CHALMERS
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Global study and implementation of Karakuri

Master's thesis in Production Engineering

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Cover: Cogs of mechanical watch depicting Karakuri in everyday life. Picture taken by Manish Vijaya Bhanu.

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Investigating Karakuri market, its development and implementation process
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Abstract

Virtual manufacturing AB is a lean based production consultancy company which specialize in four main areas, which are Industrial management, Robotics and automation, assembly and production flow and lean manufacturing products. This thesis is in concern with the lean manufacturing products which mostly uses modular flexible components to automate simple tasks like conveying kitting boxes.
With a majority portion of Swedish manufacturing industry adapting to Industry 4.0 with internet of things, high level of automation can be seen on the production floors. This high level of automation may result in the problem of over automation. Also, it is not the best economical solution to incorporate in every case, especially in the small to medium scale industries. Introducing Karakuri, which is the Japanese lean way of automating with little or no power would help in achieving better productivity. To introduce Karakuri in Europe, a thorough research on the market of Karakuri in Sweden and in Asia along with the method to design these solutions is essential, which is the main purpose of this thesis.

Currently, Virtual Manufacturing AB has only explored one application of Karakuri which is referred to as flowracks. These are specialized racks that act as a buffer to hold kitting boxes which will be fed to the operator at an ergonomic height. If one box is fetched from the rack, the preceding boxes slides due to gravity to make available to operator at the same position. Virtual Manufacturing AB are interested in understanding the core concept of karakuri, its application and the market for it.

A market research on Karakuri was conducted with the aid of interviews, surveys and literature. It provided a good insight on the awareness, application, potential growth and current trends of Karakuri and its market between Asia and Europe. A practical industrial case of waste management was undertaken to understand and realize the design method of Karakuri solutions. This thesis has established a design method of Karakuri and highlighted the the factors that is essential to introduce the concept in Europe.

Keywords: Karakuri, low cost automation, mechanism, market, IoT.

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1
Introduction

This chapter describes the background to the thesis followed by the project objectives and scope. A brief description of the current state will conclude the chapter.

Lean manufacturing is a methodology resulted from Taiichi Ohno's contribution over decades to Toyota production system (TPS) in Japan. The primary focus of lean methodology is aimed at reducing waste, decreased time and increased quality. Since lean was introduced and its immense potentiality was recognized, industries around the world which are normally inclined towards automation have been making attempts to incorporate lean into their own industrial culture.[2]

In their book 'Strategic Thrust of Manufacturing Automation Decisions: A Conceptual Framework', C Madu and N Georgantzas mention that industries have a desire to automate process to improve the productivity or speed as a solution to match the ever growing market and demands. This desire to automate may lead to unforeseen circumstances leading to a degree of automation that is neither significant nor economical. An example case study of a penicillin production company was mentioned to illustrate the necessity of automating only to a certain extent to prevent over-automation and might often lead to frustrating results [46]. Highly automated manufacturing plants not only imposes the problem of high initial and operating cost but also demands extremely skilled labor. Automating by just the right amount at the right places can draw huge benefits by creating a semi automated environment with relatively unskilled labor. Having that mentioned, it cannot be denied the fact that there are applications where high level of automation proves to be efficient and economical. It is possible to automate a process to such extent that the whole project may be regarded as uneconomical. Hence having the right amount of automation plays a very important role in an industry. [1]

Karakuri, also known as low cost automation, is a part of Lean manufacturing strategy and often neglected in favour of automation. It is essential to note that even the western countries who have successfully implemented lean, fail to embrace the whole lean methodology and culture. There are many examples where companies have incorporated only the main aspects of lean such as 5S, pull system, continuous flow and standardization, but fail to absorb the whole culture. This section states the purpose and description of the project along with a brief background and limitations. [2]

1.1 Background

Karakuri in Japanese translates to trick or mechanism. It was first recognized with the introduction of mechanical dolls capable of achieving complex motion without using any source of power. The same concept was later introduced into manufacturing industries. In this context, it can be defined as achieving motion with no power or low power to increase the level of automation using existing components such as levers, cams, links, gears, spring and utilizing freely available phenomenon like gravity. It provides a cost-effective, lean & maintenance-free flexible solutions with a much sooner return of investment.

Virtual Manufacturing AB is a supplier of lean-based production development services and Karakuri related products. The company has been successful to recognize the potential of Karakuri and has successfully designed few material handling racks which is commonly known as gravity flow racks. These products are generally used for easy storing and transport of components in small bins. However, the company so far has not stepped out of material handling applications and is now looking forward to explore the market of Karakuri across Europe and Asia to be introduced into the Swedish market. This demands acquiring knowledge on different Karakuri products across various field, both in Asia and Sweden. With a majority portion of Swedish manufacturing industry adapting to Industry 4.0, high level of automation can be seen on the production floors. As a production consultancy company, Virtual Manufacturing has also set its footprint in this next generation of manufacturing industry and as a future step would look into the possibilities of integrating new smart technologies into Karakuri which can better fit in Swedish industries.

1.2 Project objectives

The purpose of this project is to investigate the market of Karakuri products in Asia and Sweden to increase the awareness of its potential/applications. This project further involves implementation of Karakuri as a validation of the concept by designing a new product in a field other than material handling. The suggested solution will demonstrate the design method of Karakuri. The fourth industrial revolution has entered the industries who adopt new smarter technologies which are more readily available and cheaper than before. The possibilities of using simple sensors for automating production processes are numerous. This research furthermore introduces to the possibilities to integrate new technologies with Karakuri. The project objectives based to the purpose was recognized as follows:

- Comparing Karakuri applications in the Global market to the Swedish market.
- Suggest a Karakuri solution to demonstrate design conceptualization.

1.3 Project scope and delimitation

This project aims at conducting a study on low cost automation by comparing the Asian & the Swedish markets. A practical industrial case will be taken up and addressed with the concept of Karakuri solution. It also involves building a working prototype as a proof of concept, however it does not include the development of the complete product. The project also involves investigation of integrating Karakuri with technology as a step towards future. However, this is only to introduce future possibilities of the concept and a detailed study on emerging technologies is not under the scope of this project.

1.4 Current state Analysis - Concept Validation

Karakuri in Europe is mostly revolved around material handling and flow racks as mentioned in section 5.1.2. To better understand the core concept of Karakuri, a real industrial problem was taken up as an attempt to implement Karakuri in a field other than material handling. This test case not only promotes the potential of Karakuri, but also could encourage lean thinking. This case is based on the Volvo Skövde plant. The description of the case is as follows: Waste handling is often neglected in industries and it can be significant if looked upon the non value adding time an operator spends on handling the waste. Most of the industries use waste bins similar to the one shown in figure 1.1 below. These bins require plastic ties like shown in the figure 1.2.

Figure 1.1: Waste bin.

Figure 1.2: Plastic ties.

The operator needs to perform three sets of tasks for every change over or every time the the bin is full. First one needs to wrap one plastic tie at the top followed by another ties about 30mm below the first one. Lastly one needs to cut the plastic off in between the two ties in order to take away the filled waste bag. This process is depicted in the figures 1.3 to 1.8 shown below. The problem with this technique or method is that, it takes about 28 seconds on an average to achieve this. 28 seconds may appear a short time to be considered to improve or invest in new resources.

Figure 1.3: Step 1

Figure 1.4: Step 2

Figure 1.5: Step 3

Figure 1.6: Step 4

Figure 1.7: Step 5

Figure 1.8: Step 6

Let us consider the waste handling process at the company under consideration, Volvo Skövde to better perceive the scale of the problem. A 3d model was built to better understand the current state of the plant which is shown in the figure 1.9. Only a section of the plant is considered where the kitting process is done.The operator picks parts along the path and places them at the kitting wagon. The parts are present in a line of pallets on either side of the path way. The waste bins are present between the pallets at random spots. The parts in the pallets are usually packed with plastic or carton boxes and every time the operator picks a part, he is required to go the nearest bin to dump the plastic waste and continue to the next pallet.

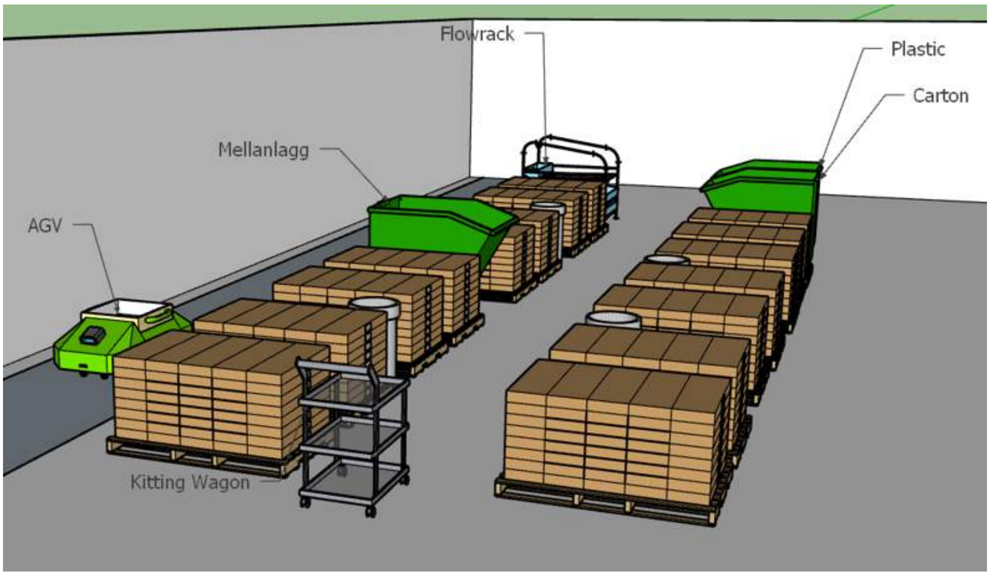

Figure 1.9: Volvo, Skövde current state

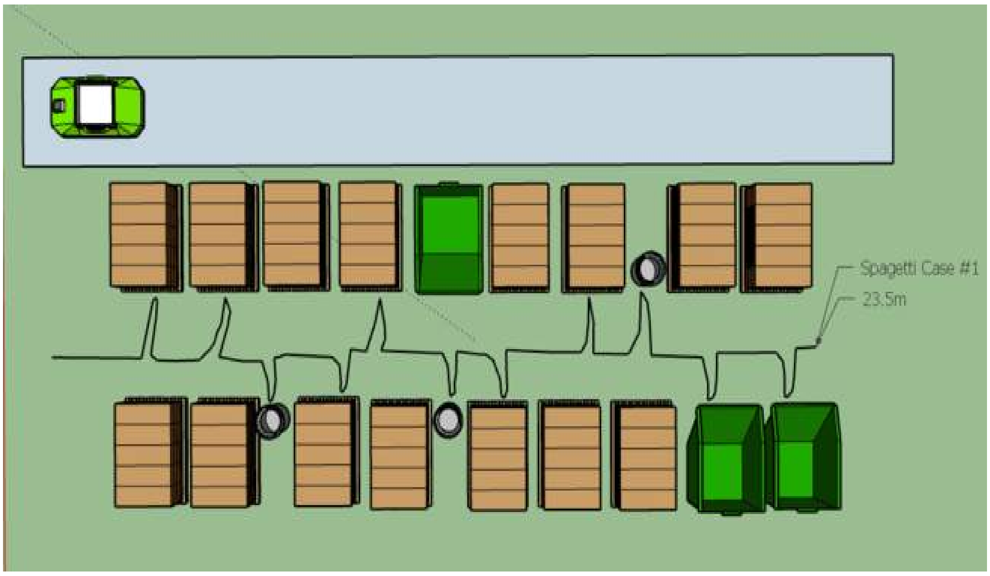

Figure 1.10: Spaghetti diagram of the operator path

Apart from the waste bins in between the pallets, there are two main dumping bins at the end where the waste from all the small bins are to be collected and dumped. The two bins are to be segregated for plastic and carton wastes. There is also a small vertical trolley for storing the thin rectangular sheets that are present in the pallet of components used to separate different layers of components. This trolley is referred to as 'mellanlag' by the operators. An AGV would fetch the main bins off the station.

The point to note here is the amount of non value adding time spent on these activities. The operator not only has to walk between bins every time to throw away the plastic, but also travel to the main dumping bins every time the small ones are full. The path that an operator takes is shown by a spaghetti diagram in the figure 1.10. It can be seen from the figure that an operator is involved with a lot of non value adding motion which can be categorized under 'Muda' in lean terms. Different colours depicts the different instances of kitting process. To sum it up, the process would involve the following steps:

1. Go to a pallet and fetch a part.
2. Dispose the plastic waste to the nearest bin between the pallets and cartoon waste directly to the main dumping area.
3. Perform the steps as described in the figures 1.3 to 1.8 every time the small bins between the pallets are full.
4. Throw the filled plastic bag in the main dumping area at the end.
5. Repeat the above steps.

The current state of the plant (one station) has about 8 to 10 waste bins between the pallets. Let us take an example of 10 bins to illustrate the amount of time wasted non value adding activities. For simplicity, lets assume each bin consumes roughly about 30 seconds to change over every time the bin is full. In a 8 hour production day, lets consider that the bins are full about 4 times a day. Hence the amount of

time spent per day only to change the waste bins is :
10 bins * 30 sec/bin * 4 change over/day = 1200 sec = 20 min

It is important to note that the above time calculated does not include the walking time between the bins and the time required to travel to the main dumping area to discard the plastic bags. The spaghetti diagram show in the figure 1.10 shows the travel path of the operator and it can be said that a lot of waste movement is involved just to clear out the filled waste bags. It can be imagined the time and effort that is invested just to handle the waste.
This project taken up considers providing a Karakuri solution that can cut down the time and effort required to handle the waste bin between the pallets and also suggest a layout that can improve the overall productivity.

2
Methodology

This chapter is about the methods used and how the chosen techniques are implemented. This provides a clear understanding of how each and every phase has been planned and executed to obtain the final results.

A market study has been carried out to gain a better insight into the subject of Karakuri. The study can be done by various methods, of which there are 5 most commonly used methods. They are surveys, focus groups, personal interviews, observation, and experimentation/test trial. Either one or more of these methods can be used in a market study. For this thesis, surveys, interviews, and experimentation have been considered as they involve direct inputs from the professionals in the industries. Also, experimentation provides a chance to practically verify the findings. A triangulation among these three methods will yield in clear answers and draw clear conclusions and provide recommendations. The final result will be an amalgamation of the findings.

