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Analysis of Economical and Quality Aspects of Cable Manufacturing Process

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Abstract

This research paper describes an extensive review of manufacturing processes, techniques, materials, and technologies, highlighting waste and cost reduction implications for manufacturing.

The demand for power and domestic cables in various industries has witnessed significant growth over the years. As a result, manufacturers continuously try to increase their production and focus on quality management. This research paper aims to explore the different types of cables, their applications, and technical and physical data.

The purpose of the article is to improve time performance and production by analyzing the effects of introducing Lean methodology in low-voltage cable manufacturing. This study made use of several Lean approach tools, such as focused enhancement, OEE, and daily performance evaluation. It is important to understand the current manufacturing process practiced in power cable factories. The study describes the practical impacts and outcomes of these technologies to support businesses in implementing lean thinking. Results and practical consequences show that the manager can quickly identify and remove manufacturing waste from the process by using the technique. By increasing the effectiveness, the resource allocation at the end of the procedure can be optimized. The manufacturing sector must certify the process for successfully implementing lean methodology. The successful use of lean methodology has been linked to reducing changeover time in project execution. A qualitative research approach was employed to gather empirical data using semi-structured interviews as the second method of data collection.

The results show that the use of this methodology can lead to a 50 percent reduction in time, that is, from 200 min to 100 min. This technique may be used by other industries, such as the manufacturing sector, to shorten shipping and production times. Moreover, lean techniques are demonstrated through pilot projects so that they may be used on different types of machinery.

Language: English

Key Words: Production, Material, Standard, Quality

List of abbreviations

AAC	All Aluminium Conductor
ACSR	Aluminium Conductor Steel Reinforced
ASTM	American Society for Testing and Materials
BASEC	British Approvals Service for Cables
BDS	British Standard
BS	Bangladesh Standard
BS2004	British Standard I According to Imperial system
BSTI	Bangladesh standards and testing Institution
CR	Conductor Resistance
EMI	Electromagnetic Interference
FCC	Federal Communications Commission
FR	Flame Retardant
FRLS	Flame Retardant and Low Smoke
IACS	International Anneal Copper Standards
IEC	International Electro-Technical Commission
IoT	Internet of Things
IR	Insulation Resistance
kN	Kilo Newton
NEMA	National Electrical Manufacturers Association
PE	Polyethylene
PVC	Polyvinyl Chloride
QC	Quality Control
RBD	Rod Break Down Machine
RFI	Radio Frequency Interference
SPC	Statistical Process Control
XLEP	Cross-linked Polyethylene

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1 Introduction

The field of cable manufacturing has witnessed significant demand and remarkable advancements over the years, driven by the escalating demand for reliable and high-performance cables in various industries. Cables are an essential component of modern infrastructure, supporting critical applications ranging from power transmission and telecommunications to data centers and automotive systems. This research paper focuses on the manufacturing process of cables, the application areas of cables, and potential related challenges.

1.1 The client

Paradise Cables Ltd was started as a private limited company on June 01, 1983, for the purpose of producing the best quality electrical wires and cables in a potential network. The company is looking forward to providing high-quality electrical cables and wires by using the best raw materials from primary manufacturers, ensuring perfect quality. The company produces almost all types of cable, which is generally used in most electrical networks. The main goal of the company to become a leading manufacturer of PVC/XLEP insulated low-voltage cables, medium-voltage cables, telecommunication cables, FR/FRLS cables, instrumentation cables, and overhead conductors.

1.2 Purpose of the research

The goal of research on cable manufacturing is to provide an in-depth analysis of the processes involved in creating cables, including the range of tools and materials used, quality control systems, and safety requirements. The research study aims to examine different cable types, their applications, and the numerous businesses that depend on them, such as those in the telecommunications, electrical, and construction industries. The research paper may also investigate the most recent advancements in cable production, including automation and digitization, as well as its trends and developments at present.

The most recent developments and trends in cable production may also be included in the report. The report may also examine fresh materials and technologies that are being researched to produce cables that are more durable and effective.

Professionals in the cable manufacturing sector might greatly benefit from the research paper on cable manufacturing descriptions. It offers an exhaustive review of the sector, including best practices and possible improvement. The document may also be utilized by academics and students to gain a deeper understanding of cable production and its use in many sectors.

1.3 Research Question

The manufacture of numerous types of cables used for transferring electrical power, telecommunications, and data is a challenging and crucial process known as cable manufacturing. This process makes use of a wide range of various materials, tools, and procedures and can significantly affect the cabling's ultimate performance and quality.

In the context of cable production, the research questions in this thesis are as follows:

- **How** can the flame retardant of cables be improved during manufacture using innovative processes or materials**?**
- **What** economic factors are involved with various cable production techniques, and **what** impact do they have on total cost-effectiveness?

In the scope of the first research question, It will be discussed about flame retardant cable and its materials. In modern life, flame retardant cable’s demand is increasing day by day. Most cable manufacturing companies are trying to improve cable materials and processes.

In the second research question, cost-effectiveness and cable production methods will be covered. The most crucial element in the cable sector is cost reduction. This study is focused on investigating the effects on cost-effectiveness.

2 Overview of company products

The main raw materials of the company include copper, aluminum, PVC, and XLPE. Copper and aluminum are imported from foreign countries. More than 50 types of cables are produced by this company. Most of them are standard wires, while the other ones are client requests.

This company uses 99.99% pure copper with the highest level of electrical conductivity. We maintain International Anneal Copper Standards (IACS). We use fully annealed copper that is well-compacted, circular or sector shaped. This ensures minimum loss throughout the length of the cable. It saves huge amounts of electrical energy and helps to reduce electricity bill.

This company produces 100% of the product with flame retardant (FR) PVC compound, which are suitable to endure fire. Our FR & FRLS cables have a high oxygen index, lower smoke, and self-extinguishing properties. The Provability of fire spreading of this cable is almost 0%. People can see when they are trapped and breathe safely for a longer time in fire conditions. FR cable is shown in Figure 1.

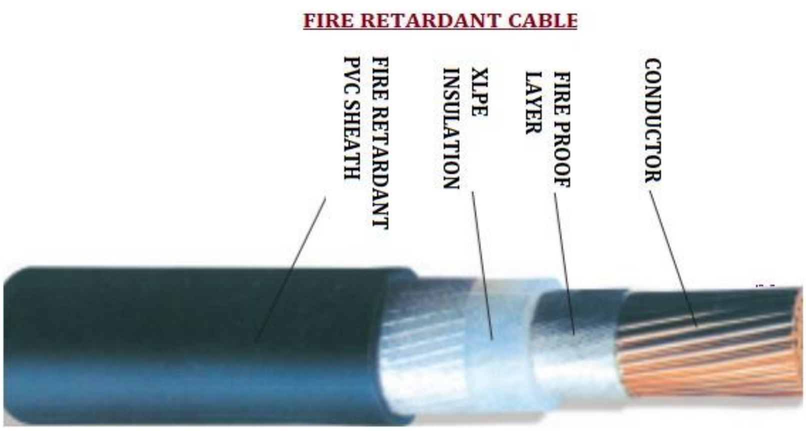


Figure 1. Flame retardant cable

3 Technical descriptions

This research paper explores the crucial function of technical descriptions in promoting understanding, communication, and creativity across a range of technical areas. Technical explanations serve as a link between abstract ideas and their implementation in the real world, facilitating seamless information transfer between experts and beginners.

3.1 Cables

A Cable is a single conductor or multi-conductor twist, and it is insulated by PVC. Electrical cables are made of copper or aluminum because of their excellent conductivity. Cable raw materials are copper, aluminum, PVC, copper tape, XLPE, etc.

3.2 Why is copper used to make electrical wires?

Because electrical current must flow indefinitely through a conductor, it requires a path with low resistivity and high conductivity. Copper is the best metal compared to other metals.

Copper is an incredibly ductile material. It easily bands and has a high elongation capacity. Copper can be easily twisted and banded with minor risk. In a service line, we need high-conductive and low-resistive material.

Some material comparisons are shown below in Table 1.

Material	Electrical Conductivity (10.E6 siemens/m)	Electrical resistivity (10.E8 ohm's)	Thermal Conductivity (W/m.K)	Thermal Expansion Coef. 10E.6(K-1) from 0 to 100 ^{o}C	Density (g/cm3)	Melting Point ^{o}C
Silver	62.3	1.7	420	19.2	10.6	961
Copper	58.5	1.8	402	17	8.9	1082
Gold	44.3	2.3	317	14.12	19.3	1065
Aluminum	36.9	2.7	238	23.6	2.7	660

Table 1. Material Comparison

3.3 Type of cable

There are several types of cable, such as single core, 2-core, 3-core and 4-core. Those cables are discussed below.

3.3.1 Single core cable (unsheathed)

A single core cable is made without PVC as per requirement. Different sizes as per standard and customer requirements. Single core cables are without annealed cable and difficult to bend; however, they have a long service life and are not readily oxidized while being used, for example, 4.12 mm, 3.69 mm.

3.3.2 Single core cable (sheathed)

Single core cables are made by a single conductor or twisted multi-conductor. Product range

BYA FR skin coated – 1.00 rm - 25 rm cable. (rm = multi wire round conductor)

It expresses by 1 x 25 rm. Here 1 means single core and 25 means 25 rm cable. Paradise cables produce up to 25 rm Fr single core skin coated cable.

Application

This type of cable application is for general purposes. It can install embedded conduits, surface mounted, or similar closed systems. It should be fixed, protected installation light fitting, and inside application. The voltage range is up to 1000V AC or & 750 to Earth DC.

Design

Plain copper, annealed copper, electrolytic copper, or aluminum, solid or stranded circular, complying with appropriate IEC 60228 criteria, and FR PVC thermoplastic material,75 ^{o}C working temperature are required for insulation in single core cables.

Color Identification:

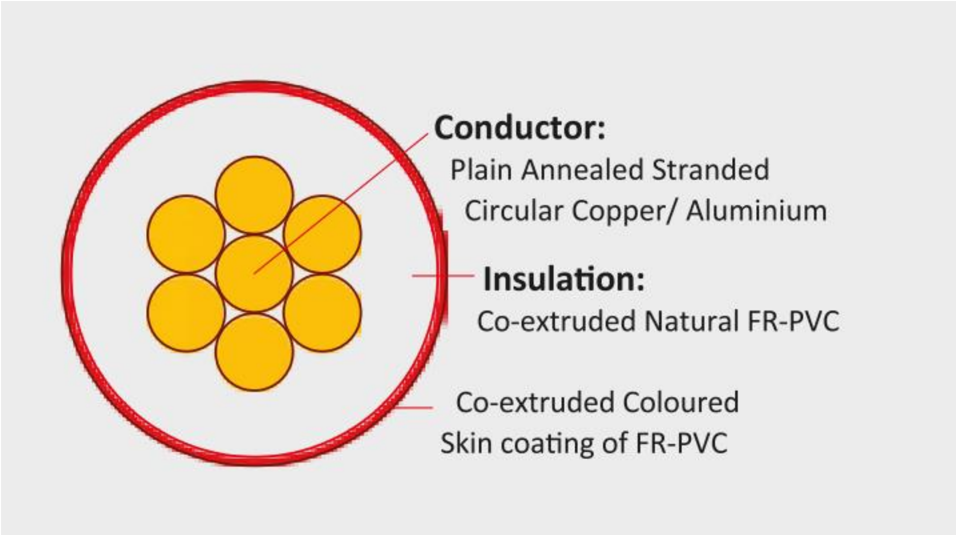


Figure 2. Conductor cross sectional structure [8]

3.3.3 Circular twin, 3-core, 4-core (sheathed)

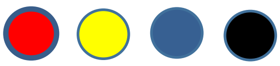
Twin, 3-core, 4-core cable laid up and then insulated by PVC. Cables are made as per standard and customer requirements.

Application

Installation in a dry or humid location, on a cable tray, and on a non-metallic surface.

Design

Plain copper, annealed copper, electrolytic copper, or aluminum, solid or stranded circular, complying with appropriate IEC 60228 criteria, and FR PVC thermoplastic material, 75 ^{o}C working temperature are required for insulation in single core cables. PVC thermoplastic material, 75 ^{o}C operating temperature, complying with applicable requirements of BS 7655, are required for inner sheathing insulation. PVC thermoplastic material, 75 ^{o}C operating temperature, BS 7655 applicable requirements are required for outer sheathing. FRLS is also applicable as per customer requirements.

Color Identification: 

Sheath: 

3.3.4 Flat twin with or without (sheathed)

Plain anneal copper insulated. Core laid up or without laid or flat in form. The outer sheath is insulated with or without gray PVC as per customer requirement.

Application

It should be used as a dry or dump location for permanent installation by screwing over walls. It is suitable for installation on board or embedded in plaster, and it can be used in non-metallic conduits.

Design

Plain copper, annealed copper, electrolytic copper, or aluminum, solid or stranded circular, complying with appropriate IEC 60228 criteria, and FR PVC thermoplastic material, 75 ^{o}C working temperature are required for insulation in single core cables. PVC thermoplastic material, 75 ^{o}C operating temperature, complying with applicable requirements of BS 7655, are required for inner sheathing insulation. PVC thermoplastic material, 75 ^{o}C operating temperature, BS 7655 applicable requirements are required for outer sheathing. FRLS is also applicable as per customer requirements.

