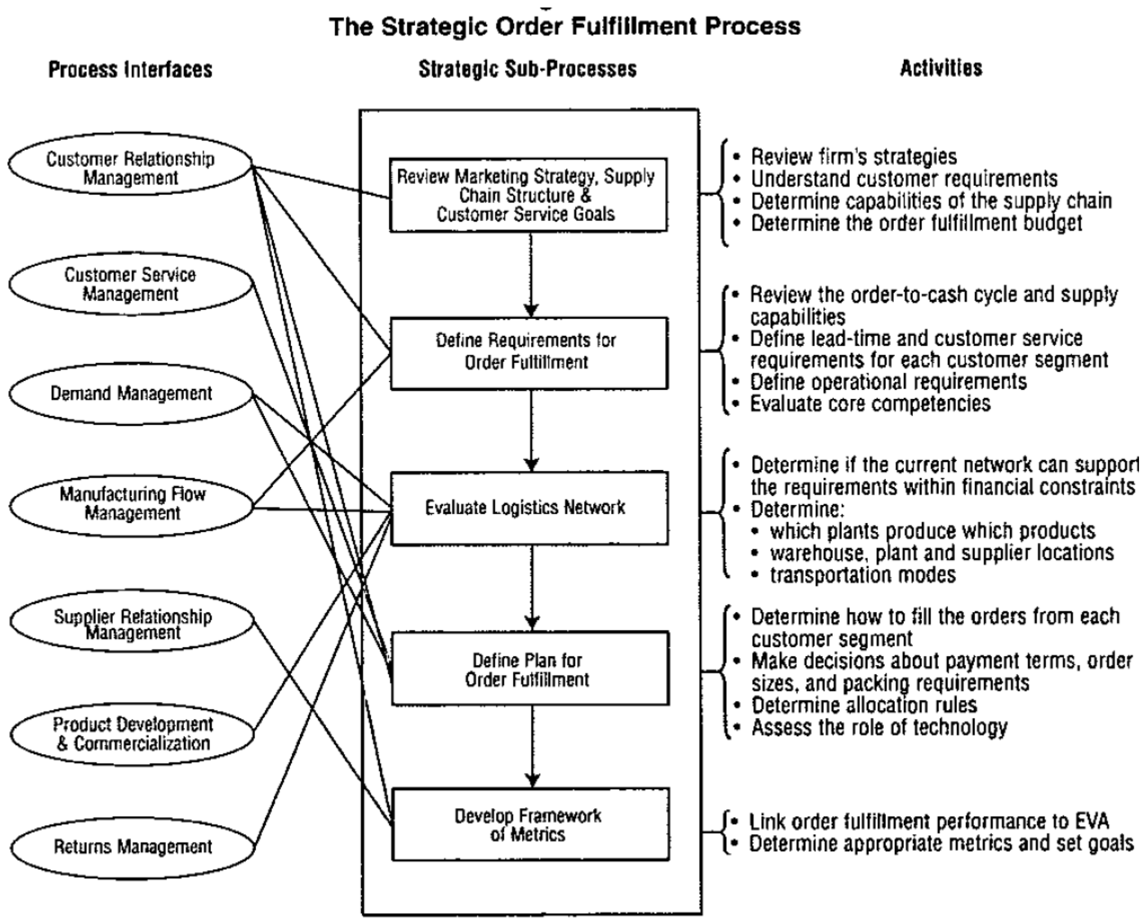

Figure 2. The Strategic Order Fulfillment Process. (Keely L. Croxton, 22)

At the strategic level, the process team designs the operational order fulfillment process. This includes designing the network, establishing policies and procedures, and determining the role of technology in the process. This requires interfacing and communicating with multiple functional areas within the firm, and can be enhanced by working with suppliers and customers to develop network and a process that meets the customer's requirements in a cost effective manner. The order fulfillment process needs to be designed around the customer, but within the limits of the firm's business and marketing strategy. (Keely L. Croxton, 22)

Another view to the order fulfillment process is from the Krajewski and Ritzman. This approach is more general than Croxton's approach.

The order fulfillment process produces and delivers the service or product to the firm's customers. There are four key nested processes: (1) customer demand planning, (2) supply planning, (3) production, and (4) logistics.

(1). **The customer demand planning** process facilitates the collaboration of a supplier and its customers for the purpose of forecasting customer requirements for a service or product. Customer demand planning process is a business-planning process that enables sales teams (and customers) to develop demand forecasts as input to service-planning processes, production and inventory planning, and revenue planning. (Krajewski, L.J and Ritzman, L.P., 445)
(2). **The supply planning** process takes the demand forecasts produced by the customer demand planning process, the customer service levels and inventory targets provided by inventory management, and the resources provided by aggregate and detailed capacity planning to generate a plan to meet the demand. Regardless of whether the firm is producing services or a product, this process is critical for effective execution in the supply chain. (Krajewski, L.J and Ritzman, L.P., 445)
(3). **The production** process executes the supply plan to produce the service or product. Nonetheless, the production process must be integrated with the processes that supply the inputs, establish the demands, and deliver the product to the customers.
A key aspect of order fulfillment is the logistics process, which delivers the product or service to the customer. (Krajewski, L.J and Ritzman, L.P., 445)
(4). A key aspect of order fulfillment is the **logistics** process, which delivers the product or service to the customer. (Krajewski, L.J and Ritzman, L.P., 445)

Also very generally define order fulfillment process Russell and Taylor.
Order fulfillment – the process of ensuring on-time delivery of a customer's order. (Russell, R.S. and Taylor III, B.W., 473)

As shown from different authors have different approach to the order fulfillment process, but in general order fulfillment process is process, which faces toward customers. This process can be customers only interaction with the company. Generally order fulfillment process starts from customer order; then customer order is processed and if needed are made some procurement or production; after that order is delivered to the customer and for final step feedback from the order fulfillment process is gathered.

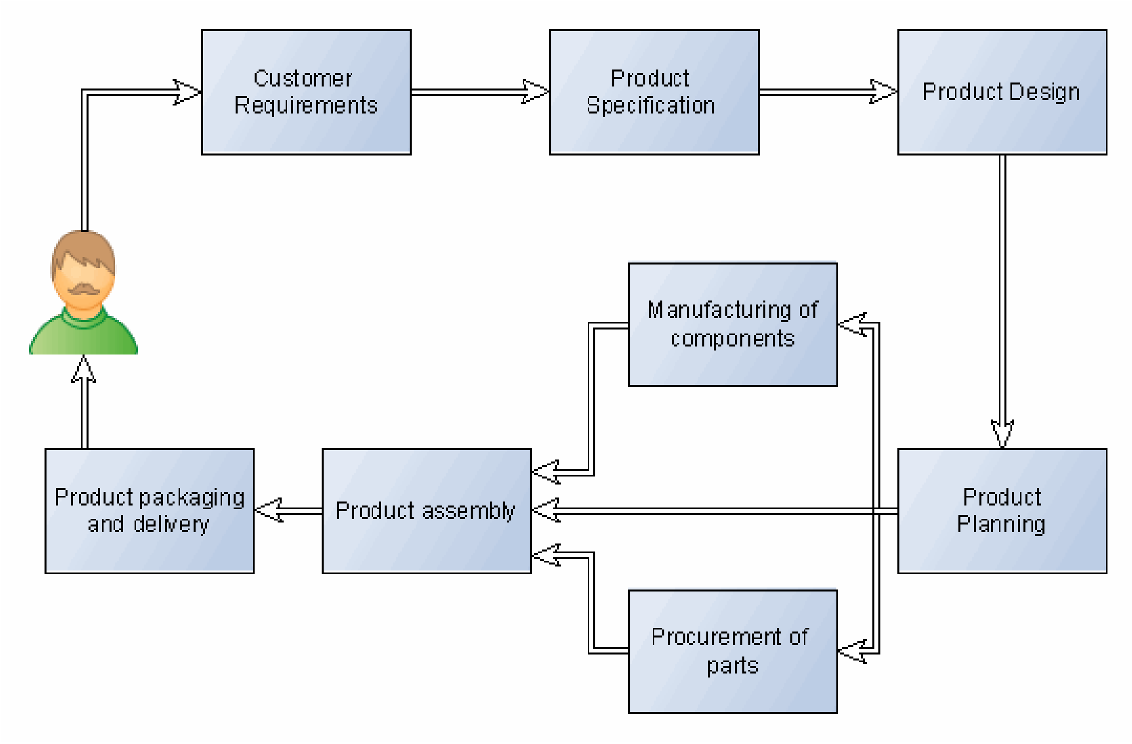

Figure 3. Summary of order fulfillment process. (Source: Author)

2.1.1 Order fulfillment and business strategy

Company can choose between different business strategies that all have impact on the final result of order fulfillment process and order fulfillment time. Well-chosen strategy, which is implemented on excellent way, can lead company to success and can create good competitive advantage.

Strategy is how the mission of a company is accomplished. It unites an organization, provides consistency in decisions, and keeps the organization moving in the right direction. Operations and supply chain management play an important role in corporate strategy. (Russell, R.S. and Taylor III, B.W., 17)

Senior management, with input and participation from different levels of the organization, develops a corporate strategic plan in concurrence with the firm's mission and vision, customer requirements (voice of the customer), and business conditions (voice of the business). The strategic plan focuses on the gap between the firm's vision and its current position. It identifies and prioritizes what needs to be done to close the gap, and it provides direction for formulating strategies in the functional areas of the firm, such as marketing, operations, and finance. It is important that strategy in each of the functional areas be internally consistent as well as consistent with the firm's overall strategy. (Russell, R.S. and Taylor III, B.W., 17)

A customer-driven operations strategy requires a cross-functional effort by all areas of the firm to understand the needs of the firm's external customers and to specify the operating capabilities the firm requires to outperform its competitors. Such a strategy also addresses the needs of internal customers because the overall performance of the firm depends upon the performance of its core and supporting processes, which must be coordinated to provide the overall desirable outcome for the external customer. Competitive priorities are the critical operational dimensions a process or supply chain must possess to satisfy internal or external customers, both now and in the future. Competitive priorities are planned for processes and the supply chain created from them. They must be present to maintain or build market share or to allow other internal processes to be successful. Not all competitive priorities are critical for a given process; management selects those that are most important. Competitive capabilities are the cost, quality, time, and flexibility dimensions that a process or supply chain actually possesses and is able to deliver. When the capability falls short of the priority attached to it, management must find ways to close the gap or else revise the priority. At times, management may emphasize a cluster of competitive priorities together. For example, many companies focus on the competitive priorities of delivery speed and development speed for their processes, a strategy called time-based competition. To implement the strategy, managers carefully define the steps and time needed to deliver a service or produce a product and then critically analyze each step to determine whether they can save time without hurting quality. To link to corporate strategy, management assigns selected competitive priorities to each process (and the supply chains created from them) that are consistent with the needs of external as well as internal customers. Competitive priorities may change over time. For example, consider a high-volume standardized product, such as color ink-jet desktop printers. In the early stages of the ramp-up period when the printers had just entered the mass market, the manufacturing processes required consistent quality, delivery speed, and volume flexibility. In the later stages of the ramp-up when demand was high, the competitive priorities became low-cost operations, consistent quality, and on-time delivery. Competitive priorities must change and evolve over time along with changing business conditions and customer preferences. (Krajewski, L.J and Ritzman, L.P., 31)

	Definition	**Process Considerations**	**Example**
Cost			
1. Low-cost operations	Delivering a service or a product at the lowest possible cost to the satisfaction of external or internal customers of the process or supply chain.	To reduce costs, processes must be designed and operated to make them efficient using rigorous process analysis that addresses workforce, methods, scrap or rework, overhead, and other factors, such as investments in new automated facilities or technologies to lower the cost per unit of the service or product.	**Costco** achieves low costs by designing all processes for efficiency, stacking products on pallets in warehouse-type stores, and negotiating aggressively with their suppliers. Costco can provide low prices to its customers because they have designed operations for low cost.
Quality			
2. Top quality	Delivering an outstanding service or product	To deliver top quality, a service process may require a high level of customer contact, and high levels of helpfulness, courtesy, and availability of servers. It may require superior product features, close tolerances, and greater durability from a manufacturing process.	**Rolex** is known globally for creating precision timepieces.

3. Consistent quality	Producing services or products that meet design specifications on a consistent basis	Processes must be designed and monitored to reduce errors, prevent defects, and achieve similar outcomes over time, regardless of the "level" of quality.	**McDonald's** standardizes work methods, staff training processes, and procurement of raw materials to achieve the same consistent product and process quality from one store to the next.
Time			
4. Delivery speed	Quickly filling a customer's order	Design processes to reduce lead time (elapsed time between the receipt of a customer order and filling it) through keeping backup capacity cushions, storing inventory, and using premier transportation options.	**Dell** engineered its customer relationship, order fulfillment, and supplier relationship processes to create an integrated and an agile supply chain that delivers reliable and inexpensive computers to its customers with short lead times.
5. On-time delivery	Meeting delivery-time promises	Along with processes that reduce lead time, planning processes (forecasting, appointments, order promising, scheduling, and capacity planning) are used to increase percent of customer orders shipped when promised (95% is often a typical goal).	**United Parcel Services (UPS)** uses its expertise in logistics and warehousing processes to deliver a very large volume of shipments on-time across the globe.

6. Development speed	Quickly introducing a new service or a product	Processes aim to achieve cross-functional integration and involvement of critical external suppliers in the service or product development process.	**Zara** is known for its ability to bring fashionable clothing designs from the runway to market quickly.
Flexibility			
7. Customization	Satisfying the unique needs of each customer by changing service or product designs	Processes with a customization strategy typically have low volume, close customer contact, and an ability to reconfigure processes to meet diverse types of customer needs.	**Ritz Carlton** customizes services to individual guest preferences.
8. Variety	Handling a wide assortment of services or products efficiently	Processes supporting variety must be capable of larger volumes than processes supporting customization. Services or products are not necessarily unique to specific customers and may have repetitive demands.	**Amazon.com** uses information technology and streamlined customer relationship and order fulfillment processes to reliably deliver a vast variety of items to its customers.
9. Volume flexibility	Accelerating or decelerating the rate of production of services or products quickly to handle large fluctuations in demand	Processes must be designed for excess capacity and excess inventory to handle demand fluctuations that can vary in cycles from days to months. This priority could also be met with a strategy that adjusts capacity without accumulation of inventory or excess capacity.	**The United States Post Office (USPS)** can have severe demand peak fluctuations at large postal facilities where processes are flexibly designed for receiving, sorting.

Table 1. Definitions, process considerations, and examples of competitive priorities. (Krajewski, L.J. and Ritzman, L.P., 32)

Table 1 indicates different business strategies and key success factors; which company can choose and implement. These strategies affect processes in the company and also competitive advantages. For example concentrating on the delivery speed (quickly filling the customer order); then according to delivery speed strategy is defined that process should be designed to reduce lead time (order fulfillment time) through keeping capacity cushions, storing inventory and using premier delivery options; which will give the time advantage. Dell concentrated on the delivery speed and engineered - customer relationships, order fulfillment and supplier relationship processes to support short order fulfillment time.

As seen before, chosen strategy with its competitive priorities is base for designing order fulfillment process. Order fulfillment time depends from this chosen business strategy. For example if company have chosen low-cost operation strategy, then the order fulfillment process and also result of this process is very different from the company, which has implemented top quality strategy. In the low-cost operation strategy is concentrated on the reducing costs and processes are designed and operated to make them efficient and another hand top quality strategy is concentrating on the delivery of top quality and it may require superior product features, close tolerances and greater durability.