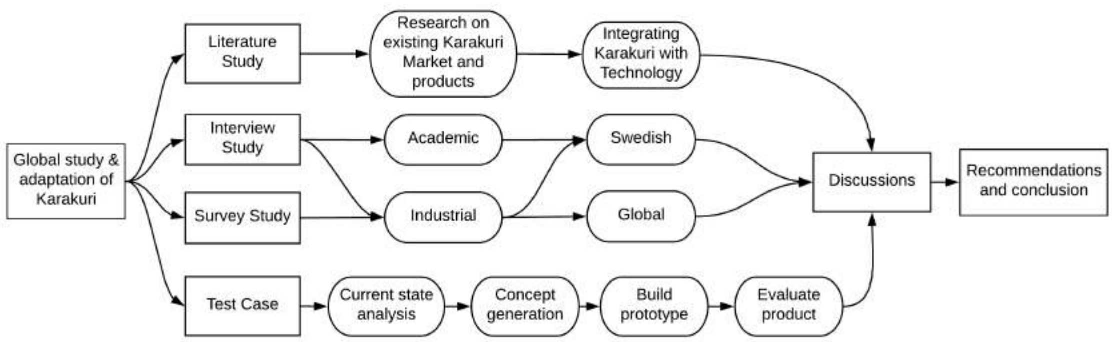

Figure 2.1: Process Diagram

2.1 Literature Study

With the project objectives set to determine the global market for Karakuri and drawing a comparison between the Swedish and global market, a comprehensive study on Karakuri was conducted by critically analyzing published body of knowledge. For this purpose, prior research studies, theoretical articles and journals have been read and reviewed.

The literature study was conducted with the aid of databases like Scopus, Web of Sciences, Business Source Premier, IEEE Xplore and Google Scholar. The findings from the literature study was used to get a detailed information on the history, case studies, examples of low cost automation that can be used in further studies. The studies will also help understand the differences in continuous improvement culture, the market strengths and the difference of Karakuri application. The study into adapting latest technologies has been limited to technologies that have emerged in the last decade and few trending technologies.

The search was conducted using a combination of keywords such as Karakuri, IoT, Low Cost Automation, and manufacturing market. Furthermore, to keep the search relevant to the present times, the search was conducted with respect to articles and books published in the last two decades.

2.2 Interview Study

Qualitative analysis is made through the interviews with the industrial stakeholders, as well as academic stakeholders from Chalmers University of Technology.

The interview was first conducted internally with consultants at Virtual manufacturing who had previously worked with Karakuri. The major focus on the interviews was targeted on the market of Karakuri and the design aspects that needs to be considered. To get a different perspective on the topic, a couple of academic interviewees were also interviewed. The figure 2.2 below shows the ratio of academic to industrial interviewees interviewed. To get a good insight from a technology perspective, a researcher who is working on Karakuri IOT which is funded by the Swedish government was also interviewed.

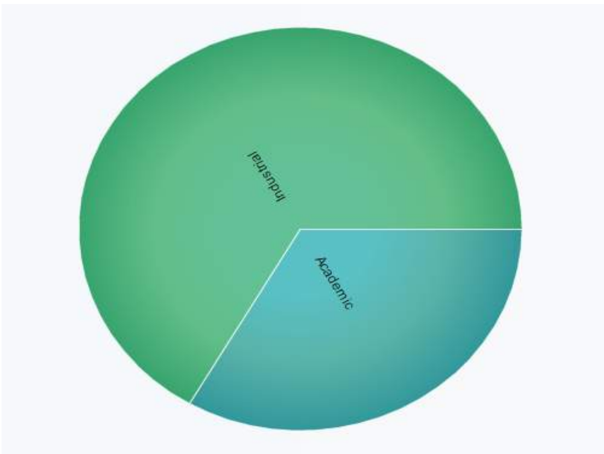

Figure 2.2: Ratio of industrial to Academic interviewees

Coding

To comprehend and extract useful data of the interviews conducted, all the data collected were coded. Coding is a technique to categorize data that may be unstructured or complex. It involves analyzing and examining the entire data as a whole, followed by breaking down chunks of information into relevant categories. It is a power technique to bring together all the relevant information under a specific category or identify patterns to perceive the data as a whole group. It is usually done by marking similar content of text with a code label which is later used for comparison and analysis. The label is named such that it defines the underlying information or concept. The process requires thorough and careful inspection of every text in order to comprehend useful information. There are different types of codes that can be used which are:

- Priori codes - Presupposed as interesting or from pre-existing theories.
- Grounded codes - Emerges from data without any preconceptions
- Descriptive codes - Forms a summary description of what is happening
- Analytical codes - Codes based on analytical thinking showing interactions, connections and meaning.
- Hierarchical / non-hierarchical codes - Sorting of codes as they are generated

A combination of the above mentioned codes were incorporated to deduce the required results. Analysis of these codes can be deduced through manual approaches or computer based approach. Computer based approach was chosen for this study which provides greater degree of flexibility and analysis capabilities.

To interpret the findings from the interviews more appropriately, coding was implemented as described above and an online tool "Dedoose" was made use. It is a qualitative data analysis software aimed at facilitating research. The software is very collaborative which is fluid in integrating different types of data and efficient in mixed method data management and analysis features. The results obtained can be analyzed with interactive data visualization options. The software is built on an online platform (web application) which makes it extremely flexible and efficient to access and retrieve information. The software is accessible from: http://dedoose.com/.

2.3 Survey Study

Virtual manufacturing AB employs a web based marketing platform called 'emarketeer'. It is a powerful online tool for conducting surveys and marketing purpose. The application also supports intensive data visualization. A structured set of questions aimed at extracting the most critical aspects of the study from the receiver was framed. Graphics interchange format (GIF) images with appealing Karakuri products obtained by rendering few products produced within the company were created, which was used to enhance the survey and make it more appealing. The survey can be found under Appendix A

With clear and concise questionnaires, a sample group can be analyzed representing the target market. With a larger sample group, a more reliable results can be obtained. There are various methods of conducting a survey such as:

- In-person surveys are typically interviews conducted in populated destinations. These are convenient to present people with samples of products, packaging, or advertising and gather immediate feedback. In-person surveys are seen to generate response rates close to 90 per cent, but at a bigger cost.As this involves time and labor, the costs per interview can go up-to 100 dollars per interview.

- Surveys conducted on telephone cost lesser than in-person surveys, but can be more expensive than sending out mails. However, as consumers are not fond of telemarketing, participation in phone surveys is much lower. Telephone surveys are seen to achieve 50-60% response.

- Mail surveys are relatively much cheaper than the other methods and is capable of reaching a broad audience, however, the response rate is much lower at around 5-15%. Though the returns are much lower in comparison, small companies resort to this method due to ease of use and cost effectiveness. Online surveys are generate varied results and the data cannot be reliable on in most cases. However, with a known group of audience online surveys can yield more trusting and faster opinions and preferences.

In our case, the team saw it fit to conduct a mail survey, considering the costs and accessibility.

2.4 Concept Validation

Concept Generation-
Gallery method of concept generation has been used to generate different design concepts and be able to provide more than one solution. The method follows a process where each member of the team presents a design concept in the form of a sketch. It is usually done with a group of people where each member presents their own solution individually which will be displayed later on for further discussion. There will be no form of communication between the members while drawing their solution. Since the team had only two members, each author came up with two concepts for better analysis.

- The problem statement is presented and a brief discussion is allowed for clarification.
- Each participant draws their ideas on to a paper with some notes if required.
- The ideas generated are put forward for display followed by a discussion
- All the ideas are reviewed thoroughly and the most promising solution is selected and further developed. [26, 27]

The Karakuri solution that has been developed required few components that are not readily available and has been newly designed. Additive manufacturing (AM) or rapid prototyping methods which are generally referred as 3D printing were employed to manufacture these components. This new manufacturing method is quickly gaining popularity because of its extreme flexibility in creating complex designs efficiently. Product realization becomes extremely efficient as they allow production of prototypes which match the final designs in terms of form, fit and function. In order to build a model using additive manufacturing a 3D CAD model is required to be constructed to the exact dimensions with prescribed tolerances. CATIA V5 was used as a tool for all the designs in this project. There are several additive manufacturing methods present like SLS, Stereo-lithography, poly-jet, FDM, etc. Fused deposition modelling (FDM) was incorporated for being economic and accurate. FDM is a technique where plastic material is extruded through a heated nozzle which traces the cross section of the parts being printed and build up layer by layer. The parts were designed and printed followed by continuous improvement methodology to perfect the design [28].

3

Theory

This section provides a theoretical background that has been used which forms the foundation to this thesis work.

3.1 Lean Production

Lean production works on a simple, yet vital, concept of eliminating waste and providing good quality product and services. The concept of Lean revolves around keeping the manufacturing costs as low as possible while achieving good quality. Waste in a production line can be perceived as any activity that has no value from a customer or a client. Lean Enterprise Research Centre(LERC) identified that 60% of manufacturing related activities that happens through a production process can be viewed as non-value adding by the customers. Wastes to be reduced cover a broad and thorough range of wastes related to wastage of resources, overburdening machines and operators and unevenness in work loads. This results in improved product/services, smaller inventory and improved work quality. All these in turn lead to building a stronger relationship with the clients and suppliers [31].

The concept originated from within Toyota as a way of working or a culture, of being very efficient. Toyota engineer Taiichi Ohno, has been credited for developing the core principles of Lean. Apart from reducing waste the core principles also stressed on empowering workers. This meant training operators in being multi-skilled and capable of managing and leading. This resulted in becoming more flexible and use resources efficiently [32]. Margaret Rouse (2009), in her column, summarizes the principles of lean as:

- Eliminate waste
- Minimize inventory
- Maximize flow
- Pull production from customer demand
- Meet customer requirements
- Do it right the first time
- Empower workers
- Design for rapid changeover
- Partner with suppliers
- Create a culture of continuous improvement (Kaizen)

As Jeffery K. Liker points out in his book "The Toyota Way", the principles of lean can be articulated into four basic segments for better understanding its application.

They are long-term philosophy, the right process will produce the right results,add value to the organization by developing your people, and continuously solving root problems drives organizational learning. It can also be gathered that these segments are but a set of tools to help an organization develop a culture of working [2].

3.1.1 Kaizen (Continuous Improvement)

Jeffery K. Liker, in his book "The Toyota Way", refers to Toyota Way or the Lean productions as "a system designed to provide the tools for people to continually improve their work" [2]. This concept of continually improving work processes, product quality and cost efficiency are all a common goal. This principle is often referred to as "Kaizen", which in Japanese translates to improvement. In his book "Out of the Crisis" (1982), Dr. Deming shared his philosophy of continuous improvement. It can be gathered that improvements are both to benefit individual and the whole organization. Being an integral part of lean, the principles put forward my Dr. Deming all revolve around reducing wastes while improving quality [30]. A flowchart to better understand the reasons for continuous improvement can be seen below in figure 3.1.

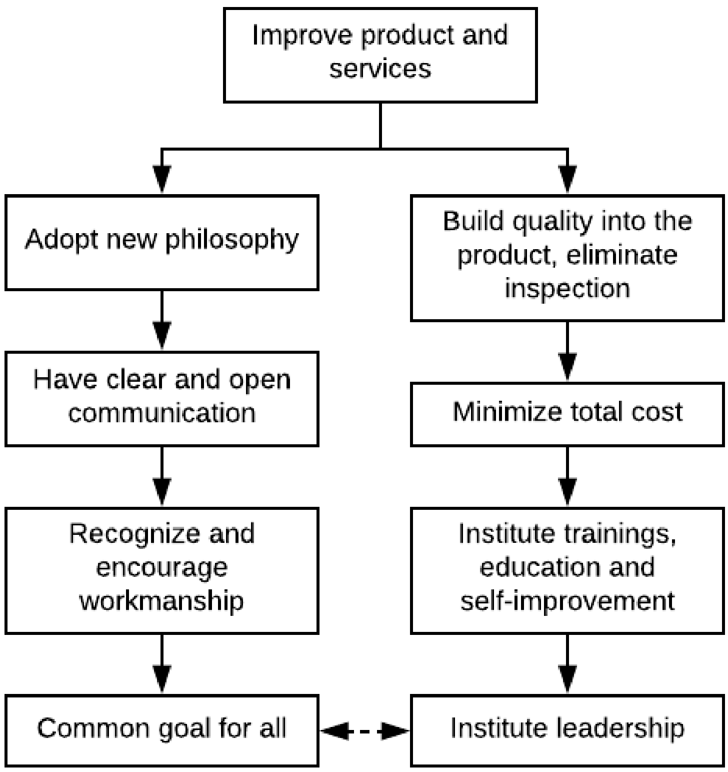

Figure 3.1: Kaizen process [30]

The principles as stated by Dr. Deming can be explained with understanding the core value of lean, to improve quality. Quality of the final product/service the customer receives is as equally important as the working processes and work life quality of the operators. For this reason Kaizen has to be carried out at different levels in an organization. On the manufacturing level, improvements are done to provide better products, reduce manufacturing costs, inventory and inspection. On a leadership level, improvements are made with change management, enabling clear and consistent communications, recognizing and motivating good workmanship and providing training and education aimed at self-improvement and becoming multi-skilled. By expanding the knowledge base of the operators, the employees are equipped with broader understanding of the work flow and also identifying room for improvement.

Kaizen on a work floor is carried out to not only improve cycle and lead times but also ergonomics and cognitive ergonomics. Most improvement activities are broken down into smaller incremental steps [30]. The process is also seen as a learning experience in problem solving and developing creative solutions. These experiences are further shared with the organization and used in future trainings there by ensuring no mistake is taken forward. By providing these trainings,workers are made capable to identify problems and to come up with solutions on their own. Reducing overall costs is crucial factor with respect to both customer and the organization. Hence it is vital for identifying room to reduce costs and indulging in Kaizen activities to improve productivity. On the manufacturing floor the 7 common wastes to be reduced as per Lean production are: overproduction, excess motion, waiting, unnecessary, processing, transportation, excess inventory and defects. With continuous improvements, it is possible to identify and eliminate these wastes.