Color Identification:

Sheath:

3.3.5 Flat 3-core, 4-core (sheathed)

Plain anneal copper insulated. Core laid up or without laid or flat in form. The outer sheath insulated with or without gray PVC as per customer requirement.

Application

It should be used as a dry or dump location for permanent installation by screwing over walls. It is suitable for installation on board or embedded in plaster, and it can be used in non-metallic conduits.

Design

Plain copper, annealed copper, electrolytic copper, or aluminum, solid or stranded circular, complying with appropriate IEC 60332 criteria, and FR PVC thermoplastic material, 75 ^oC working temperature are required for insulation in single core cables. PVC thermoplastic material, 75 ^oC operating temperature, complying with applicable requirements of BS 7655, are required for inner sheathing insulation. PVC thermoplastic material, 75 ^oC operating temperature, BS 7655 applicable requirements are required for outer sheathing.

4 Cable manufacturing process

The manufacturing of cable will be discussed in this chapter. Two types of cable are produced by this company. Power cable and domestic cable.

4.1 Copper/Aluminum plant

Paradise Cable Company uses 99.99% pure copper and aluminum, which melt in copper and aluminum plants, respectively. Copper and aluminum have melting points of 1150 and 450 degrees Celsius, respectively. The copper plant produces 8 mm of copper rod. The copper rod is then fed into the rod-breaking machine.

Figure 3. Copper rod 8.0 mm [8]

4.2 Rod break down machine (RBD)

RBD machines receive copper rods from the copper plant. In this machine, a copper rod is pulled through synthetic diamond or carbon dies. The machine is programmed with a set of dies based on the requirements. This machine draws various-sized conductors. For example: 3.52mm, 3.65mm, etc. The machine is filled with lubricant, easy to pass copper rod, and long life of dies. In this process, a significant amount of heat is produced in dies.

4.3 Raw material properties

A metal-forming process known as wire drawing has a high rate of deformation. Significant heat is produced throughout the procedure, mostly because of friction at the wire/die interface. Haddi et al. demonstrated in [2] that the capability of a drawing process primarily depends on three features: (a) the raw materials characteristics, (b) the die geometries, including the die angle and the die length, and (c) the processing conditions, such as the drawing speed and friction at the die and wire interface. Regarding the last factor, heat is generated by the friction associated with the pressure generated by the plastic deformation. The friction is proportional to the normal tension at the wire/die interface. Because of the relative movement between the material and die, this friction generates heat. This is characterized by wear on both surfaces in touch because of friction at the wire/die interface. For specific die geometry, the friction at the interface may result in a non-uniform heating of the wire. Lubricant is an important factor in the drawing process. When wire passes through the die, it produces heat, and it is alleviated by the lubricant. Wei-Liang Qian et al. showed a figure finite element setup used for the study of the tribological problem present in the Figure.

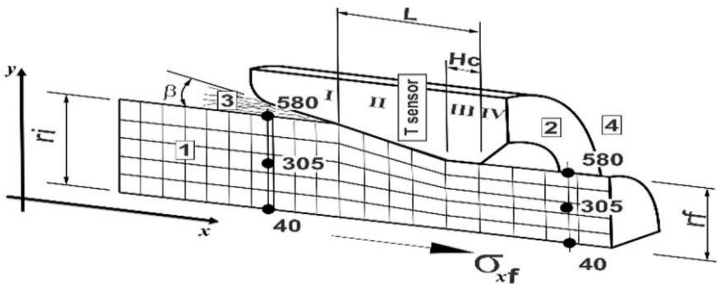


Figure 4. A scheme of the adopted single block wire drawing process (wei-Liang Qian 2020) [4]

1: Mobile triboelement— Wire, 2: Stationary triboelement—Die, 3: Interface triboelement—Lubricant, 4: Middle triboelement: Atmosphere, I: Entrance zone, II: Reduction zone (die angle equal to 2β), III: *Hc*-Bearing zone (with a die length of *Hc*), IV: Exit zone, T sensor: the location of the thermocouple, L: contact length, node 580—on the surface of the wire, node 305—intermediate region, node 40—the center of the wire, β is the semi-angle reduction, *σxf* the wiredrawing stress, while *ri* and *rf* indicate the initial and final radii of the wire, respectively.

According to Bitkov, the ratio of the wire drawing process, which is drawing stress to the yield stress during the process, is as follow,

$$\frac{\sigma_{xf}}{\sigma_0} = \frac{\frac{\sigma_{Xb}}{\sigma_0}+2.f.\beta.\ln\frac{r_i}{r_f}+\frac{2}{\sqrt{3}}(\frac{\beta}{sin^2\beta}-\cot\beta)+2\mu\{\cot\beta.[1-\frac{\sigma_{Xb}}{\sigma_0}-\ln\frac{r_i}{r_f}].\ln\frac{r_i}{r_f}+\frac{H_c}{r_f}\}}{1+2\mu.\frac{H_c}{r_f}}$$

Where, σ_0 = yield stress,

σ_{xb} = indicates the backward stress,

σ_{xf} = represents the wire-drawing stress. Here, the backward stress is exerted by the capstan, which is in the opposite direction of the
wire-drawing stress.

Lubricant plays an important role in the wire drawing process. The important reason is it reduces the die friction and, subsequently, the power required for drawing and heat generation. The wire is kept at a modest temperature since liquid lubricants are renowned for their effectiveness in dissipating heat in practice.

4.4 Lubricant

The lubricant spreads to the surface of the wire or cable before it enters the die. It helps to reduce the amount of force required to pull the material, though. Some common types of cable wire drawing lubricants include:

Mineral oil-based lubricants: Mineral oil-based lubricants are the most common type of lubricant used in the wire and cable industry. They are cheap and provide good lubrication and protection properties.

Synthetic lubricants: Synthetic lubricants are made from synthetic materials and are designed to provide superior lubrication and protection properties compared to mineral oil-based lubricants. They are frequently used in high-performance applications.

Water-based lubricants: Water-based lubricants are designed to be more environmentally friendly than oil-based lubricants. They are mostly used in applications where the wire or cable will be in contact with food or other sensitive materials.

4.5 Intermediate copper draw machine

This machine copper draw-in requires a smaller size. For example: 0.52mm, 0.73mm etc. Most of the conductors are used in domestic cable making.

4.6 Superfine machine

This machine draws 0.193 mm and 0.14 mm copper. Most of the copper is used in the braiding machine.

4.7 Twisting

Twisting in cable manufacturing is an important process where the process includes intertwining multiple strands of wire or cable to create a single, thicker, and more robust cable. The main goal of twisting is to improve the cable's strength and durability while also reducing electromagnetic interference and reducing outgoing and incoming noise.

During the twisting process, individual wires or groups of wires are wrapped around each other to form a tight helix. The degree of twist, or the number of turns per unit length, is carefully controlled to ensure that the final cable has the desired properties.

One of the primary advantages of cable twisting is improved mechanical performance. Twisted cables are less likely to break or kink, and they are better able to withstand bending and torsion forces. They are, therefore, perfect for usage in industries like robotics, automotive, or aerospace, where the cable will be subjected to high degrees of stress.

Reduction of electromagnetic interference (EMI) is another important advantage of wire twisting. The magnetic field is created around the wire when current flows through the electrical wire. This field may interfere with surrounding electronic equipment, resulting in signal deterioration or even failure. By twisting the wires together, the magnetic fields cancel each other out, reducing the amount of EMI that is generated.

4.8 Twisting machines

There are a couple of types of twisting machines.

4.8.1 Bunching machine

This machine has a twisting capacity of 2 rm to 16 rm. It is a high-speed bunching machine that can produce 10km of cable in 60 seconds.

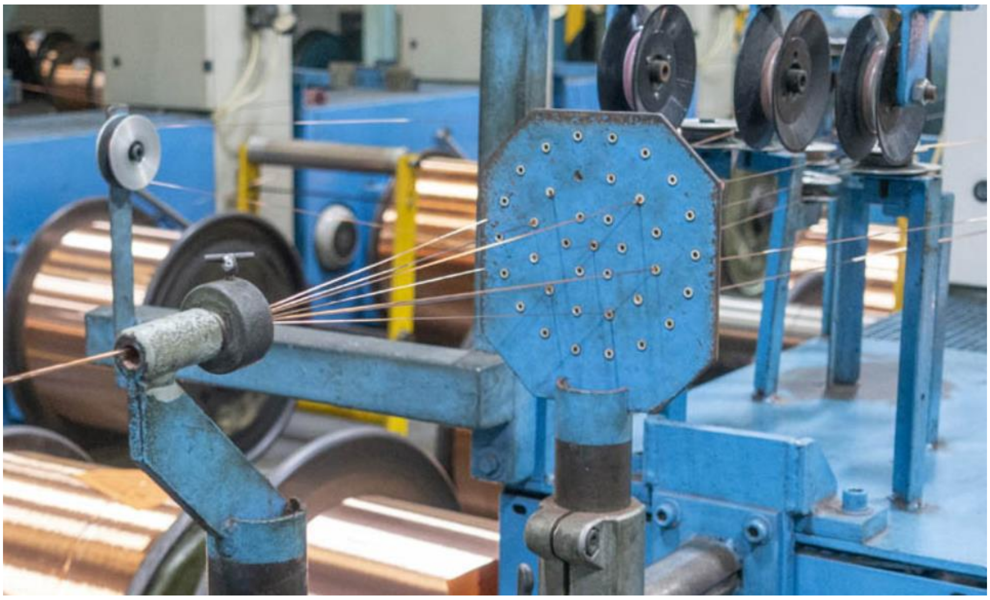


Figure 5. Bunching machine [8]

4.8.2 Stranding machine

A stranding machine is an important piece of machine used in the cable manufacturing industry. This machine produces twists or strands of multiple wire or cables together to form a single, stronger cable. The stranding process is essential in cable production, such as power cables, communication cables, and coaxial cables. The stranding machine consists of multiple rotating bobbins that hold the individual wires or cables. These bobbins are arranged in a circular pattern around a central axis. As the bobbins rotate, the wires or cables are pulled through a guide and twisted together to form a single cable. There are many types of stranding machines, including rigid and planetary stranding machines. In a rigid stranding machine, the bobbins rotate around a fixed axis, while in a planetary stranding machine, the bobbins rotate around a central axis that is also rotating. The planetary stranding machine is preferred for producing high-quality cables, as it offers better control over the stranding process and produces cables with a uniform twist. In this machine, a 6-wire system is the most common and simplest stranding system. This machine has a center element, and 6 wires are helically laid around this center element. One single conductor and other 6 conductors round it, and more layer which is required. For example, 1+6+12+18+24 etc.

Figure 6. Stranding machine [8]

4.8.3 Stranding direction

The stranding elements are going from front left to downright, which is looking on a right-stranded rope. The “Z” character indicates this direction. The character “S“is symbolic of left stranding.

This machine is mostly used to make power cables. There are lots of types of stranding machines. Example: 61 bobbins stranding machine, 43 bobbins stranding machine. The requirement of the character “S or “Z” is dependent on the center of the character, which either goes right to left or left to right.

4.9 Compacting

There are 2 types of compacting.

Round conductors

A round conductor is usually made by stranding a nipple and compacting a roller. One wire goes through, and the rest of the wires are twisted as a layer and reducing the cross-section area of individual wires.

Sector conductors

Sector conductors are mainly used in energy cables. It depends on design and customer requirements such as 60^{o}, 90^{o}, 100^{o}, and 120^{o} sectors.

4.10 Types of machines

There are many types of stranding machines in the cable industry. Those are.

- Tubular and skip stranding lines.
- Rigid stranding lines
- Planetary stranding machines
- Closing machines

4.11 Extruder machine

A crucial piece of machinery utilized in the cable production sector is the extruder machine. By forcing molten plastic through a die, it is utilized to create the cable's core.

Plastic pellets or powder are melted, mixed, and transported by the extruder machine from a hopper to the die, where they are molded into a certain profile. The device comprises an electric heater-heated barrel, a screw, and a motor that turns the screw. The plastic material is pushed through the screw and out of the die after being fed into the barrel, where it is heated and melted by the heaters.

A variety of cable cores in varying diameters, forms, and materials may be produced using the extruder machine. The most prevalent plastics used in the production of cables are polyethylene (PE),

10 rm cables insulation process in Figure 7.

Figure 7. Insulation process [8]

PVC and cross-linked polyethylene (XLPE) are examples of plastic materials. The plastic material can also have fillers, colors, and other additives added by the extruder machine to enhance the cable's mechanical strength, flame retardant, and UV resistance.

Power cables, communication cables, and coaxial cables are just a few of the many cable kinds that the extruder machine may be used for. The output of the machine is influenced by its size, design, and usage circumstances. Large extruder machines can produce high volumes of cable cores, while small machines can produce low volumes of specialty cables. Cables are coated with PVC or XLEP as per requirement. This step is called the insulation stage. Most domestic cables are insulated in one layer, and power cables are insulated in one or more layers, Inner insulation and outer insulation. Example: 10 RM domestic cable, one-layer coated cable 3-core 95-Rm insulation, on the other hand, is a three-step process, similar to PVC+XLEP+PVC.

