ACCOMODATING PRODUCTION TO THE MARKET DEMANDS OF THIS ERA

Improving the Production Flow of Distribution Transformers Line in ABB Turkey through Process and Layout Optimizations to Advance into a More Flexible and Leaner Production System

TUNC ATLIHAN

Master of Science Thesis

Royal Institute of Technology (KTH)
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ABSTRACT

In the last decades the old manufacturing ideology which is based on only quantity has faded away. With globalization of the world, competitors in all industries have risen and instead of buyers searching for suppliers, now the manufacturers have to get to customers by distinguishing themselves from the other competitors. The main problems that the manufacturing companies face changed from how they can produce more to how they can get their product to customers more quickly in a changing market while improving the efficiency of their production. Hence most of the manufacturers tend to use lean manufacturing techniques to get a more flexible and agile production systems.

The Distribution Transformer Factory of Asea Brown Boveri Turkey is facing with similar problems in adapting the customer-oriented production. The company is using a design-to-order system to meet each customer’s specific needs but the compatibility with its production system is discussable. Although the yearly capacity demands can be easily met, the system doesn’t show the flexibility to quickly accommodate its production to deviating customer order.

The objective of this project is to create a new agile manufacturing system that can effectively meet the changing demands. In the first phase, from the data gathered from the production floor, a current state value stream map is created to get a clear view of the present situation. Through improvement on the marked processes a new production model, with less throughput time and increased reactiveness to changing demands, is created in future state value stream map. In the second chapter, the bottleneck that stands as the capacity and flexibility constraint of the system is unraveled according to the model created. A new changeover system is implemented and a formulation to generate process times to help the scheduling activities is created. Lastly a new inventory layout system is introduced which will support the new improvements in system constraint as well as all the other process.
Preface

This report is the result of Master Thesis Project done as the final part of International M.Sc. Programme of Production Engineering and Management in Royal Institute of Technology, Sweden. The thesis has been conducted between June 2010 and December 2010 in Turkish Branch of Asea Brown Boveri(ABB) Group.

In these first few lines I wish to express my gratitude for the people who have supported me through this period.

First of all, I would like to give my thanks to all my Colleagues in ABB Turkey for their inspiring and informative advices, especially Melih Adali who as my project head helped me to form all my study.

Secondly I wish to express my gratitude to my professors in Royal Institute of Technology for their teachings that give me the knowledge to carry out this research and special thanks to my project coordinator, Ove Bayard for his assistance.

Finally, my family who have their undying support to me through the master degree as all my life, have my thanks and love.
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CHAPTER 1 - INTRODUCTION

1.1 Company Background

Asea Brown Boveri(ABB) is one of the largest engineering companies in the world and is a global leader in power and automation technologies. The company has operations in approximately 100 countries with 119,000 employers and registered in the Swiss, Stockholm and New York stock exchanges.

The history of ABB starts in 1880s with the forming of two different companies, Allmana Svenska Elektriska Aktiebolaget(ASEA) and Brown, Boveri & Cie(BBC). In 1883 ASEA is established by Ludwig Fredholm in Sweden as a manufacturer of electrical lighting and generators. In 1891 BBC was incorporated by Charles E.L. Brown and Walter Boveri in Switzerland and in a few years after the forming became the first company to transmit high-voltage power. Through the 20th century both of these companies had grown to important figures and became fierce competitors in the field of power industry. In 1988 these two strong competitors announced their intent to merge because of the reasons to combine their expensive research and development efforts and unify the markets they were strong at.(ASEA in Scandinavia and northern Europe; BBC in Austria, Italy, Switzerland and West Germany) The new group has established its headquarters in Zurich and started its operations on January 5, 1988 with a revenue of 17.83 billion dollars and 160,000 employers. From the merging to this day, ABB had grown into Eastern Europe and Asia markets, and nearly doubled its size by increasing its revenues to 31.8 billion dollars.(2009)
The organization structure of ABB is divided into 5 main branches based on the type of products. These main divisions are listed in order of share of revenues:

- **Power Products** – The division operates in the field of production of components for the transition and distribution of electricity. The key products of the group are transformers; automation relays; High Voltage (HV) & Medium Voltage (MV) switchgears and circuit breakers. The division holds %30 of total revenue.

- **Low Voltage Products** – The field of this division is to produce equipment for low voltage usage. Circuit breakers, drivers, motors, and wiring accessories are typical products of the group. %25 of the total revenues are held in LVP.

- **Process Automation** – The main purpose of the division is to supply customers with products and solutions for automation and optimization of industrial processes. The group holds %22 of revenue.

- **Power Systems** – The division provides turnkey system for power grids and power plants. The most common systems provided are, transformer centers, FACTS, HVDC, HVDC Light and power plant automation systems. %18 is of the revenue is held by this division.

- **Discrete Automation and Motion** – Regarded as robotics also, the group provides products and services for industrial production. The key products are driver, programmable logic controllers (PLC) and industrial robots. The group has the lowest percent of the revenue, with %5.

**ABB Elektrik Sanayi A.S.** is the Turkish branch of ABB Group. Its history dates back to 1965, when company formed under the name ESAS for production of transformers in Turkey. It had started its production of distribution transformers (DT) with USA design of Kuhlman Electrics, and to 80s became an important figure in Turkish Industry. In 1987 %53 of its shares were bought by ASEA and one year after that, when BBC and ASEA cohered, the company merged into the ABB group. The Turkish factory has become the European focus factory for Large-Medium Distribution Transformers in 2005 and right now ABB Elektrik Sanayi A.S. is one of the leaders in power industry of Turkey with 3 factories and 3 service centers.

**1.2 Aim and Objectives**

With the globalization of the World, the competition has increased greatly in energy sector with a huge number of new companies. To get a good market share, the energy companies has to stand out
in this mass with its qualifications such as product quality, supply lead time and customization for buyers. As one of the old-established energy companies, ABB keeps a sizable amount of market share by meeting the demands of the time. The company is known for its product quality and customized product that are designed in regard to customer specifications. However it needs to increase the effectiveness of production system to reduce the supply lead times and adjust to changing demands.

The aim of this project is to implement a new production system that will enhance the flexibility and efficiency of the current one. The objectives to accomplish this goal are:

- Creating a new production model from the deep understanding of current situation.
- Generating creative solutions to constraints, which stand as a bar to elevating the system, and implementing them.
- Carrying out improvement activities that support the constraint solutions as well as increasing the efficiency of the overall system.

1.3 Scope

There is a huge range of transformer products in Turkish branch of ABB. They are classified to different groups based on their properties and the production of each class is carried in different plants or areas. Therefore a specific group of products should be chosen as the focus product group to carry out the project.

The Power Products Group has the biggest share of all groups in the Turkish branch of ABB. The transformers division in this group has two separate factories in Dudullu (16,670m²; 9,570m² closed) and Kartal (31,000m²; 9000m² closed). While Kartal Factory focuses on the manufacturing of power transformers, Dudullu Factory focuses on distribution transformers. These two types are classified based on their power capacities as; up to 30 MVA transformers are called distribution transformers (DT) and transformers with bigger capacities are named power transformers(PT). This project is carried out on the floor of Dudullu Distribution Transformers Factory so DT products will be the subject of the research.

Another classification based on power capacities, is done at the DT factory. This time the distribution transformers are divided to 3 groups for different production lines: small distribution transformers(SDT), medium distribution transformer(MDT) and large-medium distribution transformers(LMDT). The classification of the 3 lines is as:
- SDT line – line for the production of smallest type of transformers
  \[\text{SDT} \leq 315\text{kVA} \quad \text{max} \ 36\text{kV}\]

- MDT line- the middle production line where MDT are manufactured
  \[315\text{kVA} < \text{MDT} \leq 2500\text{kVA} \quad \text{max} \ 36\text{kV}\]

- LMDT line- the line where both large and semi large transformers are produced.
  \[2500\text{kVA} < \text{LMDT} < 10\text{MVA} \quad \text{max} \ 36\text{kV}\]
  \[10\text{MVA} < \text{LDT} \leq 30\text{MVA} \quad \text{max} \ 72\text{kV}\]

As the power capacity increase, the size and the complexity of the transformer increase. Therefore, although the production processes are the same, the time and manpower needed for operations differs for each line. For SDT and MDT line, the operation times, types of machines used and personnel assigned to the tasks are similar. However the LMDT line’s flow is much different than the other lines. The LMDT products are much larger and more complex designs, so a standardization of the process can’t be done like the other ones. Due to the complexity of the products, this line requires more labor and some processes do not use PLC machines unlike the other lines. For all these reasons, the LMDT line is excluded from the project and SDT&MDT products, which are similar in many ways, are chosen as the focus product family of the project.
CHAPTER 2 - THEORY AND METHODOLOGY

2.1 Theory

There are various theories used throughout the research. In this chapter they will be explained briefly.

2.1.1 Theory of Constraints

The theory of constraints is a management theory, first introduced by Goldratt, in his book “The Goal” where the story of Alex Rogo, the manager of a plant in a problematic state, is told. The book first questions the old thinking of productivity in the manufacturing company by realizing the fact that although all the divisions of the manufacturing plant assumed to think that they have separate prime objectives or goals, which they should focus on achieving; in reality the true goal of the whole organization is to make money and all the rest should be classified as necessary activities. From this, it is deducted that activities that activities which does not make the company move closer to its goal is unproductive and the company should focus on activities which moves it closer to its goal.

As the theory formed around this idea, the flow of the system is idolized as a steel chain which always breaks at its weakest link irrelevant from the strength of the other links therefore the strength of the whole chain is equal to the strength of this weakest link. When considering a organization this link refers to a process or department that limits the system from achieving its goal. In terminology this is called a constraint and can be viewed as a structural bottleneck which determines the capacity of the whole system. TOC concludes the limits of an organization to at least one or a limited number of constraints and to evolve, the organization should restructure itself to these constraints and solve them by using the five focusing steps of theory of constraints.

Before starting the five step analysis of TOC, to gain perspective for the analysis, two facts should be identified:

- The definition of the system and its goal purpose(goal)

Because the constraint is relatively perspective and can be viewed different from division to division, the definition of whole system’s goal is a prerequisite for defining the true constraint of a system. As mentioned above, in manufacturing companies, choosing making money as the primary goal can satisfy the demands and conditions in most situations.
The way to measure the system`s purpose

After stating the goal of the organization, the methodology to measure this goal should be defined. As in the example of the book “The Goal”, when the character assigned the plants goal as making money, he had to throw his old techniques of calculating productivity to trash and define new terms such as throughput, operating expenses and rate of return.

After these definitions analysis can be carried with the five focusing steps in below

- **Step1: Identify the System`s Constraint**
  
  In this step the capacity of each process is measured and then by comparing the actual throughput with the capacities, the constraint which has the highest capacity utilization rate is found. The constraint is identified ether not enough sales in the market, no enough materials from vendors or inefficiency of a process in an internal resource.

- **Step2: Decide How to Exploit the System`s Constraint**
  
  The second step is to identify the key factors in the constraint that can be used to manipulate the capacity of it. In this step actions to increase the production rate in the capacity limits are done. These actions can be reduction of waste, decrease in setup times for internal constraints; reducing scraps or finished inventory for raw material constraints; and increasing quality, fastening lead times for market constraints.