3.2 History of Karakuri

The term ‘Karakuri’ goes back to the 17th century where it referred to any device that was used to trick, tease or surprise a person. This element of surprise was assimilated in the puppets that was proficient of achieving complex movements to astonish people for entertainment. These mechanical dolls are often referred to as ‘Karakuri ningyo’ in Japan. Though the origination of the dolls dates back to over 1500 years ago, they have been more popular in the last couple of centuries. It has turned out to be a craft that raised feelings and emotions through subtle movements of the puppets. These dolls and devices capable of achieving motion and action have been seen to be the predecessor to robots. Karakuri can be classified into three main categories, ‘Butai Karakuri’, ‘Zashiki Karakuri’ and ‘Dashi Karakuri’. While Butai Karakuri are puppets used in theatre, ‘Zashiki Karakuri’ and ‘Dashi Karakuri’ puppets ether used to play with and to perform in religious festivals respectively. Turning into a tradition, puppets appeared on every religious festival. One of the most popular among these is the zashiki Karakuri mechanism, which is a tea-serving robot as shown in the figure 3.2. The forward motion of the doll was initiated by introducing the weight of the bowl on the doll hands. A certain distance of travel is achieved by moving its feet or a concealed wheel which are powered by a wound-up spring. Once the bowl is lifted off the tray to drink the tea, the doll stops in its position. Upon drinking the tea and placing the empty bowl in the doll hands, the doll turns around and traverses back to it original position. This motion is achieved due to the difference in weight of the empty bowl, which turns the doll around and transverses back to its original position. Extending beyond puppets or robots, Karakuri contributed to the industrial modernization of Japan.[4]

Figure 3.2: Tea serving Karakuri doll [5]

The Karakuri tea-carrying dolls have inspired for many more such mechanism driven trick worthy dolls. These dolls are capable of shooting arrows, dancing and even writing. They can be quite expensive and are popular in festivals and theaters.Karakuri has since been referred to devices that are capable of handling complex movements and tasks with little or no exterior assistance. These doll mechanisms have been inspired to come up with smart solutions to assist operators on a manufacturing floor to ease manufacturing and material handling. Mechanical gadgetry were more prominent before he onset of electric motors and computers to automate and ease a process. With electricity now easily available of the floor, motors, sensors and computers have taken the front seat in assisting operations. But mechanical gadgetry capable of achieving tasks with no external power source but only green energy like gravity, elasticity and magnetism are prominent on the work floor. Samuel Bentham portsmouth block-shaping machine and Jacquard loom where the machines were able to automate shaping ten wooden blocks are examples of simple mechanisms used to automate complex tasks. The term Karakuri in Japan often is referred to ingenuity as it is a reminder of creative dolls and offers a positive overtone [6].

3.3 Common Karakuri Mechanisms

Most elements of a machine are made of simple or basic mechanisms such as lever, cams, linkages, springs, gears and cranks. Even with the advancing electronic technology, simple and basic mechanisms continue to play a vital role in converting and transmitting force from source to the machine. The source can be either human power, motor or engine. Karakuri revolves around using imagination to evolve on these simple mechanisms to make operations more convenient and comfortable. In case of Karakuri the force to activate the mechanism is usually achieved with a combination of human power, gravity, magnetism and elasticity.

In this following section we read about some of the common mechanisms used in our Karakuri study to achieve kinematic motion and transfer of energy.

3.3.1 Levers, Gears and springs

Levers
Lever is one of the oldest mechanisms invented by mankind. A lever is used to multiply applied mechanical force or change direction of force. With innumerable applications for a lever, they are often overlooked in our daily activities. A major application of a lever, small force turns into a big force. Through applying a small force over a large distance, a larger force is applied on the opposite end [**?**].

Gears
A gear is a type of mechanical component consisting of a rotating wheel with teeth (cogwheel) that is capable of meshing another cogwheel or a chain, belt, axle, rack with teeth. Gears are primarily used for transmitting torque while controlling sped, torque and direction of motion [**?**]. A cogwheel or a gear which does not have a complete set of tooth around its pitch circle is known as a Mutilated gear. These are used when you do not want the gear to be engaged throughout its rotation or there is no necessity for complete rotation of the cogwheel. By using a mutilated gear you can control the time for which you want to engage transmission of motion, resulting in a discrete rotational motion where input shaft goes through a complete rotation whereas the output shaft undergoes stop and turn motion [9].

Springs
Springs are machine elements or components that go through momentous deformation. The compliance nature of these components enable them to accumulate recoverable mechanical energy. Springs exist in many forms, be it a simple tension bar, or a helical compression spring or an extension spring. A tension spring is usually wound with a predetermined pre-load to ensure deformation only occurs after the load acting reaches a certain minimum value. The functioning of Torsion springs are very similar to that of a simple free body who rely on bending for their action. They require a specially designed end to be able to transmit load [10].

3.4 Sustainability

The definition of sustainability has been a debatable topic and different authors perceive it differently but one of the most widely known definition is stated as, "Sustainability is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainability includes advancements in three essential categories that includes economic, social and environmental aspects. From the various cases and arguments mentioned above we can extract the sustainable aspects of Karakuri and analyze how sustainable Karakuri actually is.
Social sustainability deals with the impact that an organization makes on the society and how their activities effect the people. Karakuri contributes to the well being or working conditions of the workers by reducing the level of effort they put in to

achieve a particular task. Karakuri also considers ergonomic aspects and ease the work of repetitive tasks,which help counter long term health risks. Also, it does not result in labour lay offs unlike conventional automation where robots would replace humans which affects the labour union as well as the companies policies. From these implications we can consider Karakuri to be socially sustainable.
Economic sustainability is with respect to the economic growth of a country or in this case, a business. It can be viewed as maintaining high and stable levels of economic growth. Karakuri can be implemented across various sectors of industries as seen in section 5.1.1. This historic old concept which is fairly new to Europe can dramatically support small to medium scale industries which also encourages new initiatives and start-ups. This can contribute to the economic growth significantly which makes Karakuri economically sustainable.Lastly, since the approach withholds the use of any external power or cause any pollution makes it environmental friendly. Hence Karakuri can be regarded as truly sustainable in all three aspects of social, economical and environmental.[13]

4

Results

This section highlights the significant findings of this thesis

4.1 Global presence of Karakuri

Lean manufacturing mythologies has gained a larger and wider audience in the past decade with Toyota being the forefather of this methodology. With Karakuri being an integral part of lean, its applications are seen globally [6]. As mentioned in section 3.2, Karakuri is a part of the lean culture, it depends on how lean is adopted and developed in different parts of the world.

4.1.1 Karakuri in Asia

Asia, particularly Japan has been the source of lean culture and a hub for continuous improvements over the decades. Being an integral part of lean, Karakuri inherits this culture of continuous improvement. This calls attention to the Karakuri exhibition which is a podium for the latest advancements of Karakuri in industries. The Japan Plant Maintenance Association has been holding this exhibition popularly known as "Karakuri Improvement Exhibition" since 1993. It aims to disseminate the key developments in Karakuri across the industries and also, to contribute to the further development of Japanese manufacturing industry. About 400 works of actual products and models of Karakuri improvements by companies across Japan will be exhibited. It involves examples of Karakuri implemented in various fields of industries. Shedding light on these examples not only highlights the most recent developments in Karakuri, but also illuminates the spectrum of its applicability. A few of the cases are mentioned below:

- **Company** - Lake Hamana electrical
  Title - Load carrying cart
  Application Field - Safety and environmental improvement
  Power transmission mechanism - Gear/pulley
  Overview - The scrap (waste material) produced at cold forging is around 18kg. The scrap is disposed about 5 times in a day. In order to eliminate this workload, a transportation cart is used that makes it possible to dispose the scrap without touching it.

- **Company** - JTEKT

Title - Automatic tilting drum
Application Field - Safety and environmental improvement
Power transmission mechanism - Balance lever
Overview - When the amount of liquid inside the drum is reduced, it can be tilted by the force of the spring and it can be used up to the end

- **Company** - Honda Motor Co., Ltd.
  Title- Remodel of a shooter **Application Field** - Productivity improvement · Work improvement
  Power transmission mechanism - Gear / pulley
  Overview - The work-piece's own weight is the power source, and when the work-piece is placed on the bucket of the inclined shooter, the bucket slides and moves due to gravity. When the work-piece is removed, the bucket returns to the original position.

- **Company** - Japan Climate system
  Title - Screw fishing made easy
  Application Field - Productivity improvement/ Work improvement
  Power transmission mechanism - Link mechanism
  Overview - The bolt for assembling the product is automatically supplied to the hand (processing point) of the worker.

- **Company** -Toyota Kirloskar Auto Parts INDIA
  Title - DOCO trolley/ Lift
  Application Field - Transportion
  Power transmission mechanism - Gear / pulley
  Overview- The trolley is used as a dolly and also as an assembly jig conveyor, that does not need an external power source.

- **Company** - Toyota Motor Corporation
  Title - One piece
  Application Field - Productivity improvement/ Work improvement
  Power transmission mechanism - Springs and Levers
  Overview - A lever is pushed to cut out a thin gasket that is difficult to remove.

- **Company** -DENSO
  Title - Friendly workshop **Application Field** - Productivity improvement /Work improvement
  Power transmission mechanism - Balance lever
  Overview - A 'friendly workshop' in which personal belongings start to follow automatically. The future-type work space unit which is designed to suit elderly people and those physically disabled.

- **Company** - Aisin Seiki
  Title - Karakuri thread cutting machine

Application Field - Productivity improvement / Work improvement
Power transmission mechanism - Power gear / CAM mechanism
Overview - Assist in making threads for screws.

The Karakuri exhibition also recognizes top participants with the best designs in the event and presents various awards in different categories. The winners of the Karakuri Improvement Foundation Exhibition 2016 and 2017 were as follows:

- Best trick improvement award 2016
  Toyota Auto Body Co., Ltd.
  Title - Welcome party bumper
- Trick improvement award 2017
  Denso Corporation
  Title- Friendly workshop [7]

There are a lot of companies participating in these exhibition to showcase their Karakuri developments. The list of companies present at the Karakuri exhibition are as follows:

Aisin KeikinzokuCo.,Ltd.
Aisin Takaoka Co.,Ltd.
Asahi Kasei Microdevices Co.
Calsonic KanseiCo.Gifu Auto Body Industry
Kobe Steel, Ltd.
Kobelco Construction Machinery Co.,Ltd.
Kobelco Cranes Co., Ltd.
Suntory Products Ltd.
Sanwa Shurui Co., Ltd
TAMURA Co.
Daihatsu Motor Co., Ltd.
TCM Co.,Ltd.
DENSO Co.
Toyoda Gosei Co., Ltd.
Toyota Motor Kyushu Inc.
Toyota Motor East Japan, Inc.
Toyota Motor Hokkaido, Inc.
Toyota Industries Corporation
Toyota Auto Body Co., Ltd
Toyota Boshoku Co.
Panasonic
Pan Pacific Copper Co.,Ltd.
Fuji Heavy Industries Ltd.
Hokkaido Joint Oil Stockpiling Co., Ltd.
Mazda
Mazda J-ABC Karakuri Doujo Co.
Malox Co., Ltd.
Mitsubishi Heavy Industries, Ltd.
Ube Industries, Ltd.
JX Nippon Oil Energy

Few of the interesting case studies from different parts of Asia are mentioned below.

Case study 1

Karakuri in production aims to eliminate or reduce the effort required to perform a human task by using simple mechanical devices or jigs. Material handling is one of the most important processes in the industries, especially if it involves movement of heavy components. This continuous repetitive task consumes a considerable amount of time and if it involves automation, then a constant supply of energy would also be required. The case study mentioned by Rani, Saravanan, Agrewale, & Ashok,(2015) describes how a small manufacturing plant in Asia transformed its pneumatic material handling equipment into a low cost Karakuri design. The plant located in India, Asia uses pneumatic machines to lift and tilt heavy components. Since these machines requires high power which also faces frequent power cuts, a lean way was chosen to deal with the problem, i.e to come up with a Karakuri design which could accomplish the same maneuver. The existing machine was redesigned based on Karakuri mechanisms which would then use gravity over electricity with the added advantages of low maintenance, low cost and reduced cycle time. The solution implemented worked successfully and showcased the potential of Karakuri kaizen.

The Tilting unit, which is used to tilt the component up to a certain degree, enabling the operator to carry out his task with ease. This process was initially done by placing the component in the fixture and using a pneumatic actuator to tilt the fixture to a certain degree. With the objective of the project to eliminate energy consumption and complexities of pneumatic actuators and introducing Karakuri Kaizen, the team designed a new system using counter weights to enable the tilting motion instead of the pneumatic actuator. This was done by first discussing the process at the floor level and then using the videos provided by Japan Institute of Plant Maintenance's (JIPM) as base material for concept generation. Post finalizing the concept with the industry responsible, 2D drawings were made with accurate measurements. In order to gain more approvals for the concept, a simulation of the working model was made for better visualization. Following the concept of Karakuri Kaizen, time was invested in only generating the major operation and the rest was through trial and error during the manufacturing phase. Counter weights were linked through a chain sprocket to the carrier to counter the weight of the work-piece placed on the carrier. The fixture would tilt with the added weight and a stopper would stop the carrier at the correct angle. The counter weights are added in a incremental form for having a smoother tilting motion. A air damper was used to slow down the reverse motion of the carrier when the work-piece was lifted off the fixture.The proposed system was tested and the results found the cycle time was reduce by 27.5%. A break even analysis was carried out to find the break even point, which was found to be 1.5years. The new system made impressive saving on power consumption.

Case study 2

As mentioned before Karakuri is a concept that can be applied in various sectors of the industry. Packaging is one such sector and is one of the most important aspect of any industry. Carton boxes are one of the most widely used in the industry which possesses the desired strength of withstanding handling and stacking loads.
There are commercially available automated machines that are employed today that fold the flat cartons obtained from the manufacturer. These highly automated machines are extremely expensive and requires strict maintenance which makes it unsuitable for small scale industries. The case study mentioned in Yashvant Khire & Madnaik (2001) describes a Karakuri mechanism for making a carton box from flat card boards. The flat card boards so obtained from the manufactures are marked with various impressions of folding lines. The traditional folding technique required hideous manipulation of the carton and a set of full time employees. The new Karakuri product would achieve this folding sequence with reduced time and effort. It contained few supporting guides that help fold the carton at the marked positions actuated by a lever and spring mechanism. The earlier dexterous manual manipula-

tion was reduced to few simple steps in the new machine. The productivity increase was recorded to increase by 8 times and with a total cost of $200. It also helped to cut down the operator requirements by 50%.

Japan has only a handful of companies dedicated to manufacture of Karakuri products. A couple of them are listed below.

Toyota L&F (Logistics Forklift)

Toyota L&F is an integral part of Toyota dedicated totally to logistics development. They provide logistics solutions to help companies reach an economic logistics costs. This branch of Toyota handles the complete logistics of the company right from transportation to automatic storage systems by applying their years of expertise gained from 'monozukuri' (manufacturing). As internal logistics is a very important part of a facility, Karakuri shooters are extensively used by Toyota. Right from efficient storage up until order picking, Toyota fully incorporates low cost racks and shooters. They also offer guide tours and courses on latest logistics systems. [14]

Yazaki

Yazaki Corporation is a Japanese company who have set their foot across various industries such as automotive, agriculture, industrial, etc. The dedicated industrial sector places its focus on production development that includes assembly support systems, shooters, AGV's, etc. The company also produces all the basic components that may be required for a flow rack/shooter like rollers, plastic containers, pipes, connectors, etc. Yazaki also has a logistics sector which designs and manufactures Karakuri products for different applications. Apart from the shooters of a wide range of specifications, it also has Karakuri conveyors, work benches, wagons, cart, etc. The company has also designed a order picking system with pick to light function. [15]

4.1.2 Karakuri in Europe

As mentioned in previous sections, though Karakuri is a Japanese term and more commonly found in Asia, it is an integral part of Lean method of manufacturing. While, Lean Manufacturing is increasingly becoming popular in Europe, Karakuri has begun to gain an audience as well. As seen from section 5.1.1 one may realize that, though Lean is not adopted as a culture, parts of lean are being implemented individually. Karakuri is one such methodology that is gaining audience as the Low Cost of Automation of the east. Unlike in Toyota or Nissan, Karakuri is not developed internally as part of the companies continuous improvement strategy but commonly outsourced to consultant companies to "automate" with low costs. Though there are not many companies exploring the possibilities of Karakuri, there are a few that are bringing in technology from the east into the west. Some of leading firms exploring Karakuri and their products are mentioned in the section below:

Table 4.1: Karakuri Companies in Europe.