4.12 Armoring

Armoring is a process used in cable manufacturing to provide mechanical protection to the cable. Cables that need to be installed in harsh environments, such as underground or underwater, require additional protection against damage caused by external forces. Armoring provides this additional protection by adding a layer of metal wire or tape around the cable.

The armoring process involves several steps. First, depending on the use, the cable is prepared by adding insulation and conducting wires as necessary. Next, the cable is wrapped in a layer of metal tape or wire. Depending on the purpose, many types of metal can be utilized for armor, although often steel, aluminum, and copper are employed.

The metal layer is then "stranded," or shaped, into the required shape. Metal wires are twisted or braided together to provide a more flexible and enduring structure during stranding. The addition of an outer sheath, which is commonly constructed of plastic material, is the last stage in the armoring process. The sheath shields the cable from elements that might harm it, including chemicals, moisture, and other substances.

There are different types of armoring techniques used in cable manufacturing, including:

Wire Armoring: In this technique, the cable is wrapped with a layer of steel or aluminum wire. The wires are tightly packed together to create a strong, durable shield around the cable.

Tape Armoring: In this technique, the cable is wrapped with a layer of metal tape. The tape is typically made from steel or aluminum and is applied in a helical pattern around the cable.

Figure 8. Armouring process [8]

Braided Armoring: In this technique, the cable is covered with a braided layer of metal wires. The braids are formed by weaving the wires together in a specific pattern, creating a flexible and strong shield around the cable.

5 Flow charts of cable production

Flowcharts in this chapter display the process of cable production. It demonstrates the production process in detail. The flowcharts show the production process from top to bottom, step by step. The flowcharts show the relationship between production and quality.

5.1 Process flow chart for HT cable

This flowchart illustrates the manufacture of HT (High Tension) cables step by step. More than 1000 Volts are carried between conductors, and 600 Volts are carried between conductors and ground via a high-tension cable. The RBD machine receives the aluminum/copper rod first, followed by the stranding machine. Following that, there are some steps like copper tape, core placement, and final insulation.

Process flow chart for HT cable

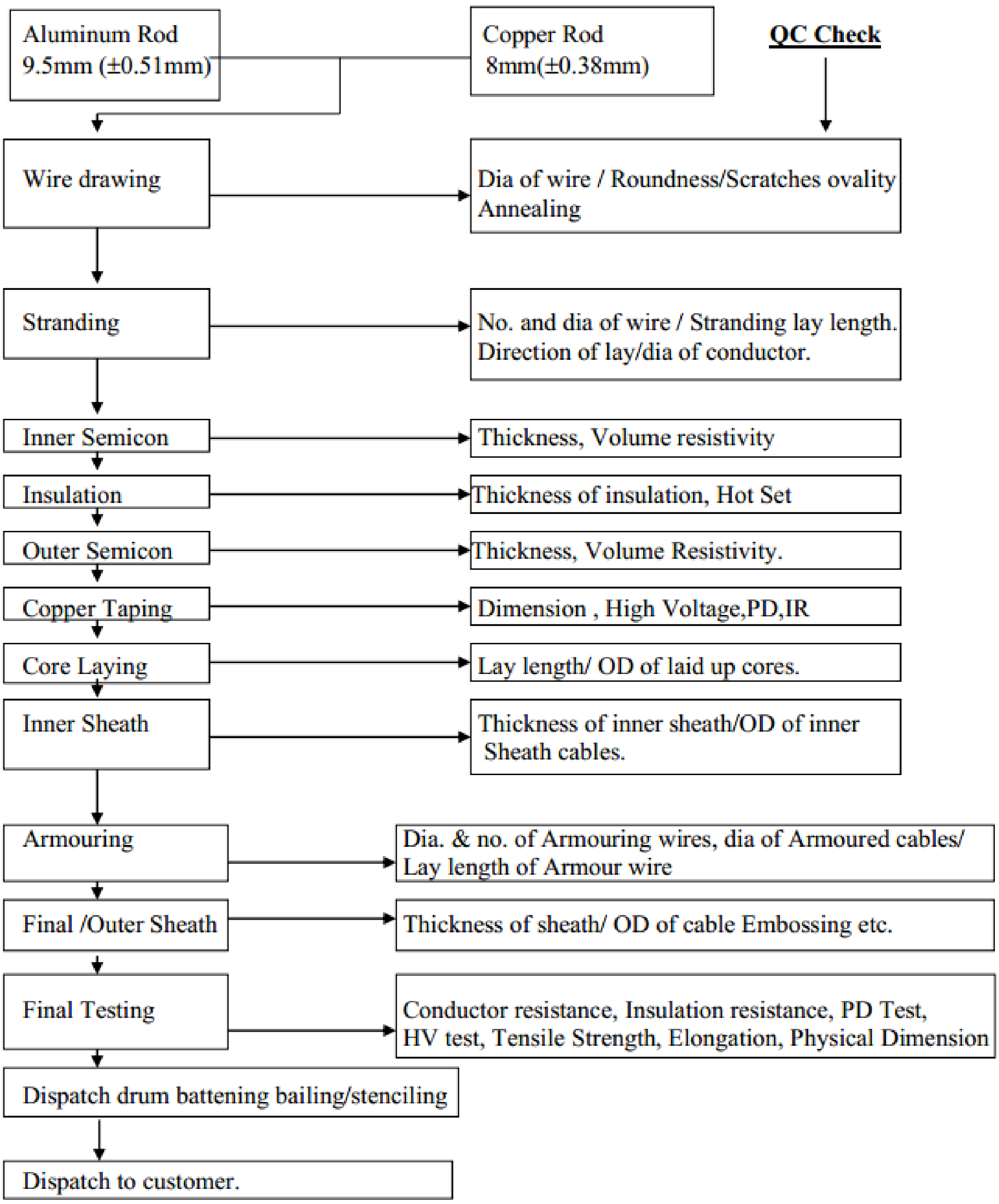


Figure 9. Process flow chart for HT Cable [8]

5.2 Process flow chart for single/Multi Core domestic cable

The domestic single and multicore cable production process flow chart shows the entire process from raw materials to the finished cable product. The processes of cable manufacture, such as wire drawing, insulation, stranding, and sheathing, are depicted in this diagram. The flow chart aids in understanding the complex procedures and quality control methods employed to assure the production of dependable and secure domestic cables for a variety of applications by providing a clear visual picture of the manufacturing process.

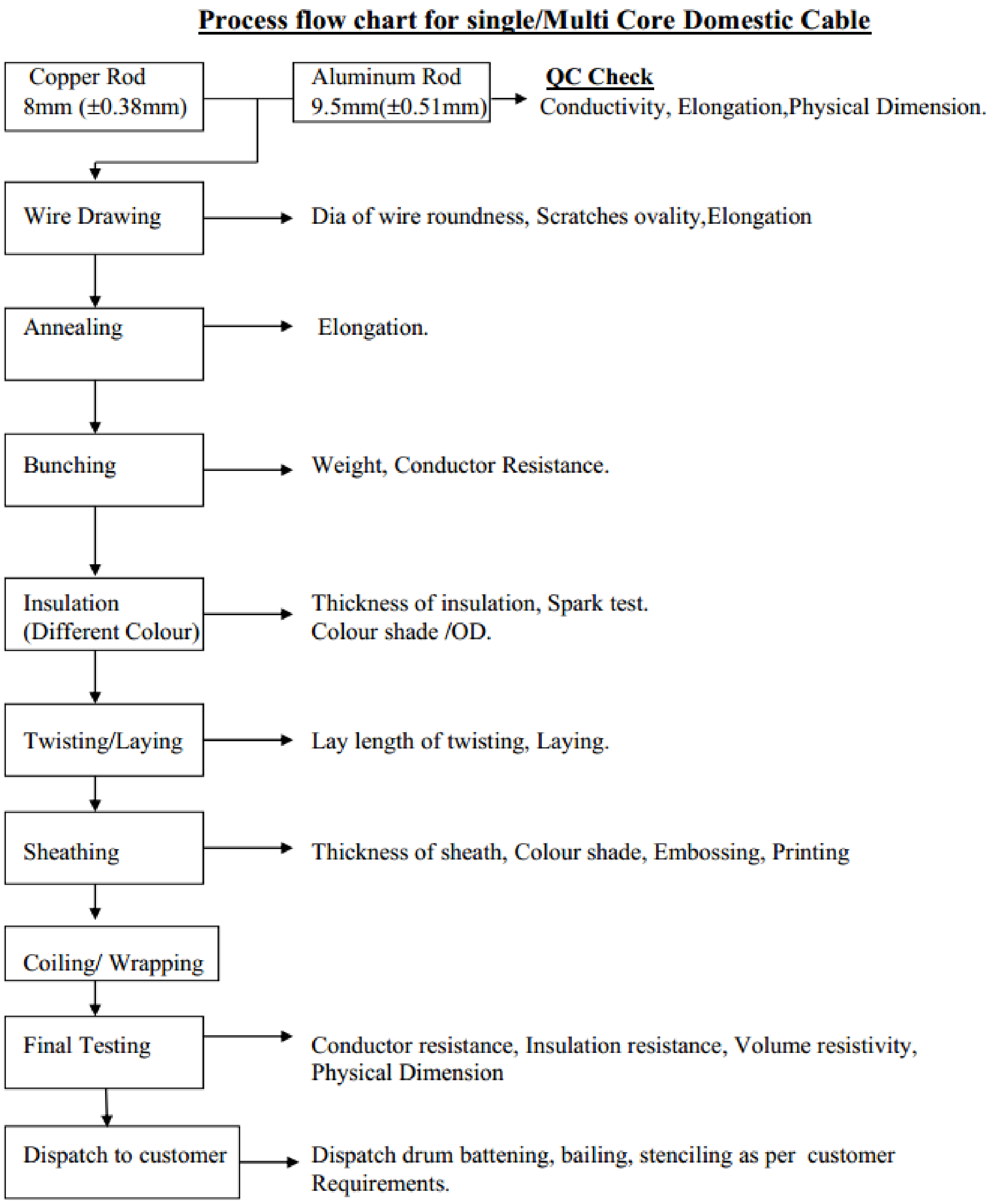


Figure 10. Process flow chart for single/multi core domestic cable [8]

5.3 Process flow chart for ACSR Bare/ Insulated conductor

The production process for ACSR conductors, which are widely used in electrical power transmission and distribution systems, is shown visually in a process flow chart for ACSR (Aluminum Conductor Steel Reinforced) Bare/Insulated Conductor. Aluminum's excellent conductivity and lightweight are combined with steel's durability and strength in this type of conductor.

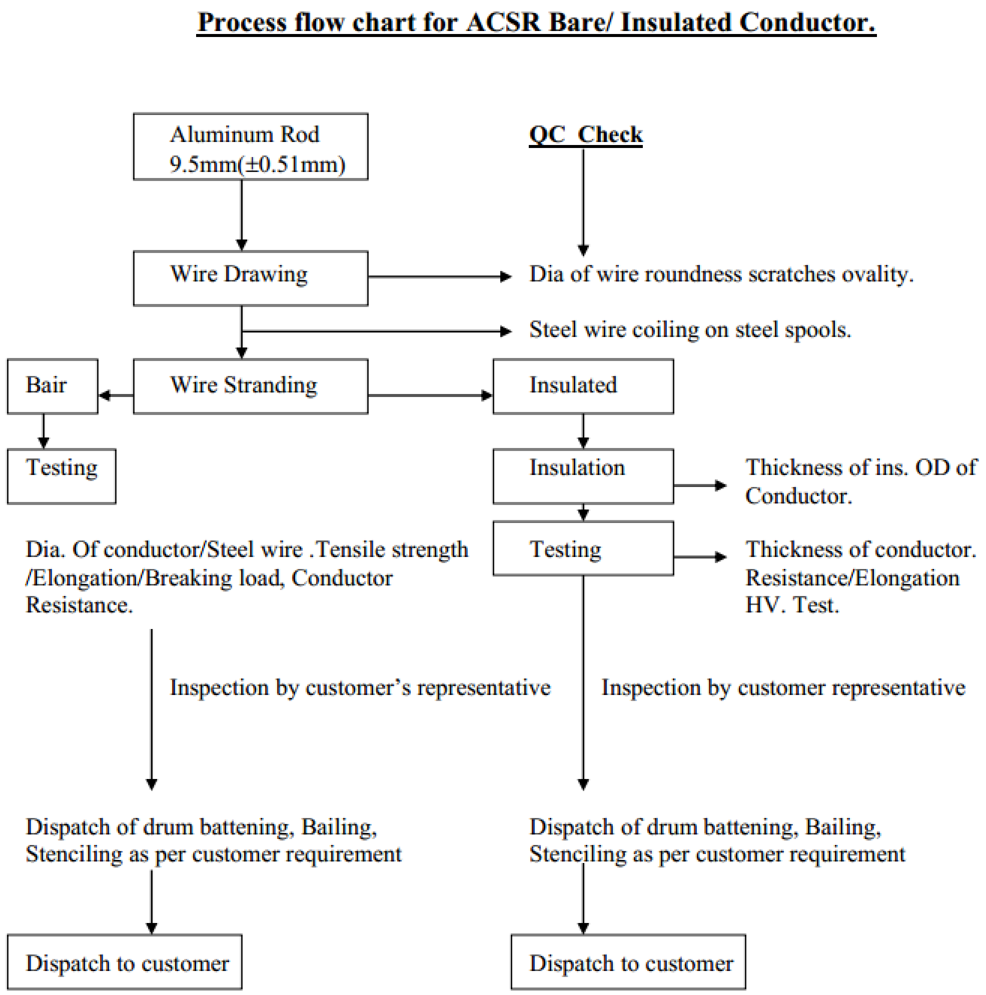


Figure 11. Process flow chart for ACSR Bare/ Insulated Conductor [8]

5.4 Process flow chart for AAC Bare / Insulated conductor

AAC (All aluminum conductor) conductors, which are widely used in electrical power distribution systems, are produced using a systematic manufacturing process, as shown by a Process Flow Chart for AAC (All Aluminum Conductor) Bare/Insulated Conductors. The outstanding electrical conductivity and lightweight characteristics of the AAC conductor, which is made of high-quality aluminum strands, make it appropriate for a variety of overhead transmission and distribution applications.