2.1.2 Order fulfillment and manufacturing strategy

Order fulfillment process is also affected by the choice of manufacturing strategy of the company. Main purpose of order fulfillment process is to respond and fulfill to customer orders. Some customers need products; which are customized for their needs; other can use not customized products. Customization affects manufacturing strategies and order fulfillment duration. Following is overview of different manufacturing strategies according to Stevenson:

- **Engineer-to-Order**. With this approach, products are designed and built according to customer specifications. This approach is frequently used for large-scale construction projects, custom homebuilding, home remodeling, and for products made in job shops. The fulfillment time can be relatively lengthy because of the nature of the project, as well as the presence of other jobs ahead of the new one. (Stevenson, 682)

- **Make-to-Order**. With this approach, a standard product design is used, but production of the final product is linked to the final customer's specifications. This approach is used by aircraft manufacturers such as Boeing. Fulfillment time is generally less than with Engineer-to-Order fulfillment, but still fairly long. (Stevenson, 682)
- **Assemble-to-Order**. With this approach, products are assembled to customer specifications from a stock of standard and modular components. Computer manufacturers such as Dell operate using this approach. Fulfillment times are fairly short, often a week or less. (Stevenson, 682)
- **Make-to-Stock**. With this approach, production is based on a forecast, and products are sold to the customer from finished goods stock. This approach is used in department stores and supermarkets. The order fulfillment time is immediate. A variation of this is e-commerce; although goods have already been produced, there is a lag in fulfillment to allow for shipping. (Stevenson, 682)

These approaches have different order fulfillment process and durations. Depending on the company's customers; promises and provided values to the customer, company should choose the suitable strategy for using. Also, some products limit the number of available approaches, for example home remodeling can't use make-to-stock approach. Companies can choose and implement different approaches and it has effect on the order fulfillment process time. Make to stock approach can have shorter order fulfillment times than engineer to order, but also make to stock strategy means that company has more inventories and it can be devastating to the cash flow of the company. Company should know its values and promise to the customer according to those values.

2.1.3 Order fulfillment and value chain

Companies; which want to achieve competitive advantage by delivering greater value to customers, and then managers need to understand which activities are especially important in value creating process and which activities are less important. Good way to analyze and understand is using value chain concept.

The value chain describes the categories of activities within and around an organization, which together create a product or service. The concept was developed in relation to competitive strategy by Michael Porter.

Primary activities are directly concerned with the creation or delivery of a product or service. For example, for a manufacturing business:

● **Inbound logistics** are activities concerned with receiving; storing and distributing inputs to the product or service including materials handling, stock control, transport, etc. (Johnson, G., Scholes, K., and Whittington, R., 110)

● **Operations** transform these inputs into the final product or service: machining, packaging, assembly, testing, etc. (Johnson, G., Scholes, K., and Whittington, R., 110)

● **Outbound logistics** collect, store and distribute the product to customers, for example warehousing, materials handling, distribution, etc. (Johnson, G., Scholes, K., and Whittington, R., 110)

● **Marketing and sales** provide the means whereby consumers/users are made aware of the product or service and are able to purchase it. This includes sales administration, advertising and selling. (Johnson, G., Scholes, K., and Whittington, R., 110)

● **Service** includes those activities that enhance or maintain the value of a product or service, such as installation, repair, training and spares. (Johnson, G., Scholes, K., and Whittington, R., 110)

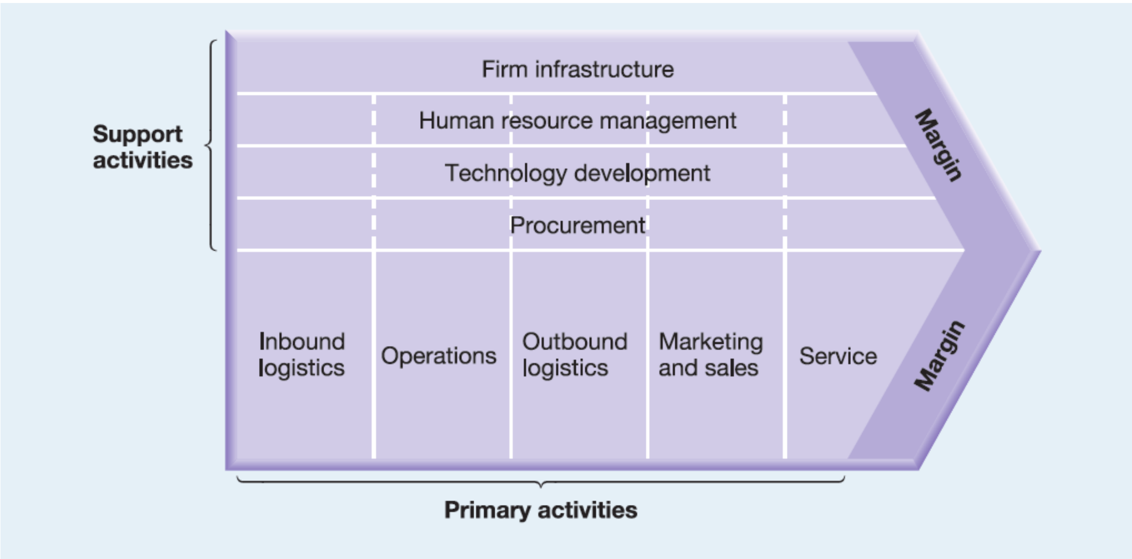

Figure 4. The value chain within a organization. (Johnson, G., Scholes, K., and Whittington, R., 110)

Each of these groups of primary activities is linked to support activities.
Support activities help to improve the effectiveness or efficiency of primary activities:

● **Procurement**. The processes that occur in many parts of the organization for acquiring the various resource inputs to the primary activities. (Johnson, G., Scholes, K., and Whittington, R., 111)

● **Technology development**. All value activities have a 'technology', even if it is just know-how. Technologies may be concerned directly with a product (for example, R&D, product design) or with processes (for example, process development) or with a particular resource (for example, raw materials improvements). (Johnson, G., Scholes, K., and Whittington, R., 111)

● **Human resource management**. This transcends all primary activities. It is concerned with those activities involved in recruiting, managing, training, developing and rewarding people within the organization. (Johnson, G., Scholes, K., and Whittington, R., 111)

● **Infrastructure**. The formal systems of planning, finance, quality control, information management, and the structures and routines that are part of an organization's culture.
The value chain can help with the analysis of the strategic position of an organization in two different ways. (Johnson, G., Scholes, K., and Whittington, R., 111)

Order fulfillment process covers the entire value chain and interacts with supporting activities at the value chain. The end result of the order fulfillment process needs good interaction between different departments and smooth flow of materials and information. Order fulfillment process can point out different kind of problems in value chain. Studying the order fulfillment process can lead to increase of the throughput and also productivity.

2.1.4 Order fulfillment time

As described before order fulfillment process is one of the core processes of the company. To understand and monitor order fulfillment process at the manufacturing company is important to measure duration of the order fulfillment by author's opinion. Order fulfillment time and also product quality are two main characteristics, which customer can feel and are important for achieving customer satisfaction. In this thesis is concentrated on the time. Also using time more for value adding activities will increase the productivity. It is important to understand order fulfillment time. To understand, which time components are in the order fulfillment time estimation is needed overview of different sources and authors; who define order fulfillment time.

Order fulfillment time is defined by the different sources and authors as following:

- Order fulfillment - Creating, preparation, and delivery of the order to the customer. (Pande, P.S.; Neuman, R.P. and Cavanagh, R.R., 160)

  Equation for order fulfillment time can be written as,

  $T_{OFP} = time_{creating} + time_{preparation} + time_{delivery}$.

  In which:

  $time_{creating}$ - time elapsed during the creation of the order

  $time_{preparation}$ – time elapsed during the preparation of the order

  $time_{delivery}$ – time elapsed during the delivery of the order to customer

- Order fulfillment lead time – number of days from order receipt to customer delivery. (Russell, R.S. and Taylor III, B.W., 443)

- Order fulfillment is in the most general sense the complete process from point of sales inquiry to delivery of a product to the customer. In its broadest definition, the possible steps in the process are: sales order, order configuration, order confirmation, order handling, order processing, delivery and settlement. (Keely L. Croxton, 28-30)

  Equation for order fulfillment time can be written as,

  $T_{OFP} = time_{sales\ order} + time_{order\ configuration} + time_{order\ handling} + time_{order\ processing} + time_{delivery} + time_{settlement}$.

  In which:

time $_{\text{sales order}}$ – time elapsed during the creation and confirming the sales order

time $_{\text{order configuration}}$ – time elapsed during the sales order configuration

time $_{\text{order handling}}$ – time elapsed during the order handling (example: invoices, packing slips, etc.)

time $_{\text{order processing}}$ – time elapsed during the order processing

time $_{\text{delivery}}$ – time elapsed during the delivery the order to the customer

time $_{\text{settlement}}$ – time elapsed during the final settlement of the customer order

-Order fulfillment is elapsed time from confirming customer order until delivery to customer. Order fulfillment time consist of production preparation time, production cycle time and product delivery time. (Uuenduslik tootmine,78)

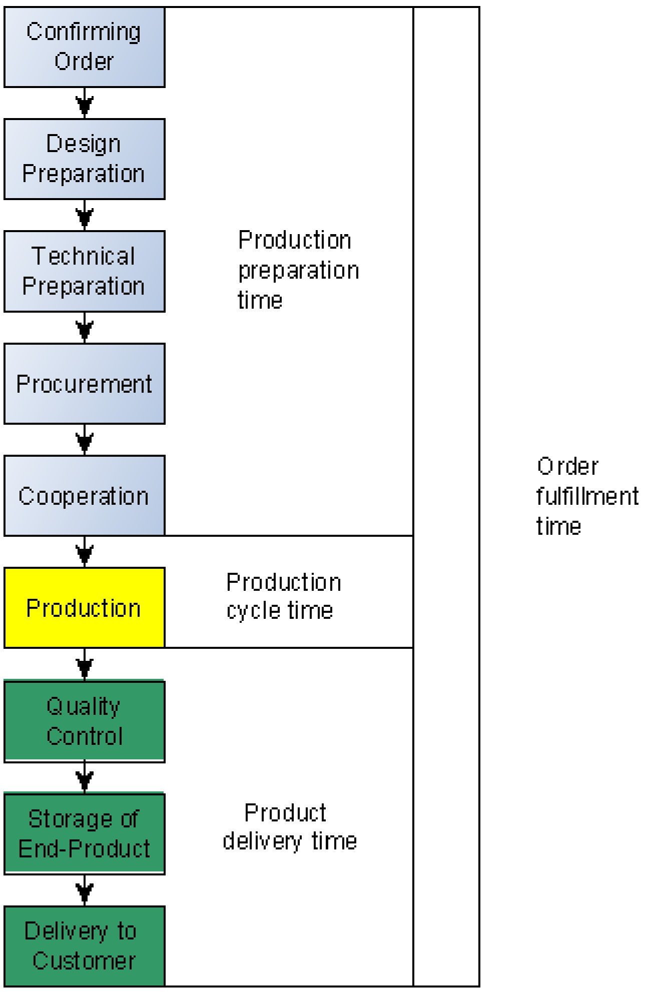

Figure 5. Formation of order fulfilment cycle time. (Uuenduslik tootmine, 79)

Production preparation time consist of time elapsed during: confirming the order, design preparation of the order, technical preparation of the order, procurement of component of the order, needed cooperation between the departments and companies to fulfill the order.

Production cycle time consist of time elapsed processing the order at manufacturing.

Product delivery time consists of time elapsed during: quality control of the finished goods of order, storage of finished goods of order and order delivery to customer as agreed.

Order fulfillment time is defined by various authors in the different level of the details. Generally the idea and the meaning of the order fulfillment time is same for various authors, but the different approaches differ from each other only by level of the details.

In this thesis is used the meaning of order fulfillment time as described in the Figure 4. There are three major group of time components, which add up as order fulfillment time. First, there is production preparation time. Second, there is production cycle time and third there is product delivery time. These three time components add up as order fulfillment time. These three time components cover all value chain. In this thesis to model the time estimation model is deeper investigated the production cycle time component. To understand the production cycle time is needed to investigate throughput time.

2.2 Throughput

Order fulfillment time is general time, to find out the value adding time and activities is needed more detailed view. One of these metrics in the manufacturing area is throughput and throughput time. By concentrating and finding deeper understanding about production process and components of this process throughput is next phase to investigate. In the Figure 4 is throughput measured at the production stage.

Manufacturing processes are different and materials are handled in different ways and stages in the manufacturing process. According to Molloy, Warman and Tiley; common activities; which are involved in manufacturing:

-**Material cutting:**

- Turning:
- Milling;
- Drilling;
- Boring;
- Grinding;
- Broaching;
- Planing;
- Electrochemical machining (ECM)

-**Material Forming:**

- Bending;
- Forging;
- Hot pressing;
- Sintering;
- Punching;
- Spinning;
- Extrusion;
- Vacuum forming

-**Casting:**

- Sand;
- Pressure die;
- Injection molding;
- Lost wax;

- Gravity die;
- Centrifugal

-**Fabrication:**

- Welding adhesives brazing fixing:
  - N.C. systems;
  - Manual;
  - Robotic

-**Treatments:**

- Hardening;
- Cleaning;
- Material deposition:
  - Spraying;
  - Plating

-**Assembly:**

- Manual;
- Robotic;
- Fixings;
- Machine;
- Adhesives;
- Solders

-**Test and Measurement**

(Molloy, O., Warman, E.A. and Tilley, S., 69)

This list is example of activities; which define the throughput of the manufacturing process. Not all companies use all these activities. In general throughput of the manufacturing process is defined by the value adding activities in each stages, also level of productivity increasing depends on the amount time wasted on the non-value adding activities.

It is important to monitor and managed throughput, also understand the components, which add up as throughput time.

Reducing the throughput time has many benefits, including lower inventory, reduced costs, improved product quality (process problems can be found more quickly), faster response to customer orders, and increased flexibility. In addition, a shorter throughput time means that the first batch of finished goods will reach the customers sooner, which helps reduce the time-to-market. Much effort is spent to reduce throughput time by improving manufacturing planning and control systems and developing more sophisticated scheduling procedures, and these efforts have shown success. (Herrmann, W.J. and Chincholkar, M.M., 417)

Throughput is next level on details for finding the root causes of non-value added time and also key to understand the possibilities to increase the productivity of the company. Time measurement of the throughput is easy to implement and good metrics to follow from the management of the company.

2.2.1 Throughput time

To manage the production throughput time measuring is important. To understand, the meaning of the throughput time is important to investigate the definitions of throughput time by various authors and sources.

Throughput time describes production and is defined by various authors and sources as following:

The throughput time (sometimes called the flow time) is the interval that elapses as the manufacturing system performs all of the operations necessary to complete a work order. This throughput time has many components, including move, queue, setup, and processing times. (Herrmann, W.J. and Chincholkar, M.M., 417)

Equation for throughput time can be written as,

T_{TP} = time $_{move}$ + time $_{queue}$ + time $_{setup}$ + time $_{processing}$.

time $_{move}$ – time; which is needed to move product in the production process

time $_{queue}$ – time; which is accumulated during the waiting between workstation

time $_{setup}$ – time; which is needed to setup machinery for certain type product production

time $_{processing}$ – time; which is needed for processing product

Job Flow Time - The amount of time a job spends in the service or manufacturing system is called job flow time. It is the sum of the waiting time for servers or machines, the process time, including setups; the time spent moving between operations; and delays resulting from machine breakdowns, unavailability of facilitating goods or components, and the like. Job flow time = Time of completion - Time job was available for first processing operation. Note that the starting time is the time the job was available for its first processing operation, not necessarily when the job began its first operation. Job flow time is sometimes referred to as throughput time or time spent in the system, including service. (Krajewski, L.J and Ritzman, L.P., 772)

Equation for throughput time can be written as,

$T_{TP} = time_{waiting\ for\ machines} + time_{process} + time_{setup} + time_{moving} + time_{delays}$

$time_{waiting\ for\ machines}$ – time; which is accumulated during the waiting to machines process previous activity

$time_{process}$ – time; which is needed for processing product

$time_{setup}$ – time; which is needed to setup machinery for certain type product production

$time_{moving}$ – time; which is needed for moving product

$time_{delays}$ – time; which is accumulated during the delays (extraordinary maintenance, breakdowns etc.)