Company & Product	Power Source	Mechanism	Overview
AIO - Modular Flow Racks	Gravity, elasticity & pnematic actuators	Gears, rollers, pulleys, springs	The company even provides a Karakuri Kaizen Kits and DIY software which enables the user to design and assemble their own product using the blueprints, tutorials, components [19],[20]
Item	Manual, gravity & elasticity	Gears, rollers, pulleys, springs	Online platform to design customized solutions alomg with standard material handling products. The company specializes in foot and hand operated shooters, corner handling and magazine handling solutions [21], [22].
Trilogiq	Manual, gravity & elasticity	Gears, rollers, pulleys, springs	Products ranging from cart, trolleys, ergonomic workstation to low cost automated guided vehicles (AGV). The company also provides the possibility to customize, design and order simple tube and bracket solutions online, for flowracks, conveyors and workstation [23].
Virtual Manufacturing AB	Manual and gravity driven	Springs, rollers	Specialization in lean based solutions in the form of flow racks, trolleys, AGV, workstation equipment [24].
Beewatec	Manual, gravity & elasticity	Gears, rollers, pulleys, springs	roducts dedicated to production and logistics such as internal logistics, assembly work places, transportation, storage, modular systems [25].

There are some interesting case studies that have been documented here to better understand ho Karakuri is perceived and applied in the European interpretation of Karakuri. These studies represent in-house Karakuri solutions as well as solutions developed with the help of consultants.

Case Study 1: Volvo GTO, Gent
Caron Serge, Volvo Construction Equipment's current Senior VPS Coach, in his previous role worked with implementing Karakuri solutions at the Volvo GTO plant in Ghent, Belgium. As Caron mentions in his interview, among the many Karakuri solutions developed at the plant, one that stood out was the Magnetic bolt picker. The case involved one of the operators to pick two metal bolts from a bin of bolts and place them on a chassis body for assembly purpose. The pick and place operation was found to be tedious as the picking exactly two bolts among several other bolts was consuming time and was not ergonomical. For this purpose a solution was developed where a mechanical arm, attached with two magnetic plates was used. These arms were capable of reaching down into the box with the push by the operators and come up on its own as a spring actions. The magnetic plates at the end of the arm was capable of picking exactly two bolts from the bin. A video of the same can be found in the appendix section **??** . This simple solution is an example of how simple mechanism can produce ingenious solutions.

Case Study 2: Virtual Manufacturing AB
Virtual Manufacturing AB is a consultant company providing lean based solutions of production relate process and planning. As mentioned in the table 4.1, the solutions related to lean based manufacturing include flow racks, trolleys, work station equipment. The company along with BeeWaTec has developed several Karakuri based flowracks as solution for material handling and buffer management.

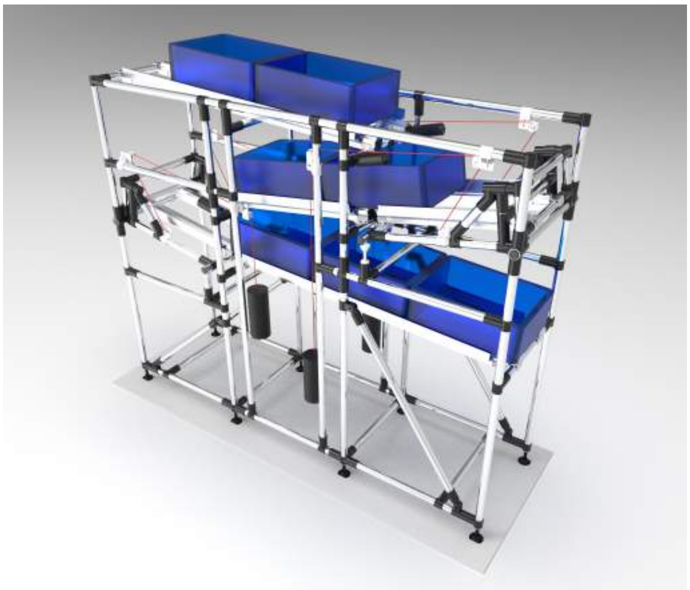

Figure 4.1: Auto feed for improved inventory handling

The solution proposed here in figure 4.1 is an ingenious solution to handle buffer when there is space constraint on the work floor. The solution was developed to ensure there is a continuous feed of material, represented with the blue kitting boxes. The operator used the material from the front end, while another operator can feed in new material from the back. By utilizing the weight of the material and gravity, along with some simple mechanical links, strings and rollers, an automated inventory handling solution is developed. The solution provides better ergonomics and works without any external power source.

Figure 4.2: Flowracks are extensively used in material handling.

Several such innovative solutions are developed in regards to improving material handling and kitting processes as seen in figure 4.2. A video of a shooter used in material handling can be found in the appendix section **??**. Though there are various successful solutions developed, some have been unsuccessful as they do not take into account ergonomics standards of particular companies. For example, Hydralslanga was developed by Virtual Manufacturing AB as a solution for handling hydraulic cables at Volvo Construction Equipment AB, Braås, Sweden. Hydralslanga, as seen in figure 4.3, was successfully able to handle the hydraulic cables and achieve the required task. However, the company found the product to be designed outside the prescribe ergonomics standards of Volvo. As these standards differ from one organization to another, not all solutions are universally acceptable.

Figure 4.3: A solution developed to handle heavy hydraulic cables.

4.2 Global manufacturing competitiveness

Figure 4.4: Drivers of Global Manufacturing Competitiveness [29]

With a countries manufacturing capability being vital in determining the countries economic prosperity, it is important for a country to know how its competitors are performing in order to remain competent. Deloitte Touche Tohmatsu Limited (Deloitte Global) along with the US council have been conducting research on global manufacturing capabilities to determine every countries competitiveness with respect to skilled labour, exports and technology intensiveness. The research was conducted by collecting survey results from 500 senior manufacturing executives. This survey enables us to understand the competing factors in the current manufacturing sector and plan for the future by analyzing the predictions for 2020[29].

2016 (Current)		
Rank	Country	Index score (100=High) (10 = Low)
1	China	100.0
2	United States	99.5
3	Germany	93.9
4	Japan	80.4
5	South Korea	76.7
6	United Kingdom	75.8
7	Taiwan	72.9
8	Mexico	69.5
9	Canada	68.7
10	Singapore	68.4
11	India	67.2
12	Switzerland	63.6
13	Sweden	62.1
14	Thailand	60.4
15	Poland	59.1
16	Turkey	59.0
17	Malaysia	59.0
18	Vietnam	56.5
19	Indonesia	55.8
20	Netherlands	55.7

2020 (Projected)			
Rank	2016 vs. 2020	Country	Index score (100=High) (10=Low)
1	(▲ +1)	United States	100.0
2	(▼ -1)	China	93.5
3	(⟷)	Germany	90.8
4	(⟷)	Japan	78.0
5	(▲ +6)	India	77.5
6	(▼ -1)	South Korea	77.0
7	(▲ +1)	Mexico	75.9
8	(▼ -2)	United Kingdom	73.8
9	(▼ -2)	Taiwan	72.1
10	(▼ -1)	Canada	68.1
11	(▼ -1)	Singapore	67.6
12	(▲ +6)	Vietnam	65.5
13	(▲ +4)	Malaysia	62.1
14	(⟷)	Thailand	62.0
15	(▲ +4)	Indonesia	61.9
16	(▼ -1)	Poland	61.9
17	(▼ -1)	Turkey	60.8
18	(▼ -5)	Sweden	59.7
19	(▼ -7)	Switzerland	59.1
20	(▲ +3)	Czech Republic	57.4

Figure 4.5: Shifting dynamics among global manufacturing nations [29]

4.3 Technology with Karakuri

The evolution of sensors have resulted in the development of smarter devices having tremendous capabilities of processing and data collection making them extremely accurate. On the other hand, decreased manufacturing costs has enormously increased the availability as well as resulted in the development of smaller, more powerful and inexpensive sensors. The newer versions include embedded technical processing and wireless networking ability. These progressive capabilities finds its place in the modern spectrum of requirements for unique applications ranging from industries to defense. [16]

More recent emerging trends can be regarded as the internet of things which is commonly referred as IoT. IoT exploits the true potential of the internet. It is a system of interrelated computing devices/ machines that can sense and collect data from its physical environment. This data can be transferred across the internet without requiring human-to-human or human-to-computer interaction which can be utilized for smart applications. But it is essential to note that sensors have existed much longer than the internet has, and much longer than the Internet of Things (IoT). We can draw a conclusion that combining the IoT with lean can catapult productivity and possibilities to new limits[18].

4.3.1 Current technologies

A brief description of the current sensors and technology used in the market is presented here to better understand the current market and the various options available, that could be integrated with Karakuri solutions and bring Karakuri onto the world of IoT.

- **iBeacon- Bluetooth :** Working on the core principle of Bluetooth Low Energy (BLE), iBeacon is a technology developed for mobile devices to interact with signals from other beacons. With the BLE, beacons are capable of utilizing wireless network at low energy and much lower costs (6o-80% lower). Using BLE the beacons are able to broadcast small packets of data, which can be used to access location at a micro-local scale and advertising, discovering information [33].

- **Vibration Sensors :** The vibrations from a moving object, be it material on a conveyor belt or an electric motor can be used to determine the linear velocity, displacement and acceleration. These vibrations can further be measured and displayed to determine count or to detect abnormality. With in-numerous applications on a work-floor ranging from simple count keeper to analyzing the health of a machine, vibration sensors are being extensively used and considered as vital technologies in the test section [34].

- **Smart Position Sensors :** 3 dimensional measurement has increasingly gained audience as it helps in better understanding position and layout of a scene and since been considered to be a vital technique in the computer vision sector. Highly accurate results can be achieved by using imaging arrays and this information can be sued to analyze a given scene remotely and accurately [35].

- **Bosch MEMS Sensor :** Bosch's micro-electric-mechanical systems sensors have found innumerable applications in the world of automotive, mobiles and manufacturing. The sensors are capable of handling multiple inputs, logging the process data and analyzing the data to achieve continuous monitoring. The sensors are also user friendly, flexible and readily available [36].

- **Object Detecting Sensors :** There are several sensors that have been used for detecting objects or obstacles. Depending on range, accuracy, quality and cost, the sensors vary. Another factor to be considered is the amount of light, sound, magnetic field and other similar factors which influence the choice of sensor. Though the application remain similar to each other the sensors vary based on their functionality. Some of them are listed below [37].

  - **Inductive sensor** : These types of sensors are commonly used to determine position working on the principle of a transformer. By detecting alternating electrical current, presence of a conductive object is inferred [38].

  - **Photoelectric sensors** : These sensors work on the principle of reflective light. They primarily emit a light beam to reflect upon a surface and determine is presence or absence. The change in light quality is also used to determine the presence of an object, hence also classified as a proximity sensor [39].

- **Capacitive sensor** : This is another proximity sensor working on the principle of change in magnetic field due a presence of a conductive object. They have smaller ranges but with a change in the magnetic flux, they can detect the presence or absence of an object [40].
- **Ultrasonic sensor** : Similar to photoelectric sensors, ultrasonic sensors use sound wave of a specific frequency as a medium to reflect off the objects surface to determine the objects distance. This is done by calculating the time taken for the reflected sound wave to reach back. When a object to be detected is transparent or in a different medium ultrasonic sensors are used as sound waves reflect of surface while in a different medium too [41].
- **Vision Sensor**: Vision sensors use the principle of a camera to capture a scene and then determine the presence of an object by comparing it to a stock image. By sensing the shape and light density, these sensors are capable of accurately detecting orientation of the object as well [42].

4.3.2 Emerging technologies

Considering that each passing day sees a dawn of new technological advancement and innovative solutions, and adopting to new technologies to keep up with the market standards and to achieve better productivity and quality, it is important to be wary of emerging technologies. As such,some emerging technologies are explored in this section that hold relevance to Karakuri based applications. As these technologies are comparatively new and in some cases still undergoing research, availability and costs are a concern.

- **Project Soli - Google** : Using radars at high frame rates, these sensors are capable of deducing gestures made to control objects [43].
- **RFID implants** : RFID implants offer the possibility to locate and track persons and objects. electromagnetic and inductive coupling are the used as a power source and communicate data[44].
- **Lensless Smart Sensors - Rambus** : These sensors work on the principle of eliminating the need for lens or a focusing component by introducing a ultra-miniaturized refractive part to help focusing. This enables to produce smaller sensors and can cos much lesser and provides innumerable applications in all sectors[45].

4.4 Interview study

Interviews gives a chance to obtain valuable inputs directly from the people in interest.To get a wider perspective, interviews were conducted with people from both academic and industrial background. The academic interviewees are the head of the Lean Management program at Chalmers University and is a part of the Supply Chain and Operations Management. Both the interviewees have extensively worked with studying the Lean Methodologies and the adaptation of Lean globally. The industrial interviewees are mostly employees from Virtual manufacturing AB and few other external clients of the company. All the inputs from the interviews are broken down and coded as described in section 2.

One of the major aspects of this study is to get an idea of the market of Karakuri in Sweden compared to Europe. Awareness of the concept of Karakuri in itself among Asian and Swedish industries is a big question. The figure 4.6 shown below depicts the awareness of karakuri in both the Asian and Swedish market on the scale of 1 to 10. It also provides a view from an academic and industrial perspective.