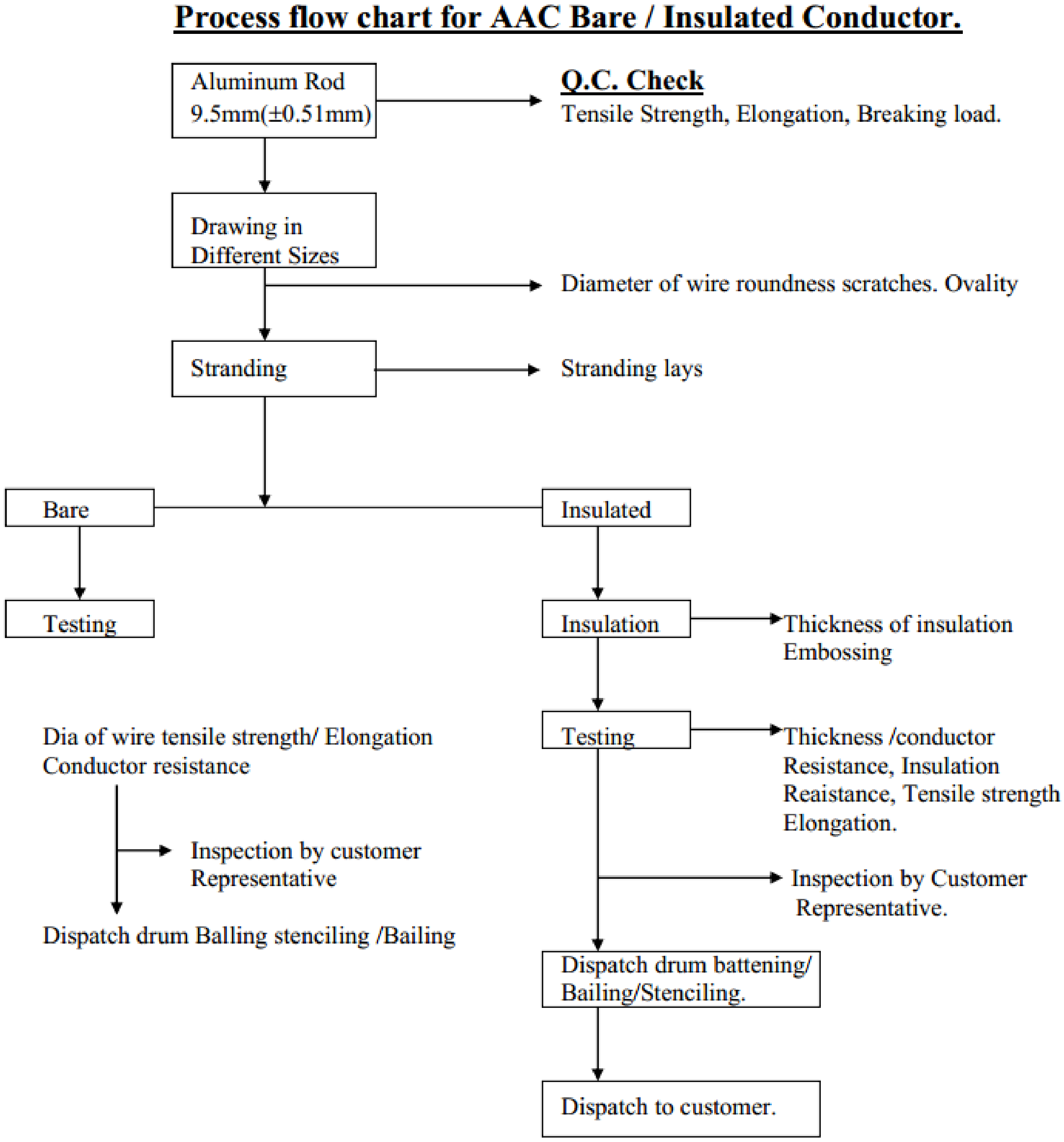


Figure 12. Process flow chart for AAC Bare / Insulated Conductor [8]

5.5 Process flow chart for Single/Multi core power cable

Various steps are included in a process flow chart for the production of single- and multi-core power cables to ensure the creation of high-quality, reliable cables suitable for electrical power transmission. Multi core power cable best suitable for industrial applications. Compared to multi-core cable, which is more resilient to high stress and temperature, single core cables are less susceptible to high-stress environments and temperature.

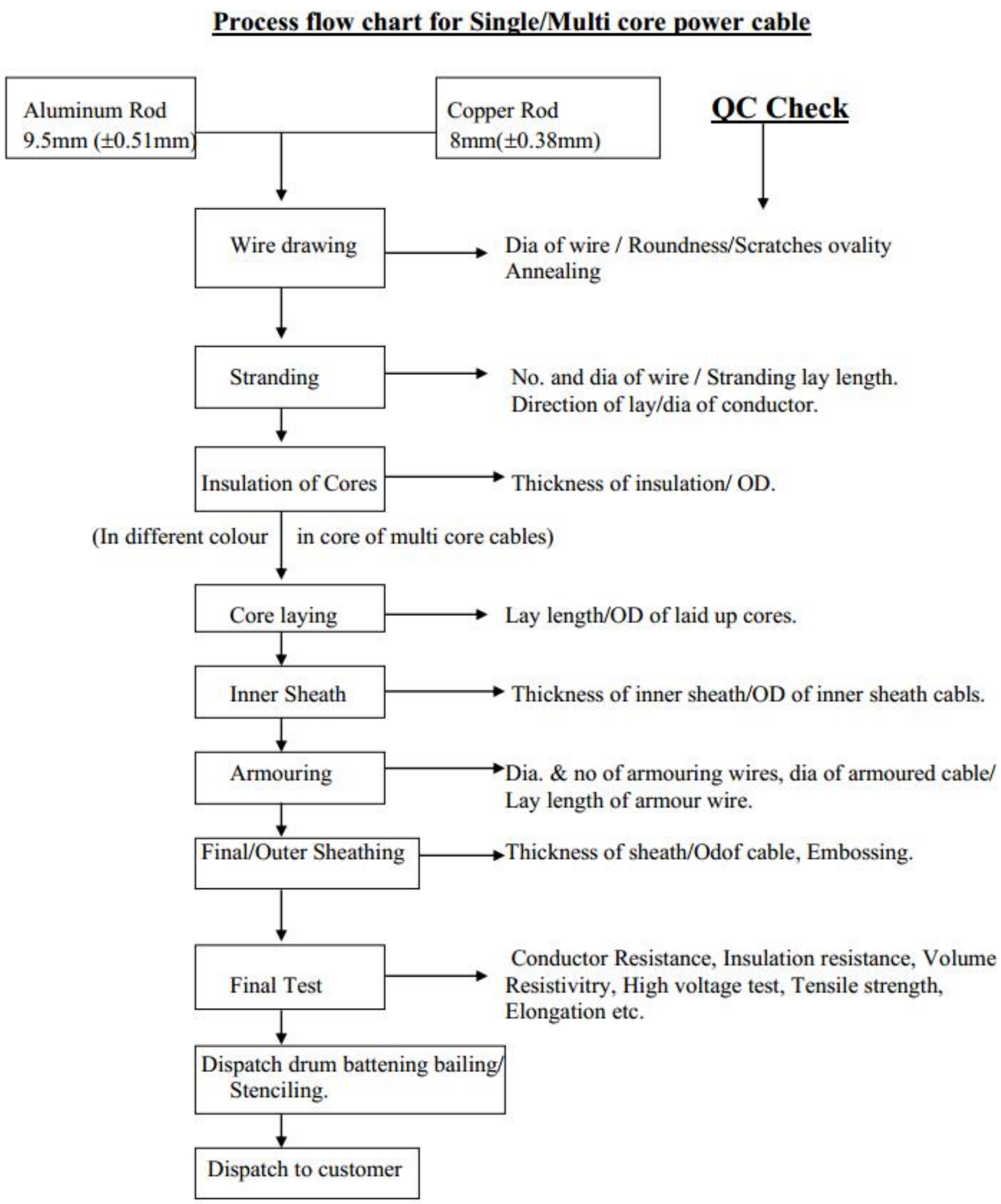


Figure 13. Process flow chart for single/multi core power cable

5.6 Process flow chart for PVC Compound.

There are various processes, from raw material preparation to the finished product. In this process Quality control (QC) department checks VR(volume resistivity), tensile strength, and elongation.

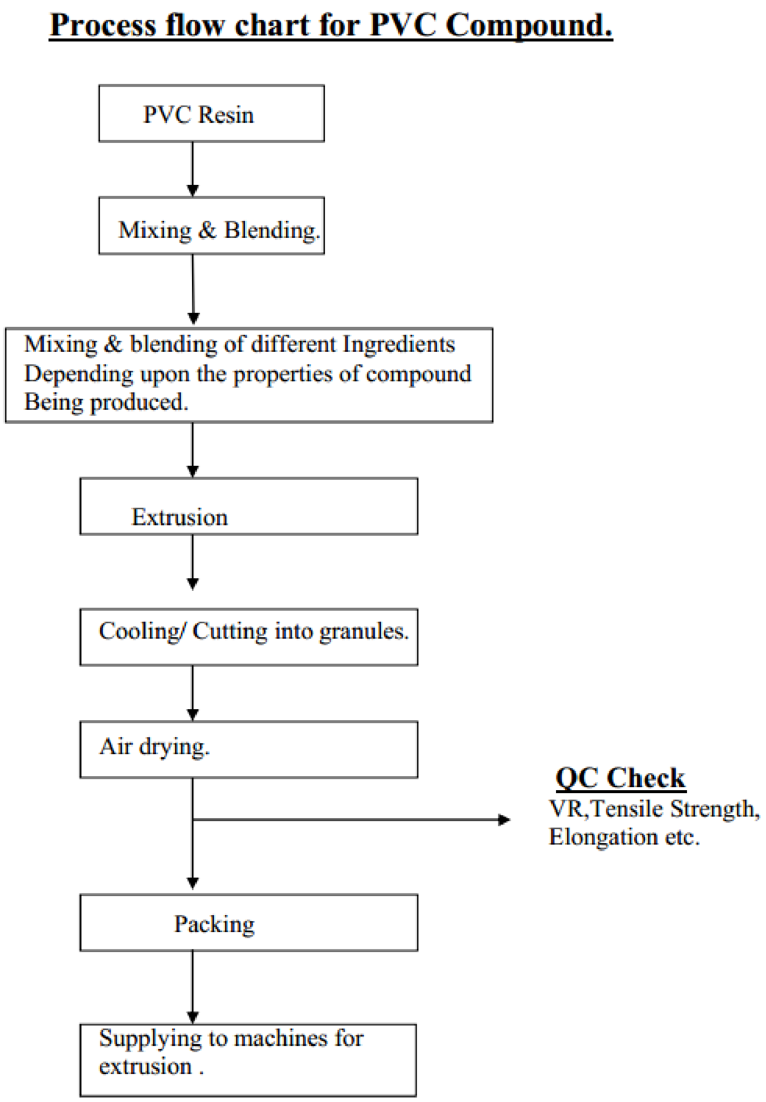


Figure 14. Process flow chart for PVC compound [8]

5.7 Process flow chart of copper plant

This flow chart shows step-by-step copper/aluminum rod production. Every day we produce 20 MT copper and 8 MT aluminum.