- **Step3: Subordinate Everything Else to Constraint**
  
  This step is where most of the management activities takes place to maximize the rate of throughput. The management sets its own rules and standards in this stage and change the behavior of emotional resistance which prevent the constraint from being solved. All the non-constraint resources are planned according to the constraint to insure feeding the process with material. The drum-buffer-rope model is applied in this planning phase.

- **Step4: Elevate the System Constraint**
  
  This is the stage; the decision is made if the productivity of the bottleneck which has been improved in the last two steps is satisfying. If the capacity of the process meets the market demand, than the bottleneck has moved to another process. However if the production is not in the level which is desired still, then new resources should be invested. In the case the bottleneck is an internal source; implementation of additional shifts, hiring new personnel, outsourcing or investment of new machines can be the solution. In other cases where the bottleneck is either in
raw materials or sales, new suppliers or new customers should be found. The ideal improvement would be to increase the constraining process to the whole system’s limit, but in continuous improvement, improving the capacity of the system above the next most significant constraint is good enough.

- Step 5: Prevent Inertia, Go to Step 1 if the Constraint is Solved

In continuous improvement thinking, inertia to act on advancing the system is unacceptable. Therefore once the constraint is solved, it is required to go back to step 1 of identification of constraint because by breaking a constraint, a new one is created in the system. The important thing is to keep the constraint in check and move it to a desired process so that control over the whole system can be maintained. However in some cases where there is no way to improve the system any further, it might be needed to change the structure of the whole system.

2.1.2 Lean Manufacturing

The concept lean manufacturing roots back to production systems developed by the Japanese manufacturers after World War 2 in response to the shortages of material, financial and human resources. The prime example is the Toyota Production System which Taichi Ocho developed with inspirations from the Ford Production System in 1940s. As the system developed over the years and the Japanese has passed their western counterparts, the book “The Machine Changed the World” (Womach, Jones, Ross; 1990) published from the studies in Massachusetts Institute of Technology, made an awareness of the benefits of lean manufacturing to all industries.

The principle behind the lean manufacturing is utilizing activities that add value to the final product from the customer’s perspective. This utilization can be achieved by reducing or abolishing of the non-value activities called wastes. The Japanese culture define the wastes in continues improvement in three broad categories: muda, translated wasteful activity but in common practice it is simply referred as any kind of waste to be eliminated; mura, translated unevenness like excess variation due to non-standardized work; and muri, translated overexertion as the reduction in efficiency due to work beyond limits. In lean manufacturing the primary focus is on reduction of muda and it is categorized in 7 groups:

- Overproduction- It is the waste caused by manufacturing a product before it is required. Mostly believed to be the worst kind of waste because it covers all the other kind of wastes. It results in high inventory and waiting times, also lowers the quality of the products.
• Waiting- This type occurs because of the waiting times of products between processes. The researches show that in the traditional batch and queue manufacturing %99 of the product life cycle is waiting meaning only %1 is value added. Reduction in this waste achieves a much shorter throughput time and smoother material flow.

• Inventory- Any kind of excess raw material, component and finish product is included in this group. It is usually viewed as a symptom of poor processes where batching occurs. Because cash is tied to these material for unknown period, it has a negative impact in cash flow of the company. To keep this extra material extra storage should be created so another cost. Implementation of kanban systems are the solutions to this problem in lean.

• Transportation- Moving parts from one location to another is not a value-adding process. Moving the parts from warehouse to operation sites or shuffling the inventory to get the right components can be viewed in this group. It should be noted that some transport in necessary but they should be minimized with defining the shortest paths.

• Unnecessary Movement- Any kind of unwanted movement of the production personnel is in this group. The movement of worker outside of their process are to get tools or materials should be eliminated. Also the work place should be organized in such a way that the operator should not do unergonomic movements like bending or stretching that will decrease their efficiency in the long run.

• Over processing- Using the wrong techniques or taking unnecessary steps that extends the process are in this waste group. Using larger scale equipment or trying to narrow the tolerances than necessary can be used as examples. Not only the cost with extended process times are increased, also it creates an over fatigue on workers.

• Defects- The last type is the defects caused by caused by errors in process and creates a waste of inventory and time because of the rework. Creating quality systems for every station is a good way of preventing this wastes.

Value Stream Mapping

Value stream mapping (VSM) is visual lean manufacturing tool used for the analysis and realization of the material and information flow. The method consists of creating a one page picture of all processes in a company from the receiving of the order from customer to shipping of the product. The purpose of the VSM is to visually document both the value-adding processes and the wastes for easier identification and create a baseline for improvements. The method is carried on 4 steps as:
1. Step1- Define Product or Product Tree
   A product family which share common processes from order entry to shipment is defined.

2. Create the Current State Value Stream Map (CSVSM)
   The scope of the VSM is defined and information on the processes in the boundaries is gathered. From this analysis an initial map is drawn and areas of improvements are noted.

3. Create the Future State Value Stream Map (FSVSM)
   A new map is created by changing the flow to a desired state to fit the needs.

4. Develop an Action Plan to Convert the CSVSM to FSVSM
   An action plan is created to implement improvements in the areas noted and oversee the efficiency of the changes.

![Figure 2.1 A VSM example created by me in a previous project for KTH](image)

2.1.3 Motion Analysis

Motion analysis is the studies that conducting analysis from a visual series to create data from the processing of two or more sequential images. The information that is created from the images are based on specific time-points, hence the motion can be converted to time-dependent data. It is used in computer, electrical and industrial engineering sciences. In industrial sciences, the usage of computer vision is called machine vision, which is the analysis of images to produce time data in controlling processes and activities.

In its applications on manufacturing; by using video cameras and analysis software, analysis are carried out on the efficiencies of assembly lines and production machines. Also by creating a library of the machining data, the underlying factors for malfunctions and defects can be monitored.
Avix Method

Avix is a family of video based software designed by SOLME A.B. It has several modules which aim to enhance the user’s competitiveness in its products and processes by supporting the industrial functions.

Avix method is one of the modules of the Avix product tree that focuses on motion and time analysis used especially on manual assembly processes. The software can be used on:

- Time and motion studies
- Cost and optimization calculations
- Improvement of productivity in single workstations
- Optimizing tooling and lay-out for a workstation
- Continuous improvement
- Measuring productivity and improvement potential
- Documenting the manufacturing processes
- Investment and outsourcing decisions.

The usage of Avix Method is quite simple. The video images of processes are integrated to the software. First every operation is separated by assigning the object of focus and the motion of the operator according to defined categories (e.g. assembling, adjusting, waiting…) by an analyzer. If desired the tools which are used in the operation can be specified. Also the number of undesired operator activities such stretching and bending can be inserted. After all the motions are defined, the software creates a chart by the dividing the work to productive, semi-productive and waste areas. More reports over the process can be acquired and it creates a data base to pinpoint areas of future improvements. An example program window of Avix is shown in figure 2.2.

![Figure 2.2 Example window of AVIX program](image-url)
2.1.4 TRIZ

TRIZ is a problem-solving method, taking its name from the first letters of Russian words “Teoriya Resheniya Izobretatelskikh Zadatch” meaning “Theory of Inventive Problems Solving”, which is also widely abbreviated as TIPS. Unlike other methods such as brainstorming which bases on random idea generation; TRIZ uses algorithmic approaches to improvements and inventions so it relies on knowledge on the patterns of problems and solution, instead of intuition of individuals.

Figure 2.3 Problem finding techniques

The TRIZ theory is first created in 1946 by Genrich Altshuller, a Russian scientist working for the USSR Patent Institute. In his work many inventors had seek consult from him and this led him to search for standard methods of problem solving. However what he found was mostly psychological tool, not meeting the demands set. He concluded that an inventive problem solving method should:

1. Be Systematic, a step by step process
2. Lead to ideal solution in a range variety of options
3. Not be related to psychological tools and be repeatable
4. Able to reach inventive/innovative knowledge
5. Able to add to inventive/innovative knowledge

In the years following Altshuller had studied over 200000 patents to understand how these problems are solved. As a matter of fact, from that day on the patents are still being researched by his follower to improve his method. Now over 2 million inventions are studied and they are divided to 5 levels.
As the table shows over 90% of the solutions to all the problems are present and the creativity involves finding that solution and altering it to fit the problem at hand. The basic idea behind TRIZ is to create a database of problems and solutions which can be used to adapt the problem at hand.

**Table 2.1 List of Invention Levels**

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>INVENTION LEVEL</th>
<th>RATIO</th>
<th>NEEDED KNOWLEDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>KNOWN SOLUTION</td>
<td>32</td>
<td>KNOWLEDGE OF INDIVIDUAL</td>
</tr>
<tr>
<td>2</td>
<td>MINOR IMPROVEMENT</td>
<td>45</td>
<td>KNOWLEDGE OF COMPANY</td>
</tr>
<tr>
<td>3</td>
<td>MAJOR IMPROVEMENT</td>
<td>18</td>
<td>KNOWLEDGE OF INDUSTRY</td>
</tr>
<tr>
<td>4</td>
<td>NEW CONCEPT</td>
<td>4</td>
<td>KNOWLEDGE OF CROSS INDUSTRIES</td>
</tr>
<tr>
<td>5</td>
<td>DISCOVERY</td>
<td>1</td>
<td>EVERYTHING</td>
</tr>
</tbody>
</table>

Altshuller stated that all solutions to problems, create their own problems. He identified contradiction as when a feature in a technical system is improved another one is worsened. Therefore to solve a problem one must know the reaction that the action will bring. By studying over 1.5 million invention problems Altshuller identified 39 standard engineering features which lead to contradictions.
Also from his research on the 1.5 million inventive solutions, Altshuller has identified the common solutions to similar problems. By using this, he had created “40 Inventive Principles” which can be used as guidelines in problem solving. He formed the “Contradiction Matrix” by putting standard engineering features in a 39*39 matrix and put at most 4 inventive solutions to each intersection.