Throughput time – the time for a unit to move through a process. ((Slack, N., Chambers, S. and Johnston, R., 106)

Throughput time is next level in details to investigate the time usage and to point out value adding time component. Slack, Chambers and Johnston is using very general view for throughput time definition. Other sources have three components which are common – time for processing, time for setup, time for moving; then one source is using more general approach – time in queue; but Krajewski and Ritzaman have divided this time component into two components – time for waiting for machines and time for delays. In this thesis is used the Krajevski and Ritzman approach, which defines as following –

$T_{TP} = time_{waiting\ for\ machines} + time_{process} + time_{setup} + time_{moving} + time_{delays}$

There are different components on time estimation and to understand better the interaction between various time components is needed also next level in details for the time estimation.

To explain throughput time following figure is constructed.

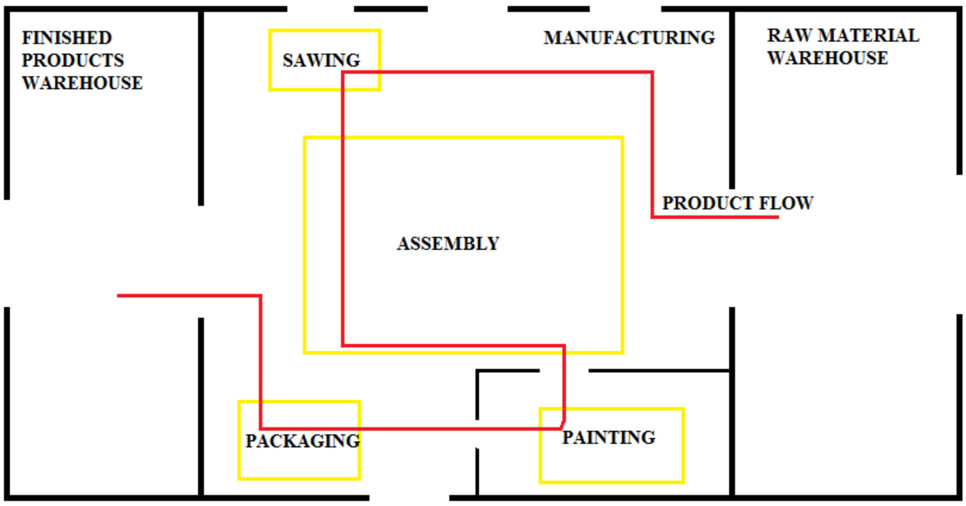

Figure 6. Example of the manufacturing flow with activities. (Source: Author)

In the Figure 6 is example schema of the manufacturing layout with manufacturing activities and workplaces. From the raw materials warehouse are taken materials, which are converted at the manufacturing area to the finished products and then delivered to the finished goods warehouse. Products have to go through the sawing phase; then assembly phase; then painting phase and finally packaging. Throughput time of this manufacturing process is calculated as sum of following time components:

1. time $_{\text{waiting for machines}}$ = waiting time at the sawing unit + waiting time at the assembly unit + waiting time at the painting unit + waiting time at the packaging unit.
2. time $_{\text{process}}$ = processing time at the sawing unit + processing time at the assembly unit + processing time at the painting unit + processing time at the packaging unit.
3. time $_{\text{moving}}$ = time, moving to the sawing unit + time, moving to the assembly unit + time, moving to the painting unit + time, moving to the packaging unit.
4. time $_{\text{delays}}$ = delay time at the sawing unit + delay time at the assembly unit + delay time at the painting unit + delay time at the packaging unit.

2.3 Cycle time

Indication of general time usage is given by the order fulfillment time; the throughput time gives more detailed view of time consumption on the manufacturing process, but to understand the root cause is needed indication at the workplace level. Cycle time can give the indication about time consumption at the workplace level. Cycle time is the next important and useful performance measure. Cycle time can be divided into two:

-A single station cycle time;

-A cycle time for line.

Which kind of metrics use – line or station is depending on the manufacturing; but for starting is needed line cycle time and after that is important to understand the station cycle time.

Reduced or improved cycle time can increase customer satisfaction and give competitive edge. Agile companies can implement new product faster and have better time-to-market ratio, also they have ability to change and meet changing demand. Fast cycle times, also give cost advantage, because these companies have effective processes and low inventory.

Some advantages of short cycle time are:

1. Company can handle more orders, than competitor and have more opportunities to fulfill customer requirements.
2. Long cycle times increase work-in-progress inventory, which increases the financial and operational risks and challenges.
3. Long cycle time can decrease the product quality (products get contaminated; broken, etc.)

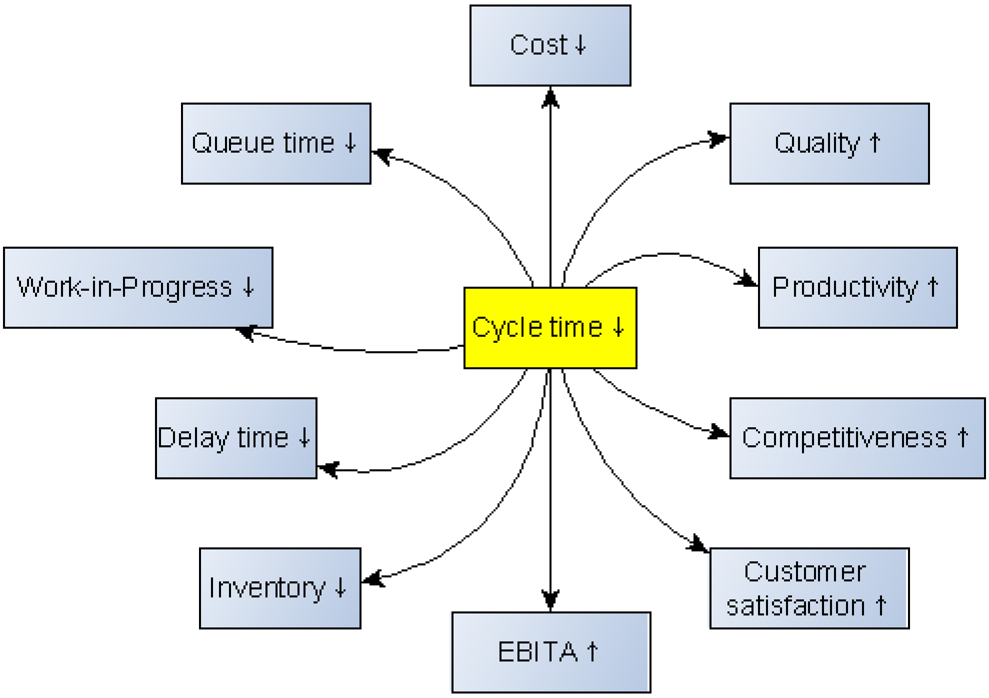

Figure 7. Cycle time reduction relationship with other key indicators. (Source: Author)

At the Figure 7, are illustrated different relationships between cycle time and other key indicators used usually for the management of company. Cycle time have impact on various key indicators at the company. Reduced cycle time have increasing effect on competitiveness (company can achieve with same amount input more output than previously), productivity, quality, earnings before interest, taxes and amortization (EBITA) (with improved cycle time the productivity and quality improves, which also increase earnings) and customer satisfaction (improved cycle time leads to shorter delivery times, which impact customers satisfaction). Also reducing cycle time have decreasing effect on inventory level (no need to hold so much for safety level), delays (improved cycle time shortens the delivery times), work in progress inventory, queue time and that overall reduces the cost of the product.

Cycle time is already in detailed view and it can indicate the value adding time and non-value adding time usage at the production. Reducing cycle time can affect positively company’s results.

2.3.1 Cycle time definition

To understand, the meaning of the cycle time is important to investigate the definitions of cycle time by various authors and sources.

Definition (Station Cycle Time): The average cycle time at a station is made up of the following components:

1. Move time
2. Queue time
3. Setup time
4. Process time
5. Wait to batch time
6. Wait in batch time
7. Wait to match time

(Hopp, W.J and Spearman, M.L., 327)

Move time is the time jobs spend being moved from the previous workstation.

Queue time is the time jobs spend waiting for processing at the station or to be moved to the next station. **Setup time** is the time a job spends waiting for the station to be set up. **Process time** is the time jobs are actually being worked on at the station. **Wait to batch time** is the time jobs spend waiting to form a batch for either (simultaneous) processing of moving, and **wait in batch time** is the average time a part spends in a (process) batch waiting its turn on a machine. Finally, **wait to match time** occurs at assembly station when components wait for their mates to allow the assembly operation to occur. (Hopp, W.J and Spearman, M.L., 327)

Equation for cycle time can be written as,

$T_{CT} = time_{move} + time_{queue} + time_{setup} + time_{process} + time_{wait}$

In which:

$time_{move}$ – time jobs spend being moved from the previous workstation

$time_{queue}$ – time jobs spend waiting for processing at the station

$time_{setup}$ – time job spend waiting for the station to be set up

$time_{process}$ – time jobs are actually being worked on at the station

$time_{wait}$ – sum of time jobs spend waiting to form a batch, time part spends in a batch waiting its turn on a machine and time at assembly station when components wait for mates to allow the assembly operation to occur.

Definition (Line Cycle Time): The average cycle time in a line is equal to the sum of the cycle times at the individual stations less any time that overlaps two or more stations. ((Hopp, W.J and Spearman, M.L., 329)

Cycle time – the average time between units to output emerging from a process. Cycle time for the layout = time available / number to be processed. ((Slack, N., Chambers, S. and Johnston, R., 209)

The following kinds of time make up production cycle time:

1. Setup time – the time that a part spends waiting for a resource to be set up to work on this same part.
2. Processing time – the time that the part is being processed.
3. Queue time – the time that a part waits for a resource while the resource is busy with something else.
4. Wait time – the time that a part waits not for a resource but for another part so that they can be assembled together.
5. Idle time – the unused time; that is the cycle time less the sum of the setup time, processing time, queue time, and wait time.

(Chase, R.B., Aquilano, N.J. and Jacobs, F.R., 672)

Equation for cycle time can be written as,

$T_{CT} = time_{setup} + time_{process} + time_{queue} + time_{wait} + time_{idle}$.

The cycle time, which is also called variously average cycle time, flow time, throughput time and sojourn time, of a given routing is the average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing. ((Hopp, W.J and Spearman, M.L., 230)

Cycle time is important variable in the design of product layouts and has influence on the design decisions.

There are lots of definitions on the cycle time; it is very well-defined time component by various authors. In general it consists of the following time components:

time for moving; time for queue; time for setup; time for processing and time for waiting. In this thesis cycle time is defined as following.

$T_{CT} = time_{move} + time_{queue} + time_{setup} + time_{process} + time_{wait}$.

At the Figure 6 is illustrated example of manufacturing process flow with workstations to explain the process flow with workstations and to explain cycle time formulation. Cycle time is formulated at the workstation. For example cycle time at the assembly workstation is sum of:

- moving time to the assembly workstation and at the assembly workstation;
- queue time at the assembly workstation:
- setup time at the assembly workstation to before product can be processed;
- processing time at the assembly workstation;
- waiting time at the assembly workstation.

2.4 Productivity

Productivity is a measure of the efficiency of production or company or process, depending from the needed level of details. Usually productivity can be expressed as ratio of output to inputs in the production process.

Productivity = Output / Input = Product (services, result) / Resources (costs) (Eedo, K., 5)

Also productivity has connection with efficiency and savings.

Productivity = Results / Inputs = Fulfillment of goals / Consumed resources = Efficiency / Savings (Eedo, K., 6)

Decrease of the productivity causes (activates) following negative chain reaction: increase of resources for the produce product unit > increase of output prices > decrease of competitiveness > difficulties on sales and marketing of product > decrease of profit and profitability > negative impact on the labor, capital, etc. (Eedo, K., 6)

There are many different productivity measures. The choice between them depends on the purpose of productivity measurement and, in many instances, on the availability of data. Broadly, productivity measures can be classified as single factor productivity measures (relating a measure of output to a single measure of input) or multifactor productivity measures (relating a measure of output to a bundle of inputs). Another distinction, of particular relevance at the industry or firm level is between productivity measures that relate some measure of gross output to one or several inputs and those which use a value-added concept to capture movements of output.
(OECD,12).

Type of output measure	Type of input measure			
	Labour	***Capital***	***Capital and labour***	***Capital, labour and intermediate inputs (energy, materials, services)***
Gross output	Labour productivity (based on gross output)	Capital productivity (based on gross output)	Capital-labour MFP (based on gross output)	KLEMS multifactor productivity
Value added	Labour productivity (based on value added)	Capital productivity (based on value added)	Capital-labour MFP (based on value added)	-
	Single factor productivity measures		***Multifactor productivity (MFP) measures***	

Figure 8. Overview of main productivity measures. (OECD, 13)

These are measures of labour and capital productivity, and multifactor productivity measures (MFP), either in the form of capital-labour MFP, based on a value-added concept of output, or in the form of capital-labour-energy-materials MFP (KLEMS), based on a concept of gross output. Among those measures, value-added based labour productivity is the single most frequently computed productivity statistic, followed by capital-labour MFP and KLEMS MFP. (OECD, 13)

Also commonly is used term – total productivity. This means that when all outputs are added together and then divided with the sum of all inputs.

Measurement of productivity is important for company and also to the state. It gives indications to the company – about added value to the process and also to find ways improve productivity. The measurement of industries productivity gives feedback about competitiveness and vitality of this industry. Low productivity does not support development and sustainability of the industry.

2.4.1 Labor productivity

Labor productivity is one of mostly used economic indicators by the data of OECD. Labor productivity is good tool to measure competitiveness and growth of the economy. Also it is good to measure possibilities to improve according to the other countries; industries and companies. Labor productivity can be measured by the quantity of the products finished by the employee during some time period.

Labor productivity, based on gross output can be calculated as:
Quantity index of gross output / Quantity index of labor input (OECD, 14)

Shows the time profile of how productively labor is used to generate gross output. Labor productivity changes reflect the joint influence of changes in capital, intermediate inputs, as well as technical, organizational and efficiency change within and between firms, the influence of economies of scale, varying degrees of capacity utilization and measurement errors. Labor productivity only partially reflects the productivity of labor in terms of the personal capacities of workers or the intensity of their effort. (OECD, 14)

Labor productivity, based on value added can be calculated as:
Quantity index of value added / Quantity index of labor input (OECD, 15)

Shows the time profile of how productively labour is used to generate value added. Labour productivity changes reflect the joint influence of changes in capital, as well as technical, organisational and efficiency change within and between firms, the influence of economies of scale, varying degrees of capacity utilisation and measurement errors. Labour productivity only partially reflects the productivity of labour in terms of the personal capacities of workers or the intensity of their effort. (OECD, 15)

2.4.1.1 Overall labor effectiveness

Overall Labor Effectiveness (OLE) is a metrics that measures the utilization, performance, and quality of the workforce and its impact on productivity.
Similar to Overall Equipment Effectiveness (OEE), OLE measures availability, performance, and quality. A manufacturer can improve shop-floor productivity, and therefore the level of profitability, by understanding the interdependency and trade-off of these factors and managing them in real time.