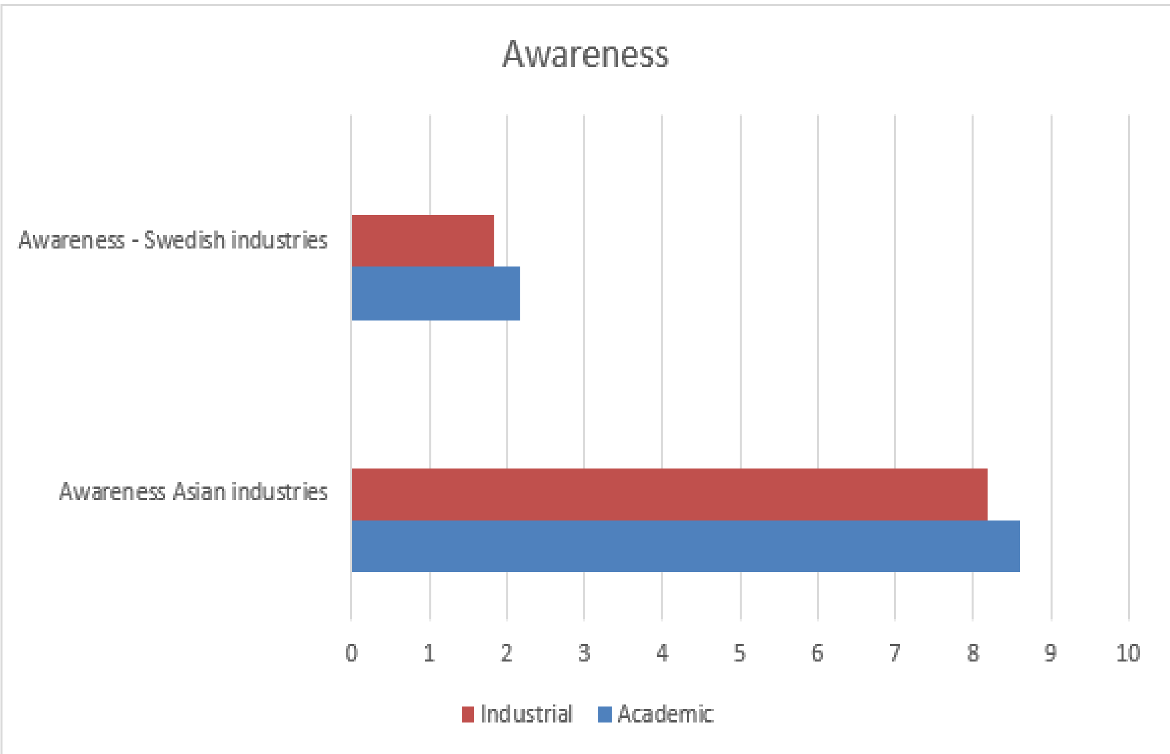

Figure 4.6: Awareness - Asian vs Swedish industries

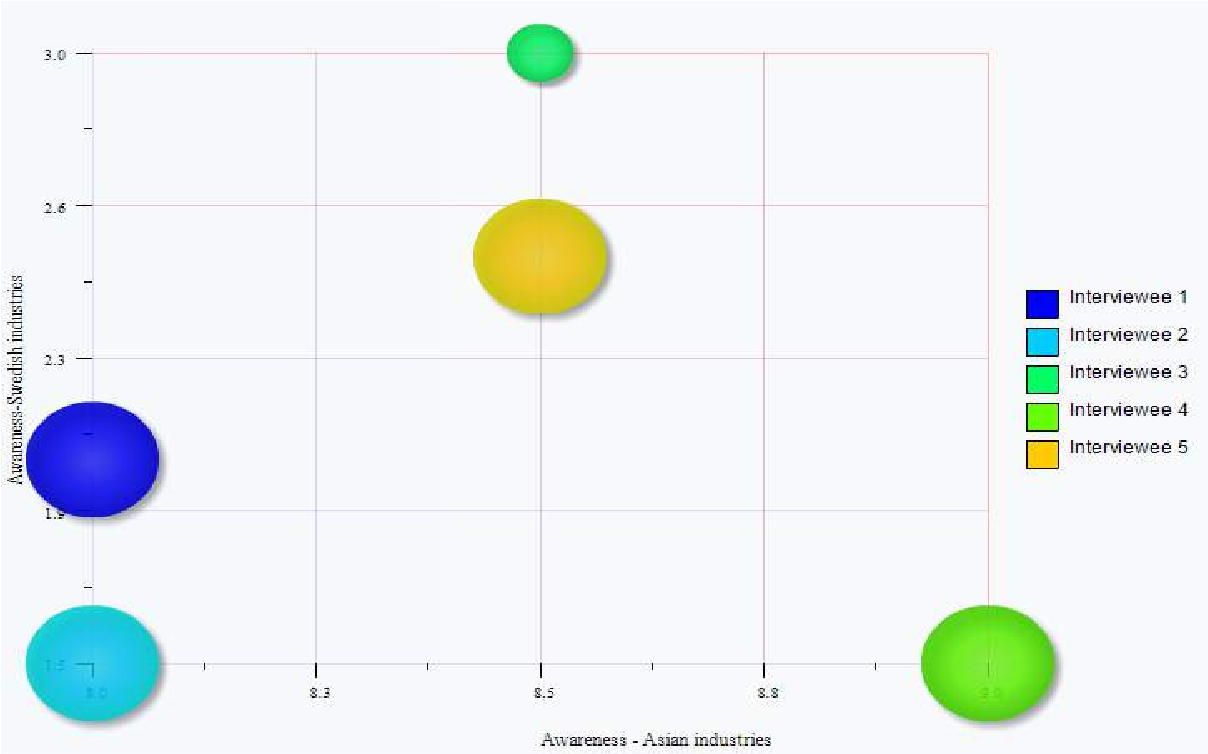

Figure 4.7: Awareness - Asia vs Sweden with potential growth

The above figure 4.7 shows the awareness plot over the difference axes where the size of the circle depicts the potential growth of Karakuri in Sweden. All of the parameters are on the scale of one to ten. The potential growth is only with respect to Sweden. The figure 4.8 shows how the academic and industrial interviewees scaled the applications of Karakuri for material handling alone and other applications.

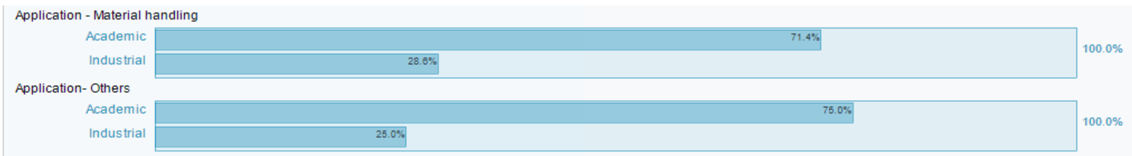

Figure 4.8: Application of Karakuri - frequency percentage

All of the industrial interviewees commented on the design aspects of Karakuri. It is possible to derive two main critical factors or the main reasons the product fail that must be considered while designing. Ergonomics and mechanical failure were found to be the most critical factor that every interviewee mentioned. Most of the products at Virtual had failed mostly due to ergonomics followed by failure in mechanism. The bubble chart shown in the figure 4.9 below shows the weight of the two critical factors with the size of the bubble depicting the importance of data collection. Also, the figure 4.10 provides the percentage of the total interviewees who mentioned about ergonomics and how critical it can be while considering any kind of production design.

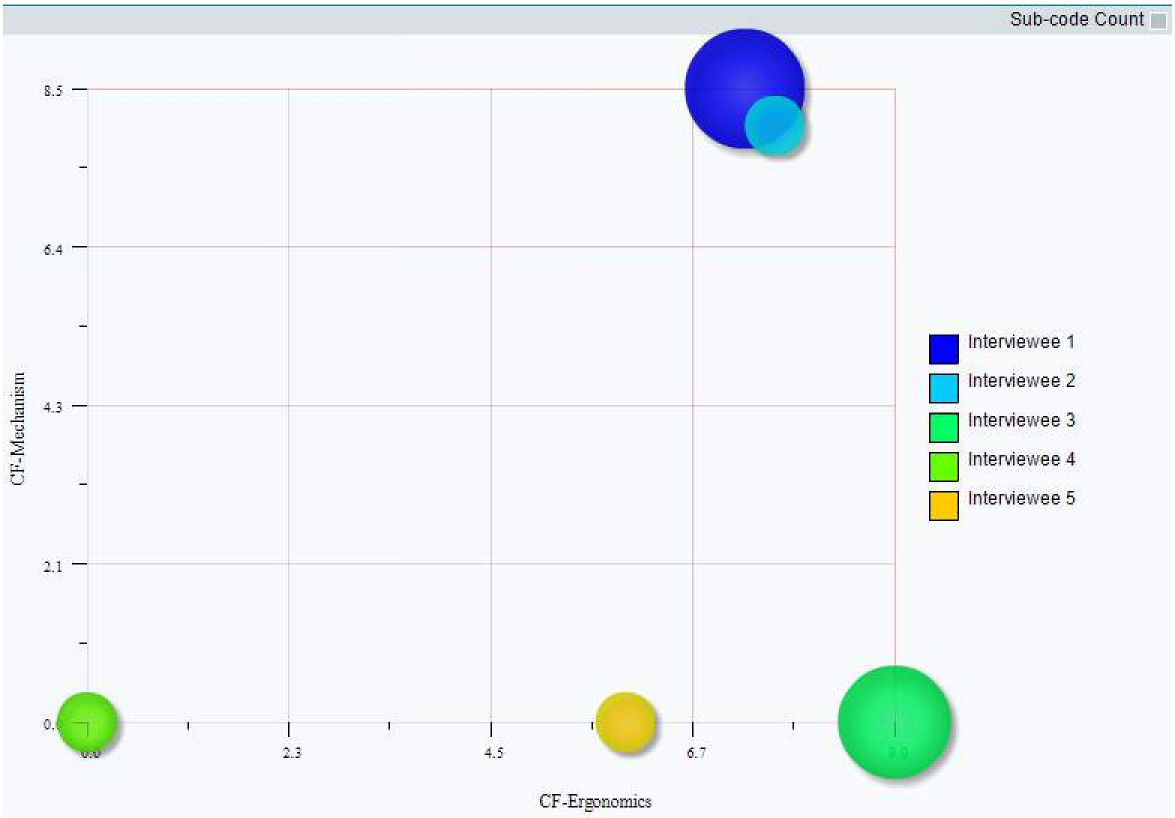

Figure 4.9: Critical factor in design

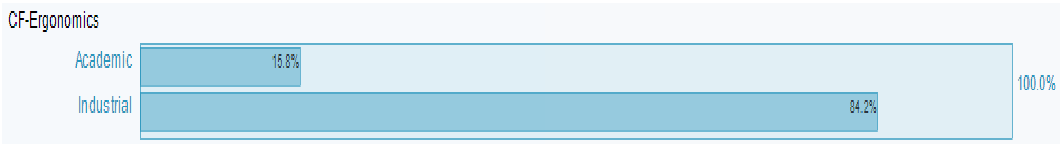

Figure 4.10: Critical factor percentage

The below figure 4.11 shows all the factors considered and their corresponding weight. It can be seen that the potential growth of Karakuri in Sweden has the highest weight of 89 among all the other factors considered. If looked upon the awareness, there is a vast difference between the awareness in Asia compared to Sweden. Finally as mentioned before, the critical factors to be considered while designing are ergonomics and mechanism.

Code Weight Statistics

Code	Count	Min	Max	Mean	Median	Mode	Range	Sum	SD	Variance
Average lead time to propose	2	2	2	2	2	2		4	2	
Awareness - Asian industries	10	8	9	8.4	8	8	1	84	2.84	0.26
Awareness-Swedish industries	12	1	3	2.16	2	2	2	26	0.97	0.51
CF-Cost	3	6	7	6.66	7	7	1	20	4.74	0.33
CF-Ergonomics	7	7	9	8	8	9	2	56	3.41	1
CF-Mechanism	3	8	9	8.33	8	8	1	25	5.92	0.33
Importance of Problem analysis	3	5	7	6.33	7	7	2	19	4.62	1.33
Importance of data collection/	3		8	2.66			8	8	4.98	21.3
Potential growth	10	8	9	8.9	9	9	1	89	2.98	0.09

Figure 4.11: Code weight statistics

The interview for the internal employees at VM was mainly carried out to analyze and understand the design process of Karakuri at VM and awareness of Swedish market. One of the interviewee expressed that usually, the projects revolved around improving material flow with focus on either reducing lead time or improving work procedure for the operator. The method of designing a Karakuri at VM is as follows: First the team would analyze the customer requirements and consider different solutions. Some of the parameters to consider when finalizing on a design as listed by the interviewee are space and material availability, weight of the components, ergonomic standards and also the overall costs involved. The whole process of drawing up a solution and proposing it to the clients takes two weeks on an average. The process involves communicating ideas, taking inputs and negotiating prices, the conceptual design and realizing the product.

One of the project which was for SAAB aimed at providing a solution for kitting at various work stations. The interviewee expressed that the Swedish manufacturing sector is not aware of the term “Karakuri” and engineers vaguely interpret the concept as "Fattigmans automation" and lack the deep knowledge of the core concept. According to him, there needs to be an increased awareness on Karakuri which can help tackle industrial issues the lean way. In contrast to the previous design method mentioned above, another interviewee described a method which diverges with the previous one. In this case the designing usually started with a pen and paper followed by CAD design and finally build a prototype.

Another consultant who was interviewed was previously associated with Volvo construction equipment and was associated with one of the Karakuri project which was for Volvo Borås. The aim was to provide a Karakuri solution to help assist the handling of hoses which are about 1 to 4 metres long. The mechanism that was designed successfully worked but it was perceived as a complicated solution. The ergonomics was also considered not being in the safe zone and the complicated mechanism added to the total costs, making it less economical. It was learnt that data gathering and presentation of the solution are very critical factors and the interviewee commented that people tend to think of the newer technologies and terminate the possibilities of achieving the same result with low cost innovative solutions. It came to notice that there was not enough data gathered except few pictures and notes which makes it difficult to comprehend the entire scale of the problem. The general opinion on Karakuri is that these solutions are very innovative and can achieve the desired results in half the price compared to high tech automation approach, but there is a need to convey the solution to the clients effectively through simulations than the current way of presenting CAD models. There have previously been instances where the industry fail to recognize an ergonomic problem even if it exists, until someone has reported a complaint and see no need for a solution.

One of the interviewee, while studying Lean Methodology at Toyota in Japan, had noticed Karakuri or Low cost automation being extensively used for material handling. Flowracks in collaboration with Automated Guided Carts (AGC) were the most common form of Karakuri witnessed. In his opinion, Sweden has high level of education and is capable of handling complex production solution. However, there is lack of knowledge and experience of working with Karakuri (LCA) and this is the reason for increased automation in the Swedish manufacturing Industry. To achieve competent low cost automation it is crucial to adapt continuous improvement (kaizen). This can be achieved by taking small steps towards automating a process or operation with Karakuri. The firm should also be open to how they achieve this and sharing knowledge. Toyota's success in adopting Karakuri can be credited to their openness and willingness to share. As Lean way of manufacturing is growing through Sweden, adapting Karakuri kaizen would benefit the large scale companies as they go down the Lean path. The knowledge shared her can benefit small and medium scale industry in adopting low cost automaton and closing the gap level of automation (LOA) between them and Large scale industries.

4.5 Survey Study

As learned from section 4.4 determining the market awareness and knowledge of Karakuri as a concept in Sweden was a crucial part of the study. From both the interview and the survey study it was evident that the knowledge of Karakuri and its application was considerably lower. From the survey results shown in the image 4.12, it can be seen that though some members in the industry have acquaintance with the term "Karakuri", not many are aware of its functions and applications of it.