Table 2.2 List of Engineering Features

<table>
<thead>
<tr>
<th>1. Weight of moving object</th>
<th>21. Power (argon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Weight of stationary object</td>
<td>22. Loss of Energy</td>
</tr>
<tr>
<td>3. Length of moving object</td>
<td>23. Loss of substance</td>
</tr>
<tr>
<td>4. Length of stationary object</td>
<td>24. Loss of information</td>
</tr>
<tr>
<td>5. Area of moving object</td>
<td>25. Loss of Time</td>
</tr>
<tr>
<td>6. Area of stationary object</td>
<td>26. Quality of substance and the matter</td>
</tr>
<tr>
<td>7. Volume of moving object</td>
<td>27. Reliability</td>
</tr>
<tr>
<td>9. Speed</td>
<td>29. Manufacturing precision</td>
</tr>
<tr>
<td>10. Force</td>
<td>30. External harm affects the object</td>
</tr>
<tr>
<td>11. Stress or pressure</td>
<td>31. Object generated harmful composition</td>
</tr>
<tr>
<td>12. Shape</td>
<td>32. Ease of manufacture</td>
</tr>
<tr>
<td>13. Stability of the object's structure</td>
<td>33. Ease of operation</td>
</tr>
<tr>
<td>14. Strength</td>
<td>34. Ease of operation</td>
</tr>
<tr>
<td>15. Duration of action by a moving object</td>
<td>35. Adaptability or versatility</td>
</tr>
<tr>
<td>16. Duration of action by a stationary object</td>
<td>36. Device compactness</td>
</tr>
<tr>
<td>17. Temperature</td>
<td>37. Difficulty of detecting and measuring</td>
</tr>
<tr>
<td>18. Illumination intensity (argon)</td>
<td>38. Extent of automation</td>
</tr>
<tr>
<td>19. Use of energy by moving object</td>
<td>39. Productivity</td>
</tr>
<tr>
<td>20. Use of energy by stationary object</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.3 List of 40 Principles of Triz

Altshuller’s 40 Principles of TRIZ

| 1. Segmentation | 16. Dynamics |
| 2. Taking out | 17. Perforation of excessive actions |
| 3. Local Quality | 18. Another dimension |
| 4. Asymmetry | 19. Mechanical vibration |
| 5. Merging | 20. Periodic action |
| 7. "Nestled doll" | 22. "Blessing in disguise" |
| 8. Anti-weight | 23. Feedback |
| 12. Equivalently | 27. Cheap short-living |
| 13. The other way around | 28. Mechanics substitution |
| 14. Synchronicity | 29. Pneumatics and hydraulics |
| 15. Dynamics | 30. Flexible sheets and thin films |
| 31. Porous materials | 32. Color changes |
| 33. Homogeneity | 34. Discoloring and recovering |
| 35. Parameter changes | 36. Phase transitions |
| 37. Thermal changes | 38. Strong oxidants |
| 39. Inert atmosphere | 40. Composite material films |
In the problem solving case, the inventor must identify his own problem and compare his action and reaction features with TRIZ contradictions. If the solution does not meet a reaction, it is the ideal solution. However, if the problem is not too simple, the solution is accepted to meet a resistance. When the improving feature and worsening feature is both identified, the solution can be generated by using the principles found in the intersection of the matrix.

![Figure 2.5 A Section of Contradiction Matrix](image)

For complex problems, ARIZ, the algorithmic solution method of TRIZ, is used. It is a 85 step-by-step procedure to solve problems.

### 2.2 Methodology

This project is an applied practice-oriented research because it is carried out to solve a problem in an industrial institution. Therefore the framework of the project is based on the design cycle of practice-oriented research methodology.

![Figure 2.6 Design Cycle of Practice Oriented Research](image)
The design cycle is adapted to the problem at hand so its disposition is a little different in the project. In the project the problem finding phase and diagnosis phase has interlocked with each other. The problems are identified through data collection and observation of the created current state VSM through literature study of lean manufacturing. At the same time the diagnosis is carried from analysis of current state VSM and improvement areas are identified. At the design step, the new production model is created in the future state VSM.

In the intervention step, improvements to reach the idolized model are done. Each improvement can be viewed as a design cycle in themselves because they show a similar structure. In the VSMs the problem finding and diagnosis parts are done for each individual problem. Then through an improvement approach of using both TOC and Lean Manufacturing techniques in harmony; the solutions to elevate the system constraint and continuous improvements to eliminate wastes of the system are done at the same time. This could be counted as the sub-design part of intervention step because through literature study (TRIZ, Motion Analysis...) various methods are researched and effective solutions to the problems are created. Then the improvements proposed are implemented first through a pilot are to see results in bottleneck operations and through calculating the benefits from a simulation in layout changes.

In conclusion the results of each improvement and progress covered on the new model are discussed. Lastly future work that can be done to advance this research is described.

---

**Figure 2.7 Research Framework**
3.1 Introduction to Products and Production Floor

Transformers are static devices that transfer electrical energy from one voltage level to another through induction with minimum losses. The first discovery of the three-phased transformers which are used today dates back to 1890s. Although new technologies are developed and different kind of transformers are being produces today, the most common old design still is the most popular one. The main parts of a transformer are shown in the figures below.

![Figure 3.1 Standard Distribution Transformer and Its Components](image)

Although there are some designs such as amorphous transformers where some parts change due to the different shape of the core; the parts in the active part are same in every design. However parts on the tank of the transformer vary a lot. Except the corrugated tank, nearly all other parts are optional and are used according to the wishes of the customers. A better view of the core and the winding can be seen in figure3.2.
ABB production is based on build-to-order system meaning that the production starts after the customer’s order is received. So the production cycle begins when sale department confirms the project and sends the requirements of the customer to the design department. The design department does not categories the specifications of the project to standard products but create new design for each customer with the help of CDS, a tool for standardization of design. The reason of this is the vision of ABB to create transformers specific to each customers demand. Because of the huge number of the new designs, there is always a work load in this department and the process takes from 2 to 3 weeks.

After the creation of the designs, they are passed to the production planning department. The planning department checks the manufacturability of the designs and makes an inventory check based on the bill of the materials. If no revision for the design is required, the materials lacking in the inventory is ordered by the supply chain group in this department. The production schedule is created for both the core pre-assembly line and the assembly line. The production plan in the assembly line is created according to the bottleneck operation, HV winding, and all the downstream and upstream operations are scheduled based on that operation. After the materials are gathered from the suppliers the production begins. In the production phase the production planning department oversees the process of the production advancement and creates daily orders according to it. These orders are transmitted to production supervisors and through them to operators working on the machines.
The pre-assembly line is the core production workshop. In this workshop the silicon steel raw material are shaped in to central core of the transformers. The inventory of silicon steel varies due to the order strategy based on prices of metal market. However a constant inventory is always kept due to the material’s long supply time because ABB buys all of the silicon steel from off-shore suppliers.

The first process in the pre-assembly line is core slitting. Here the wide silicon steels coil sheets are passed through blades for being split to desired thickness. The thicknesses are arranged with shrinkage in both ends of the coil, the silted pieces rolled again to coils to be passed to the next process.

The second process is core cutting. The slit coils are cut and shaped into desired forms. The sheets can be formed rectangular, triangular ended (45° is the most common) or even amorphous. The core stacking process can be combined to core cutting because once the sheets are cut they are moved through the machine automatically to be stacked. Each sheet is released over each other by sliding through a pin to create the multilayer core form. The operators introduce the project to the PLC and make sure that the pins are correctly placed so sheets misplace. The process map of core workshop can be seen in figure 3.3.

![Figure 3.3 Process Flow of Pre-Assembly Line](image)

One important fact about the pre-assembly line is that, it cannot create desired numbers of intermediate products and keep up with the production rate of the assembly line. The reason of this is the insufficient production capacity of the machines in the core cutting and core stacking processes. Therefore although the core slitting capacity can keep up with the production pace, the core cutting and stacking operation are done to subcontractors or even manufactured cores are acquired directly from suppliers. The pre-assembly can manufacture %50 of the cores necessary in the production of the transformers and the rest %50 is supplied by other means. However right now a new core cutting & stacking machine has been brought to the workshop and its implementation is
still going on. When the new machine becomes fully-operational, the need of out-sourcing will be eliminated.

The main assembly line starts with the LV winding process. Both SDT line and MDT line has one machine each for this operation. One coil before the finish of the project, a signal is given to the material handling personnel for kitting. The insulation paper where they are arranged for production in paper workshop and the conductor sheet rolls positioned in their open inventory locations are brought to the kitting area in front of the machine. In most of the project the cores produced are carried to this area because winding will be rolled over them. However in some projects the winding is not done this way but to wooden block with the same width of the core. In these projects, the windings are stacked to the cores after the HV winding process. ABB is still trying to standardize all its production to winding over core but still there are some exceptions.

In the change-over for a new project, first of all the operator replaces the insulation paper and the conductor metal coil. Then he places the core and inserts the project’s program to the PLC and the operation begins. The operation consists of covering the coil by rolling the thick insulation paper and the metal foil over it. Also according to the design in specific laps, aluminum leadout plates are be cold-welded on the machine. However because aluminum oxides quickly, the leadouts should be grinding just before the welding so the operator should leave the workspace to go to the grinding machine.

The second operation in the main assembly line is the HV winding. For this operation there are 4 machines in MDT line and 3 machines in SDT line. The coils created in the first operation are moved through the conveyor to the second work area. They are picked by manipulators and placed to the HV winding machines. The change-over of this operation is similar to its predecessor. After the resources are gathered by the kitting signal, the insulation paper and the conductor wire holdings are replaced, and the program is installed. The operation is carried on by rolling the conductor wire over the coil while at the same time covering it with thin insulation papers. Again in specific lap leadouts are created but this time it is done by cutting the wire and bending it to the side of the coil. Once the operation is done the coils are picked by manipulators and placed over the conveyor again. Because the HV winding is the bottleneck of the main assembly line, a more detailed explanation will be done in chapter 4.

The third operation is Assembly on Table. There is open machine for SDT line and one Machine for MDT line again. In this operation, 3 coils, manufactured in HV and are ready in the conveyor, are assembled to form the base of the transformer. The operators first place the 3 coils to holders on the machine and then positions the upper and lower cores as the tip of the first 3 coils will stack with
them. After this yokes and sidings are assembled. In the end of the process, the base as one piece is picked by a crane and carried to the waiting area in front of the next workstation. The windings which are done not on cores but instead on wooden blocks are combined their cores in this phase.

The next operation is LV&HV Connectors Assembly. In this workstation the SDT and MDT lines are merged and both operations are done in the same workspace. There two parts for this operation which is handled by two different workers. In the first phase of the operation, the LV bushings and the wires are connected and the tap changer is assembled. After LV connectors the second operator assembles the HV bushings and wires and passes the product to the next station with crane.

The fifth operation continues as a single line for SDT and MDT. In the tanking operation the cover of the transformer, tank, is lowered to the active part and assembled with screws. The bushings are fastened again and the transformer is ready to pass to the next phase.

In the insulation drying operation, the MDT products and SDT products separates again. The MDT products go the Low Frequency Heating (LFH) and the SDT ones to Natural Flow Heating (NFH). First the parts are put to heating cells in batches and conductor wires are attached to its ends. Then the number of the inserted parts and their specifications are identified the program. The machine first vacuums the air in the cells so no moisture can affect the process. After this, under a constant circuit the transformers are dried so the insulation papers of windings are stuck to each other.

In the end of drying operation the first thing is to fill the tanks with oil. Otherwise the insulation papers will react with the water particles in the air and all the process will go to waste. After the oil is filled the pressure test is carried and the transformers are carried to test waiting area for cooling to room temperature.

The tests are common for both types of the products. The products are put to a conveyor in the chamber and setup for the testing. There are two tests per product and the area is arranged as a cellular layout. Two workers do the tests in a circular flow: while one operator finishes the first test and pass the part to the second phase, the other operator finishes the second test and brings a new product to testing chamber.
The last operation is the finishing and shipping. Finally the accessories specified by the customer are assembled to the transformer and then the transformers are packed for shipping.

The process flow of the main assembly line is as figure 3.4.

![Figure 3.4 Process Flow of Main Assembly Line](image)

### 3.2 Current State

#### 3.2.1 Data Analysis of Current Production

A companies’ capacity in carrying out production planning and improvement implementation operations is parallel with collecting accurate data from the production floor. It is hard to maintain an efficient data gathering system; therefore most companies have only vague ideas about their processes. The biggest problem is the lack of information flow between production floor and higher management due to traditional manufacturing.