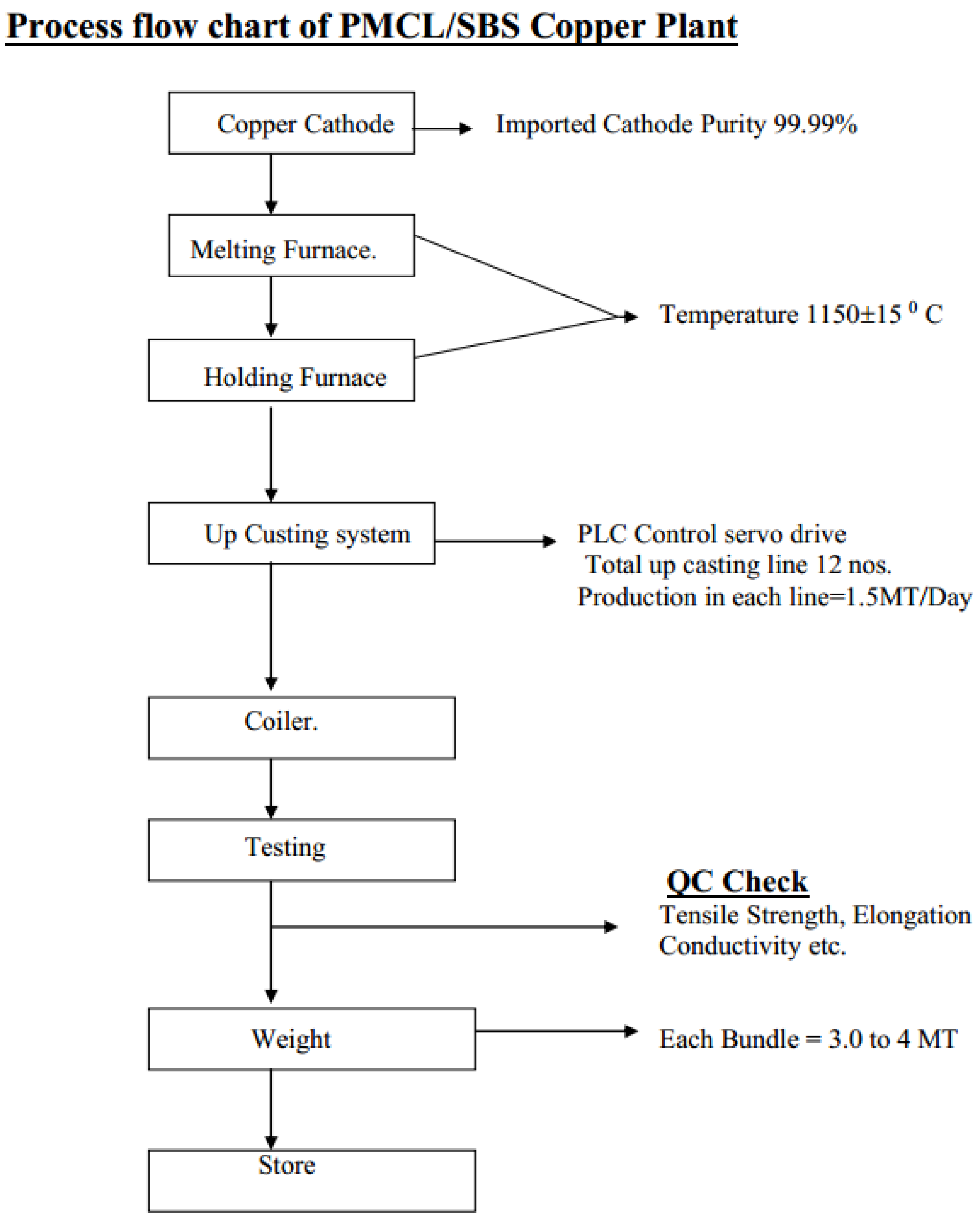


Figure 15. Process flow chart of the copper plant [8]

5.8 Flow chart for activities of the design department

The Design Department ensures the creation of high-quality and effective cables that satisfy industry standards and client needs, playing a significant role in the manufacture of cables. The flow chart covers every phase of the cable design process, emphasizing crucial duties and how they relate to one another. Cable makers may streamline their design procedures, improve the quality of their products, and ultimately help the cable sector develop by using this methodical approach.

Flow chart for activities of Design Department.

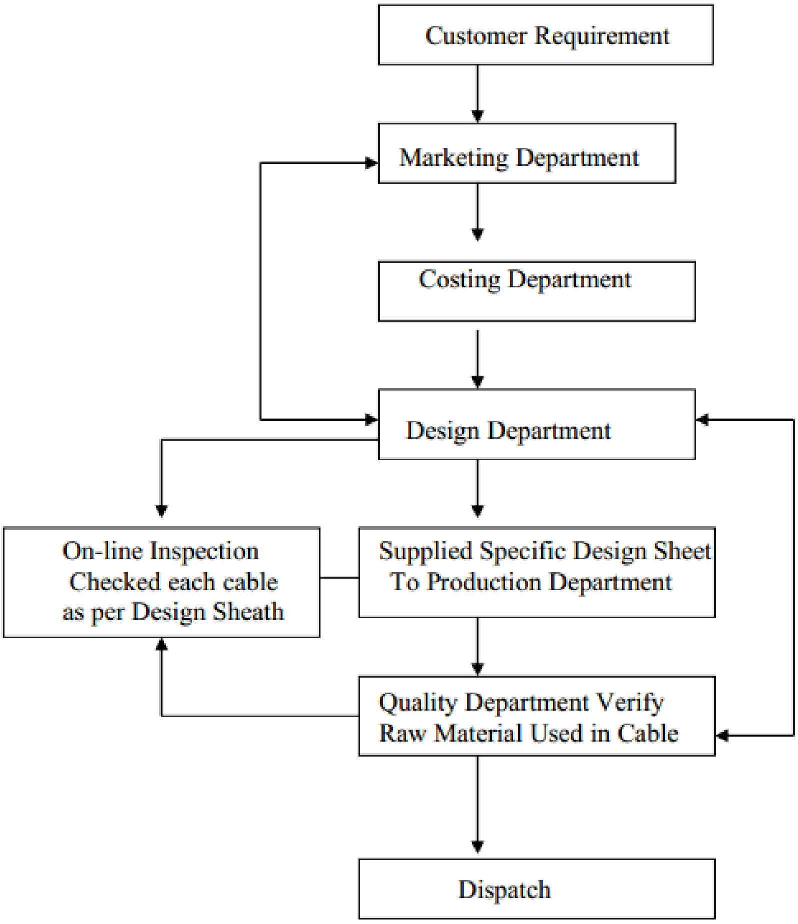


Figure 16. Flow chart for activities of the design department [8]

6 Methodology

This chapter explains the research approach, which is qualitative research using both case studies and semi-structured interviews.

Bhandari says that qualitative research involves collecting and analyzing non-numerical data (e.g., text, video, or audio) to understand concepts, opinions, or experiences. It can be used to gather in-depth insights into a problem or generate new ideas for research. Bhandari also says that qualitative research is the opposite of quantitative research, which involves collecting and analyzing numerical data for statistical analysis.[12]

According to Fossey E. and Harvey C,. qualitative research aims to address questions concerned with developing an understanding of the meaning and experience dimensions of humans' lives and social worlds. Central to good qualitative research is whether the research participants' subjective meanings, actions, and social contexts, as understood by them, are illuminated.[10]

6.1 A case study of power cable

The purpose of the research was to examine the impact of introducing lean methodology in a low voltage cable plant to improve productivity and timeliness. This research made use of a number of distinct lean methodology techniques, such as scheduled maintenance, internal maintenance, focused improvement, OEE, and daily performance reviews. The present manufacturing procedure used in power cable factories must be understood. This research describes the useful outcomes and benefits of various tools to assist businesses in implementing lean thinking. Practical ramifications: findings show that managers may quickly identify and get rid of production waste by using the approach.

According to Sekaran and Bougie, case studies focus on collecting information about a specific object, event, or activity, such as a particular business unit or organization. Sekaran and Bougie also say that the idea behind a case study is that to obtain a clear picture of a problem, one must examine the real-life situation from various angles and perspectives using multiple methods of data collection[14].

6.1.1 Case study

This research analyzes the five lean concepts shown in Figure 17, identify value, value stream mapping, generate flow, develop pull, and pursue perfection. The three TPM (Total productive maintenance) pillars of scheduled maintenance, autonomous maintenance, and targeted improvement are applied in this study. Each pillar was used in accordance with its own set of objectives to improve the manufacturing process, address issues with mass production, and improve customer satisfaction.

Lean method: Lean is fundamentally a business method that encourages the flow of value to the customer by following two essential principles: continuous improvement and respect for people. Jim Benson of Modus Cooperandi defines lean methodology in this way: "Lean is both a philosophy and a discipline that, at its core, increases access to information to ensure responsible decision-making in the service of creating customer value."

Total productive maintenance (TPM): TPM is a comprehensive approach to equipment maintenance that aims for flawless production.

- No Breakdowns
- No Small Stops or Slow Running
- No Defects

In addition, it values a safe working environment.

- No Accidents

To maximize the operational effectiveness of equipment, TPM stresses proactive and preventative maintenance. By emphasizing strongly empowering workers to assist in equipment repair, it blurs the line between the responsibilities of production and maintenance.

When a TPM program is put in place, equipment ownership becomes a shared responsibility, which motivates plant floor employees to participate more. This can significantly increase production (by speeding up processes, cutting down on cycle times, and removing flaws) in the correct setting.

OEE (Overall Equipment Effectiveness): A metric called OEE (Overall Equipment Effectiveness) measures the proportion of manufacturing time that is actually productive. It was created in order to precisely track the development of "perfect production" in order to assist TPM initiatives.

- An OEE score of 100% is perfect production.
- An OEE score of 85% is world-class for discrete manufacturers.
- An OEE score of 60% is typical for discrete manufacturers.
- An OEE score of 40% is not uncommon for manufacturers without TPM and/or lean programs.

SMED (Single-Minute Exchange of Die): Using SMED (Single-Minute Exchange of Die) technology, equipment switchovers can be performed in under one minute. The core idea behind the SMED system is to simplify and streamline the remaining stages while converting as many changeover steps as feasible to "external" (done while the equipment is running). Aiming to cut changeover times to "single" digits, or less than 10 minutes, gave rise to the name Single-Minute Exchange of Die.

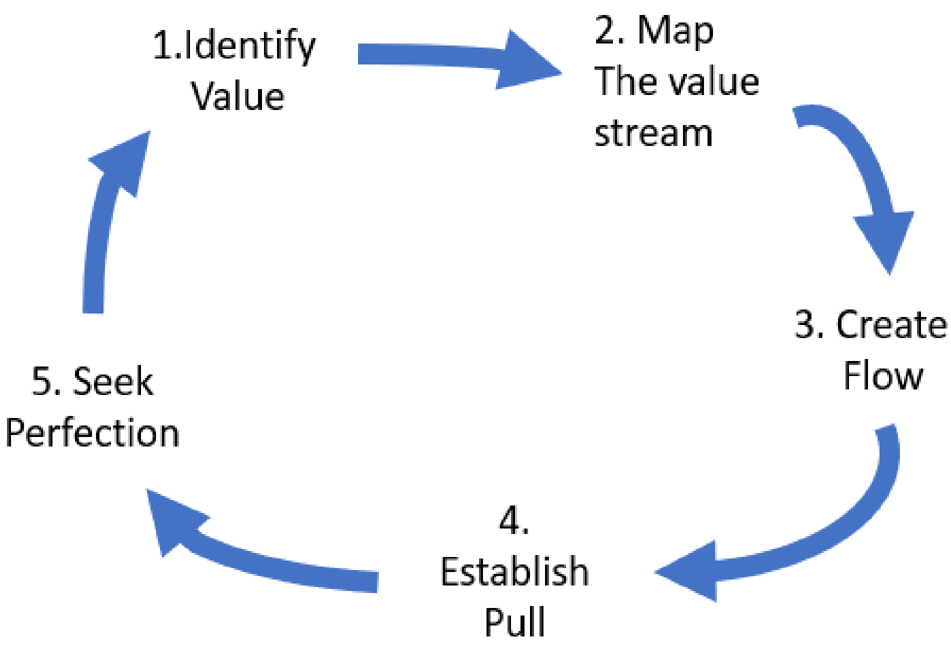


Figure 17. Lean principles [11]

6.2 Applied methods

This study was planned in 3 phases, as described in Figure 18.

- Frame-up.
- Identify and execute.
- Evaluate and maintain.

We provide an overview of the scope of work involved in each stage of implementing lean techniques in order to increase productivity and decrease downtime.