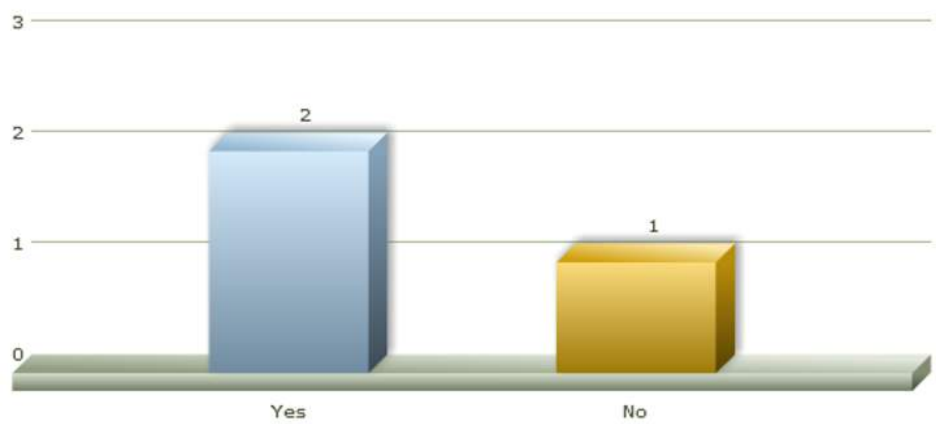

Figure 4.12: Awareness of the term "Karakuri"

The survey also addressed the fact that the concept of Karakuri was more prominent in Material Handling in the form of flow racks in Europe, as mentioned in earlier section. The participants all concurred that the concept of Karakuri can be applied to various sectors of a manufacturing facility like Kitting lines, Assembly lines and to improve ergonomics. This made it evident that are unexplored sectors of Karakuri that are open for exploring.

4.6 Test case

4.6.1 Concept Validation

The current state of the problem was completely analyzed and with the aid of the pre-study/interviews, a Karakuri solution was proposed. The process of how the solution was generated and the method of product realization from concept to prototype can be referred in section 2.

4.6.2 Concept Generation

It is clearly known from the previous sections that Karakuri does not involve any use of external source of energy and automating a process that involves multiple steps is rather a challenging task. The current method uses plastic ties as seen in figure 1.2, and was concluded from the current state analysis that it consumes a lot of time. An alternative to plastic ties was chosen to be used. The figure 4.13 shows a bag sealer which is generally used as a house commodity to easily seal plastic bags of left over food or bread. It uses a sticky tape combined with some simple mechanism to seal the cover as it is passed through the slot. The process is a lot faster compared to plastic ties as it only requires about 2 seconds to seal.

Figure 4.13: Bag sealer

The idea is to use two of these bag sealers in parallel that helps achieve two seals with a small gap between, which is exactly as required for the purpose. As known from the old process, the next step is to cut the plastic bag between the two seals. When the two plastic bags are placed parallel to each other, a small space is left in between which can be utilized to place a cutter. Hence the new process involves forcing the plastic cover into the slots of the bag sealer which seals the bag at two places followed by a cutter in between which cuts off the plastic bag in between the seals. The next stumbling challenge is to automate this entire process and generate a concept to achieve this.

Gallery method is used for concept generation and only the best chosen alternative will be described in this section. Two concepts were developed as per the method and one of them was finalized for further improvement based on careful examination. The concept that was finalized is shown in figure 4.14 below.The alternative concept that was disregarded can be found under Appendix B.

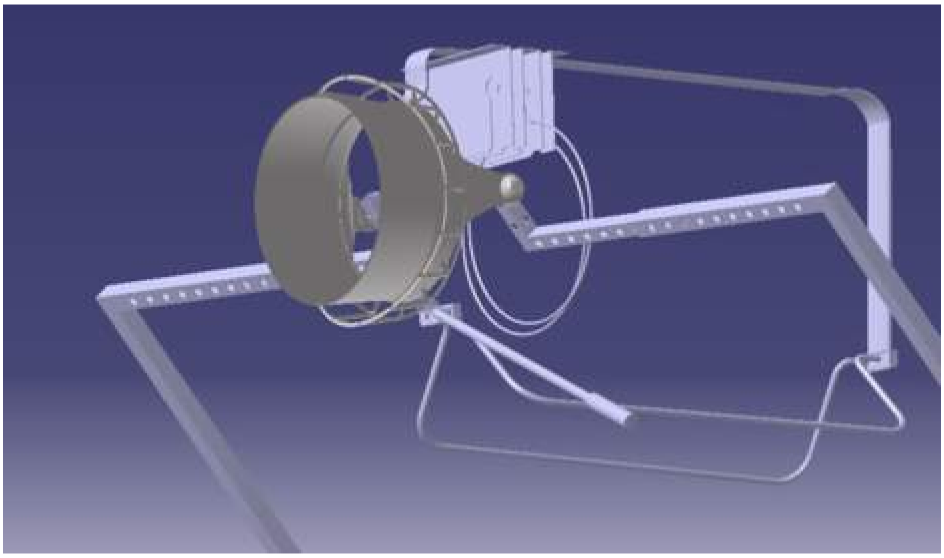

Figure 4.14: Concept 1

The above shown concept is just an ambiguous depiction of the working and does not indicate the full working mechanism. This particular concept was derived by considering Volvo Skövde facility. Since presenting a full product is disregarded from the scope of this project, only the vital working Karakuri mechanism will be addressed in the following sections. Hence, in this case the focus will be only on the sealing and cutting mechanism.

The concept makes use of two bag sealer as mentioned before which is fixed to the supporting structure at one end. The plastic waste bag which is is available in a 100 m continuous roll is placed around the circumference of the cylindrical structure. Wires of suitable material will be used to compress the plastic bag and guide through the slot of the bag sealer. These wires are connected to a handle which when actuated pulls the wire. The wires that guide the plastic through the slot of the bag sealer, seals the plastic at two places with some space between. At the end of the sealing process a cutter will be actuated by the same lever, cutting the plastic in the space between the two seals. Hence, both the sealing and cutting is achieved in one motion of the handle. Two supporting rods are present that helps sustain the weight of the filled plastic bag. The product can be placed directly above the main dumping bin. The ends of the rods are connected to a gearbox which is actuated by the same handle that helps open up the rods outwards causing the filled plastic bag to drop down.

A adjustable supporting frame which can be adjusted as per the ergonomic height of the operator is provided to hold the bin and provide stability. Therefore, the concept proposes to seal, cut and drop the waste plastic bag in just one motion of the lever. The figure 4.15 shows the full view of the concept proposed.

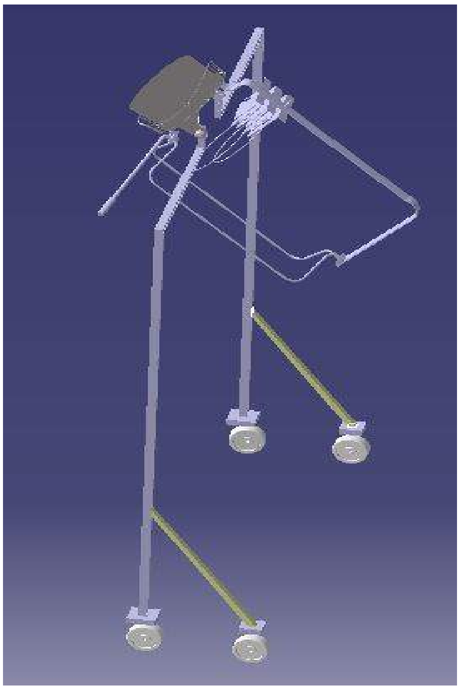

Figure 4.15: Concept 1: Isometric view

4.6.3 Prototype

Once the concept is generated, the next step is to build the prototype. It may be noted that building of the prototype is taken up as the next step violating the traditional method of product development. The reason to violate the design process is one of the key findings of this project and will be addressed in the section 5.

Figure 4.16: 3D printed parts

Figure 4.17: Before improvement

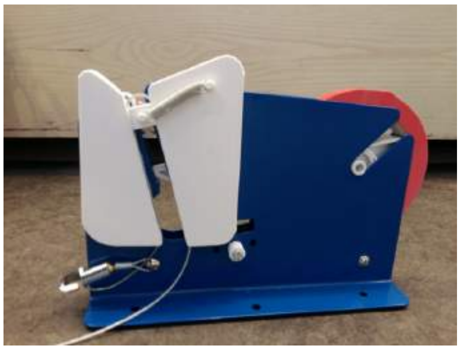

Figure 4.18: After improvement

Hence the following step in the design process was to start building the prototype. The mechanism was planned to be realized section by section, i.e, first the guiding of the plastic into the slot using the wires was addressed followed by cutting and finally the specific unique solution needed to be implemented at the Skövde plant. Hence the mechanism of guiding the plastic into the slot was looked in detail initially. Based on the concept developed, few supporting parts of the working mechanism were designed to the scale using 3D CAD modelling. Rapid prototyping was used to 3d print the parts. The figure 4.16 shows the guide plates and pulleys that was designed which aimed at guiding the wires and also providing some surface that could help the plastic slide into the slot.

Figure 4.17 shows how the parts were initially planned to be placed. Upon testing, it was realized that the wire may slip out easily and the design did not seem robust. Hence as per 'Kaizen' principles, the design was continuously improved and tested to get the optimum result. Upon improvement, a slider with recoil was added for stability as shown in figure 4.18. The new improvement would also help controlled movement of the wire and hence the plastic bag that will be dragged along with it. The mechanism worked perfectly fine except that there was an increased amount of friction due to the low quality 3d printed parts. Since the mechanism worked well on one side, it needed to be replicated on the other side of the bag sealer to have a complete stable guiding mechanism. At this stage the true potential and importance of Kaizen or continuous improvement was practically known.

Figure 4.19: Slider on all sides

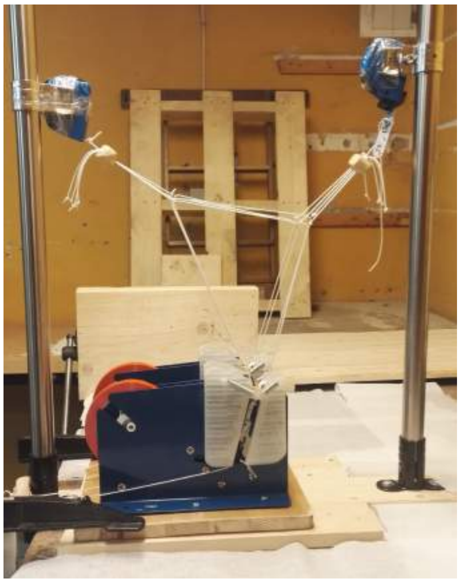

Figure 4.20: Final prototype with recoiler

Figure 4.19 shows when all the sides of the bag sealer has been replicated with the sliding mechanism. It was tested and the results turned out to be fruitful. At this stage, the mechanism would help achieve two seals at the same time with just one pulling action. Now that the sealing was achieved, a recoiling mechanism had to be incorporated in order to pull back the wire that would have sealed the plastic. For this purpose a little research of the Karakuri components had to be made. It came to our notice from one of our discussion meetings with a German company Beewatec that they have introduced a new Karakuri component into their catalog called a 'Karakuri motor'. This motor needs to be initially rotated by some manual means or usually achieved through gravity which when released rotates back. It incorporates a coil spring whose tension is continuously increased as it is initially rotated and when released, the tension in the spring causes the motor to rotate back to its hope position. This is exactly what we needed in our application but on a much smaller scale as these motors produce up to 4.8 Nm which is too high. Hence, it was decided to replicate the concept of Karakuri motor which was found in a simple measuring tape. It works on the same principle as the Karakuri motor expect that it is used in a different application. The measuring tape were tuned to increase the tension in the springs and used as a recoiler. The casing and the tape itself were not removed so as to convey the concept of Karakuri clearly. The torque produced by these measuring tape were just enough to pull back the wire. The figure 4.20 shows the mechanism with the recoiler. It can also be analyzed from the figure that a triangular profile is created with the wire when it has been pulled back to its home position. Between this space is where the plastic cover would fit. In other words, the wires would be around the plastic bag after every seal to make it possible for dumping trash for the next cycle.

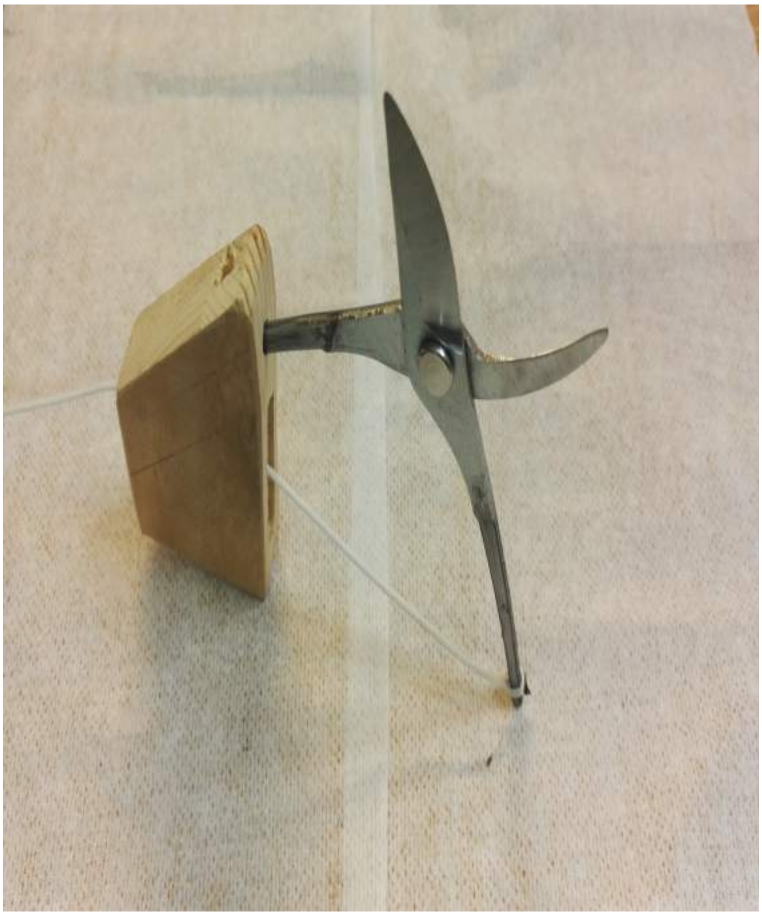

Figure 4.21: Cutter

It should be noted that the old method of using plastic ties that consumes about 30 seconds was reduced to about 11 seconds at this point using the Karakuri mechanism that was build and without incorporating a cutter. That is, with just the sealing being automated and using a normal scissor to cut, the net time required to achieve the task was reduce to less than 11 seconds, a good 63 % increase in efficiency.