- **Availability** — There are many factors that influence workforce availability and, therefore, the potential output of equipment and the plant. OLE goes beyond simple coverage to help manufacturers ensure they have the person with the right skills available at the right time. OLE also accounts for labor utilization. Understanding where downtime losses are coming from and the impact they have on production can reveal root causes, which can include machine downtime, material delays or absenteeism that delays a line startup. (Reliableplant webpage)
- **Performance** — When employees cannot perform their work within standard times, performance suffers. Effective training can increase performance by improving the skills that directly impact the quality of output. A skilled operator knows how to measure work, understands the impacts of variability, and knows to stop production for corrective actions when quality falls below specified limits. Accurately measuring this metric can pinpoint performance improvement opportunities down to the individual level. (Reliableplant webpage)
- **Quality** — A number of drivers contribute to quality, but too often the effort to improve quality can result in a lowering of labor performance. When making the correlation between the workforce and quality it is important to take certain factors into consideration including the training and skills of employees, if they have access to the right tools to follow procedures, and their understanding of how their roles drive and impact quality.(Reliableplant webpage)

2.4.1.2 Worker time usage

To understand and measure the labor productivity is important to measure time usage of the worker in the manufacturing process. There are few approaches, which handle the worker time usage. This field is not so thoroughly investigated. One of the good approaches is described at the Mehaanikainseneri käsiraamat edited by Kulu.

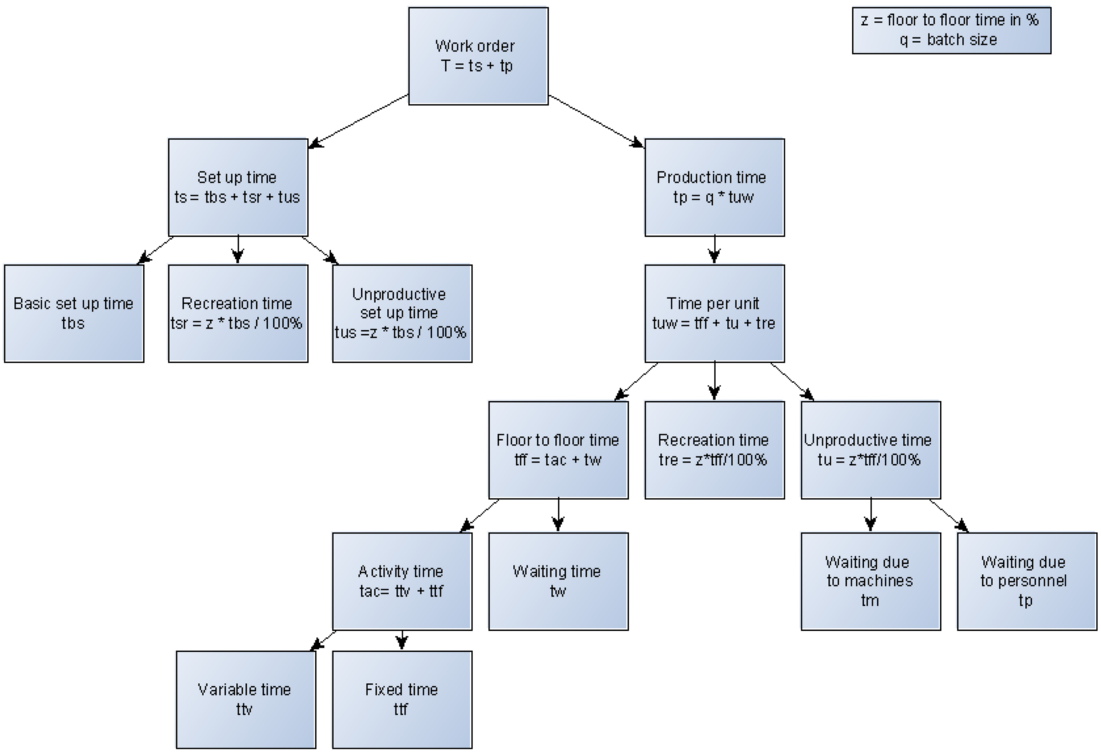

Figure 9. Worker time usage (Mehaanikainseneri käsiraamat, 322)

It all starts with work order, which consist of the two time components: setup time and production time. Setup time consist of basic setup time; recreation time and unproductive setup time. Production time is calculated from time per unit using batch size. Time per unit consist of floor to floor time; recreation time and unproductive time. Floor to floor time consist of activity time and waiting time. Activity time consist of variable time and fixed time. Unproductive time consists of waiting due to machines and waiting due to personnel.

To increase the productivity is important to monitor the shares of the non-value adding times. Non-value adding times can be summed from unproductive setup time; floor to floor waiting time; waiting time due to machines and waiting time due to personnel. The share of this kind of non-value adding time is important metric and in case the share of non-value adding time is over 50% then, there is possibility to increase the productivity by finding out the root causes of the non-value adding time creation.

2.4.2 Productivity of equipment

Productivity in production is achieved with cooperation of worker and machines. Investment to the equipment are usually costly and in returns it is important to manage and maintenance of the equipment. The more time equipment is available for using the better result in terms of productivity can be achieved.

2.4.2.1 Overall equipment efficiency

The one part of productivity is also depending from the machines. The best way to monitor is the overall equipment effectiveness.

Overall equipment effectiveness is based on three aspects:

- Availability time – when equipment is available to use;
- Quality – the quality of product the equipment produces;
- Speed – the throughput rate of the equipment.

Overall equipment effectiveness is calculated by multiplying an availability rate by a performance or speed) rate multiplied by a quality rate.

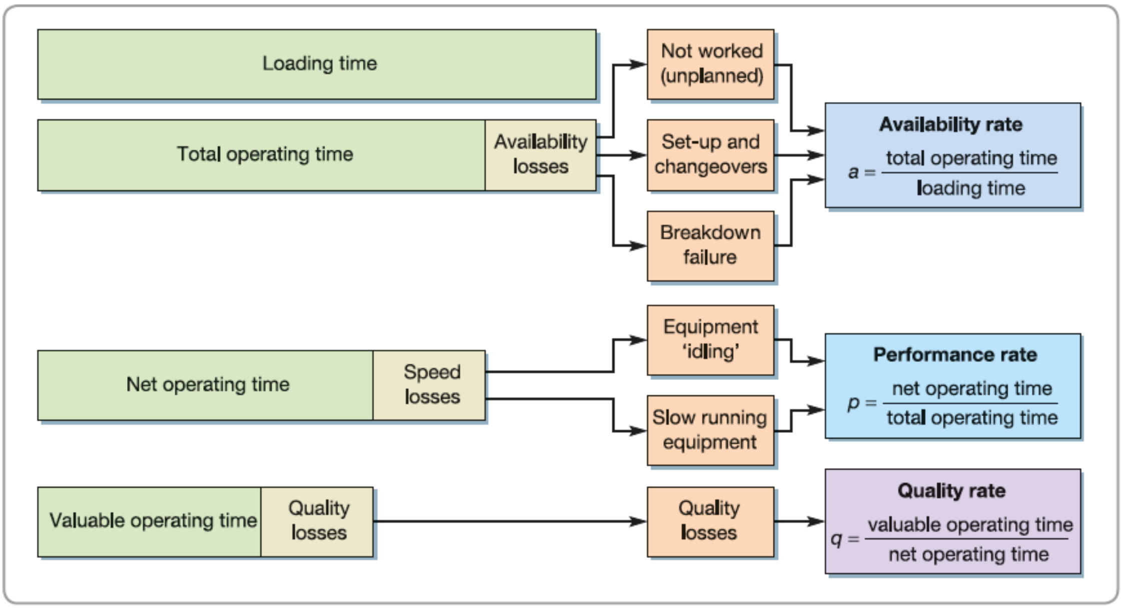

Figure 10. Overall equipment effectiveness. (Slack, N., Brandon-Jones, A. and Johnston, R., 332)

Some of the reduction in available capacity of a piece of equipment (or any process) is caused by time losses such as set-up and changeover losses (when the equipment or process is being prepared for its next activity), and breakdown failures when the machine is being repaired. Some capacity is lost through speed losses such as when equipment is idling (for example, when it is temporarily waiting for work from another process) and when equipment is being run below its optimum work rate. Finally, not everything processed by a piece of equipment will be error free. So some capacity is lost through quality losses. (Slack, N., Brandon-Jones, A. and Johnston, R., 332)

For equipment to operate effectively, it needs to achieve high levels of performance against all three of these dimensions. Viewed in isolation, these individual metrics are important indicators of plant performance, but they do not give a complete picture of the machine's overall effectiveness. This can only be understood by looking at the combined effect of the three measures, calculated by multiplying the three individual metrics together. All these losses to the OEE performance can be expressed in terms of units of time – the design cycle time to produce one good part. So, a reject of one part has an equivalent time loss. In effect, this means that an OEE represents the valuable operating time as a percentage of the design capacity. (Slack, N., Brandon-Jones, A. and Johnston, R., 333)

2.4.2.2 Machine maximum available time

There is also another approach to calculate the machine time and productivity. It is well explained by the Slack, Chambers and Johnston.

Maximum available time							
Valuable operating time	Quality losses	Slow running equipment	Equipment idling	Breakdown failure	Set-up and changeovers	Not worked (unplanned)	Not worked (planned)

Figure 11. Machine maximum available time. (Slack, N., Chambers, S. and Johnston, R., 298)

This figure shows how maximum available time is eroding by the different factors and components. This model takes into account different cases; when available time for machine is lost – maintenance; holidays and other time wastes; which is created on the production process.

2.5 Operational time usage

Kanawaty is using general time model; which can be used to cover labor and also machine time usage model components.

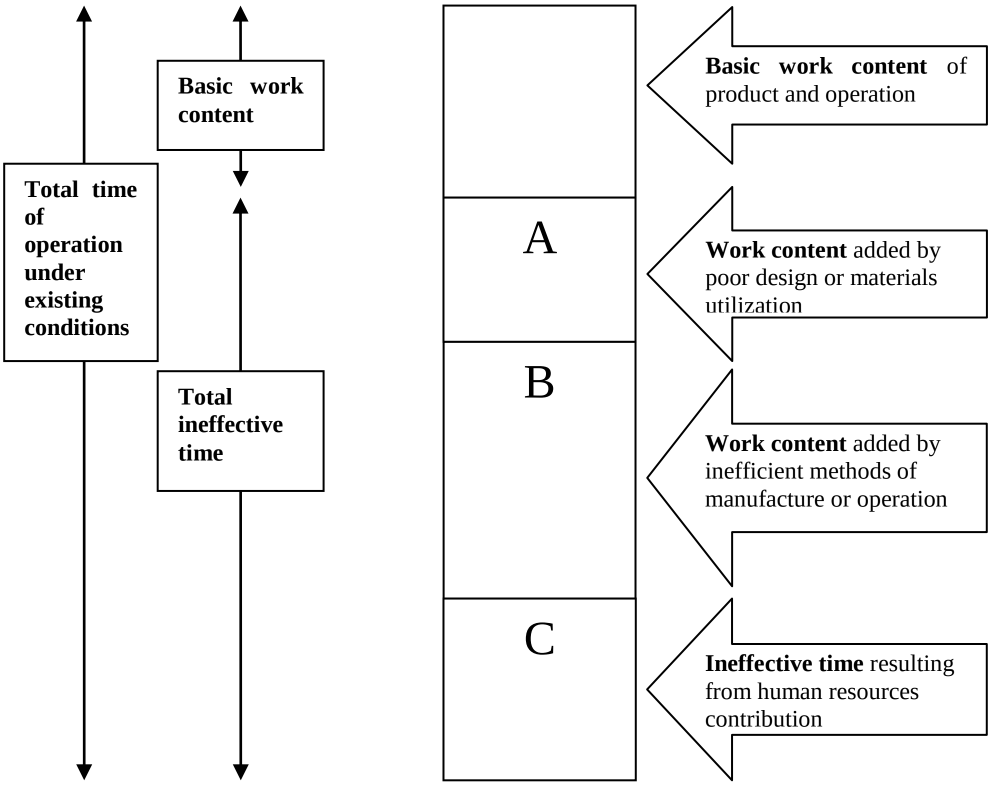

Figure 12. How operational time is made up. (Kanawaty, G., 10)

The basic work content is the time taken to manufacture the product or to perform the operation if the design or specification of the product or service provided were prefect, if the process or method of operation were perfectly carried out, and if there were no loss of working time from any cause whatsoever during the period of the operations (other than legitimate rest pauses permitted to the operative). The basic work content is the irreducible minimum time theoretically required to produce one unit of output. (Kanawaty, G., 10)

The work content is increased by the following:

A: Work content added by poor design or specification of product or its parts, or improper utilization of materials.

A.1. Poor design and frequent design changes

A.2. Waste of materials

A.3. Incorrect quality standards

(Kanawaty, G., 11)

B: Work content added by inefficient methods of manufacture or operations.

B.1. Poor layout and utilization of space

B.2. Inadequate materials handling

B.3. Frequent stoppages as production changes from one product to another

B.4. Ineffective methods of work

B.5. Poor planning of inventory

B.6. Frequent breakdown of machines and equipment

(Kanawaty, G., 12)

C: Work content resulting mainly from the contribution of human resources.

C.1. Absenteeism and lateness

C.2. Poor workmanship

C.3. Accidents and occupational hazards

(Kanawaty, G., 12)

This model of operational time is good to use and covers also time wastes from different stages of value chain. For example poor design, this has huge effect on the productivity, but root cause is hard to find.

2.6 Process efficiency and Equipment effectiveness

Process efficiency and overall equipment effectiveness can are related and it gives feedback about company. Kletti and Shumacher have studied and constructed following chart.

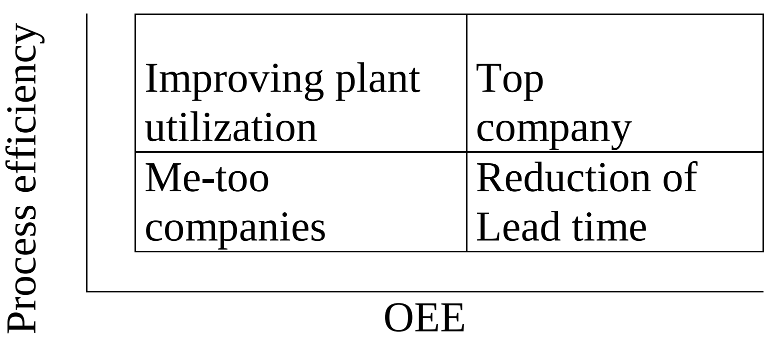

Figure 13. Process efficiency and OEE relationships. (Kletti, J. and Schumacher, 74)

Companies with high process efficiency and overall equipment effectiveness are according to the Kletti and Schumacher Top company of the industry. These companies have used strategies and approaches right and probably are the best companies on the industry. Companies with high process efficiency and low OEE, should improve the plant utilization. Companies with low process efficiency and low OEE, are me-too companies; which do not excel on the industry and are mediocre companies. Companies with low process efficiency and high OEE can improve and reduce the lead time.
If we make simplification and reduce process efficiency to the overall labor efficiency, we can have OLE and OEE relationships, which in authors opinion are correct.

3. Case study

This thesis concentrates on the SME segment, SME is defined differently in various fields of science. In this thesis is used SME definition from the official European Union Journal, which states SME as following:

The category of micro, small and medium-sized enterprises (SMEs) is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million.

Within the SME category, a small enterprise is defined as an enterprise which employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 10 million.

Within the SME category, a microenterprise is defined as an enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million. (Official Journal of the European Union)

The company; which is used at this thesis, is an Estonian company. The staff of the company consists of average 10 people. The company has the characteristics of a small-sized enterprise (SME) as defined by the Official Journal of the European Union. The company is fully owned by an Estonian capital and has no subsidiaries.

The company is specializing in production of material processing equipment and product range consists mainly of conveyor solutions, belt scales and also conveyor components and spares.