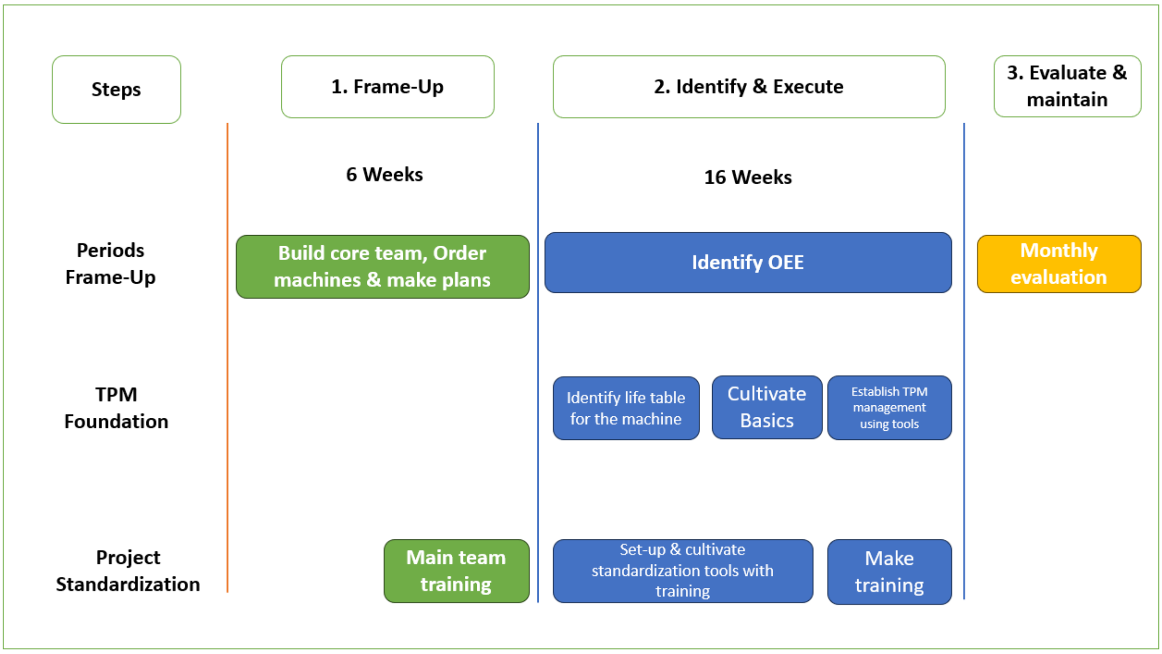


Figure 18. Project plan [11]

6.2.1 Frame-Up

Choosing and assigning a major team was the purpose of this phase. Then, machines were sorted in order according to many factors, including capacity consumption, circumstance, and obstruction procedure. Following the installation of each machine in order, each machine group was given a specific amount of time and resources. The primary staff then received effective lean training thanks to the OEE measuring and reporting system that was put up, which included tools and meetings.

6.2.2 Identify and execute

This phase's goal was to use various methods to choose pre-existing devices. We also made sure the primary team received assistance throughout the installation. Then, we established a standard operating procedure (SOP) and identified and carried out the TPM basis, including the life table.

6.2.3 Evaluate and maintain

Creating a performance evaluation system with a set frequency and accountability was the aim of this phase. Regular audits were also started to make sure the outcomes were maintained, as indicated the Table. The table shows three ranks. Rank A indicates a serious problem; rank B indicates a mid-level problem, and rank C indicates rear type of problem.

Attribute	A Rank	B Rank	C Rank
S—Safety and environmental effects	Failure would result in serious environmental problems in the surrounding area	Failure might result in certain safety and environmental problems in the surrounding area.	Failure wouldn't impact the environment or safety in the surrounding area.
Q—Quality and Revenue	Failure might result in the production of defective goods or have a negative impact on income.	Failure would result in a modest change in quality or income.	Failure would affect neither quality nor revenue
W—Working (operating) condition	24 hours working	7 to 14 hours working	irregular, working only
D—Delay factor (opportunity) condition	Failure would shut down the entire factory	Failure would shut down the relevant system only	Stand-by unit available/more economical to wait for failure and then repair
P—Period (failure interval)	Frequent stops (every six months or more)	sporadic stops (approximately once a year)	Very hard for any stops (less than once a year)
M—maintainability	Repair time: 5 hours or more Repair cost: over 2600 USD	Repair time: 1 - 5 hours Repair cost: 400 - 2400 USD	Repair time: less than 1 hour Repair cost: less than 350 USD

Table 3. Criteria for evaluating equipment.

6.3 Tools selection

As a proof of concept, we chose to put the fundamental elements of the TPM framework, as depicted in Figure 19, as well as additional lean approaches, including standardization, Visual Management, and SMED, into practice on a machine. The implementation of these components, which have a direct influence on the performance of the production process and deal with problems encountered in controlling demand, was decided upon in consideration of the maximization of benefit.

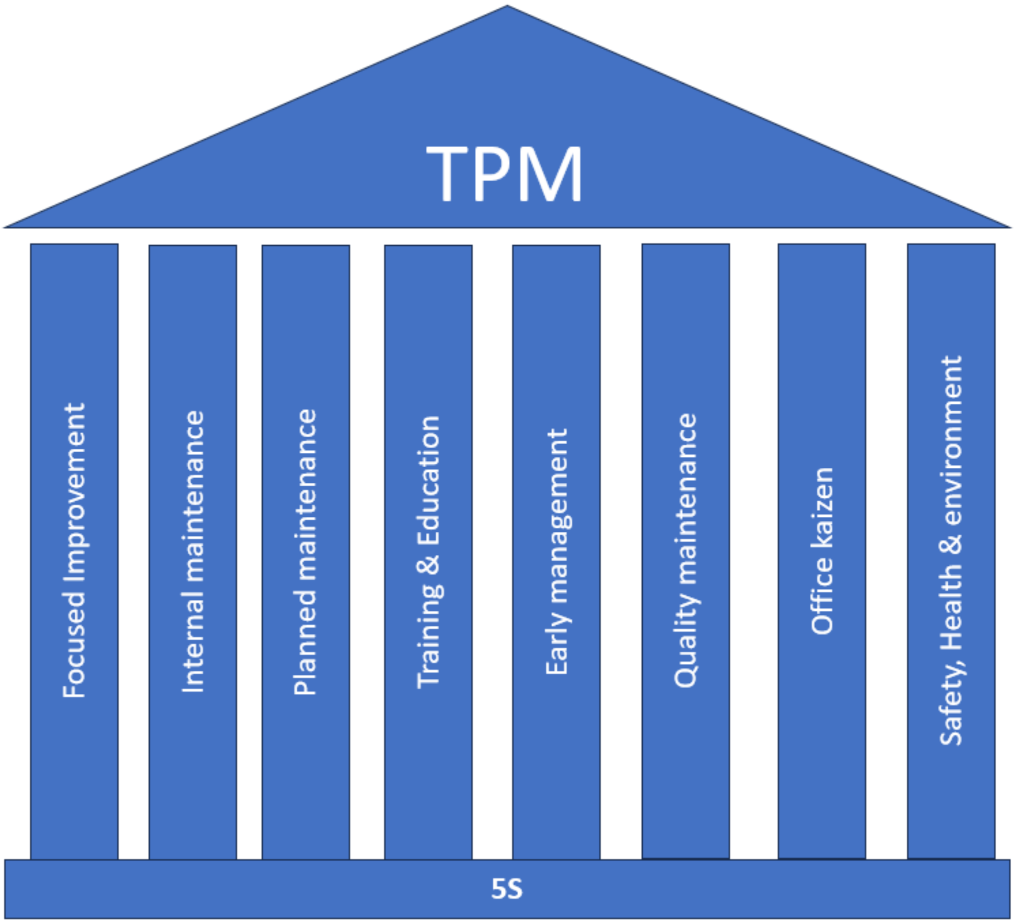


Figure 19. TPM pillars [11]

In TPM, pillars of planned maintenance, autonomous maintenance, and focused improvement were implemented. Each pillar had its own sequence of activities.

6.3.1 Planned maintenance

Based on the production team's expertise and the original equipment manufacturer's guidelines, the planned maintenance goal was to list all the actions necessary to maintain the machines. Data collection to aid in decision-making and efficient equipment maintenance was another goal.

As shown in Figure 20, each piece of equipment was first ranked according to its effect on process performance as well as other elements, including safety, quality, downtime, failure frequency, and maintenance cost. Based on its rating, the machine drum twister was chosen for proof of concept. Then, a cross-functional team made up of employees from the production and maintenance departments was established to raise knowledge of the machines and equipment. They concentrated on cataloging each assembly and subassembly in accordance with the product flow.

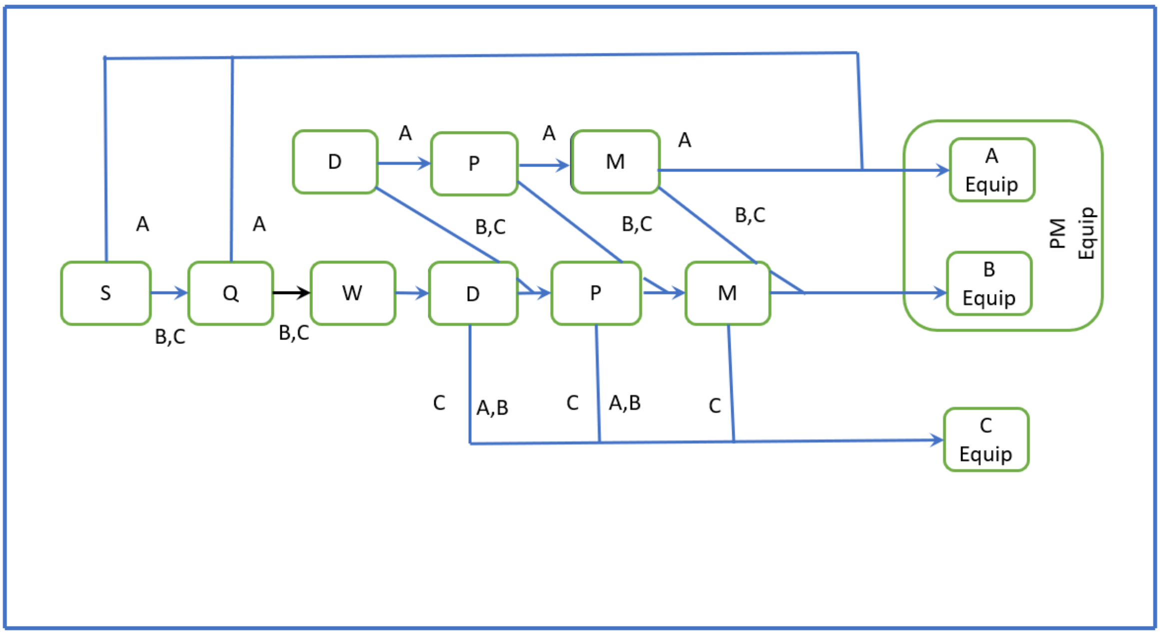


Figure 20. Evaluation of machine ranking [11]

Observations were taken about the state of the machinery as the various components of the machine were identified. The parts that needed to be replaced and the ones that would require maintenance in the future were also identified. The team then created a life table to include the maintenance chores necessary for each machine assembly, the tools and spare parts needed, and significant information like the supplier and part pricing.

The team also looked at how much time was needed for the indicated tasks to be completed by the machine operators and the maintenance staff. A maintenance schedule was made for each piece of equipment using all of this data. The planned maintenance schedule was implemented and followed to enhance equipment condition and return the machinery to its original state.

6.3.2 Internal maintenance

In this pillar, work was done to increase operator skill levels so that they could do small maintenance jobs and cut down on the time needed by the maintenance personnel. Operators may prevent process downtime by taking prompt action through daily cleaning, lubrication, inspection, and tightening activities, which is a significant result of its deployment. Seven internal maintenance procedures were carried out, as shown in Figure 21, starting with a preliminary cleaning to remove dust and debris and reveal any concealed flaws. Then, to avoid the equipment accumulated with dirt and dust, contamination sources were looked into.

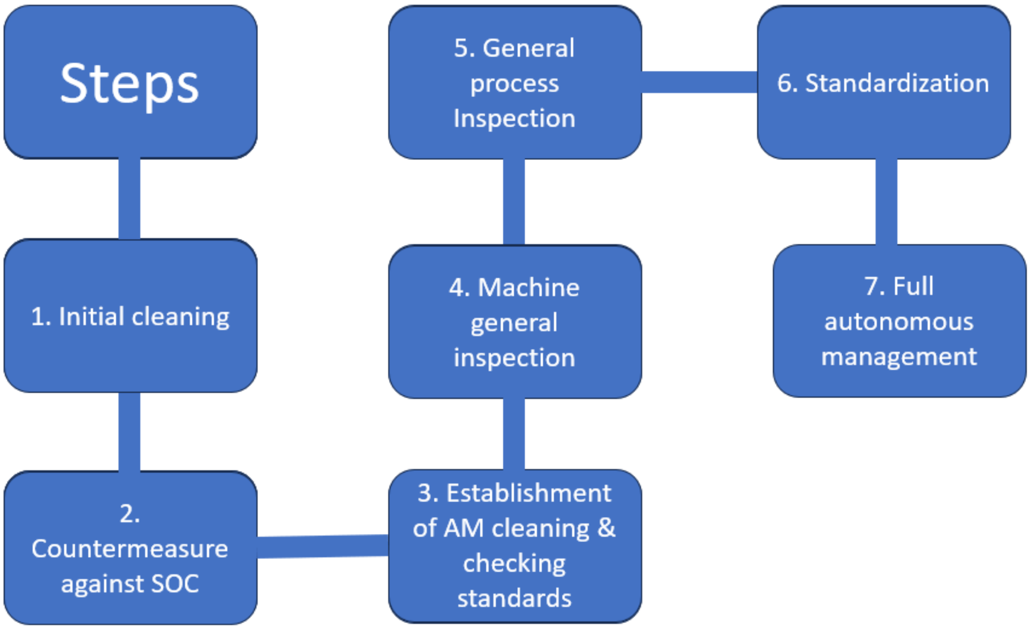


Figure 21. Internal maintenance steps [11]

Then, to ensure that the daily performance of the fundamental three requirements of cleaning, lubrication, and tightening, standards and routine cleaning were developed. By giving operators training in the best methods for checking the equipment, the capability of the operators was also enhanced. To assist operators in carrying out routine maintenance operations, standard operating procedures, and work instructions were developed.