Now that the entire sealing process was working as expected, the next step in the process is to cut the plastic between the two seals. Hence, the cycle of improving continued and a metal cutter similar to a scissor was chosen and a supporting structure was made using wood. One end of the cutter handle was fixed while the other end was tied to a wire causing it to close and cut when pulled. The idea was to attach the wire actuating the cutter to the same handle that causes the sealing process. This way both sealing and cutting would be achieved in a single action. Upon several tests, it was seen that the cutter chosen was not the optimum for this application as the plastic would not cut in one action and multiple repetitive actions were requires in order to effectively cut the plastic. Also, the net force required to actuate the whole mechanism increased drastically. Hence this option was eliminated. Due to the time constraint, other options were not explored, but a suitable alternative was suggested. The alternative that was suggested was a hot wire that uses a 3 - 9V battery and was seen to be the right choice for this application.

Figure 4.22: Karakuri Bin - Modular design

Once the wire mechanism was efficiently working, It was planned to take a modular approach for the bin by having two separate units. One is the entire bag sealer unit fixed on top of a support and the other is to have the frame built using standard pipes and components. Hence the concept 1 suggested in section 4.6.2was further improved and approached with a much simpler design as shown in figure 4.22. This adds to the flexibility of the product all together as it can be adopted to any dimension of the plastic bag easily. It can be seen that the new mechanism that was designed can be mounted at the side and at the top of the bin. A continuous roll of plastic is wound around the top rectangular pipes. As the trash is thrown into the bin, new plastic gets pulled from the top till it touches the bottom of the bin. When the bin is full, the mechanism can be actuated and hence sealing and cutting the filled plastic big which can be chucked away to enable new plastic bag for the trash to be thrown. It should be noted that the this does not imply for the specific application in the Volvo Skövde plant and is for a more general application. The specific design for Volvo is as suggested in concept 1 where the filled bag get dropped into the main trash container placed below it with the help of the support rods.

5

Discussion

This section draws useful information from the results to interpret and describe the significance of the findings

5.1 General discussion

In this section, we discuss the general finding of the Study of Karakuri and draw a comparison between the Asian and the European Industry with respect to adapting Karakuri. Although the term Karakuri is Japanese, the core value and functionality can be seen all over the world with varied adaptation level. The discussion will also shed light onto the over automation and manufacturing competitiveness seen in Asia and Europe.

5.1.1 Karakuri in Asia

- The examples mentioned in section 4.1.1 suggests that the concept of Karakuri can be implied in various sectors of industries like transport, construction, production, material handling, etc. This suggests the significance of the concept and how it can be implemented in almost every scenario of an industry. As such, the flow-rack systems of material handling has had a major presence in the industrial sector but also has had enormous applications in other fields. It is also worth noting that even the large scale global companies like Toyota, Nissan and Honda take a step towards the lean approach upfront, unlike their competitive western counterparts who are extensively inclined towards high level of automation. It also indicates all the essential benefits that Karakuri inherits such as productivity and flexibility. Another imperative and most important attribute can be regarded as sustainability which can in turn be linked to the inherit properties of Lean.
- Lean methodology has its focus on the three M's that is the Muda, Muri and Mura. Muda refers to the waste or which adds no value, Muri is the unnecessary stress on equipment & employees and lastly, Mura is the waste from uneven flows and imbalances. All three aspects are well integrated in the lean concept which are reflected on 'Karakuri'. It can be deduced that Karakuri effectively addresses all these three aspects. It is possible to back this statement by the following speculations; Muda includes the seven kinds of wastes which are transportation, inventory, motion, overproduction, over processing, defects and waiting. Karakuri counteracts all or few of the wastes mentioned

above for example, the gravity flow racks prevents unwanted transportation or motion. Muri is overburdening people or resources and since Karakuri improves the working conditions or reduces the number of steps required by the operator to achieve a task, it can be said that Karakuri addresses the second category of waste, Muri. The Karakuri packaging machine example mentioned in the section 4.1.1 supports this statement. Lastly Mura is the unevenness in production which is mostly due to demand fluctuations and since Karakuri products like gravity flow racks can easily adapt to handling both rapid increase or decrease in demand through its modular design, it can be considered truly flexible.[18]

- One of the most important results that can be drawn is that Karakuri in Asia has its roots and existence within the industries themselves. All the examples of Karakuri mentioned in the previous section are not products developed by companies dedicated to Karakuri or Karakuri manufactures. Instead these are independent industries from various sectors manufacturing different products who have designed and come with their own Karakuri solution adapted for their unique application as a step towards continuous improvement. This suggests that Lean methodology and Karakuri is well integrated in the culture which reflects on their industries.

5.1.2 Karakuri in Europe

As seen from the leading companies in Europe offering Karakuri solutions, it can be seen that complete potential of Karakuri is yet to be completely utilized. The Karakuri solutions can be mostly seen to be used by consulting firms to provide efficient material handling products and not as a manufacturing strategy adopted by industries. As mentioned earlier in section 5.1.1, adopting Lean methodology dictates adaptation of Mura, Muda and Muri. The Karakuri products commonly found in Europe only partially fulfills the three M's, leaving room for more improvement opportunities. Though continuous improvements play a vital role in many of the industries, automation using technology is more prominent in this part of the world. The biggest difference that can noted is the lack of awareness of the concept in the European industries. Major companies like Volvo adapt lean principles in their strategy but can be noted that it fails to incorporate every aspect of lean.

It is worth noting that the level of automation in Europe is much higher compared to Asia and adopting Karakuri as it is in Asia may not seem to be the best option for industries in Europe. This points out to new opportunities of improvement or combining the traditional Karakuri with the newer technologies. This combination can better match the requirements of the European industries and also help reducing the comparatively high production costs.

Though cost is a major factor to consider Karakuri, other factors like flexibility, ease of implementing, ease of assembling, ergonomics can all together greatly benefit any industry.

5.2 Literature, interview and survey study

5.2.1 Literature

The most important issue that can be brought up after an extensive study on Karakuri is the cultural difference between the countries. Karakuri in Japan is a part of their culture since it dates back to the 1800's with the introduction of the mechanical dolls. These dolls that used no external power source were used to perform shows to the general public and hence a good handful of the non industrial population are aware of the term Karakuri and what it means. Since it is this same concept of Karakuri that is being implemented in a different field of application which is production, nearly everyone on the production line have an awareness of this concept. The workers themselves are trained with workshops on Karakuri in most cases. They are also encouraged to build or suggest their own Karakuri solution if they feel a need to ease their work by increasing the level of automation. This can be supported by the findings of the Karakuri exhibition presented in section 4.1.1 where different companies who are not dedicated Karakuri companies have come up with their own Karakuri solutions for their manufacturing facility.

In contrast, the Swedish manufacturing industries rely on external companies who can develop and provide Karakuri solutions for them. Most of the interviewees suggest that there exists a lack of awareness in the industries and this can be seen evidently through the difficulty in finding published paper/journals on this topic in Sweden. This lack of awareness is what is being converted into a growing opportunities to companies like AIO, ITEM and Virtual Manufacturing AB to provide Karakuri solutions. This points to another skepticism if these companies who provide Karakuri solution are fully aware of the core concept of Karakuri, why are all of them focused on material handling or flow racks? Also, there is a whole issue if the perception of Karakuri being wrongly interpreted in Sweden. Are the industries deeply underestimating the potential of Karakuri as 'Fattigmans' automation? Can the lack of knowledge in industries be related to inherit culture of Sweden to automate leading to over automation? These question gives rise to a whole new research questions like:

- How to overcome the cultural barrier for Karakuri implementation in Sweden?
- Can Karakuri be implemented in other areas of production?
- How to integrate Karakuri with IoT?

While understanding the drivers for a nation to be competitive, we can see from the figure 4.4, section 4.2 that talent (educated/skilled labour) remains the first while cost and productivity are seen to be in the second and third place respectively. It can be seen that the need for decreasing overall costs and achieving better productivity go hand in hand along with possessing a strong supplier network. From figure 4.5, section4.2, it can be inferred that there is a prediction for shift in dynamics by the year 2020, where Asian countries will compete with the European nations for higher rankings. From the report, it was evident that the Asian manufacturing market, though posses lower technologically skilled labour they are able to compete with lower labour and production costs. Though this seems like an advantage for the cost competitive Asian market, in the long run advanced manufacturing technology possessed by the developed nations is predicated to take the front seat and improve competitiveness.

5.2.2 Interviews

From the awareness graph in section 4.4, a conclusion could be drawn that the general awareness of the concept of Karakuri in Swedish industries is considerably lower compared to Asia. Since the concept dates back to 1800's of the Japanese history of the mechanical dolls, it is well embedded in the Japanese culture. Hence it won't be erroneous to say that a substantial sum of non-industrial population would know of the concept of Karakuri. It can be seen from the graph that the difference between the average weight of both the sets (academic and industrial) is quite scant. The paramount factor to consider here is that the interviewees believe that the awareness of Karakuri in Asia has an average of 8 while that in Sweden is around 2. This significant contrast in the awareness can be concluded as one of the major drawbacks of the Swedish Karakuri market. Although, the handful of people who have come across the concept vaguely know it as "fattigmans automatisering" or aware of only the flow racks used in material handling. This suggests that the Swedish industry has less awareness of the core concept of Karakuri.Another important aspect to note here is how all the interviewees have stressed on potential growth of Karakuri in Sweden. An average of score of 8.5 was seen for potential growth on a scale of 10. It can be drawn from the graphs in section 4.4 that the potential growth of Karakuri in Sweden is tremendous.

As mentioned earlier, few of the industries in Sweden know Karakuri as flow racks or mostly used in material flow bins. The statistics shown in the figure 4.8, section 4.4 depicts the frequency of the number of times the application in material handling was mentioned over other application. It was observed that 71% of the times academic interviewees suggested that application of Karakuri in Sweden was mostly material handling. The academic interviewees also cited other applications of Karakuri greater number of times than the industrial interviewees. In comparison to academic interviews it was noticed that only 25% of the industrial interviewees knew or mentioned other application of Karakuri other than material handling. This clearly points out the lack of knowledge in the Swedish industry on the true concept and potentials of Karakuri.

It is seen that all of the interviewees mentioned ergonomics as the critical factor, with an average score between 7 and 9 on the scale of 1 to 10. A high score of 8.5 on the mechanism was seen as few of the products had failed completely due to mechanical design failure. Data collection and analysis also plays a very important role in the design phase and few of the interviewees mentioned that there is need to acquire more accurate data that better fits the requirements of the customers. There were also a comment on the unsatisfactory level of data presented before the design phase. Hence, it can be said that ergonomics is the most critical factor to consider while designing but the product in itself may fail completely due to mechanical failure or lack of information on requirement. This can be co-related to the methodology used for designing Karakuri. The new method as proposed in section 5.3 suggests that continuous improvements can be used to tackle the damage of mechanical failure. This also saves valuable time and resources. A solid proof for this statement can be related to the example case mentioned by one of the interviewees in section 4.4. The Karakuri solution that was provided to SAAB faced failure and the main reason for this was recognized as failure in the mechanism. This example can be considered to illustrate the importance of having a structured standardized method of building a Karakuri. This can be connected to the methodology described in section 5.3. Following this method would eliminate the possibilities of such errors and also save valuable resources.

It can also be seen that the academic interviewees had lesser interest on the design aspects and concentrated more on the applicability of Karakuri and its adaptation in the factory or the market. While the industrial interviewees have their focus on the design aspects. The figure 4.10 shows that about 85% of the industrial interviewees mentioned on the critical factor of ergonomics.

There is an immense potential to come up with new products in diverse fields which can provide better results and flexibility across the industries. Sweden is mostly focused on material handling i.e similar to kitting boxes. Europe usually has many restrictions like ergonomics, maximum weight one should handle, etc. There still exists industries where it is done completely manually. It is possible to deduce that Sweden either has a very high level of automation or just pure manual labor. Where as in Japan, manual work is avoided with smart innovative solutions like Karakuri allowing gravity to do the work which takes less skill to operate and has low maintenance.The quality of Karakuri can be linked to Minomi, which is lean concept where there is no use of containers, boxer or bins to handle materials and the components are stored and presented to the line using the same special fixture. Such concepts are not present in Sweden, expect for a few cases like Scania, Södertälje where they employ some form of material handling. There is a huge potential to such innovative solutions in Sweden but there is also lack of knowledge. Another aspect that can be pointed out is the way Low cost automation/fattigmans automation can be perceived as mentioned previously. This was mentioned by almost all of the interviewees that it can be wrongly perceived as cheap solution rather than smart and innovative. Another important drawback in implementing Karakuri or any kaizen activities in Sweden is the hierarchy of personnel or departments that exists. For example, an operator in a Japanese industry will be governed by a supervisor, support engineers and senior workers who take direct initiative to implement kaizen or any other change, making the average lead time to implementation very short. Where as in Sweden, the hierarchy of different departments like engineering, material handling, line feeding, production manager, etc. comes in the way of kaizen, making it hard to implement any change as one needs to go all the way to the higher authority. This is the point where the cultural difference is evident. These engineering departments tend to have a more sophisticated approach, inclined towards automation which usually results in the problem of over automation. Hence it is important to have an organized workshop and facilitate good communication which is usually the barrier in Sweden. It may be simpler to adapt Karakuri and may be well suited for such industries where the level of automation is very low compared to the big industries where it is very high. It also facilitates Lean as one of the main characteristics of a pull system is to have a batch size as small as possible and a continuous flow. Finally, it should not be neglected that there is a lack of knowledge and experience on Karakuri and also, it should be considered to label it in another way that better fits for Swedish industries.

5.2.3 Surveys

The surveys gave a better picture on few of the major questions concerning Karakuri like awareness of the term Karakuri, awareness of the latest trends in karakuri, etc. The different questions can be found in appendix A. The results also give a direct indication of few of the aspects that was mentioned in the interview study for comparison.
This lack of awareness of Karakuri in Europe also rises the question as to why Karakuri hasn't seen much applications in Europe as much it has in Asia. As seen in section 1, Karakuri is an integral part of Lean and its Kaizen activities, where lean is not seen as tools but the culture of an organization. The past two decades has seen Lean manufacturing techniques being adopted globally but there has been a stark difference in the adaptation of lean as a culture as stated by the participants of the survey. It was mentioned that Lean in Europe is seen to a set of tools, like the 5 Whys, 3M, 7 wastes and 6S, which can be adopted to solve a particular issue. While this might be true in some cases it is to be noted that Lean in Japan is seen as a culture adopted by an organization. The survey question addressing this concern gave a clearer picture on why Karakuri and Kaizen activities have taken a back seat. The interview and survey results pointed a very different approach by the Europeans towards Lean manufacturing. It was further learned that it is the tools of Lean that are more often adopted than Lean as a concept and a culture.