The company has assembly plant and its own sales and marketing, engineering and production planning and procurement functions. In the assembly plant at the shop floor is also included quality control and shipping stations. All components for the products are manufactured by subcontractors and only the assembly is done in-house.

3.1 Products information

The company is using make to order strategy for manufacturing. That means – the production and design of the products mostly take place after the customer order. The offered products of the company are for the business customers and can be divided into three:

- Conveyor solutions;
- Weighing and batching systems;
- Components and spare parts.

Additional to the products company also offers additional services to customers – calibration of scales and also project management.

The main product is conveyor solutions to the business customers. The company offers different types of conveyors:

- Belt conveyors – mainly used in mining industry, ports and terminals, food industry and production of building materials;
- Screw conveyors – mainly used for transporting wood chips, cement and agricultural products;
- Roller conveyors – mainly used in various packaging lines;
- Chain conveyors – mainly used in timber industry and areas where a line with multiple loading areas is needed;
- Mobile conveyors – mainly used for the transportation and piling of bulk materials.

Figure 14. Belt conveyor - product of the company.(Source: Picture from company)

Figure 15. Screw conveyor - product of the company.(Source: Picture from company)

Figure 16. Roller conveyor - product of the company. (Source: Picture from company)

The product from conveyor product group will be in focus also the case study as example for the time study. The chosen product used in the case study is - belt conveyor ABC 800/6000.

3.2 Product drawings and Bill of Materials

Order fulfillment process for conveyor solution starts, with sales order. At the stage of product design and development are made drawings and also bill of materials of the conveyor. These drawings first describe concept of the solution and then detailed view of conveyor. These drawings are base for assembly of conveyor and also for procurement of components.

As company is not manufacturing parts of conveyor, their main task is to assembly and sell. Very important part is also bill of materials; which is first used to procurement of components; then as checklist as part of preparation to assembly. Afterwards this information is base for subassemblies and finally to the main body assembly. Drawings and bill of materials also help to make inspection at the quality control stage; they are used as checklist to ensure, that nothing is missing or incorrectly assembled. Following are drawings of the Conveyor ABC 800/6000.

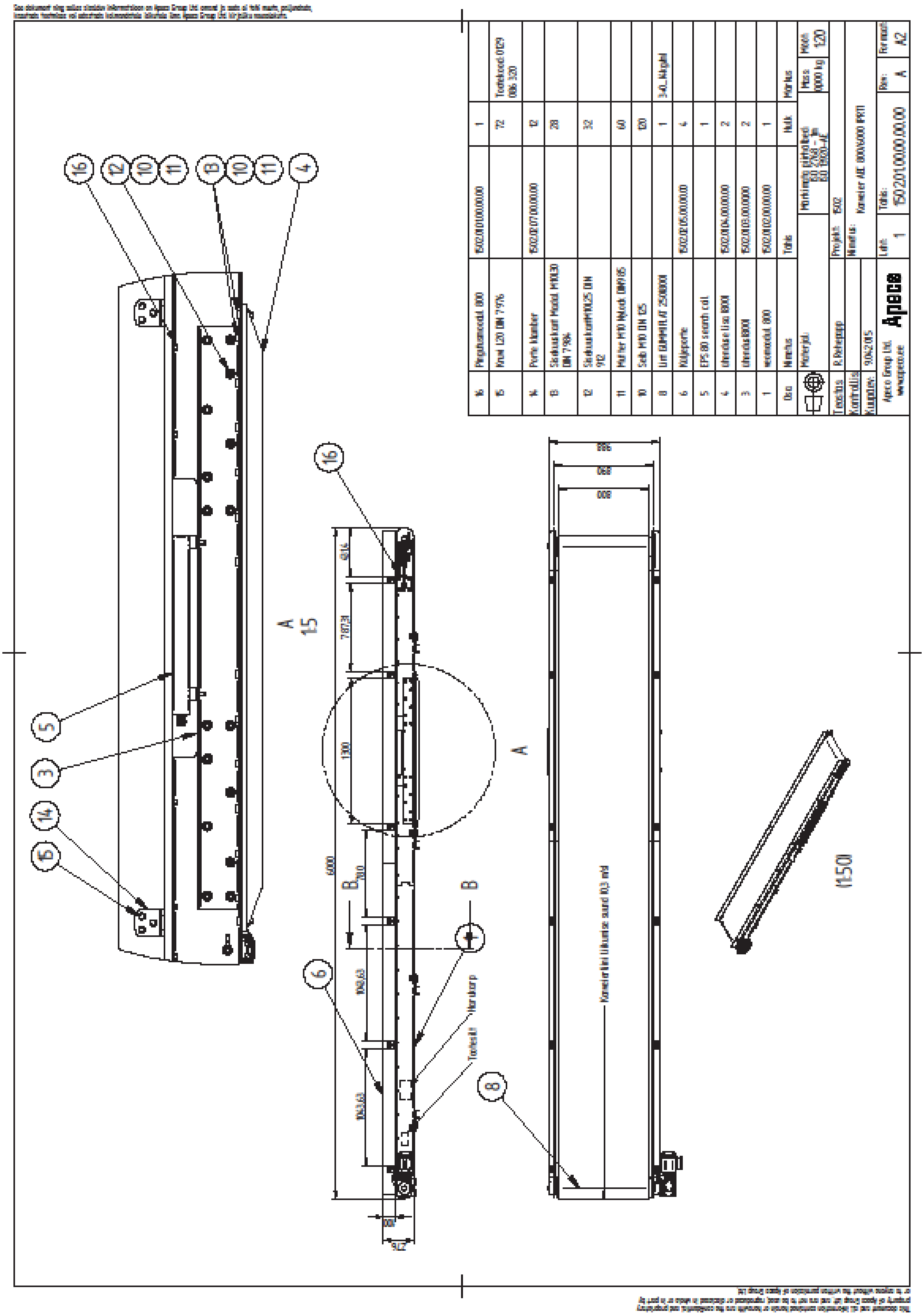

Figure 17. Main drawing of conveyor ABC 800/6000. (Source: Document from company)

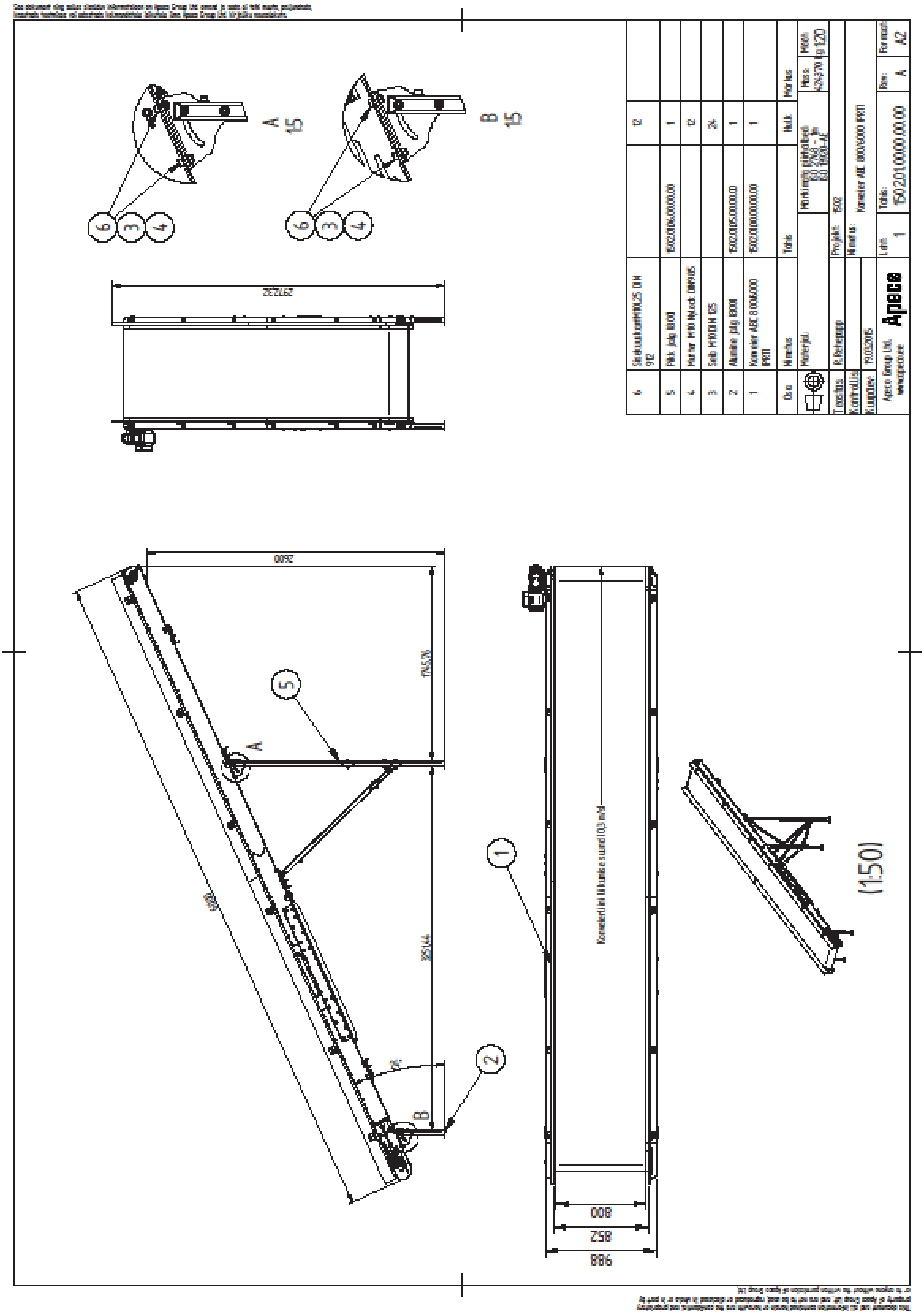

Figure 18. Drawing of the conveyor 800/6000. (Source: Document from company)

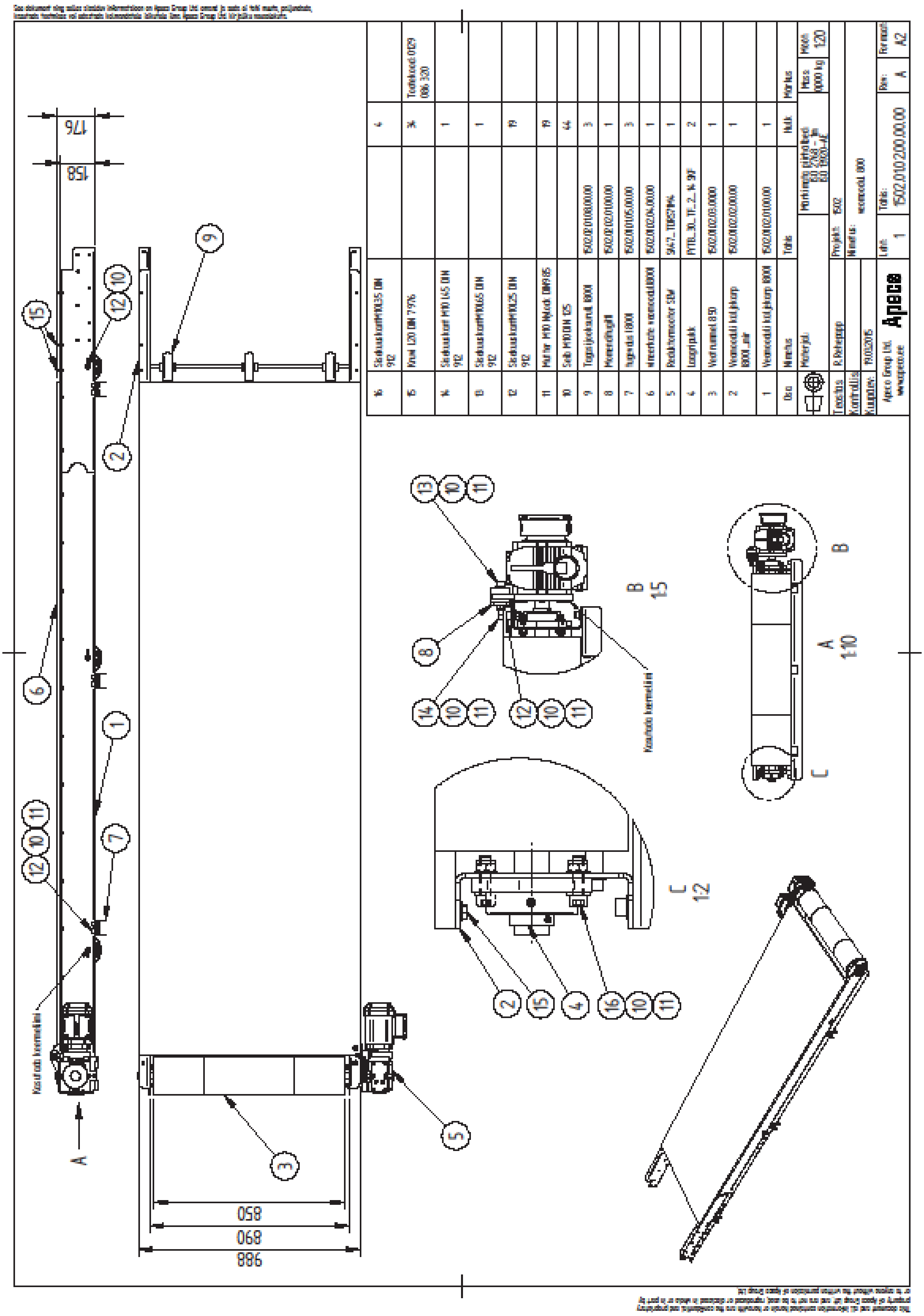

Figure 19. Drawing of the transport module 800. (Source: Document from company)

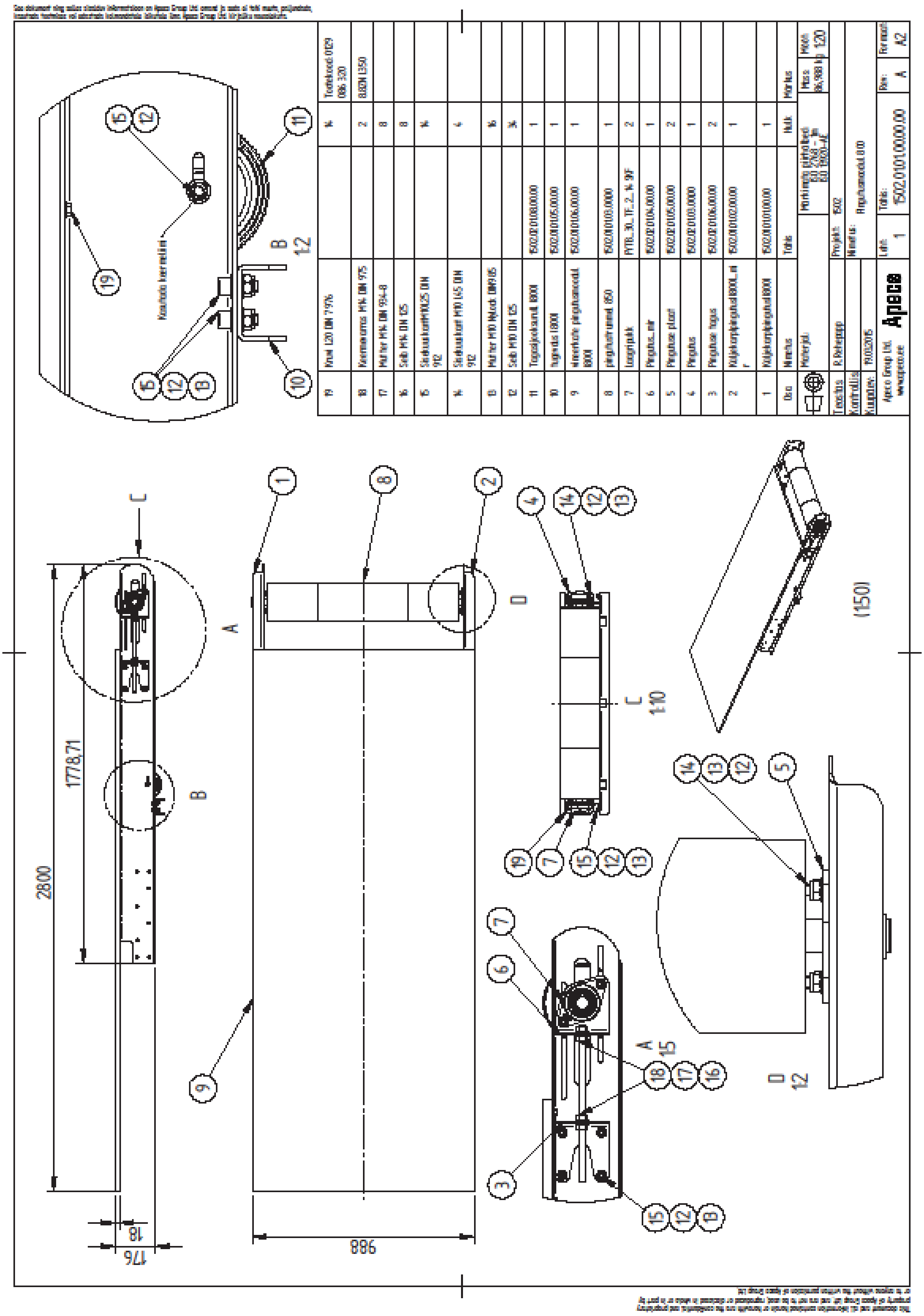

Figure 20. Drawing of the tensioner module 800. (Source: Document from company)