6.3.3 Focused improvement

Employee participation in improvement projects is one of the defining characteristics of the Lean methodology. The A3 problem-solving and Kaizen programs were started by the team. The A3 problem-solving template is a technique for methodically locating problems, addressing them, and ensuring that they do not return. The procedure follows a cycle known as Plan-Do-Check-Act, which entails the following steps:

1) Describe the issue or problem by providing examples of when and where it first occurred, how frequently it occurs, under what circumstances it occurs, and why the issue needs to be resolved;

2) Calculate the time and quality loss to estimate the Cost of the issue;

3) Dissect the issue until you identify its underlying source;

4) Determine remedial measures;

5) Take those steps, and if the deadline is missed, escalate the issue to management;

6) Verify the outcome using quantitative data based on price, duration, and quality;

7) After root cause actions are taken, monitor any recurrent problems.

6.3.4 Overall equipment effectiveness (OEE) & daily performance review

Although manufacturing equipment is theoretically intended to operate at a certain level of productivity, real performance is generally substantially worse than the theoretical expectation. The term "invisible productivity loss" is used to describe this, and it has to be carefully identified and investigated. These unseen costs may be divided into six different sorts of losses, according to TPM. TPM employs overall equipment effectiveness to draw attention to these losses so the team may concentrate on developing a production metric.

By calculating availability, which is the amount of time the machine is available for production performance, speed, and quality of the machine's performance, we were able to start educating staff on how to compute OEE in accordance with Table 4. The machine's OEE was calculated using the product of these variables, as illustrated in Figure 22.

OEE (Availability × Performance × Quality)	
Availability	$\frac{\text{Actual operating time}}{\text{Planned production time}} = \frac{\text{Planned production time} - \text{Unplanned downtime}}{\text{Total avalible time} - \text{planned downtime}}$
Performance	$\frac{\text{Actual Runrate}}{\text{Ideal/ max Runrate}} = \frac{\text{Total Produced/actualrunspeed}}{\text{Ideal/max.abletobeproducedonequipment/runspeed}}$
Quality	$\frac{\text{Goodmaterialproduced}}{\text{Totalproduced}} = \frac{\text{Goodmaterialproduced}}{\text{Totalproduced}}$

Table 4. OEE calculation

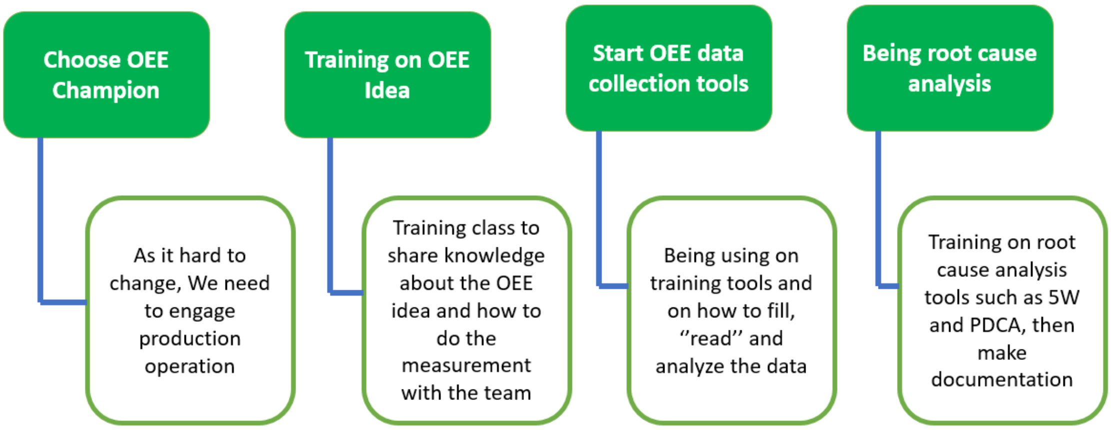


Figure 22. Determining the machine's OEE [11]

Log sheets were used to record significant data. Operators were in charge of entering information into the log sheets, which data operators subsequently utilized to upload into the calculating sheet. The production management team then evaluated a specific week to assess the performance of the line during that week and implement corrective measures to raise OEE.

For this reason, daily evaluations were created, and the work area was equipped with visual representations of the shared folder. Making process performance accessible to everyone was intended to help people identify any issues.

6.4 Single minute exchange of dies (SMED)

Following the OEE installation, the team discovered that staff changes and planned maintenance tasks have a substantial influence on machine availability. As a result, the team employed a Lean methodology tool called SMED. SMED implementation requires the following actions to be taken by a group:

1) Recognize and assess the current circumstance;

2) Record the switchover;

3) Examine the transition and apply ECRS to the tasks (Eliminate, Combine, Reduce, and Simplify);

4) Determine the steps to take;

5) Carry out the procedures;

6) Make the solutions consistent.

6.5 Qualitative research using interviews

The second form of data collection for this thesis was a qualitative research approach. This method was found suitable for this thesis as it focuses on researching the possibilities to find the problem and a suitable solution. For qualitative research, the information gathered is descriptive and relies on semi-structured interviews. According to Oakley, a qualitative interview is a type of framework in which the practices and standards are not only recorded but also achieved, challenged, and as well as reinforced.

Through the use of three semi-structured interviews, the empirical data were gathered. Empirical information is data derived through experience. Three persons participated in this interview who have more than five years of experience in the cable industry. Appendix 1 contains all the interview questions. In order to give each interviewee's perspective on the questions, the interviews are presented anonymously in this thesis work as interviewee1 through interviewee3. In the information that follows, the interviewees will be referred to by the letter and number combination i1-i3.

Several individuals who work in both Product Management and R&D provided comments on the interview questions after they were first developed by the researcher. The interview questions were modified based on the comments to better match the size of the study's inquiry.

7 Result of the study

The findings of the study will be provided in this chapter. The results from the case study present the methodology which would increase productivity and reduce waste and time in the industry. The interviews discuss related problems and solutions.

7.1 Case study

A core team was assigned and given Lean theory and practical application training as part of the application of TPM. A thorough implementation strategy, complete with a timetable and resources, was created. A staff was taught TPM ideas and documentation standards to prepare them to manage more machines in the future, and the OEE measurement and reporting system was developed.

As a successful implementation experiment, the team was able to apply the approaches on one computer. Other machines in the plant also had TPM infrastructure and standards set up; the core team assisted with assistance evaluation and implementation of the required adjustments.

7.1.1 Result of ranking

The cross-functional and core teams agreed on equipment rankings, which have been approved. 20 machines were identified as rank A, which is shown in Table 5 and Table 6. We discuss only rank A machines.

The groups of machines in Rank A include the following:

- Wire drawing and tinning equipment (Total 5 machines).
- Pairing and assembly equipment (Total 6 machines).
- Extrusion and insulation equipment (Total 7 machines).
- Packing equipment (Total 2 machines).

The plan is to start with the extrusion machines (the largest group with Rank A)

Machine number	Machine	Operations	Quality	Safety	Maintenance /Cost	Rank
1	RBD - 1	A	C	C	A	A
2	RBD - 2	A	C	C	A	A
3	RBD - 3	A	C	C	A	A
7	Niehoff int - 1	A	C	B	A	A
16	Niehoff int - 2	B	C	C	B	A
18	Niehoff int - 3	A	C	B	A	A
21	Tubular - 1	A	C	C	A	A
25	Tubular - 4	A	C	C	A	A
26	Niehoff twisting - 1	A	C	C	A	A
31	Niehoff twisting – 2	A	C	C	A	A
33	Extruder - 1	A	C	C	A	A
40	Extruder - 2	A	C	C	A	A
42	Extruder - 4	A	C	C	A	A
43	Extruder - 5	A	C	C	A	A
44	Extruder - 7	A	C	C	A	A
50	Extruder - 9	A	C	C	A	A
52	Extruder - 10	A	C	C	A	A
56	Coiling machine - 1	A	C	C	A	A
57	Packing machine - 1	A	C	C	A	A
81	Packing machine - 2	A	C	C	A	A

Table 5. Machine ranking with A rank.

Total Machines	Total Rank A machines	Total Rank B machines	Total Rank C machines
100	20	55	25
100%	20%	55%	25%

Table 6. Result of Machine Ranking

7.1.2 Machine restoration

Machine restoration was described in Figure 23

On extrusion and drum twisting machines, persistent adherence to standards was the outcome of improved operator morale. Implementing autonomous maintenance on both kinds of machinery improved adherence to SOPs by 81%.

A cross-functional team was formed to increase awareness and establish constructive expectations within the designated team, including personnel from the production and maintenance departments. Based on their collective knowledge, the team identified machine assemblies and subassemblies for subsequent comparison with OEM (Original Equipment Manufacturer) documents and testing by actually seeing the machine in operation. In order to depict the position of each assembly graphically, all machine assemblies and subassemblies were color-coded to distinguish moving components from static elements.

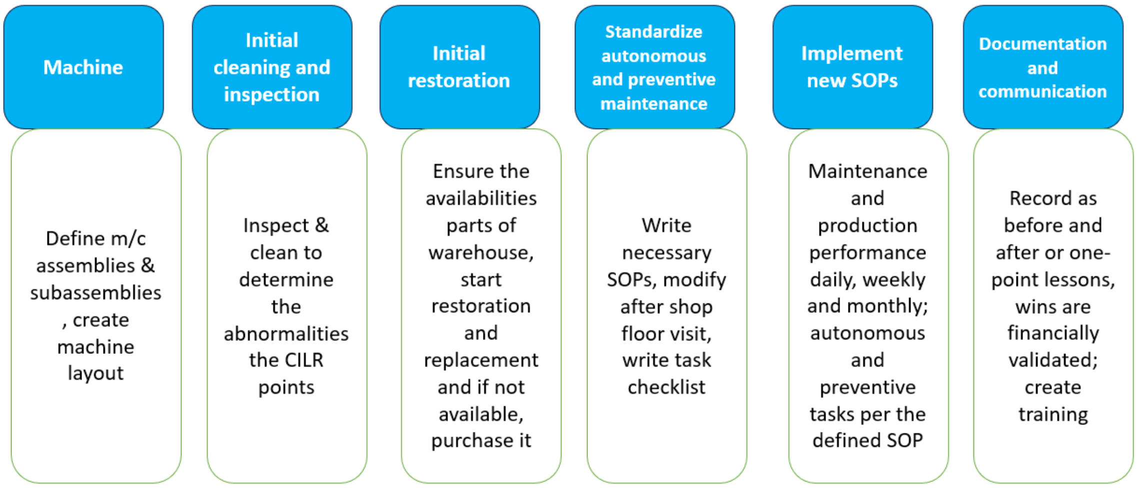


Figure 23. Machine restoration approach

During the shop floor observations, the team classified the parts as follows:

- Parts which are useful in the machine;
- Parts that require replacement;
- Parts that demand a maintenance strategy.

Based on the purchasing department's delivery dates for replacement components, a plan with the necessary time and resources for complete equipment repair was developed.

The team acquired all of the machine's existing paperwork, such as original equipment manufacturer manuals, schematics, tables, and any technical details that were accessible in the maintenance department. The team compared the OEM's proposed instructions and duties to those that were previously recorded in the life table. The group looked over the paper and evaluated its "usability". It is necessary to provide materials that can be used to teach new employees, front-line staff, and anybody else who interacts with the equipment. Therefore, even for people who cannot read or write, the content must be user-friendly. The team observed the shop floor to evaluate the level of comprehension and activity sequences and to modify work frequencies and timeframes. To make sure that the developed criteria could be met, the team revised them in light of observations made on the shop floor.

7.1.3 Drum twister

Observations

- The machine is more than ten years old. As shown in Table 8
- Preventative measures for safety and health, such as warning lights, an emergency stop button, and basics for cleaning, tightening, and lubrication, are not available.
- Pneumatic systems and gauges are not working.
- Many temporary fixes have been performed.
- Bearings did not rotate freely.
- Sliding shafts have been painted over.
- The restoration of the drum twister machine reduced breakdowns and increased speed (production capacity increased by 35% per month), as shown in Table 7.

Description	Factor	Qty	UOM
Total production Jan to Aug 2019		2700	Km
Average production per month	8	360	Km
Average production—assembly	58%	220	Km
Average production—armoring	42%	150	Km
Possible production after speed trial speed increase—assembly	55%	100	Km
Possible production after speed trial speed increase—armoring	28%	45	Km
Total increase in production capacity		140	Km
Product mix affects safety		20%	%
Based on increased speed, the average potential increase in output capacity is (km)		118	Km
Based on speed increases, the average potential increase in output capacity is (%).		35%	%

Table 7. An increase in speed yielded a 35% increase in production capacity per month.