In the recent years has carried out projects to overcome this problem. In the implementation of CP3 project, ABB has configured its SAP software to collect data of actual labor hours and material consumption. Also in the early phases of the CP3 project, a VSM was created to make an overview picture of the assembly line. However there are still problems in using these tools efficiently. First of all there is no revision on the VSM so it is out of date. More importantly the SAP production module
is not fully utilized to the everyday usage in production floor. Although the operators are responsible for writing the process times, there is no system that is overseeing nor checking them. Plus the encouragement from the higher management on this is not sufficient, so most of the time the data is not collected or unreliable. Due to the unreliability of this data, the data collection is carried through inspection of the processes and interview with the operators and production supervisors.

Data Analysis of the Main Assembly Line

For the creation of VSM, the data which will be analyzed are:

- Operation times
- Change-over times
- Batch sizes
- Number of Shifts
- Number of workstations/machines
- Number of work in processes (WIP)

The process characteristics are acquired from the production supervisors and the process timings from interview with operators for they held the best information on this topic. Although the times can deviate hugely because of the sheer number of different designs, an average time has been determined to be used. However for the number of WIP, a more direct approach has been used. For three weeks an inventory count has been made and the average has been confirmed as the WIP level. The data of the processes are shown in table 3.1.

| Table 3.1 MDT and SDT Lines Process Data |

Beside the usage of the data in the VSM, it is also important for capacity planning. In estimation the company works for 280 days a year and a day consists of 3 shifts of 8 hours with 1.5 hour breaks. The total available time is:
Because there is no efficient data about the breakdown and maintenance times an assumption of %5 breakdown time is made. So the actual total time is multiplied with a safety factor to find the actual available time:

\[ T_{Total} = N_{days} \times N_{Shift} \times (T_{Shift} - T_{Break}) \]

\[ 280 \times 3 \times (8 - 1.5) = 5460 \text{ hours} \]

The yearly demands for the STD are 1800 and for MDT it is 2200. With the demands and available time known the takt time is calculated for both lines:

**SDT:**

\[ T_{takt(SDT)} = \frac{T_{AV}}{D_{SDT}} = \frac{5187}{1800} = 2.88 \text{ hours} \]

**MDT:**

\[ T_{takt(MDT)} = \frac{T_{AV}}{D_{MDT}} = \frac{5187}{2000} = 2.59 \text{ hours} \]

After the calculation of the takt times, a capacity planning is carried out to assess if the demand is met in each station and determine the bottleneck operation for both lines. The capacities of the processes in SDT line is shown in table 3.2.
<table>
<thead>
<tr>
<th>SDT</th>
<th>No of Workstations</th>
<th>Batch Size</th>
<th>Daily Time Avaiible</th>
<th>Net Operation Time</th>
<th>Capacity(280 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV Winding</td>
<td>1</td>
<td>1</td>
<td>19,5</td>
<td>1,333333333</td>
<td>4095</td>
</tr>
<tr>
<td>HV Winding</td>
<td>2</td>
<td>1</td>
<td>19,5</td>
<td>4,333333333</td>
<td>2520</td>
</tr>
<tr>
<td>Core&amp;Coil Assembly</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>0,833333333</td>
<td>4368</td>
</tr>
<tr>
<td>LV &amp; HV * Connections</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>2</td>
<td>3640</td>
</tr>
<tr>
<td>Tanking</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>0,4</td>
<td>9100</td>
</tr>
<tr>
<td>NFH</td>
<td>1</td>
<td>6</td>
<td>19,5</td>
<td>8</td>
<td>4095</td>
</tr>
<tr>
<td>Cool&amp;presp</td>
<td>1</td>
<td>6</td>
<td>19,5</td>
<td>2,5</td>
<td>13104</td>
</tr>
<tr>
<td>Test*</td>
<td>1</td>
<td>1</td>
<td>8,125</td>
<td>0,456666667</td>
<td>4981,751825</td>
</tr>
<tr>
<td>Packing &amp; Shipping</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>1,25</td>
<td>2912</td>
</tr>
</tbody>
</table>

Table 3.2 Current Capacity Planning of SDT Line

From the listed table 3.2, it can be viewed that the HV winding process has the least yearly capacity with 2520. Therefore it can be bottleneck operation of the SDT main assembly line. Even though it is the bottleneck, still the capacity satisfies the yearly demand. HV winding capacity is followed by ‘packing & shipping’ and LV&HV Connections processes in order.
For the MDT line the capacities are as table 3.3.

<table>
<thead>
<tr>
<th>MDT</th>
<th>No of Workstations</th>
<th>Batch Size</th>
<th>Daily Time Available</th>
<th>Net Operation Time</th>
<th>Capacity (280 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV Winding</td>
<td>1</td>
<td>1</td>
<td>19,5</td>
<td>1,933333333</td>
<td>2824,137931</td>
</tr>
<tr>
<td>HV Winding</td>
<td>3</td>
<td>1</td>
<td>19,5</td>
<td>6,9</td>
<td>2373,913043</td>
</tr>
<tr>
<td>Core&amp;Coil Assembly</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>2,333333333</td>
<td>3120</td>
</tr>
<tr>
<td>LV &amp; HV * Connections</td>
<td>2</td>
<td>1</td>
<td>13</td>
<td>2,5</td>
<td>2912</td>
</tr>
<tr>
<td>Tanking</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>0,6</td>
<td>6066,666667</td>
</tr>
<tr>
<td>NFH</td>
<td>1</td>
<td>5</td>
<td>19,5</td>
<td>10,416666667</td>
<td>2620,8</td>
</tr>
<tr>
<td>Cool&amp;pres</td>
<td>1</td>
<td>5</td>
<td>19,5</td>
<td>2,533333333</td>
<td>10776,31579</td>
</tr>
<tr>
<td>Test*</td>
<td>1</td>
<td>1</td>
<td>8,125</td>
<td>0,656666667</td>
<td>3464,467005</td>
</tr>
<tr>
<td>Packing &amp; Shipping</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>1,25</td>
<td>2912</td>
</tr>
</tbody>
</table>

Table 3.3 Current Capacity Planning of MDT Line

For the MDT line, the bottleneck is again the HV winding process with a capacity of 2373 pieces a year. However the second process with the least capacity is NFH although it is done in batches. Also it should be noted that the HV winding have 4 machines actually but in the capacity planning it is noted as 3. The reason of this is that one of the machines is not used in most of the time and the operator availability at the night shifts. Most of the other processes have close capacities.

3.2.2 Current State VSM

After all the data about the main assembly line is gathered, these data are put into use for the creation of VSM for both of the lines. The current state VSM of the MDT and SDT lines are in figure 3.5.
The VSM just creates a clear picture of the material and information flow, hence to mark the problems in this flow, a deeper analyze is done. However before the analyze, a note should be done about the unfilled forms in the pre-assembly line. As mentioned before, this project was carried out before the implementation of the new core stacking machine, therefore the core workshop is included in the VSM just to show the flow of materials.

The first fact to be examined is the throughput time (TPT) because it is good identifier for both the flexibility and the efficiency of the system. The TPT of the production line shows the time interval between the production of a part starts and it is send to the customer. Thus the shorter the throughput, the more flexible the system is. Also the ratio of the value added and non-value added activities in the TPT, gives an estimate in the efficiency of the production.
From the sum of time intervals in the VSM, the TPT is calculated 8.16 days for MDT and 5.96 for SDT. The dispersion of the value added and non-value added times in throughput are shown in table 3.4.

<table>
<thead>
<tr>
<th>Throughput Time(days)</th>
<th>Value Added Time(days)</th>
<th>Waste Time(days)</th>
<th>Ratio of Value Added(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDT</td>
<td>8.17</td>
<td>1.37</td>
<td>6.80</td>
</tr>
<tr>
<td>SDT</td>
<td>5.96</td>
<td>1.00</td>
<td>4.96</td>
</tr>
</tbody>
</table>

Table 3.4 Lead Time Data of Current VSM

In both of the lines the value added time is %17 percent of the whole time, meaning the rest %83 goes to waste due to transportation and waiting. The layout of the floor is designed to minimize the distances between station and the only considerable transportation waste is in the shipping process. Thus the majority of the non-value added time is the waiting between processes. The four major waiting areas are the shipping, HV winding, assembly on table and HV&LV connectors. All these areas are identified in the VSM with a pull system from a safety stock.

The prime waiting area is the finished products inventory. In both lines almost %60 of the waiting is recorded here. The underlying factor of this huge number of WIP is the uncertainty in the upstream process and a limited number of made-to-stock products. Because the products are sent in parties, even the products which are covered with protective coatings wait for the rest of their party to be finished. This time can extend to undesired losses because the batching in the drying process and the incongruity of the test shifts with the other processes. Also if a failure is detected in one of the products in the tests, this waiting will be even prolonged because most of the times reworking the product is not possible and the production should be started from the beginning.

The secondary huge WIP area is the HV winding. It should be noted that it is an expected result due to its status as bottleneck. Because the production is scheduled according to the drum-buffer-rope system, the allocation of the resources has been based on this process. Therefore for the production in this station to continue even in the worst possible scenario a constant inventory is kept. The big volume of this stock can be related to the sovereignty of the machines, where each machine works on separate projects so must keep its own stock.

And the third important waiting area is the ``HV & LV connections``. Even the underlying cause of the waiting times in the ``assembly on table`` station is the problems in this station so the importance of the waste here increases. About the underlying factors of this huge waiting time, first this station has
the widest range of different parts to be assembled. Because of the deviation in the supply times of these parts, a huge time is wasted in waiting for the arrival of the parts. Also although it is not determined in the procedures, the operators in this station tend to work in a batch type style. Therefore the operators first wait for all the assembled parts in the same project to be ready from the previous stations and then start to work. This waiting can increase according to volume of the order in the project and if one of the connections is not supplied in time, the flow can be interrupted. One final important aspect in the waiting time is the transportation. Up until the "assembly on table" the parts were transported through conveyor belt. However the coils are carried from there to this station with cranes. Two of the three cranes on the ceiling of the plant can be used for this purpose. Due to these cranes usage in various different tasks in the all three lines of production, the unavailability of them can cause more wastes.

The production flow of both SDT and MDT lines are capacity oriented instead of tact time orientation. The clearest indicator of this is the cycle time of the bottleneck. In both of the lines the HV winding process is finished in a higher time than the tact, and especially in MDT line the cycle time is 6,1h in contrast to the tact time, 2,59h. Here the demands are met with the number of machines working on different products. A similar station is the insulation drying process where the longest process times occur. The cycle times for MDT is 10 hours and for SDT 7,5 hours. However by operating with a batching style and working for 3 shifts it meets the demand with a clear margin.

As for the flow of material through the line the first station LV winding starts with a push to keep a constant inventory for the bottleneck. From there up to the connections assembly pull systems are used. In this station the parts are pulled from the safety inventories before them according to the scheduling and supply criteria of the projects. From here on again the materials are pushed to the drying process so they can be available in one of the three cycle of operation start per day. The parts which pass this station directly goes to pressure test in the order they enter and the testing operators chose the priority of the parts according to their schedule. Finally in the packing they are again pulled according to the shipping times of the finished good.