Bill of materials for the conveyor 800/6000 is following:

Summary of Atomic Parts For 1502.asm						
Pos.	**Mark**	**Name**	**Quantity [pcs]**	**Weight (pcs), [kg]**	**Weight total,[kg]**	**Material**
1	1502.01.01.01.00.00	Side box (tensioner)(800)	**1**	12,42	***12,42***	4,00 mm
2	1502.01.01.02.00.00	Side box (tensioner)(800)_mir	**1**	12,42	***12,42***	4,00 mm
3	1502.01.01.05.00.00	Reinforcement (800)	**4**	4,40	***17,62***	4,00 mm
4	1502.01.02.01.01.00	Addition to Side box (800)	**1**	7,14	***7,14***	4,00 mm
5	1502.01.02.01.02.00	Side box (transport)(800)	**1**	20,88	***20,88***	4,00 mm
6	1502.01.02.02.01.00	Addition to Side box (800)_mir	**1**	7,14	***7,14***	4,00 mm
7	1502.01.02.02.02.00	Side box (transport) (800)_mir1	**1**	20,88	***20,88***	4,00 mm
8	1502.01.03.00.00.00	Joint(800)	**2**	7,02	***14,04***	4,00 mm
9	1502.01.04.00.00.00	Addition to Joint (800)	**2**	5,16	***10,33***	4,00 mm
10	1502.01.05.01.00.00	Leg cross beam (800)	**2**	3,61	***7,22***	
11	1502.01.06.01.00.00	Leg pipe short diagonal (800)	**2**	5,43	***10,87***	
12	1502.01.06.02.00.00	Leg pipe long diagonal (800)	**2**	5,63	***11,26***	
13	1502.01.06.03.01.00	Leg pipe longer (800)	**2**	7,88	***15,76***	
14	1502.02.01.01.00.00	Side box (tensioner)	**1**	13,18	***13,18***	4,00 mm
15	1502.02.01.02.00.00	Side box (tensioner)_mir	**1**	13,18	***13,18***	4,00 mm
16	1502.02.01.03.00.00	Tensioner	**2**	0,64	***1,28***	5,00 mm
17	1502.02.01.04.00.00	Tensioner_mir	**2**	0,64	***1,28***	5,00 mm
18	1502.02.01.05.00.00	Tensioner plate	**4**	0,34	***1,34***	5,00 mm
19	1502.02.01.06.00.00	Tensioner rear	**4**	0,63	***2,53***	5,00 mm
20	1502.02.01.09.00.00	Reinforcement (500)	**4**	3,06	***12,25***	4,00 mm
21	1502.02.02.01.00.00	Torque support (1)	**2**	0,24	***0,48***	4,00 mm
22	1502.02.02.02.01.00	Addition to Side box	**1**	7,30	***7,3***	4,00 mm
23	1502.02.02.02.02.00	Side box (transport)	**1**	21,47	***21,47***	4,00 mm
24	1502.02.02.03.01.00	Addition to side box _mir	**1**	7,30	***7,3***	4,00 mm
25	1502.02.02.03.02.00	Side box (transport)_mir2	**1**	21,48	***21,48***	4,00 mm
26	1502.02.03.00.00.00	Joint	**2**	5,92	***11,84***	4,00 mm
27	1502.02.04.00.00.00	Addition to Joint	**2**	4,39	***8,79***	4,00 mm
28	1502.02.06.00.00.00	Metal detector base	**2**	0,45	***0,89***	4,00 mm
29	1502.02.07.00.00.00	Porte clamp	**24**	0,19	***4,53***	4,00 mm
30	1502.02.08.01.00.00	Leg S' contact 1	**8**	0,82	***6,53***	5,00 mm
31	1502.02.08.02.00.00	Leg corner	**8**	0,40	***3,2***	4,00 mm
32	1502.02.08.03.00.00	Leg cross beam (500)	**2**	2,35	***4,7***	
33	1502.02.08.04.01.00	Leg pipe	**4**	1,66	***6,65***	

34	1502.02.08.04.02.00	Wheel fixing sole	**8**	0,25	***2,01***	4,00 mm
35	1502.02.09.01.00.00	Leg pipe short diagonal	**2**	5,85	***11,71***	
36	1502.02.09.02.00.00	Leg pipe long diagonal	**2**	7,94	***15,87***	
37	1502.02.09.03.00.00	Leg S' contact	**16**	0,22	***3,45***	4,00 mm
38	1502.02.09.04.01.00	Leg pipe longer (500)	**2**	9,77	***19,53***	

Table 2. Bill of Material of the Conveyor ABC 800/6000. (Source: Document from company)

These documents are base for assembly, procurement and also quality check. These kinds of documents are made for every product the company manufactures. The quality of these documents is crucial for the success of the product/solution.

3.3 Order fulfillment process flow

Order fulfillment is important process for the company, but using subcontractors the delivery time forecasts and product planning complexity increases. The company has implemented strategy, where it uses subcontractors and avoids investment to different type of tools and machinery. The company concentrates to strengths, which are – excellent technical and engineering know-how and sales and marketing of solutions. At the current phase company is using subcontractors for delivering the components, but final assembly is made by the company itself. It is crucial to offer good quality and for achieving it, company makes assembly of the product in house and also carefully selecting subcontractors for the partnership. The order fulfillment process is important process for the company and cab be illustrated as following:

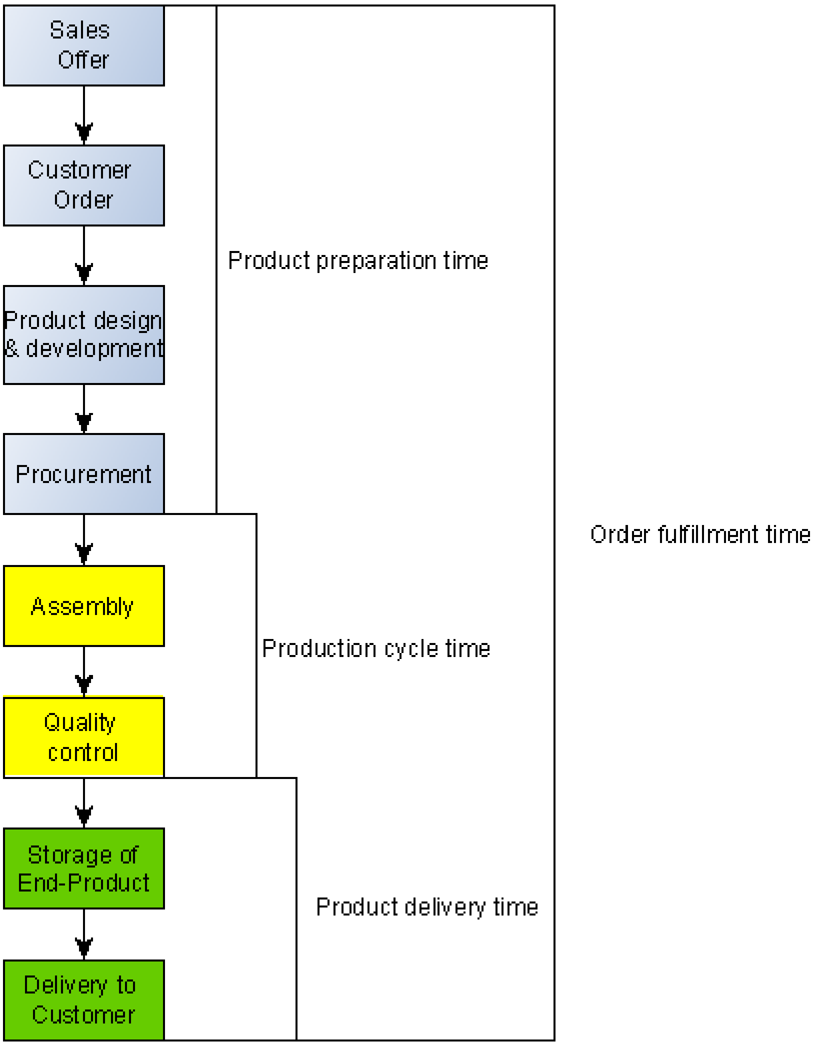

Figure 21. The core order fulfilment process in the company. (Source: Author)

Process flow is initiated with the sending of sales offer. Before sending sales offer have been made interviews and mapped the customer needs and pain. According to the customer requirements is made the sales offer. Sales offer includes cost and time assessment. After receiving sales offer customer decides to accept it or ask for correction. Decision process of customers is long, because it is business to business market and decision process is more complex than in consumer market. After receiving positive decision, then is formally made customer order, with renewed time schedule if needed. Customer order initiates the design of the solution. Engineers will design the solution of if it previously designed, then they review and if needed make corrections. From the product design and development phase is received the solution with drawings and bill of materials. Next phase is procurement, where according to the bill of materials and drawings the components for the solution are ordered from various vendors. Company does not internally manufacture the components. After procurement phase, when all components are gathered on a shelf, the assembly phase begins. Assembly process is described on the next chapter. After final assembly, when product is packed it is then put on the inventory, before delivering to customer.

3.4 Order fulfillment time influencers

Analyzing the order fulfillment process of the company, can be indicated the different areas, which have impact on the lead time at the company. It can be summed up as following:

- Subcontractors. Subcontractors are underperforming in time wise and cause components to arrive late, causing delays in the assembly and delivery to customer. In some cases it ends with penalties from customer for not fulfilling the contract.
- Purchase. It happens that purchased components do not arrive on time. There is possibility to change the suppliers, but some suppliers are hard to change, because only they can perform the manufacturing of needed components or manufacture at the acceptable level of quality.
- Measurements. Wrong tolerances or measurements of components, despite correct specifications. The changes in tolerances affect the quality of the finished product, because company has high standards on the quality. These errors are usually discovered at the final assembly.
- Various products. High mix of products does not support standardization. Company has high customization and can offer product, exactly as customer requires. Personalization of solution is considered as key strength and value of the company. The high mix of products and components makes it difficult to create standard procedures to avoid mistakes and increase the volume.
- Assembly time. Searching for equipment takes time. Most of the equipment, which is used on the assembly process, consists of general tools, which can be used for different products and operations.
- Order fulfillment time. Hard to assess the time needed for completing the order. No standardization means that there is no knowledge how much work is left to

complete the assembly of product and also how much time it will take to finish the assembly.

- Capacity utilization. Hard to assess the capacity utilization. As it is the make to order production, it is hard to forecast, when customers are ready for decisions. Especially, big and public companies have several phases on the decisions process and it can take time up to one year to reach from the sales offer to the customer order.

Order fulfillment time can define success or failure of the company. These areas should be controlled, monitored and managed. Mitigation on these areas can have great impact for the company in terms of the order fulfillment time and provided quality.

3.5 Assembly process flow

Mainly manual operations are made at the shop floor. There is hard to use any automated machines. The assembly is mostly based and done according to the 2D and 3D drawings. Only some manufacturing instructions exist, but it is hard to standardize, because assembly process is done as craft production.

Assembly process flow of company is as following:

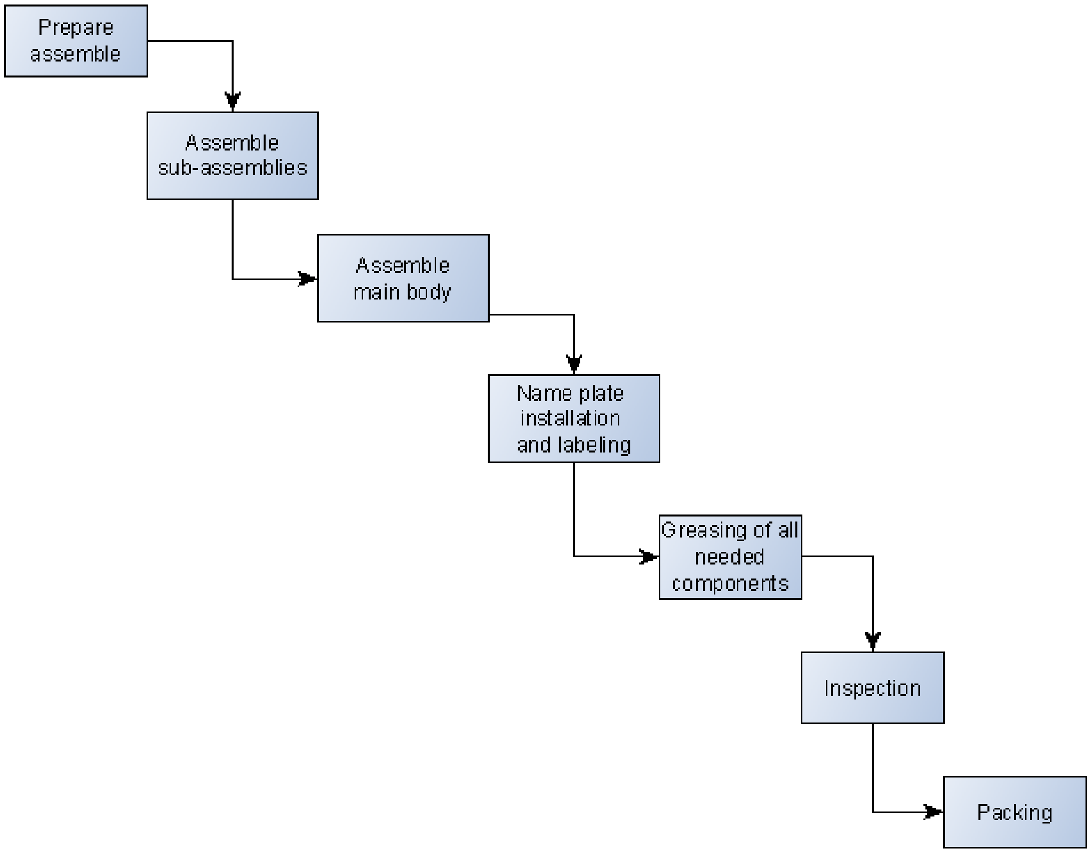

Figure 22. The assembly process flow in the company. (Source: Author)

Process begins, when components have gathered and ready to assembly. Then these components are prepared for assembly. Next step is to assemble sub-assemblies of the product. After finishing sub-assemblies then can start the main body assembles. Sub-assemble and main body assemble is most time consuming activities at this process. Next step at the assembly process flow is name plate installation and labeling. Next step is greasing of all needed components; after completing the greasing; then final inspection of the product and packing.