5.3 Concept validation

A real industrial case was taken up which aimed at proposing a solution using the concept of Karakuri. A mixed method approach was incorporated to draw the solution. This is because, it could drawn from the study that Karakuri defies the traditional way of product development which usually follows PDCA cycle(Plan, Do, Check, Act) guided by the following structure:

- Problem definition
- Concept development
- Embodiment design
- Detailed design
- Prototype
- Test
- Release

In contradiction to the above method design of Karakuri diverges to a certain extent. A new method is suggested and followed which can be structures as follows:

- Problem definition
- Concept development
- Prototype
- Continuous improvement- Kaizen
- Detailed design
- Test
- Release

This strategy starts with the 'D' in the PDCA cycle from where it is continuously improved to arrive at the final design. However, there is skepticism if this can be regarded as "DCAP" as there is some planning involved before getting to the 'D'. Hence it can be said that the new method is PDCA with an emphasis on the 'D' with little planning. It should be noted that the current method being adopted by the company for their Karakuri design is the traditional PDCA. A handful of examples where observed where the products developed by the company did not succeed due to mechanical failure. It is possible to invoke a skepticism if the company should change their current approach of design, specially when designing a totally new product. Implementing kaizen into the design process can be very fruitful which was quantified through the product that was attempted to develop in this project. These findings brings up a new research question such as:
What is the optimal design procedure of Karakuri ?

6
Conclusion

The master thesis study focuses on studying the market of Karakuri and its application along with the practical implementation to realize design conceptualization. This chapter illustrates the main features of the master thesis study.

In conclusion to the study of Karakuri, it was able to determine that Karakuri is an ingenious mechanism used to automate an operation. Karakuri works on the principle of using readily available energy such as gravity, elasticity and magnetism. There are no external power sources such as electric motors or engines used to drive the mechanism. This principle and functionality of Karakuri can be seen in various forms around the world and has been around since the advent of wheels and levers. Although only these mechanisms were further developed in only some parts of the world compared to the rest.

Karakuri in Japan, is an integral part of their culture. The mechanisms are not only used in manufacturing facilities but also used to power children toys. The concept of developing a Karakuri based solution in a manufacturing facility is usually done in-house. As such though Japan and Asia are catching up on higher level of automation, preference is given for simpler cost effective solutions. On the contrary, automation in Europe is quicker to adapt to higher level of automation. Manufacturers in Europe depend on external consultants to providers Karakuri based solutions as there is lack of knowledge of possibilities within Karakuri. The findings from the study can be briefly concluded through the following points:

- Karakuri in Asia is a part of the culture and are developed in-house by the companies.
- The awareness of possibilities utilizing Karakuri based mechanisms is comparatively very less in Europe .
- Many external companies in Europe can be seen to explore the market of Karakuri by providing unique solutions.
- There is an immense potential of combining Karakuri with Internet of Things(IoT).
- Karakuri can be implemented in a wide range of fields like transportation, construction, assembly, etc.
- Karakuri solutions should be developed by doing or to get down to the "Gemba" in Lean terms.
- Karakuri design contradicts the traditional design method of PDCA cycle and stresses more on the ’D’.
- It is possible to automate almost all simple manual tasks using Karakuri.

- Ergonomics is one of the most critical factors to consider while designing Karakuri
- The hierarchical and cultural difference between Sweden and Asia makes it hard to implement Karakuri efficiently in Sweden.
- Spreading awareness can be considered as the first step towards setting a footprint of Karakuri in Sweden.

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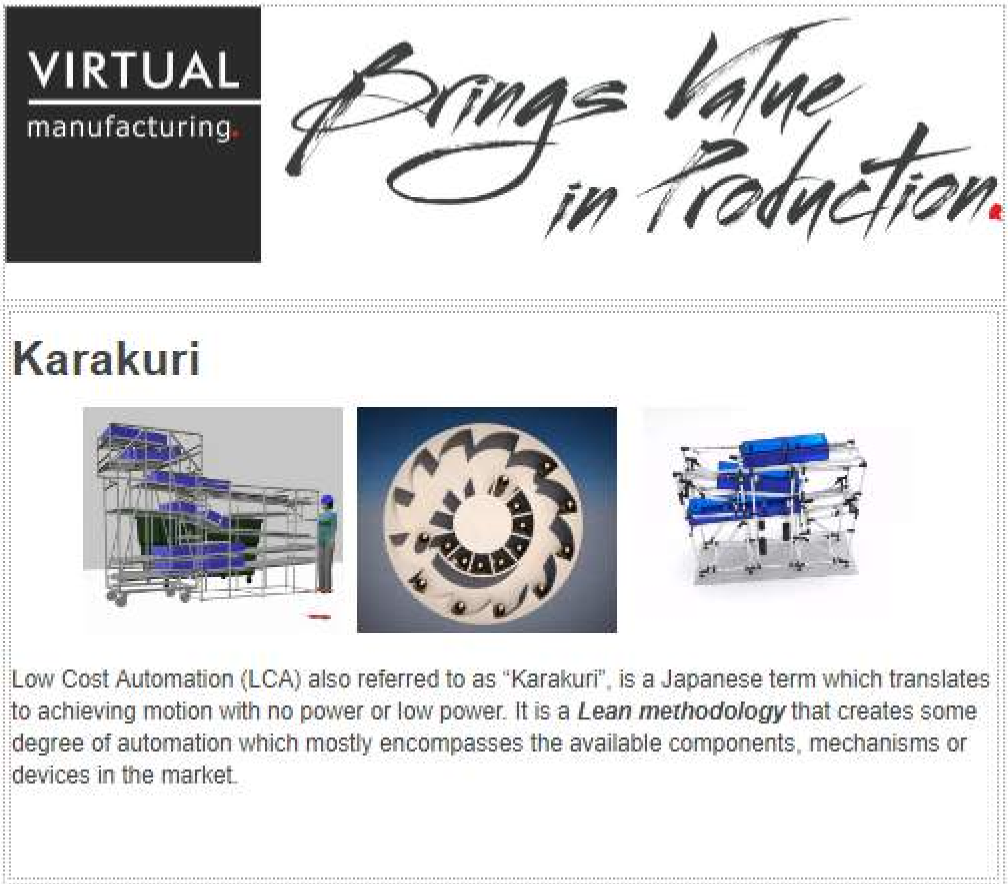
A

Appendix 1

Survey Form



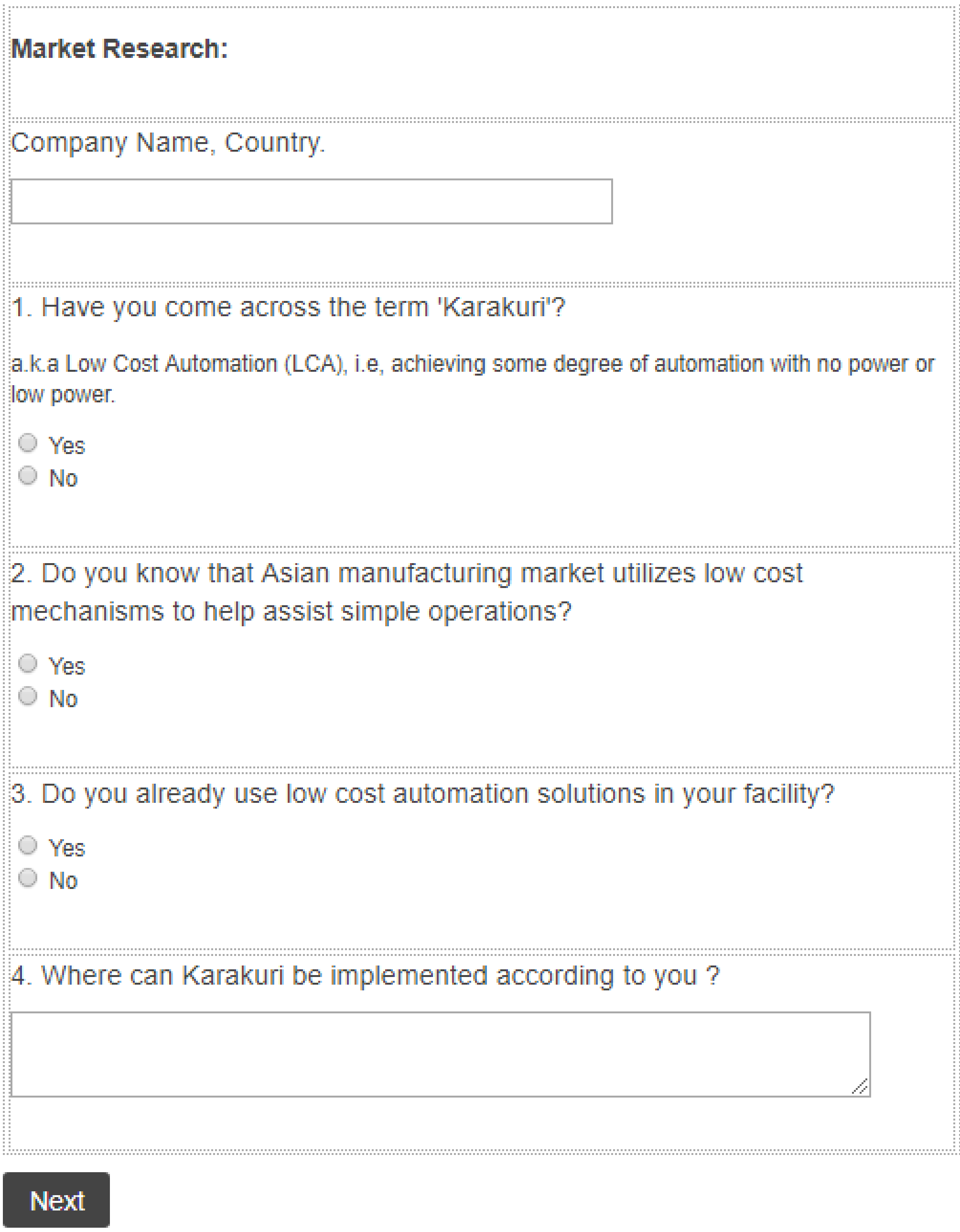
VIRTUAL manufacturing.

Brings Value in Production.

Karakuri

Low Cost Automation (LCA) also referred to as "Karakuri", is a Japanese term which translates to achieving motion with no power or low power. It is a ***Lean methodology*** that creates some degree of automation which mostly encompasses the available components, mechanisms or devices in the market.

Figure A.1: Survey form - Introduction page



Market Research:

Company Name, Country.

1. Have you come across the term 'Karakuri'?

a.k.a Low Cost Automation (LCA), i.e, achieving some degree of automation with no power or low power.

- Yes
- No

2. Do you know that Asian manufacturing market utilizes low cost mechanisms to help assist simple operations?

- Yes
- No

3. Do you already use low cost automation solutions in your facility?

- Yes
- No

4. Where can Karakuri be implemented according to you ?

Next

Figure A.2: Survey form - Page 1

VIRTUAL manufacturing. Brings Value in Production.

5. Do you think present new technologies can be integrated with Karakuri?

- No
- Yes, please specify ________

6.Karakuri is usually implemented in material handling (gravity flow racks), do you recognize any other field where it can be implemented?

- No
- Yes, please specify ________

7. Are you aware of latest trends/developments in Karakuri/ Low cost Automation?

- No
- Yes, please specify ________

8. Do you think that 'lean manufacturing' approach is different in Europe compared to Asia?

- No
- Yes ________

9. Are you aware of any blogs/forum/conferences/personnel on karakuri where we can obtain more information?

- No
- Yes ________

Please let us know how we can reach you for a quick interview.

E-Mail ________

Mobile ________

Send

Figure A.3: Survey form - Page 2

B
Appendix 2

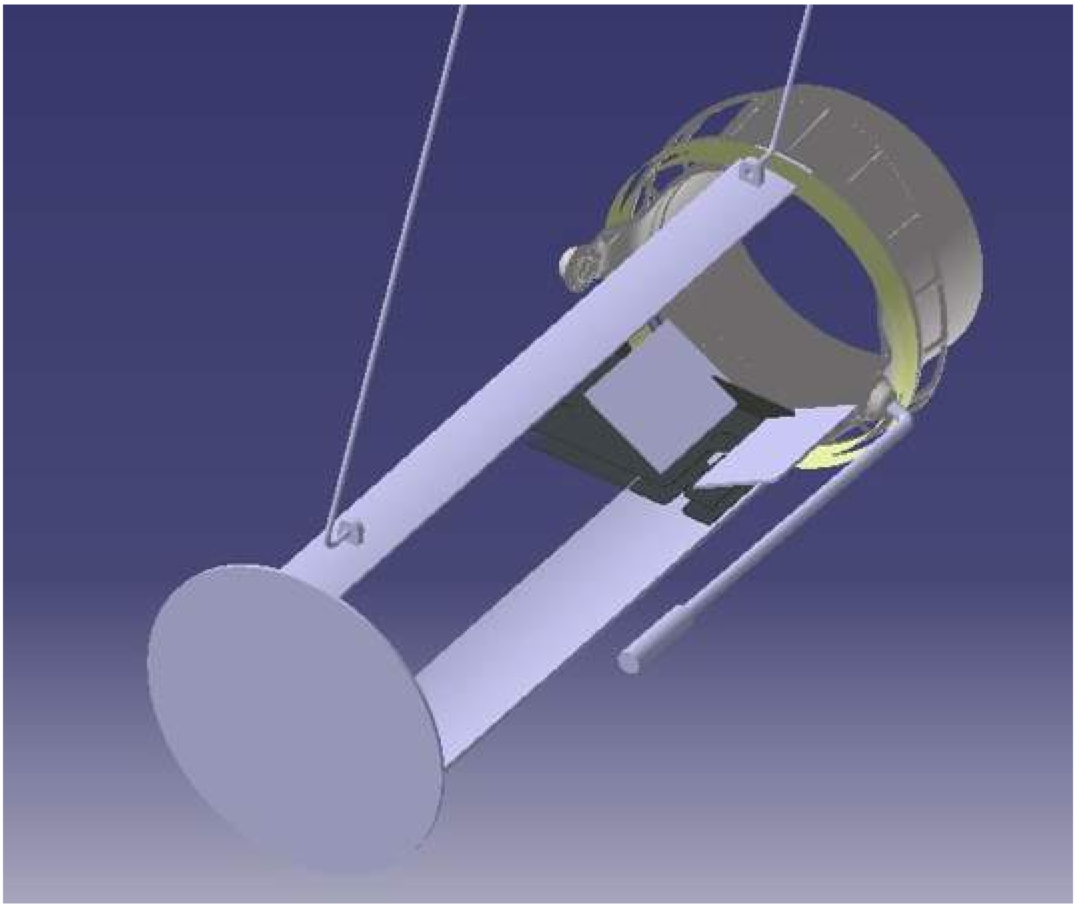


Figure B.1: Concept 2