Also one other important fact about the current state is that all the operators are dedicated to their respective stations. All the operators are specialized in their own stations and there is no rotation. In the winding processes, although the HV and LV operations share similar traits, the operators in HV can’t work LV and the versa because of the lack of knowledge on the machine. Another example of this occurs in the connections assembly station. Once again the operators, who connect the LV parts, do not help the HV assembly operators although they are in the same station.
3.3 The Idolized Production Model and Its Analysis

After the analysis of the current state VSM is done, the priorities for improvement of the line are identified. From the early calculation, it was found out that the capacity of the plant meets the demand of the market with a clear margin. Therefore the focus of the developments in the line should not be the abatement of the cycle times to increase the capacity but issues which will increase the compatibility of the company in the market.

Today with the widespread implementation of the lean manufacturing applications in the industry, the production becomes more customized according to the customer demands. ABB’s design-to-order system to order system, that each product is specified to the customer, is a good application for customer satisfaction but it can’t be said that its production system is compatible with it. The backbone of the design-to-order system is a flexible and efficient production where throughput times are low and wastes are minimal so changing from one project to another is done rapidly. However the current state VSM shows clearly that the production flow is disrupted and does not allow maximizing the advantages of the system.

Therefore in the visualization of the future VSM, the production line is composed to enhance the total performance of the system. The waiting times are lowered to diminish the throughput time; the change-over times are decreased to allow quicker passing through projects and the stations are rearranged for a smoother flow. The future VSMs for both lines are shown in figure 3.6. (For a more detailed view see appendix)
The new production model visualized in the future VSMs shows promising results while at the same time not needing huge investments. Instead of creating more resources by integrating new machines and processes to the system, it utilizes the performance of each station by allocating the existing resources more evenly.

In the future VSM, the primary improved area is the processes before the insulation drying where the flow is constantly interrupted with safety inventories. First the working style of the bottleneck is changed. The extra fourth HV winding machine in MDT is sent to SDT line and the number of machines evened with needed coils for a transformer in both lines. Instead of each machine following a project individually to lower the importance of change/over times, the change times are reduced to its half and a cell like system is visualized. In this system all three winding machines
undergo change/over at the same time and work on one coil of the same project. By this way the cycle time of the process is lowered from 6.3 hours to below the tack time and evened with the adjacent stations. The improvements carried to elevate the bottleneck operation, HV winding is in chapter 4.

The connections assembly and tanking operations were combined to a cell to cancel the waiting time before the tanking and overthrow the huge process time difference between them. The tanking process is done by the LV winding operator instead of waiting for dedicated operators of tanking and a balanced work load between LV and HV connection is assured. The operators here are trained so that they can work in both of the assemblies in the situations where one operator is unavailable. Also the work here is pure labor so a more flexible operation is advantageous.

As mentioned, no extra capacity contribution action is taken, hence from the re-arrangement of the resources, the overall capacity alters modestly. The new capacity limits of the processes are shown in table 3.5.

<table>
<thead>
<tr>
<th>MDT</th>
<th>Capacity (280 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV Winding</td>
<td>2923</td>
</tr>
<tr>
<td>HV Winding</td>
<td>2391,240879</td>
</tr>
<tr>
<td>Core &amp; Coil Assembly</td>
<td>3545,454545</td>
</tr>
<tr>
<td>LV &amp; HV* Connection &amp; Tanking</td>
<td>2426,666667</td>
</tr>
<tr>
<td>NFH</td>
<td>2620,8</td>
</tr>
<tr>
<td>Cool &amp; Ores</td>
<td>10776,31579</td>
</tr>
<tr>
<td>Test</td>
<td>3464,457005</td>
</tr>
<tr>
<td>Packing &amp; Shipping</td>
<td>2912</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SDT</th>
<th>Capacity (280 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV Winding</td>
<td>4310,526318</td>
</tr>
<tr>
<td>HV Winding</td>
<td>3863,207547</td>
</tr>
<tr>
<td>Core &amp; Coil Assembly</td>
<td>4308</td>
</tr>
<tr>
<td>LV &amp; HV* Connection &amp; Tanking</td>
<td>3033,333333</td>
</tr>
<tr>
<td>NFH</td>
<td>4095</td>
</tr>
<tr>
<td>Cool &amp; Ores</td>
<td>13104</td>
</tr>
<tr>
<td>Test</td>
<td>4981,751825</td>
</tr>
<tr>
<td>Packing &amp; Shipping</td>
<td>2912</td>
</tr>
</tbody>
</table>

Table 3.5 Future Model Process Capacities

The only important capacity changes occur in HV winding and connection assembly & tanking processes. The removal of the rarely used HV winding machine from the MDT line lowers the capacity of the station only slightly due to the positive effect of the shorter change/over times. However the implementation of this machine to the SDT line makes a huge impact on boosting the SDT capacity. The system constraint is unraveled and the overall capacity increases to approximately 3000, the capacity of the new bottleneck. In both of the lines with the adding of the tanking process to the same cell of connection assembly cell the capacity of the cell is lowered by nearly %20.
The capacity changes have an influence in the systems constraint where both lines have two structural bottlenecks with close capacities. In MDT the bottleneck, HV winding process with 2520 yearly capacity is still one of the constraints with 2391 pieces/year but then newly formed connection assembly cell is close-by with 2426 pieces/year. In the SDT line the bottleneck moves totally to two stations, packing&shipping and connection assembly cell with 2912 and 3033 yearly capacity respectively. To assign the connection assembly cell as the system constrain in both of the stations is a desired outcome because the stations status that has the most deviance in the supplied resources. Therefore by moving the constraint to this station, the upstream and downstream operations can be planned according to the supply availability of the resources here and the waiting times can be diminished.

With the new cellular working system in the processes, the material flow, between the LV winding and insulation dying is advanced to cancel the flow disruptions. In the old production system the scheduling of all the processes were done according to the HV winding and the work orders were sent to each station. With the new model the scheduling is done according to the arrival dates of the resources to the connection assembly cell and once all the materials are ready a kanban signal is sent to the HV winding to start the production. The produced part in here are passed to assembly on table and from there to connection assembly in one piece flow, hence the safety inventories which are an important part of the total wastes is obliterated. However it requires a more precise scheduling program so a system should be developed to accurately predict process times, especially for HV winding.

With a better scheduling program, provided by kanbans and less throughput time, the inventory on before the shipping can be debased to provide the goods just-in-time. Even if a defect is discovered in the testing process, with the new more flexible system the defected product can be compensated less than two days if spare parts are available. Therefore the waiting time before the shipping is estimated as 1 day.

With the improvements in the future model, the throughput times and waste ratios alter to data in table 3.6.

<table>
<thead>
<tr>
<th>Throughput Time(days)</th>
<th>Value Added Time(days)</th>
<th>Waste Time(days)</th>
<th>Ratio of Value Added(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDT</td>
<td>2,98</td>
<td>1,14</td>
<td>1,84</td>
</tr>
<tr>
<td>SDT</td>
<td>2,75</td>
<td>0,90</td>
<td>1,85</td>
</tr>
</tbody>
</table>

Table 3.6 Future Model Lead Times
The MDT line’s throughput time lowers from 8.17 days to 2.98 days which is approximately 63 percent. For the SDT line it is 54 percent where it drops to 2.75 from 5.96. The ratio of the value added increases in both stations; %38 for MDT and %33 for SDT. The analysis shows that a great progress has been made in the company’s flexibility and production efficiency. The improvements carried out to orient the company toward the future goal are explained in sections 4 and 5.

In conclusion about the VSM, it should be noted that the goals set in the future map are not written in stones. As progress is made on the production system, the goals can become unfeasible or even understated. In that case a new current state VSM should be created and new goals should be set in for the future VSM.

CHAPTER 4 - Elevating the System Constraint

To prosecute the production system in the newly formed future model, first the current system constraint should be ameliorated. Therefore a deeper analysis of the HV winding process is carried on and from these research two main problems that are blocks to the process’ evolution stand out. The first problem is the extent change over times due to its wasteful work procedure in both LV and HV winding. This problem both prevents a cellular type production and stands as the underlying factor of high safety inventories. The second conclusion is that no one has exact knowledge of the process times, thus the vague information creates inefficiencies in both production scheduling and material supplying. To overcome the problems the improvement activities conducted are:

- Development and implementation of new changeover procedures and methods
- Creation of a process time formula based on the properties of products

4.1 New Changeover System

In the new production model the cycle times of the winding processes are reduced with %66. If the changeover times are left as they are now, their ratio with process times would be 0.3. For a production line where a project change, occurs averagely every 7 products, this ratio is unacceptable. Furthermore with synchronization of the winding machines, each machine cannot make its own pace. Hence the scheduling strategy to assign one machine to a very long project to one machine and assigning the other deviating projects to other two for lowering the total number of changeovers is not applicable and if an improvement on the changeover time is not made, the new system will
decrease the efficiency instead of busting the performance. To overcome this negative effect, it is predicted that the changeover times should be at least halved. So a data analysis of the process is carried out.

4.1.1 Data Analysis of Constraint Operation

As a part of CP3 Project implementation, ABB has implemented the Avix Method software for monitoring manufacturing processes. Avix Method tool is a motion analysis program where the processes recorded by a video camera can be used to carry a deeper analysis on the methodology of manufacturing activities. From 2009 when Avix has started to be actively used, over a hundred hours of filming has been done to create an archive on all of the production processes. Whenever a new procedure or an improvement is proposed, the related files from this archive are used to base the findings.

For the LV and HV winding processes where the changeover is nearly identical except installation of different material types of conductor, there are several recording from different machines. However to have more validate data for analyzing similar problems and to create a work description additional video films from different projects were recorded and analyzed.

In both of the winding processes, it is observed that there are 4 objects of focus which the operator should make sure fitting to the project to complete the changeover. So all the changeover activities can be grouped based on which of these 4 objects that is prepared.

1. **Coil**: The changeover operations that the operator should do to ensure the coil is placed properly to start the production compose this group. Preparation of the coil holders in the machine and transportation, placing and affixing of the coil are its typical activities. In LV the conductor sheets are placed over wooden shelves for picking but in HV winding they should
be chosen among the other LV wined coils on the conveyor. These operations are carried in the front side or conveyor side of the machine.

2. Terminal: The operations concerning the object terminal are about preparing the winding machinery for production. No material change is done on this group. The activities are installation of the PLC program, or choosing of an already existing one, adjusting the frontier holders for use and checking of any malfunction. Again these operations are carried on the front side or conveyor side of the machine.

3. Conductor: These operations in this group are the activities carried out to switch the conductor material to the fitting one for the new project. In LV the conductor are sheet rolls while in HV they are either metal wires or less likely paper covered wires. According to the projects two sheets/wire rolls may be needed to install. Handling the conductors via crane, affixing wire holders, adjusting insuring the straightness of sheet/roll are counted in this group. These activities occur in the back side of the machine.

4. Insulator: The activities in this group deal with replacing the old insulation papers with the insulations fitting to the new project. In the LV machine long insulation paper rolls are used but for HV strap insulation rolls are used. Two or more rolls can be used to achieve the desired insulation thickness. The paper holders are stationed in the side of the machine.

It should be noted that all these operations can deviate from project to project. In many instances projects with same material of conductor, insulator or both sequenced continues so no changeover activity for that material is needed in the project change. By monitoring the project materials, the planning department prioritizes scheduling projects this way. Also the design department tends to use the same winding designs while making changes in the other parts because the time gap between writing a new plc program and using an existing one is huge.