At the assembly process are used general purpose tools: electrical saws; electrical drills, welding machines, disc grinders, hand tools and backing equipment.

3.6 Time estimation of assembly of the Conveyor assembly

To understand the assembly process and duration of the process has been made time study for assembly of conveyor ABC 800/6000. To achieve better overview of elapsed the time and activity; then following figure has been constructed by the author.
The time study of the conveyor assembly was carried out using following time study sheet.

Time Study sheet		
Date:	**Product:**	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble		
Assemble sub-assemblies		
Assemble main body		
Name plate installation and labeling		
Greasing of all needed components		
Inspections		
Packing		
TOTAL		

Table 3. Time study sheet for measuring processing and waiting time.

Processing time is defined as time during certain activity and waiting time is defined as time before and between activities. For example assemble main body waiting time means time before

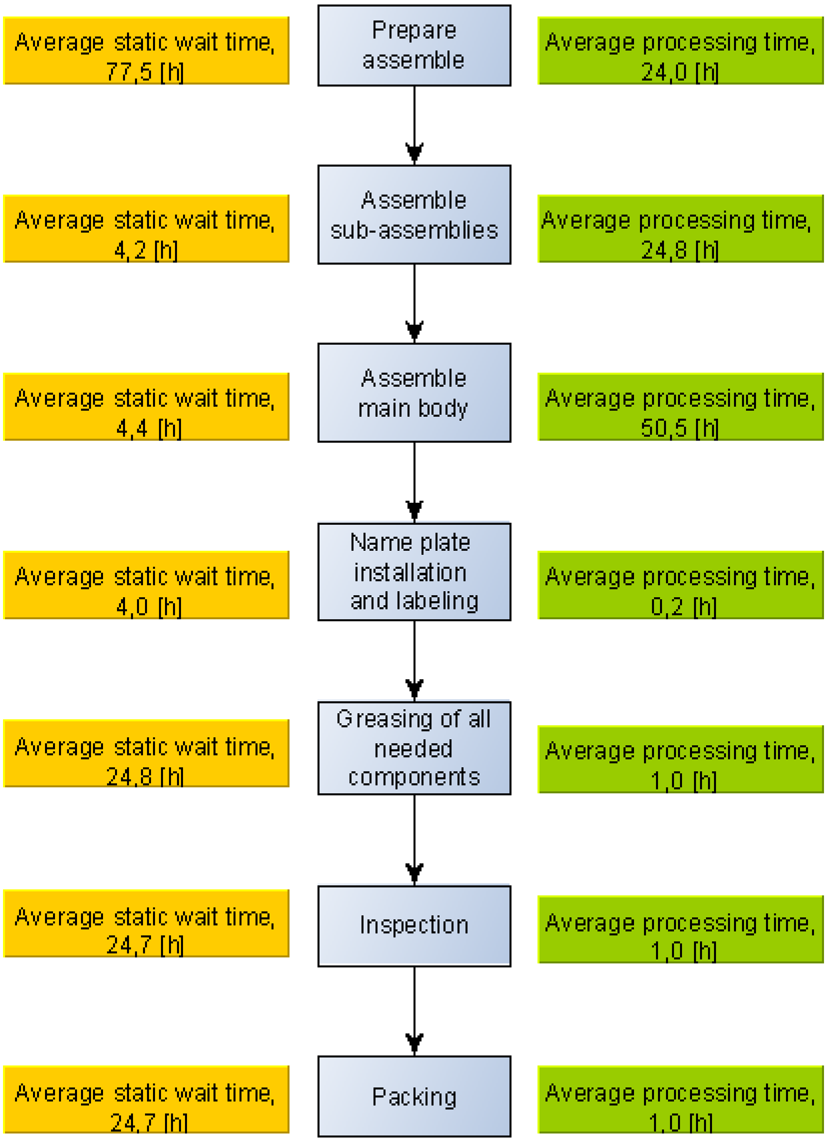

Figure 23. Assembly line process for conveyor ABC 800/6000 with the processing and waiting time. (Source: Author)

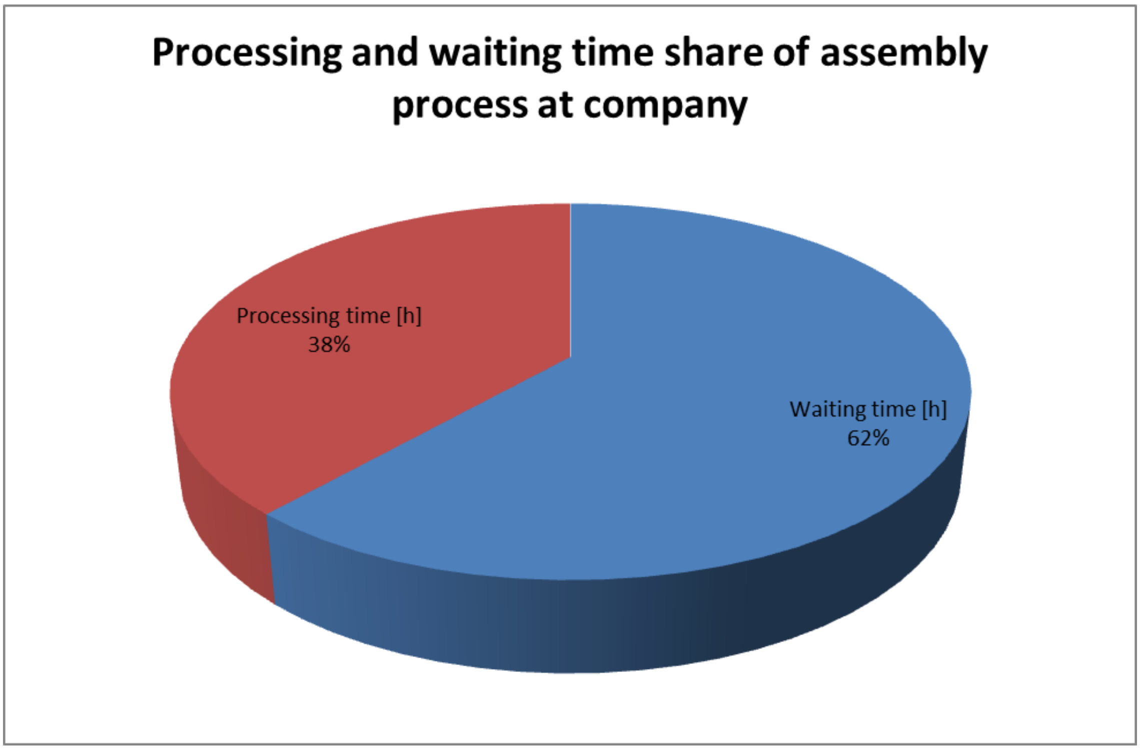

Figure 24. Processing and waiting time share of assembly process at company.(Source: Author)

Analysing the processing and waiting time shares of assembly process, then over 62% time is spent on the waiting – non value adding activity and 38% of assembly time is for processing the order – value adding activity.

To understand better the reasons and find ways to improvments, it is important to investigate processing and waiting time share by activities at the assembly process.

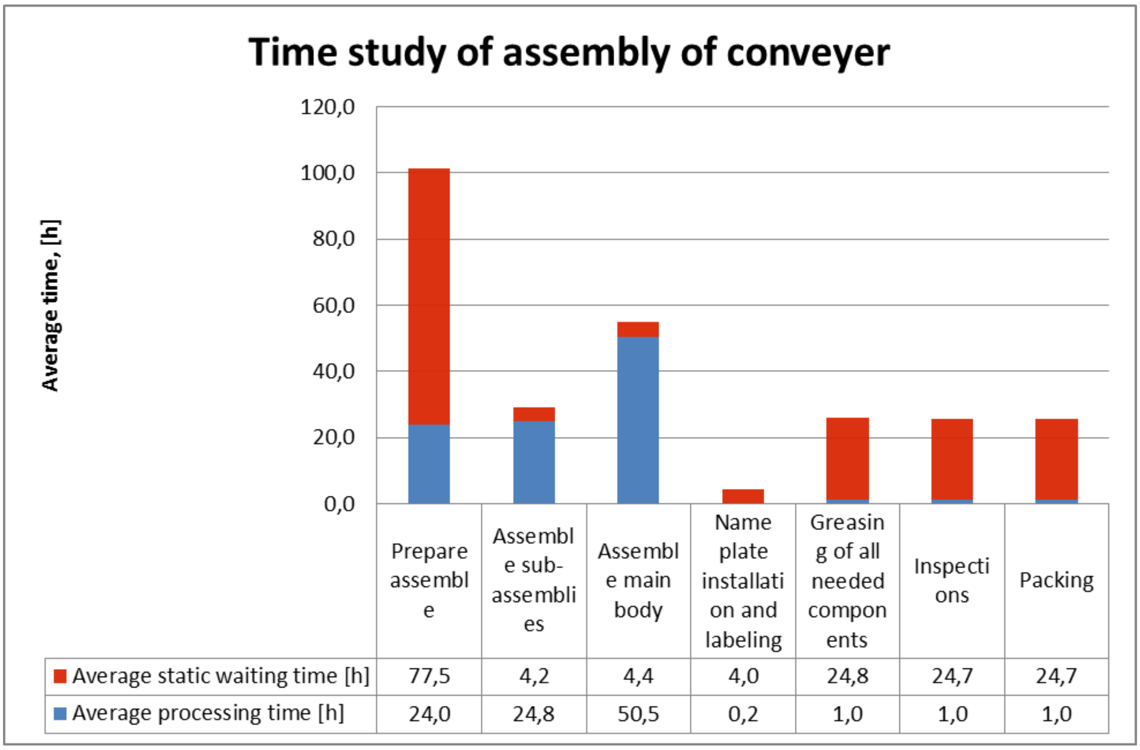

Figure 25. Processing and waiting time study of assembly of conveyor. (Source: Author)

The main waiting time is generated, when is phase - preparations for assembly. Almost 50% of all the waiting time is generated on this phase. Once the preparation is done and assembly has been started then the waiting time decreases significantly.

4. Discussion about productivity increase in company

In terms of productivity, it is important to understand time usage and management at the company.

The share of the waiting time is over 50% for the assembly process as shown from the case study. Main time is wasted at waiting on the preparation stage of assembly. According to the company, reasons for long waiting time can be concentrated usually with term – subcontractors. According to the company, there are usually time issues with subcontractors – the proposed time plan and delivery time is not correct. The company points out different reasons for this, one of reasons is - subcontractors receives bigger offer from the other company and does not honor the contract and promise of the delivery time, another reason is – subcontractors does not estimate time correctly and also one of the reasons is – subcontractors does not produce components with required quality and have to make over the components and it costs time.

To increase of the productivity and decrease the non-value adding time for the company should be analyzed the cycle time of the assembly line, as pointed out in the theoretical part of thesis. From the deeper analysis following improvement should be implemented in order to increase the productivity of the company and reduce the cycle time:

- Quality inspection of components and material before putting components on shelf to wait the time to assembly. After receiving component from subcontractor thorough inspection should take place. Quality control before assembly can prevent time losses in the assembly process. In case company should focus on the quality control before assembly then it is possible to reduce waiting time by 20%. This estimation was made by author with help from company's expert opinion. In such case overall waiting time is reduce by 14 hours. (20% from the 77 hour waiting time).

  Economic effect can be calculated as following:

  Savings - 14 hours per conveyor

  Production - 30 conveyors per year

  Total 14*30 = 420 hours per year saved.

  Average 8 euros per hour

  Total economic effect 3360 euros per year at this rate of production.

- Preventive quality inspection – quality inspection on the subcontractors' plant and also visiting the subcontractor often to follow and improve quality. This preventive activity can also discover possible delays before starting assembly. It gives also flexibility to contact and if needed reschedule the possible delivery time.
- In general is important to make list of the subcontractors; which needs more time and activity for the delivering expected level of quality. Also another list of the subcontractors; which cannot provide components with required quality and time.
- Start monitoring the cycle time and track actual performance and target performance. It helps to gather data to analyze and in author's opinion – company or person can achieve only this goal, which are monitored and measured.
- Cycle time reduction efforts must be made by assembly team, with support of information technology.
- Cycle time reductions should be supported also by the improvements in the information systems.

By improving cycle time the company also benefits the reduction of throughput time and in the end the order fulfillment time. This will increase also customer satisfaction and therefore potentially the revenue, although the impact on the revenue is also hard to estimate, but also shorter order fulfillment time means that the revenue will be received earlier.

According to the case study can be defined the time model for productivity. Cycle time consists of the following components:

- Time for production – value adding activity:
- Time for additional activities – additional time for technical purpose; setup purpose, component change.

Throughput time according to the case study can be defined as following: cycle time and additional times. Additional times consist of following components: waiting time; measure and quality time; transporting time and storage time.

Based on the case study and theoretical framework, author created easy to use time estimation model.

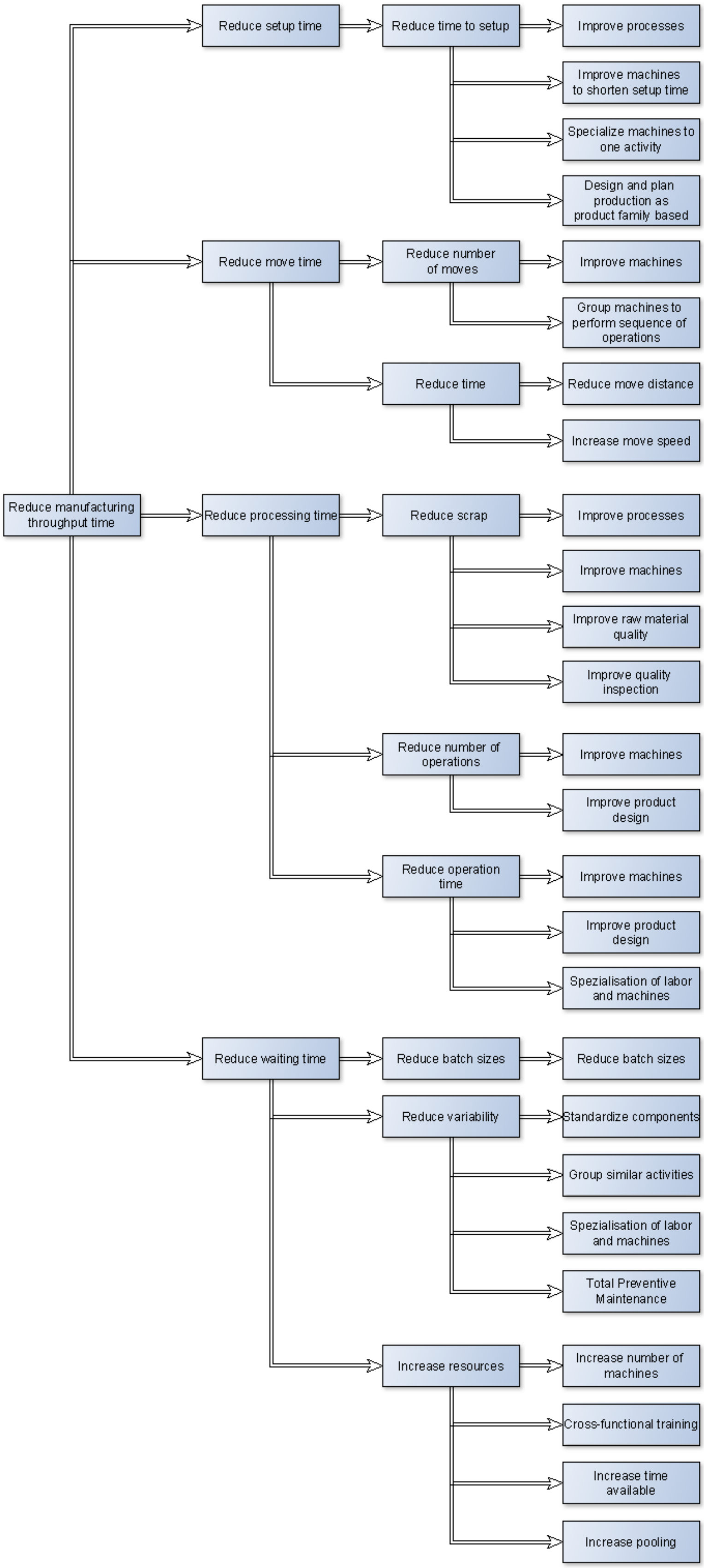

Figure 26. Throughput time model. (Source:Author)

Model begins with the intension to reduce the manufacturing throughput time. In such case it is important to concentrate on the four aspects: reducing setup time, reducing move time, reducing processing time and reducing waiting time.