The Avix analysis made from different projects are very deviating. Therefore for a deeper methodology analysis, from the data library the records which can be counted as the most standard work where all four work groups are present and has the least unexpected events occurring are chosen. The two operations were chosen are a 2500kVA transformer' HV winding changeover operation and a 400kVA transformers' LV winding changeover operation

For the HV winding, the process chosen for deeper study was project 10117. The project was the manufacturing of a transformer of 2500 kVA and its HV winding process was carried in Tuboly 294 machine. The changeover operation had been done by the dedicated operator alone save for some minor jobs which he had help from the material handling personnel. From the analysis of the operation, the task list and efficiency chart acquired from Avix is as figure4.2.
There are a total of 21 tasks in the operation which takes approximately 60 minutes. In these 60 minutes of work there is no productive part with green indication at the performance chart. The reason to this is that in theory changeover is not a value adding process but to precede it must be accomplished. Therefore it is indicated with yellow color meaning it is a semi productive work. The performance chart shows that %83 of the job is semi-productive while the rest %17 is waste. The total waste is divided to 2 groups which is %4.78 waiting while %11.89 is unnecessary activities in the work. For more detail in about the activities a task report was printed.
Figure 4.3 Task Report of HV Winding Process

The task report gives a better insight about the efficiency of all parts of operation. The type of activity, the object in focus and the tool used for the task is described. Also the timings of waste and productive activities for each task are given separately. As expected from a set-up operation the placing activities have the highest value. The other high time consuming activities are handling, adjusting, affixing and instructing.

It can be observed from the task report that the waits are divided proportionally throughout the operation. The highest waste record was the time which the operator had to walk to the insulation shop to retrieve insulation papers because it was not brought by material handling personnel.

Although the there are some waiting areas with high times, the real waste problem is caused by the small waste times spread to all tasks because added together they form nearly %12 of all operation.
As the tasks which wastes occurred are monitored, the majority of this time is seen to be spent in walking from one work place to another. Figure 4.3 illustrated above shows the layout of the machine. It can be seen that to work on the wires the operator should round the machine and reach the walk path side of the machine and the insulator switching is done at the right side of the machine. The tools are kept in the working area so the operator should walk back and forth throughout the operation. The walking times are zero in the terminal operation because the operator does not need to move for that operation but as the path he needs to walk extends the more waste is recorded. The steps of the operator are counted from the record to be approximately 300 when every step is counted as 0.8 seconds. In this calculation the path he had to to the insulation is not counted. If that is added the operator spends 10 minutes of time just walking which has no value at all and even decreases his performance because he tires himself.

A similar analysis is carried out in LV winding process for a 400kVA transformer. The winding machine in focus was Tuboly 193 machine and the operator has done the changeover all by himself. The task list and efficiency chart acquired is as figure 4.5.
The LV set-up for this transformer takes 49 minutes. It should be noted that this time could be even longer if the PLC program of the project wasn’t already present in the machine. The operator accomplishes 22 tasks to finish the operation which is one more than the HV windings’. The efficiency chart shows that the semi-productive work is %73.66 and the rest %26.34 is waste. Among the waste area %1.71 is spent on waiting. The detailed task report is as below.

Figure 4.5 Task List and Efficiency Chart of LV Winding Process
In the LV changeover the highest time consuming activity is the placing again. It should be noted that the instructions activity time is very low in this changeover. As mentioned before the program of the project was already in the machine so it greatly reduced the time.

The waste percentage is 26% which is greater than it was in the previous projects. The waste times are spread through all the processes, but their distribution is very different than the HV winding’s changeover. In this process the majority of the waste time is spent in the conductor replacement. In the HV winding the new wire rolls were carried by the operator for a very short distance with only sheer force. However in LV winding the conductive rolls can’t be carried without the aid of a crane for its heaviness. Therefore the operator should wait for the crane to be available then pick the right
roll from the inventory area and carry it. Plus the affixing of the conductor is more problematic; the time spent in this task increases further more.

### 4.1.2 Creation of New Changeover Procedures

As the data of the winding process is gathered it is seen that even if all the waste time is eliminated, it is not possible to reach the desired changeover times. The problem is not only the wastes but also the long semi-productive work carried by the operator. Hence to find a solution to this problem, a brainstorming activity is conducted. In this process, to generate creative ideas, the Triz problem solving method was used. Although this method is generally used for product design solutions, it can be efficiently applied for process improvements.

In the first step of Triz analysis, the contradiction matrix should be formed. The goal is to decrease the changeover process times. Therefore the feature which is aimed to be improved is number 25, loss of time. As for the contradiction feature, the property which is damaged by this action should be identified. If the process time is diminished by just hastening the work pace of the operator, it would lead to him to waste more energy and over exhaust himself. So the worsening quality in this problem is number 22, loss of energy. The contradiction matrix with these feature are shown in figure 4.7.

![Contradiction Matrix Intersections](image)

**Figure 4.7 Contradiction Matrix Intersections**
The intersection in the Triz matrix proposes number 5, 10, 18 and 32 among the 40 principles. These principles are:

5. **Merging**
   - Bring closer together (or merge) identical or similar objects, assemble identical or similar parts to perform parallel operations.
   - Make operations contiguous or parallel; bring them together in time.

10. **Preliminary Action**
   - Perform, before it is needed, the required change of an object (either fully or partially).
   - Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.

18. **Mechanical Vibration**
   - Cause an object to oscillate or vibrate.
   - Increase its frequency (even up to the ultrasonic).
   - Use an object’s resonant frequency.
   - Use piezoelectric vibrators instead of mechanical ones.
   - Use combined ultrasonic and electromagnetic field oscillations.

32. **Color Changes**
   - Change the color of an object or its external environment.
   - Change the transparency of an object or its external environment.

As the suggested principles are studied, while the numbers 18 and 32 are founded irrelevant with the subject because they are more related with product designs; the merging and preliminary action principles are found fitting to the changeover process. They are used as a base for the improvement solutions to the problem.

The passage, “Pre-arrange objects such that they can come into action from the most convenient place and without losing time for their delivery.” in the 10th principle, is directly pointing to the kitting activities before the changeover process. ABB already has kitting procedures to prepare all the necessary materials before the start of the projects. In the last coil before the new project, an order to the material handling is sent for them to move the needed resources to kitting areas next to the
winding machines. However as seen in the Avix analysis, due to the material handling personnel’s negligence some of the resource is not present in its kitting place causing the operator to personally pick them up or mixed in the material pile in the kitting area, creating waste due to confusion.

These wastes can be eliminated easily with the implementation of a checklist to ensure the materials are moved in time. With every new project a checklist, showing the resources to be placed before the process, can be sent for material handling personnel to fill. By this way the material handlers can see which resources are present in the kitting area and so the confusion caused by absent or mixed materials can be eliminated.

As for the real creative idea, which shortens the changeover times to desired levels is formed from the principle merging stating, “Make operations contiguous or parallel; bring them together in time.” The idea generated is to create a parallel work flow where the operations don’t need to be consequent to each other.

As shown in the Avix analysis, all the changeover tasks in the changeover processes are done by the machine’s operator alone. As they are divided to the four groups (coil, terminal, conductor, insulator) based on the object in focus, it is seen that although there prosecuting actions inside each activity group, no continuity is needed between the different groups. Therefore to complete these actions in the same time period is possible.

To assess the suitable task for dividing, the process timeline chart that is derived from the HV winding process is used. It also represents the LV winding chart for both operations are identical.

![Figure 4.8 Current Timeline of Winding Process](image-url)

Figure 4.8 Current Timeline of Winding Process
As the charts are examined, in addition to the non-prosecuting nature between the activity groups, it can be observed that no consistency in the work flow is present. The single operator first starts a task in one station, then in the middle of it, is tangled on another job, thereby constantly walking from one location to another. The aim is to create work groups which can be done simultaneously so a continuous work flow with less time can be achieved.

Because the goal is to shorten the time period to its half, a team of two operators are determined to participate in the parallel operations of the process. The tasks could be divided to a team of four where each operator gets to do one activity group but that much time reduction is not necessary and it would cause a huge loss of manpower.

An important point in dividing the operation is to create a balanced workload for the two operators participating in the changeover. Although the time needed for each activity group can differ in different projects, for most of the new projects they are close to each other. So separation of two activity groups to each operator is possible and creates similar time intervals. So time differences between activities have secondary importance while the main base factor in task dividing goes to the location of the activity.

The terminal adjustment and coil placement is done at the machine operator’s work station while the replacement of conductor and insulator is carried on the side and back of the machine. The ideal work style for best performance is to ensure that the operator never leaves his station. Therefore assigning the coil and terminal activity groups to the first operator and the rest to the second operator the optimum efficiency can be achieved. The predicted timeline charts with separating the process is seen in chart 4.9.

![Figure 4.9 Idolized Timeline of Winding Process with the New Procedure](image-url)
By taking account all these facts the new procedures for the change over process is:

**HV Winding Procedure**

**Title:** HV Winding Changeover

**Purpose:** To ensure standard work flow is followed through all HV winding changeover activities, prevent time and quality deviations in typical operations and increasing the awareness of the operators.

**Scope:** This procedure applies to all changeovers in the project changes at HV winding machines.

**Responsibilities:** Two participants, one of them the operator of the HV winding machine and the other one, either a LV winding operator or material handling personnel, is responsible for carrying out the assignment. HV winding operators are responsible for coil and terminal adjustment activity groups marked with A; LV winding operators / material handling personnel are responsible for insulator and conductor change activity groups marked with B.

**Materials:** Coil produced in LV winding process, Insulation paper rolls, conductor wire, wrench, knife, HV winding machine, Manipulator

**Procedure:**

1-B Control the checklist to ensure all necessary materials are in kitting area.

1-A Drag the right coil through the conveyor. Pick it up from the conveyor with manipulator and place it on the winding machine. Adjust the holder clips so that they will support it and take out the manipulator. Screw the clamps tightly with wrench. If a pressure indicator is present in the wrench screw until specified measurement is reached.

2-B Take out the remaining conductor wires from the previous project and place them in kitting area where they will be picked up by material handling personnel later. Drag the new conductor wire from kitting area and place them to the machine. If the wires are still in plastic package first cut the package with knife. Affix the wire to wire holders. Then, scarf the wire tightly through roller mechanism until the end comes from the terminal side, ensuring no amplitude that will jam the machine is left.

2-A Check the terminal if it is responding to commands. Introduce the PLC program to the terminal. If a project which hasn’t been done before is introducing, write the parameters and
definitions of the program. However if the project is already registered in the machine, choose it from machine memory.

3-B Take out the remaining insulation paper rolls from the previous project. Pick up the new insulation paper rolls from the kitting area and place them to paper holders at the side of the machine. Treat the papers through roller mechanism until the end of the paper comes out from the terminal side.

3-A Affix the edge of insulation paper and conductor wire that is present at the operation area to the coil.

4- If the tasks are completed before the other participant, help them in their activities.

5- In the end of the changeover process introduce the process ending date to SAP program.

LV Winding Procedure

Title: LV Winding Changeover

Purpose: To ensure standard work flow is followed through all LV winding changeover activities, prevent time and quality deviations in typical operations and increasing the awareness of the operators.

Scope: This procedure applies to all changeovers in the project changes at LV winding machines.

Responsibilities: Two participants, one of them the operator of the HV winding machine and the other one material handling personnel, is responsible from carrying out the assignment. LV winding operators are responsible from coil and terminal adjustment activity groups marked with A; material handling personnel are responsible from insulator and conductor change activity groups marked with B.

Materials: Core, leadout bar, insulation paper rolls, conductor plate rolls, wrench, rivet, LV winding machine, Crane

Procedure:

1-B Control the checklist to ensure all necessary materials are in kitting area.

1-A Adjust the clips that the core will be place to centre. Pick up the core from kitting area with crane and place it on the machine adjusted before. Screw the clamps tightly with wrench. If a
pressure indicator is present in the wrench screw until specified measurement is reached. Then place the rivet on to the machine.

2-B Take out the remaining conductor plate roll from the previous project with crane and place them in kitting area where they will be picked up by material handling personnel later. Transport the new conductor plate roll from kitting area again using crane and place them to the machine. Adjust the roll that it fits perfectly to the holding place in square shape, take of the crane and lock the mechanism.

2-A Check the terminal if it is responding to commands. Introduce the PLC program to the terminal. If a project which hasn’t been done before is introducing, write the parameters and definitions of the program. However if the project is already registered in the machine, choose it from machine memory.

3-B Take out the remaining insulation paper rolls from the previous project with crane. Pick up the new insulation paper rolls from the kitting area and place them to paper holders at the side of the machine using the crane. Treat the papers through roller mechanism until the end of the paper comes out from the terminal side.

3-A Pick up the first leadout bar from the grinding machine and place it on cold welding area over the machine. Then affix the edge of insulation paper and conductor wire that is present at the operation area to the coil.

4- If the tasks are completed before the other participant, help them in their activities.

5- In the end of the changeover process introduce the process ending date to SAP program.
4.1.3 Pilot Area Implementation

Before implementing the new procedure to all winding stations, there is a need to test it in application check the feasibility of its implementation and accuracy to the goals set. For this reason, the SDT LV winding area is chosen as a pilot area. The changeover of the same project, where a single operator done the changeover of a 400kVA transformer’s coil in Tuboly 193, is carried out with the new procedure. It is analyzed in Avix for comparison with the old method. The task list and efficiency chart acquired is seen in figure 4.11.
The data gathered shows promising results. With the implementation of the new procedure the 43 minutes changeover time has reduced to 22 minutes, nearly half of what it was while a single operator was operating. Also task was taking 3000 seconds to finish before. With the new procedure the total time spent by both operators for individual tasks is 2162 seconds. This reduction is done in the waste area where it is decreased from %24 to %2.52.

4.1.4 Operator Allocation

As all improvements the new changeover system has an aftermath that needs to be solved. To reduce the process times, a new resource which is the second operator in this case, has been introduced to the system. This resource can be provided by recruiting new personnel or changing the use of the existing personnel to satisfy the needs. The assigned job involves placing of the materials to ready the machine for production, so it fits to the work description of material handling personnel and machine operators. The new changeover system should allocate both the material handling personnel and machine operators in an efficient way so the overall productivity does not drop.

If the assumption that there are 7 products in every project is considered; every day approximately 3 projects are done which need 3 changeovers for LV winding and HV winding each. Because that all 3 machines will go through set-ups in the HV winding changeover, this corresponds to 12 machine set-ups which take around 3 hours of work load. The new procedure passes some of the work load of machine operators to material handling personnel.

The duties of material handling personnel are accepting the materials arrived from suppliers and moving them to their shelves in the stock area, ensuring that the necessary materials are in kitting places before and throughout the project; and helping the movement of products in the line in the instances the cranes are used. If the production schedule is assigned as before where every machine has its own pace in projects, the only problem would be the extra burden of scheduling one material personnel. For the LV winding changeover the problem is just this.

However the simultaneous changeover, idolized for the HV winding machines in the future VSM production, produce a more complex problem. The three HV winding machines have to go through changeover at the same time. With the introduction of parallel operations, there should be 2 operators working on each machine so a total of 6 operators are needed. 3 of them are the HV machine operators and it was thought that the rest would be material handling personnel. However
there are only two material handlers in each shift and recruiting one more was found unpractical. Hence the problem becomes how to fill the gap of missing operator.

The solution is found from a present practice. It is not written as a procedure but in team work application, the HV operators can ask for help from LV operators when they face with a problem. So who is more fitting to fill this gap other than the operators who are closest to this station plus already have knowledge on the process? Although LV operators are ideal for the task; before they can be assigned as the third participant, it should be ensured that the production flow would not be interrupted due to this.

The new assignment will add an approximately 0.25 hours extra task to LV operators for every changeover. If this time can be eradicated inside the normal production flow, the solution is applicable; otherwise another solution should be sought. When a comparison between the winding times of LV and HV is made, from the VSMs it is found out that the average HV winding times are greater with 0.3 hours in MDT and 0.15 hours in SDT. Hence in the normal flow these 0.25 hours extra task will act as a work load balance and won’t cause any disturbances.
4.2 HV Winding Machining Time Formulation

Most companies believe that they have full control of their production floor but the reality is that they have only vague knowledge based on the intuitions of their workers. Therefore, to grasp what is actually going on in the production floor is an essential part of the production engineers and managers job so that can take the reins and direct the production to better. To accomplish this, they need the right data gathering tools which will provide them accurate feedback from the production floor. One of the most vital elements in production is time. Every second delayed in producing a part is a waste of money so a equality between time and money can be formed. Therefore it is crucial for a company to know what time will be wasted in each process before hand to manage production, just as it knows which price it would pay for a service or material to manage its finance.

One of the biggest problems in ABB transformers production floor is that although the production engineers and managers have great technical knowledge on the processes, their information is lacking on the processes times which depends on mainly labor force. In the production line only the sand drying processes has standard times because the NFH and LFH machines are fully automated and they are autonomous from the project’s features. However the operation times for the rest of the processes which mainly relies on the labor force, certain limits can’t be made because they are highly depended on the changing properties of the projects. The HV winding is one these processes. In the winding process there are many variants that differ from project to project, so usually only inaccurate predictions can be made. Operators can’t give specific dates when the product will be over because no standardization of process times is done.

The importance of knowing precise machining times in the HV winding has greatly increased in the new one piece production flow idolized in the future VSM. The operation time is greatly reduced with the implementation of cellular working style to provide flexibility so emergency orders could be quickly put to production and rapid project changes can be made to market demands. However if the scheduling done in the production planning department can’t match the real time applications, then instead of a smooth flow there will be chaos and the control of upper management will be lost. Furthermore the allocation of workers in the changeover system introduced in the previous chapter is not applicable if the project finish times are set accurately. For these reasons, a research is conducted to create a formula which will generate precise machining time predictions.

The first approach was to sort the process time data gathered before according the projects and use this to create a curve out of these points. Then the variable changing between projects would be singled out and a curve fitting process would be done to produce a formula. This process needed a huge range of reliable data. The primary idea was to use the data that the operators filled in the
production module of the SAP program. However the SAP program’s this module was newly introduced and usage of its applications was limited. As a deep examination on the gathered data was made, it was seen many irregularities were present and even most of the forms were blank. Hence the idea to use the SAP data was discarded. At this point, using the data logs formed by the PLC programs of the winding machines came to mind. The estimation was that this source would be free of human factor so true data could be collected. Data logs from all the winding machines were gathered. However the way the program kept the time information was too complex, no proper time charts could be created. There were many cases that the program showed the lunch breaks as processing time or shown that the operation was finished when only half of the windings were accomplished due to restarting of the machine. Hence only a limited number of time readings could be collected and it was not enough to accomplish the task.

After the failure of the deduction method, to use induction, its counterpart, is decided. In this way, first the features of the projects which correspond as, the most important variables to cause time deviation will be identified. Then the individual times spent to create these features will be measured and all of them will be combined to generate a formula.

In identifying the key variables to the process and creating the formula, a benchmarking with the winding time generation system of ABB Polish Branch is carried out.

Figure 4.13 Process Time System Used in Polish Branch of ABB
The Polish Branch of ABB has a unique time processing system where an effective time formula is used. With just filling the project specification, accurate HV machining time data for all transformers can be generated with the program. Although the parameters used by the Polish branch stands as the base for the formulation which is being developed, it can’t be used directly. The reason of this is that the difference of production systems between branches because the status of Polish Transformers Factory as ABB’s STD focus factory which priorities SDT products. Their STD products are mainly standardized and they do mass production with much higher number numbers so their production is fully automated with CNC machines. Therefore their formulation is adapted to fit the needs of Turkish branch’s production system.

With the analysis of Polish Branch’s formula and putting an emphasis on our own production system, the parameters for the formula are identified. They are:

- Rated Power
- Thickness of Wire and Width of Wire (Twire*Wwire= Wire Area)
- Number of Wires in Winding
- Number of Total Windings
- Number of Layers
- Number of Leadouts

Because the induction method is followed, the total process has been divided to sub-operations and these sub-parts are analyzed individually. The parameters which effect these sub-operations are sorted.

1. The first time consumption is done in the preparation of the machine. This part gives the time for the placing taking out of the coil and attaching the wire to the coil to prepare for the production. Two parameters are affecting this time. They are the rated power and wire count. Unlike the Polish branch the rated power has less importance to the time. The only separation it creates is that it changes the machine which the production will be carried according to if the products are SDT or MDT. The other variable is the wire count. The preparation takes higher time if two wires will be connected instead of one. Taking account the difference of set-up times in SDT and MDT machines and extra time spent on attaching the second wire, the formulation is created.
\[ \begin{align*}
\text{if } \text{Rated Power} \geq 315 \Rightarrow \text{CountWire} \Rightarrow T_{\text{prep}} &= t_{p1} \\
\text{if } \text{Rated Power} = 1 \Rightarrow T_{\text{prep}} &= t_{p2} \\
\text{if } \text{Rated Power} < 315 \Rightarrow \text{CountWire} \Rightarrow T_{\text{prep}} &= t_{p3} \\
\end{align*} \]

2. The second part of the formula is the safety part. In most cases in the middle of the process the wire on the machine ends and forces the operator load a new wire. The part of the formula shows the time spent in this material changing. The wires rolls are standardized in weight so if the cut area of the wire increases the length of the wire decreases. With a shorter wire length, the frequency of wire changeover in the middle of the process increases. Hence the formulation oversees this parameter.

\[ T_{\text{Saf}} = A \cdot S_f \]

3. The third part is where the time spent on revolving the wires over the coil by the machine on a arranged cycle. The period of each cycle is related with number of wires and wire area. As the area of the wire and number of wires increase the rotation speed of the machine lowers so the cycle time increases. The total time is the multiplication of each cycle’s time and total number of cycles/windings so the time spent in this process can vary according to the bigness of the transformer.

\[ T_{\text{winding}} = B \cdot N_{\text{wind}} \cdot S_f \cdot (l_{\text{width}} \cdot l_{\text{thickness}})^C \]

4. The fourth part generates the time spent on the work done by the operator to form the starting and end features of each layer. There are not much variable which differ the work so an average time, D, is taken and multiplied with the total number of layers.

\[ T_{\text{Layer}} = D \cdot N_{\text{layer}} \]
5. The last part is the composing of the leadouts. Here the end wire is cut and bended to for the leadouts. Because it is a rapid process the wire area or number does not have a great importance. From many projects the forming times of leadouts are measured and their average, \( E \), is taken.

\[
T_{\text{Leadout}} = E \times N_{\text{leadout}}
\]

These sub-parts are combines to form the formula which generates the total process time. It is:

\[
T_{\text{Total}} = T_{\text{prep}} + T_{\text{Saf}} + T_{\text{winding}} + T_{\text{Layer}} + T_{\text{Leadout}}
\]

\[
T_{\text{Total}} = t_p + A \times S_f + B \times N_{\text{wind}} \times S_f \times (l_{\text{width}} \times l_{\text{thick}})^C + D \times N_{\text{layer}} + E \times N_{\text{leadout}}
\]

To confirm the reliability of the formula, it was used in various projects with different features.