In case to reduce setup time; it can be achieved with following activities: improving processes (using different kind of tools for that); improving machines to shorten the setup time; specialize machines to one activity (for example using two electrical saws with fixed angles, so can be saved setting time) and way to reduce setup time is to redesign production as platform or product family based, so same components can be used to produce different type of products.

Next area to concentrate is moving time. To reduce moving time; it can be achieved with two activities: reducing number of moves and reducing moving time. To reduce number of moves; it can be achieved by improving machines, grouping machines to perform sequence of operations. To reduce moving time; it can be achieved by reducing distance of movements or increasing speed of movement.

Another area to concentrate is processing time. To reduce processing time; it is important to reduce scrap, reduce number of operations or reduce operation time. Reducing scrap, can be achieved by improving processes so less scrap is produces, improving machines so more quality products are produced, improve raw material quality and improve quality inspection. Reducing number of operations can be achieved by improving machines or improving product design. Reducing operation time can be achieved by improving machines, improving product design or specialization of labor and machines.

Another area to decrease time consumption is waiting time. To reduce waiting time is needed improvements on reducing batch sizes, reducing variability and increasing resources. To reduce variability are following opportunities: standardization of components; grouping similar activities; specialization of labor and machines and implementation of total preventive maintenance. Increasing resources to shorten the waiting time, there are following possibilities – increasing number of machines; cross-functional training, so workers can do different kind of activities and flexibility will increase; increase available time by shorten queues and other time components; increase pooling of machines.

According to the created time model to increase the productivity, case study company should reduce processing time by improved raw material quality and improved quality control; also think about reducing waiting time by standardizing components and parts.

5. Conclusions

Lower cost, better competitiveness, decreased delivery times can be achieved by increasing productivity. In order to increase productivity for manufacturing company is important to reduce the order fulfillment time, throughput time and cycle time, because order fulfillment time indicates overall result of the process, on another hand throughput time indicates result of the manufacturing process and cycle time indicates of result of one workplace. Finding root causes at the workplace and reducing cycle time also affect positively for the throughput time and order fulfillment time.

The purpose of this thesis was to create the production time estimation model in order to increase the productivity. For creating production time estimation model first was made theoretical overview and then case study of company. At the case study was focused on the manufacturing process with its time components. The case study has provided an analysis and example to increase the productivity of the company assembly process. First estimation was made with feedback from company and implementation of improvement can increase the productivity by 20%.

The thesis also contributes to creating throughput time estimation model for manufacturing companies. Based on the theoretical research and case study was created time estimation model, which is model for the SME companies to understand the time consumption of company and to find out reason, which are causing this time. Knowing the reasons, then companies can focus on removing theses causes and increasing value adding time share and by that also increasing productivity of the company. The model uses four main time components – setup time, moving time, processing time and waiting time; with analyzing each time component have found the activities, which should be implemented in order to reduce time and increase productivity.

The project deliverable for this thesis has been achieved and first model for time estimation has been created to give better overview and understanding of the time consumptions and ways to improve value adding time.

Future Works

In the future, a similar study could be done, focusing on tools. Adding tools to use with every reason; can make this model more valuable for SME-s. So if company has indicated the reasons and want to reduce these, then is advised to the company, which kind of tools to use. For example if company has to improving processes, then is usuful to use on tool.

6. Kokkuvõte

Antud magistritöö eesmärk on uurida ja valmistada tootmisega seotud aegade hindamise mudel tootlikkuse tõstmiseks SME-des. Täpsemalt lõputöö keskendub tootmisettevõtetes kasutatavate aegade leidmisele ning mudeli loomisele.

Magistritöö ülesanded on:

- Anda kirjanduse ülevaade olemasolevates mudelitest ja komponentidest ajaarvestuses tootmises.
- Koostada mudel, mis võimaldab kergelt ja ülevaatlikult SME-del hinnata ja mõista ajaga seonduvaid komponente ja nende vähendamise võimalusi.

Käesolev töö kirjeldab sissejuhatuseks tellimuse protsessi käsitlust, selle seost ettevõtte äristrateegia ja tootmisstrateegiaga. Ettevõtte poolt valitud äristrateegia mõjutab üldiselt tellimuse täitmise aega, nii on näiteks õigeaegselt tarnitud toodangu ja vähima kuluga toodetud toodangu korral erinevad käsitlused tellimuse protsessi jaoks. Hinnatakse erinevaid kriteeriume ja fokuseeritakse erinevatele väärtustele.

Selleks, et paremini mõista aega ja selle teket, mis kulub tellimuse täitmise protsessiks on vajalik vaadelda täpsemalt tootmise läbilaskevõimet ja tellimuse läbi laskmiseks tootmisest, kuluvat aega ning selle aja komponente, milleks on seadistuse aeg, ootamise aeg, tellimuse täitmise aeg ja aeg toodangu transpordiks.

Selleks, et paremini juhtida ja mõista tootmises toimuvaid protsesse ei piisa ainult tootmise läbilaske aja jälgimisest, selleks on vaja minna sügavamale ja tuleb vaadelda töökohaga seonduvaid ajakomponente. Selleks on sobilik tsükkli aeg, selleks et mõista tema olemust tuleb uurida ja mõista, mis komponentidest see aeg koosneb ja kuidas on neid võimalik mõjutada.

Seejärel uuritakse ning selgitatakse produktiivsusega seonduvaid mõisteid. Käsitletakse nii töötajatega seotud produktiivsuse mudeleid ning ajakomponent kui ka seadmetega seotud produktiivsuse mudeleid. Tootmise seisukohast on oluline, et masinad ja töötajad töötaksid harmooniliselt teineteisega, siis saab vältida raiskamist ning luua sama aja jooksul rohkem väärtust nii ettevõttele aga ka laiemas mõistes ühiskonnale. Produktiivsuse kasv aitab kaasa tõhusamale sisendite kasutamisele ning suuremate väljundite saamiseks.

Teooria testimiseks ning mudeli formuleerimiseks on võetud üks juhtum käsitlus. Tegemist on SME sektorisse kuuluva ettevõttega, kes toodab peamiselt konveiereid, aga valikusse kuuluvad ka teised tooted. Ettevõtte põhiliseks tootmise protsessiks on kooste protsess; koosteks tellitakse allhanke korras teistelt ettevõtetelt komponente. Komponentide valmimisel alustatakse kooste protsessiga, kus algusel tehakse alamkooste ja seejärel lõppkooste, nimeplaadi kinnitamine, kvaliteedikontroll ning seejärel tarnitakse valmistatud toode kliendile. Juhtumi käsitluses kasutatakse ühe konkreetse konveieri tootmiseks kuluva aja jaotust, hinnatakse nii ooteaega kui ka töötlemiseks kuluvat aega.

Juhtumist nähtub, et peamise ajaraiskajana on enne koosteid toimub komponentide ootamine allhankijatelt – üle 50% ooteajast formuleerub just selles etapis. Uurides sügavamalt põhjuseid võib järeldada, et peamiselt tekib see aeg allhankija tõttu. Põhjuseks on kas ebavajaliku kvaliteediga tarnitud komponent või siis mitte õigeaegselt tarnitud komponent. Ettevõte ei saa oma koostega alustada ennem kui on tarnitud kõik komponendid. Koostöös ettevõttega on leitud, et on võimalik ca 20% ooteaja vähendamine, see on saavutatav protsessi parandustena, mis läbi parandatud kvaliteedi kontrolli ja kõrgema tooraine kvaliteedi suudavad vähendada ooteaega. Konkreetse konveieri süsteemi jaoks on see 14 tundi ja kogu aasta peale teeb see ca 3 360 eurose kokkuhoiu. Selles summas ei arvestata täiendava kapitali kasutamisest tekkivat lisatulu ja kasumit.

Juhtumi alusel ning teooriale tuginedes on loodud aja hindamiseks mudel. See mudel keskendub tootmise suurema läbilaske võime saavutamiseks ehk lühema läbilaskeaja saavutamiseks vajalikele ajakomponentidele. Neid komponente on neli: seadistusega seotud ajad, transpordi või toote liigutamise seotud ajad, töötlemisega seotud ajad ning ootamisega seotud ajad. Edasi käsitletakse võimalikke lahendusi nende aegade vähendamiseks.

Kokkuvõtvalt, leitud mudel on ülevaatlik ja kergesti hoomatav ning võiks leida kasutust SME sektoris tootmisega seotud tootlikkuse tõstmisel. Juhtumiga seotud kalkulatsioonid näitavad, et on võimalik saavutada paremaid tulemusi, suuri muutusi tegemata. See mudel võiks olla aluseks ettevõttele kiire hinnangu andmisel ja võimalike vahendite valimisel. Töös seatud eesmärgid said täidetud.

Tulevikus võib seda teemat edasi käsitleda ning ülesehitada mudelile vastav küsimustik, mille täitmisel saab ettevõtte esialgse hinnangu enda tootlikuse tõstmise võimalusele. Lisaks võib seda mudelit täiendada võimalike tööriistade ja töövõtete poolega. Näiteks protsessi parandamiseks on olemas palju võtteid, ettevõtte jaoks võiks olla valmis tehtud kergesti hoomatav mudel, kuidas valida õigele probleemile õige tööriist. Autor leiab, et tegemist on olulise teemaga, mida tuleks kindlasti edasi uurida.

7. Literature

1. Pande, P.S., Neuman, R.P., and Cavanagh, R.R. (2000). The six sigma way: how GE, Motorola, and other top companies are honing their performance. USA: The McGraw-Hill
2. Russell, R.S. and Taylor III, B.W. (2011). Operations management: creating value along the supply chain. USA: John Wiley and Sons, Inc.
3. Krajewski, L.J and Ritzman, L.P. (2005). Operations Management Processes and Value chains. 7th edition. New Jersey: Pearson Education
4. Hopp, W.J and Spearman, M.L. (2008). Factory physics. 3th edition. Singapore: McGraw- Hill
5. Slack, N., Chambers, S. and Johnston, R. (2007). Operation management. 5th edition. Madrid: Pearson Education Limited
6. Chase, R.B., Aquilano, N.J. and Jacobs, F.R. (2001). Operations management for competitive advantages. 9th edition. New York: McGraw-Hill
7. Jackson, S., Sawyers, R. and Jenkins, G. (2009). Managerial Accounting: A Focus on Ethical Decision Making. Canada: Nelson Education
8. Krishnaswamy, K.N. and Mathirajan, M. (2008). Cases in Operations Management. New Delhi: PHI Learning Private Limited
9. Mehaanikainseneri käsiraamat. /ed. P. Kulu. Tallinn: TTÜ Kirjastus, 2012
10. Kanawaty, G. (1992). Introduction to Work Study. 4th edition. Germany: ILO Publications
11. Keely L. Croxton, (2003). The order fulfillment process. The International Journal of Logistics Management, Vol. 14 Iss 1 pp. 19 – 32
12. Johnson, G., Scholes, K., and Whittington, R. (2008). Exploring corporate strategy. 8th edition. Italy: Rotolito Lombarda
13. Herrmann, W.J. and Chincholkar, M.M. (2001). Reducing throughput time during product design. Journal of Manufacturing Systems. Vol. 20 Iss 6 pp. 416-428
14. Uuenduslik tootmine. /ed. J.Riives

15. Stevenson, W.J. (2012). Operation management. 11th edition. New York: McGraw-Hill/Irwin
16. Molloy, O., Warman, E.A. and Tilley, S. (1998). Design for Manufacturing and Assembly: Concepts, architectures and implementation. UK: Chapman and Hall
17. Slack, N., Brandon-Jones, A. and Johnston, R. (2013). Operation management. 7th edition. United Kingdom: Pearson Education Limited
18. Meyer, H., Fuchs, F. and Thiel, K. (2009). Manufacturing execution systems: Optimal Design, Planning and Deployment. New York: McGraw-Hill
19. Measuring productivity: Measurement of aggregate and industry-level productivity growth. /ed. OECD., 2001
20. Kletti, J. and Schumacher, J. (2011). Die perfekte Produktion: Manufacturing Excellence durch Short Interval Technology (SIT). Heidelberg: Springer-Verlag
21. Eedo, K. (1997). Tootlikkuse juhtimine ettevõttes. Tallinn: Külim
22. Reliableplant webpage. New KPI measures plants' overall labor effectiveness. [WWW] http://www.reliableplant.com/Read/6388/new-kpi-measures-plants%27-overall-labor-effectiveness (Retrieved 02.04.2015)

8. Appendices

Appendix 1. Time estimation of the conveyor assembly.

Time Study sheet		
Estimation no. 1	**Product:** Conveyor ABC 800/6000	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble	23,0	77,4
Assemble sub-assemblies	25,2	4,1
Assemble main body	50,6	4,4
Name plate installation and labeling	0,2	4,0
Greasing of all needed components	0,9	24,7
Inspections	1,0	24,7
Packing	1,0	24,7
TOTAL	**101,9**	**165,0**
Time Study sheet		
Estimation no. 2	**Product:** Conveyor ABC 800/6000	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble	25,0	77,5
Assemble sub-assemblies	25,1	4,2
Assemble main body	50,4	4,3
Name plate installation and labeling	0,2	4,0
Greasing of all needed components	1,0	24,8
Inspections	1,0	24,8
Packing	0,9	24,8
TOTAL	**103,6**	**166,4**
Time Study sheet		
Estimation no. 3	**Product:** Conveyor ABC 800/6000	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble	24,0	77,4
Assemble sub-assemblies	24,7	4,2
Assemble main body	50,2	4,4
Name plate installation and labeling	0,2	4,0
Greasing of all needed components	0,9	24,8
Inspections	0,9	24,7
Packing	0,9	24,7
TOTAL	**101,8**	**167,2**
Time Study sheet		
Estimation no. 4	**Product:** Conveyor ABC 800/6000	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble	25,0	77,7
Assemble sub-assemblies	24,8	4,2

Assemble main body	50,3	4,4
Name plate installation and labeling	0,2	3,9
Greasing of all needed components	1,0	24,7
Inspections	1,0	24,7
Packing	1,0	24,7
TOTAL	**103,3**	**168,3**
Time Study sheet		
Estimation no. 5	**Product:** Conveyor ABC 800/6000	
Activity name	Processing Time [h]	Waiting Time [h]
Prepare assemble	23,0	77,5
Assemble sub-assemblies	24,3	4,2
Assemble main body	50,8	4,4
Name plate installation and labeling	0,2	4,0
Greasing of all needed components	1,0	24,8
Inspections	1,0	24,7
Packing	1,0	24,7
TOTAL	**101,3**	**169,3**