![Table 4.1 Formulated Times Based on Project Features](image)

To compare the data acquired from the formula with company's knowledge, number of products in each project on the list is generated with a program. This generation is done in a way that that it
meets the average 7 transformers per project and the number of products decreases as the rated power gets higher. These generated numbers is used on finding the average HV winding times for both of the lines.

<table>
<thead>
<tr>
<th>Average of Formulated Times</th>
<th>SDT</th>
<th>MDT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>84 min</td>
<td>126 min</td>
</tr>
</tbody>
</table>

Table 4.2 Average Times Gathered from Formulation

The results are very close to the actual data that are recorded in the production floor. The average HV winding times for per coil confirmed by the company was 2.1 hours for MDT and 1.35 hours for SDT. It can be clearly seen that the formula gives the exact data for MDT and a very close data for SDT. It is a clear proof that the formula created is very effective.

Finally to just get another view, the time data generated by the formula is compared with the limited data that could be salvaged from the machine data logs. As mentioned before, the machine data logs are not very accurate and for only some project reliable data could be gathered.

![Figure 4.14 Comparison of Times Generated from Formulation and Datalogs](image-url)
In comparison of the data generated and data logs from the machine is very different. However for the projects which high number of sample data that could be gathered from the data logs, the values are very close to each other. Such examples are:

<table>
<thead>
<tr>
<th>Project</th>
<th>kVA</th>
<th>Samples</th>
<th>Formulated time</th>
<th>Time from Machine Log</th>
</tr>
</thead>
<tbody>
<tr>
<td>8---</td>
<td>1000</td>
<td>62</td>
<td>141</td>
<td>149</td>
</tr>
<tr>
<td>9---</td>
<td>1250</td>
<td>29</td>
<td>140</td>
<td>150</td>
</tr>
<tr>
<td>8---</td>
<td>300</td>
<td>300</td>
<td>98</td>
<td>94</td>
</tr>
<tr>
<td>8---</td>
<td>800</td>
<td>11</td>
<td>136</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 4.3 Projects with Similar Times from Formulation and Machine Logs

There are many other examples like this but as mentioned it just to get another view and does not prove anything due to unreliability of the data.
CHAPTER 5 - INVENTORY LAYOUT OPTIMIZATION

In the recent years, the manufacturing world realized the significance of inventory management to cost reduction. Many companies implement inventory systems such as JIT management and Kanban systems, to minimize their inventory cost. The best example showing this importance is American Company, Wal-Mart, which organized it supply chain to the point that no stock material is kept and the inventory cost is reduced nearly to zero. For companies which’s production is an essential part of its activities, keeping a constant amount of inventory is a must. Therefore these companies try to find optimal solutions on how to keep their inventories in most effective ways. In this section, the existing inventory layout of ABB transformers plant will be improved to create a more efficient flow.

ABB transformer plant uses an open inventory system, where the material stocks are kept in shelves around the production floor. A few years back, there was debate on turning to warehouse system but an assessment with production supervisors is carried, it was concluded that the advantages predominate its downfalls. The open inventory does not need a separate construction or place to sort the materials and the transportation distances are smaller. Also all the workers in the plant can view the levels of inventory. However the open inventory is more disorderly so finding the right material among the stock pile is harder. Also the inventory occupies a place in production floor and the material handling activities carried here creates a chaotic environment.

Before the implementation of CP3 project a similar study was carried out and materials were sorted to their specific cells to get effective transportation distances. However to this day, the production floor has changed a lot, with an increase of capacity and more inventory locations. In addition to this in the previous study no system to allocate the materials, with different properties but in the same family, were designed.

The primary problem with the current layout is its although material groups are divided to different shelves, there is no system which defines how materials with different measurement in the same group distributed. In example, there are 9 shelves where Al wires are kept. However there are no rules that determine where a wire with specific measurements will be placed among them. So only the operator which put it knows its location and another operator should search all the shelves to find the necessary material. This leads to loss of time for searching. Even there are incidents that the material could not be found, thus, the production is stopped and the production schedule is interrupted. This incident is seen frequently in night shifts. Most of the material acceptations are done in the morning shifts so in night shifts the workers does not know the location of the needed resource. This leads to halt of the line until morning or changing to another project deviating from the schedule.
The new layout will:

- Provide an update to the old layout study with covering the new inventory locations.
- Create a system with a defined order where the material search is easier and faster.
- Eliminate the production halts caused by unavailability of resources especially at night shifts.
- Decrease the burden on material handling personnel to provide them time for working on the changeover process introduced in the previous chapter.

The idea behind the new layout is simple. The old shelf structure was arranged according to total weight of each material group and minimizing the transportation distances. The new layout will keep it as a base with just minor changes and add a new sorting system inside the material groups in regards to total weight of materials with different measurements. At the same time the layout will be created in regards to the distances should be covered and try to find an optimum solution. The activities that are done follow as:

1. The old inventory layout is analyzed and the production floor is examined to mark the new inventory locations which were added with the expansion of the plant.
2. The yearly raw material arrivals data are gathered from the SAP files and in the light of this, yearly holding capacities of each shelf is identified.
3. Based on the yearly amount of each raw material group (Al wires, Cu wires, Al plates ....) and distances to the operations related, they are matched with cabinet groups which there are mostly 5 shelves in each cabinet.
4. The paths of the materials from inventory location to the operation area are identified and shown in the layout.
5. The materials inside each group are sorted in regard to their distinctive variable as; Al wires, Cu wires and paper covered wires according to wire diameter; the connector wires according to the cross-section area; Al and Cu plates in according to their thicknesses. By taking account the yearly amount of materials of different measurements and trying to minimize their transportation distances they are distributed to different shelves. The new layout is created.
After the creation of the new inventory layout, a research is done to determine the degree of development. The transportation process is very chaotic in nature due to the human factor in it. Due to this the calculations are done based on assumptions.

The number of transportation operations is calculated with the division of yearly amounts of materials with the fork lift capacities. The forklift capacities are 60 Kg for wires and 100 Kg for plates. Two different time intervals are created. First one is the movement time showing the time interval...
that is spent by the operator riding the forklift to reach a location either to pick up the material or place it. The time spent here changes with the length of the path and speed of the forklift. The forklift speed is taken as a constant, 1.95m/sec. The second time interval is the search time which the operator spends searching the shelves to pick up the right material or searching for a suitable place to place it. This time could change significantly with unknown factors so this is the part which is mainly based on assumptions. In the old system where a specific material could be found in any shelf which belongs to that raw material group, the operator could either find the right place in the first try or after checking all the other shelves. The assumptions in here are that the operator spends 50 seconds to search per cabinet and in %60 of all his works he finds it in the first place. The percent of finding the material in the rest of the shelves are evenly distributed. With this formula the search time interval for each activity changes from 50 seconds to 3.5 minutes for material groups with different shelve numbers. After all of the time savings are calculated for each material group, they are added to find the overall performance improvement.

<table>
<thead>
<tr>
<th>TIME</th>
<th>OLD</th>
<th>NEW</th>
<th>IMPROVEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Search Time</td>
<td>1408369,59</td>
<td>869697,3774</td>
<td>38,31893393 %</td>
</tr>
<tr>
<td>Movement Time</td>
<td>391929,2456</td>
<td>371330,4116</td>
<td>5,25575325 %</td>
</tr>
<tr>
<td>Total Time</td>
<td>1800298,836</td>
<td>1240027,789</td>
<td>31,121 %</td>
</tr>
<tr>
<td>Total Time (Entry Included)</td>
<td>2192228,081</td>
<td>1611358,201</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.1 The Effect of the New Layout in Search Times

The new layout showed effective results. The movement time is decreased by %5.25 and search time is improved with %38.31. The yearly total time that is the sum of search time, movement time plus the transportation time at the accepting of newly arrived raw materials, has decreased from 609 hours to 448 hours with a margin of %26.5.
With the new layout the work load on the material handling personnel has been decreased approximately 35 minutes every working day. This free time could be effectively migrated to the changeover activities introduced in the previous chapter and the lower their burden. Also because the specific material’s distribution has been lowered to a limited range of shelves, the production halts due to inability to find the needed resources at night shifts is diminished.

Although the new layout is a good start for organizing the inventory, there is still much to cover to reach an effective inventory management. ABB plans to carry a project of implementing a banderol system for raw materials in the coming years. When the company knowledge on the SAP program will be matured, the inventory management will be integrated with the program. In the material acceptance a banderol will be stick to the material and the electronic data of its amount, location and project start date will be followed from the SAP. At that time the inventory layout may change and instead of a sorting system based on material properties, they can be distributed according to the date they would be used.
CHAPTER 6 - CONCLUSION

In the beginning, the aim of the research was set as to advance the production of MDTs and SDTs in ABB Distribution Transformer Plant in to a more flexible and efficient system. Through the project the objectives to accomplish this goal, generation of a new production model is done and activities to adjust the production to the new system: elevating the system constraint and improving the general efficiency with waste reduction are carried out.

With the creation and analysis of current VSM, the opportunities of improvement have been identified and a new production model is created. The new model showed improved agility and efficiency with promising results of at least % 50 throughput time reductions and % 100 increases in value-added time ratio.

The bottleneck operation, HV winding which stands as a system constraint is unraveled with reduction of its process times to one third of what it was without outsourcing while keeping the capacity constant. To prevent efficiency drops a new changeover procedure is introduced that halves the current changeover times and implementation of it in a pilot area is carried out where expected results are gathered. The operator allocation system to meet needs in the new procedure is proposed from the present resources.

Finally a new inventory layout is created to reduce the waste in transportation. % 26 time reductions are acquired with this layout to be distributed to the usage of operators in other works.

In conclusion the foundations of transition to the new agile production system are laid through the project so the research can be assessed as successful.

However there is still much ground to cover to reach the idolized production model. For future work, after the implementation of the new core machines, they should be integrated to the VSM to get the complete view of the production. Also there are still many other processes that need to be improved. The inventories, especially the finish product’s inventory, should be reduced with implementation of JIT management but to this a more standardized supply chain management system should be developed. The operators should be trained to be able to work in different stations for a more flexible system.

In manufacturing system improvements never ends. Even if the idolized model is reached perfectly in future, the value stream mapping process should be carried out again to assess the needs of the day.
A new model should be idolized; with implementation of more lines in case of capacity needed or with changes at the dying process to allow one piece flow in case of lesser throughput times needed.
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APPENDIX

Appendix A – Current State VSM of MDT Line
Appendix B – Current State VSM of SDT Line
Appendix C – Future State VSM of MDT Line
Appendix D – Future State VSM of SDT Line