Before	After
➢ Due to damaged pipes and valves, it is impossible to set the right break.	➢ The handles, valves, and hoses were changed.
➢ Lack of pressure in the air system because of a malfunctioning valve gauge	➢ Proper air pressure decreased adjustment times and helped to speed up the operation.
➢ Due to a lack of a suitable die holder, the Cable was held by cloth and a plastic plaster.	➢ To lessen cable vibration, use a good die set.

Table 8. Drum twister restoration.

7.1.4 Extrusion machine

Following the repair of the extrusion machine, as shown in Table 9.

Before	After
➢ Temporary improvements were observed, but the water was not functioning.	➢ The machine can increase speed by 80% due to the new payoff.
➢ Changeover is required once the conductor bobbin is finished, which takes 10 minutes. Stoppages are required at intervals of x mints, totaling x mints. There is daily downtime.	➢ No need to stop the machine for a changeover, which increases the availability by 12%
➢ Damage to the barrel heater cover reduced availability and performance.	➢ Machine tools repaired and replaced.

Table 9. Drum twister restoration.

The state of the machine before and after As illustrated in Table 9, the improved pay-off enables the machine to boost speed by 80% as shown in Table 10, while still necessitating a machine halt for changeover, increasing availability by 10%. The safety system has also been restored and upgraded.

Description	Factor	Qty	UOM
Total production Jan 2019 to Mar 2020		65,000	km
Average production per month	15	4000	km
Average production—extrusion	100%	4200	km
Baseline beginning of project		307	mpm
Speed test trial result (15/04/2020)		610	mpm
Possible production after speed trial speed increase	94%	4000	km
Safety factor due to product mix		15%	%
Average possible production capacity increase based on speed increase (km)		3526	km
Average possible production capacity increase based on speed increase (%)		80%	km

Table 10. Increasing speed and availability yielded an 80% increase in production capacity per month.

7.1.5 Changeover reduction using SMED

Table 11 illustrates how the single-minute Digit exchange of die (SMED) lean production technique helps to reduce waste in the manufacturing process.

Before	After
➢ Raw materials are transferred in a mixed-up way, and time is lost for searching and verification.	➢ Raw supplies brought from a staging area in a well-defined order, ready for usage
➢ Littered layout makes walking around difficult for the operator.	➢ Clearly layout designed with drop points
➢ Time lost for arranging materials for use and no hand touch.	➢ Machine tooling order system defined.

Table 11. SMED

It provides a rapid and efficient method of switching industrial processes from one round of production to the next. SMED is a lean tool that assists in shortening the time needed to switch from one operation to another. SMED is essential for lowering costs and encouraging process flexibility in addition to improving cycle time. Reduced changeover times were the outcome of the project's effective execution. The irregular raw material delivery and the poorly structured and laid out tooling caused a significant amount of time to be lost during changeovers. After using SMED, the time was cut in half, going from 180 minutes to 90 minutes.

7.1.6 Using the OEE measurement processes and tools

A metric called OEE (Overall Equipment Effectiveness) measures the proportion of manufacturing time that is actually productive. It was created in order to precisely track the development of "perfect production" in order to assist TPM initiatives.

- A group received OEE concepts training.
- The team determined the ideal procedure, roles, and duties for the participants.
- To prevent recording duplicates, a new log sheet was established.
- To guarantee that measurement was established, the team received training on the OEE database.
- Meetings were set up to go over the main reasons for significant failures.

7.2 Interviews

The interviewees were all people experienced in the cable industry. The interviewees share their experiences, knowledge, future goals, and development. The interviewees had the roles of

- Senior manager (design and lab) (i1)
- Production manager (production) (i2)
- Deputy manager (Quality control) (i3)

7.2.1 Production

Electrical cable is one of the most important things in our modern life. We transmit power and signal by electrical cable in our everyday life. Cables silently enable the information and power transfer that keeps our world connected and operating smoothly. They are the unsung heroes of our modern existence. These modest wires, which range from the simple USB cord to the sophisticated web of fiber optic cables that span countries, are essential to practically every part of our everyday activities.

1. What is your experience with the cable industry?

2. What types of cables are produced by your Company, and what are the primary applications for these cables?
4. How does your company source raw materials for cable production, and what factors influence your selection of suppliers?

Practical experience in the cable industry is an important part of employees. There is no individual degree of cable in educational institutions. Employees should update their knowledge of the new technology.

"The cable industry has been an integral part of the telecommunications sector, power sector, and industrial sector for many decades. The cable industry has experienced massive expansion and transformation, with emerging new technologies, such as high-speed internet, automation technology, and streaming services". (i1)

Cable manufacturing businesses provide a wide variety of cables for different uses. Cable companies should focus on manufacturing and quality. User demand is increasing day by day, and new types of cables are coming. The focus on smart home technologies has been a significant area of growth for the cable sector. A variety of smart home technologies that can be managed by a single app or device, including home security systems, smart thermostats, and smart lighting systems, are now being offered by cable companies. Customers now find it simpler to manage their houses, and cable providers also have additional sources of income.

The rising demand for high-speed internet connection has been one of the major drivers of the cable industry's expansion. The need for faster and more dependable Internet access has increased as people's reliance on the Internet for business, education, entertainment, and communication has increased. By making investments in new infrastructure and technology, such as fiber optic cables and DOCSIS 3.1, which can deliver internet speeds of up to 10 Gbps, the cable companies have been able to match this demand. (i2)

Our country is a developed country, and there are huge growing industries and technology day by day. The cable industry has continued to rise and evolve in response to changing customers' needs and technological advances. Cable companies are well positioned to continue to play a vital role in the telecommunications sector in the upcoming years. (i2)

We make two different kinds of cable. These cables are both residential and electrical cables. The usage of cables is widespread, including applications in telecommunications, electronics, power transfer, and building. They are used to send signals, data, and electrical power between two locations. Depending on the uses for which they are designed, firms make different sorts of cables. (i1)

We make domestic cables which range from 1.0 to 10 rm, and power cables range 10 rm to 800 rm. We produce FR skin coated building wire, FR low voltage power cables, FR medium voltage Power cables, FR communication and data cables, FR instrumentation cables, Overhead Conductor, and Customized cable. (i3)

The application of coaxial Cable is used for transmitting high-frequency signals, such as internet connections, cable TV, and radio, and it consists of a central conductor surrounded by a layer of insulating material, a metallic shield, and an outer jacket. (i2)

The common applications of twisted power cables are Ethernet networks, telephone lines, and other data transmission applications. They consist of two insulated wires twisted around each other, which helps to reduce electromagnetic interference. (i1)

The common application of USB cables is connecting devices such as printers, cameras, and smartphones to computers. (i3)

Power cables are mostly used in industry and transmit electrical power from one point to another. They consist of multiple wires or conductors wrapped in an insulating material, and they are typically used in industrial applications. (i2)

Costs can be significantly influenced by the selection of materials used in cable production, including the kind of conductors, insulators, and shielding. The overall cost-effectiveness of the cable may be impacted by the cost of some materials, which may be more expensive yet provide higher performance or durability.

When we select cable raw materials, we follow international standards to ensure the quality and safety of the cables produced. We follow Conductor Material Standards, Insulation Material Standards, Jacket Material Standards, Shielding Material Standards, and Filler Material Standards. (i1)

We use 99.99% pure copper with the highest level of electrical conductivity. The copper raw materials used in the cables should have high electrical conductivity to ensure efficient transmission of electrical signals. We imported copper and aluminum raw materials from Japan. (i1)

We focus on the conductivity of copper and aluminum. The conductor should have high electrical conductivity to ensure efficient transmission of electrical signals. The raw material must be melted in the copper plant, which ensures that the copper rod passes through the RBD machine and dies smoothly without any breakdown. (i3)

We have a PVC production plant. We import resin from Germany and other accessories collected from the local market. Our focus on insulation material is that it should be able to withstand the electrical field and prevent electrical conduction between conductors. Heat and flame retardant are the main concerning factors. It should also be resistant to heat, moisture, and other environmental factors. (i3)

We select raw materials which have good mechanical properties, such as flexibility, strength, and durability. It is most important that the cables can withstand physical stresses during installation and use. (i2)

With the advent of new technology, the cable business has seen significant development and growth. Cable manufacturing companies offer a wide range of cables for various applications. One of the main factors driving the growth of the cable sector is the increasing demand for high-speed internet connections. The most important factor is the selection of raw materials based on international standards for quality and safety. This involves using copper and aluminum with high conductivity as well as heat- and fire-resistant insulating materials. To ensure longevity and flexibility during installation and usage, the production of cables with appropriate mechanical qualities is the main goal.

7.2.2 Quality

3. What are the key manufacturing processes involved in cable production, and how does your company ensure quality control throughout the process?

Quality control is an important part of the cable industry. It should be followed by some standards and customer requirements.

Quality is a main concern in our industry. There are many processes in cable production. Those are wire drawing, stranding, insulation extrusion, jacket extrusion, shielding, cabling, making, and testing. (i1)

Our Company has established quality control standards that outline the requirements for product and service quality. These standards have been developed in consultation with stakeholders and would be clear, concise, and measurable.

Our quality control department checks and implements various stages of the cable production process to ensure compliance with established standards. These checks include product testing, inspection of equipment and facilities, and verification of customer requirements. (i2)

Our Company provides adequate training and education to its employees to ensure they are familiar with the quality control standards and procedures. Those include regular training sessions and refresher courses to keep employees up to date with the latest standards and techniques.

All quality control checks, and related activities are properly documented and recorded to allow for traceability and accountability. This includes keeping records of product specifications, test results, inspection reports, and customer feedback.

Our Company continuously monitors its quality control processes and looks for ways to improve us. It involves collecting and analyzing data on quality control checks and identifying areas for improvement. (i3)

The cable industry puts a strong emphasis on quality control while also upholding both client demands and industry standards. Several steps of the manufacturing process, including wire drawing, stranding, insulation, jacket extrusion, shielding, cabling, and testing, are involved. In collaboration with stakeholders, the organization has set concise, clear, and measurable quality control criteria. Through product testing, equipment and facility inspections, and customer specification verification, the quality control department keeps an eye on adherence to these standards. To keep current on the most recent standards and procedures, employees take frequent training sessions and refresher courses. For accountability and traceability, every aspect of quality control—including product specifications, test results, inspection reports, and client feedback—is thoroughly recorded. The business is dedicated to continuous development and frequently gathers and analyzes data on quality control inspections to pinpoint areas that may be improved.

7.2.3 Technology & Future Development

5. How does your company stay up to date with the latest technological advancements in cable production, and how do you incorporate new technologies into your manufacturing processes?

Any cable company must meet the demanding necessity of keeping informed of the most recent technological developments in cable manufacture.

To learn about the most recent technology, trends, and best practices, we go to industry conferences, trade exhibitions, and other cable production-related events. Every year we attend one of the biggest trade fairs in our country, 'Dhaka International Trade Fair'. (i1)

We have an R&D (Research & Development) department. This department researches and analyses emerging technologies and innovations in cable production by reading industry publications and case studies. (i3)

Our company works closely with our suppliers to stay informed about new products and technologies in cable production. They always inform us about new technology and development. (i2)

Our company collaborates with other companies to exchange resources and knowledge. This can assist us in keeping up with emerging trends and technology. (i1)

To provide our staff with the skills and knowledge they need to work with the newest technology and tools, our firm funds training and development programs for them. (i3)

Incorporating new technologies into manufacturing processes can be a complex process in Cable Company, but it can also provide significant benefits of increased efficiency, productivity, and cost savings. (i1)

We assess the current manufacturing processes and identify areas where technology can be applied to improve efficiency, quality, or safety. (i2)

Once the needs and opportunities have been identified, we developed a technology road map to guide the company's technology investments over time. The roadmap prioritizes the most critical areas for improvement and outlines a plan for implementation, including timelines, budget, and resource allocation. (i2)

It is important to collaborate between different departments within the company, incorporating new technologies into manufacturing processes. Our engineering, operations, IT, and finance departments synchronize and cooperate with each other. (i1)

Introducing new technology into manufacturing processes requires employees to learn new skills and processes. It's important to provide adequate training and support to ensure that employees can use the technology effectively and efficiently. (i1)

It is important for any cable industry to regularly take part in industry conferences, trade shows, and other events to keep up with the latest technical advancements. Through case studies and industry publications, the R&D department analyzed and researched new developments in cable production. It is important to collaborate with other companies to exchange resources and knowledge, aiding in staying updated with emerging trends and technologies.

6. What are some of the biggest challenges that your company has faced in cable production, and how have you overcome these challenges?

There are a lot of challenges in the cable industry such as cost reduction, quality, labor cost, production speed and efficiency, and so on.

Our company faces several challenges in cable production; we employ various strategies to overcome them.

We require a consistent supply of raw materials, including polymers, aluminum, and copper. Changes in raw material costs, availability, and quality can be difficult. We establish long-term relationships with reliable suppliers, diversify their supplier base, and engage in strategic sourcing to ensure a stable supply chain. (i1)

Cable manufacturing companies must maintain consistent product quality. Ensuring that cables meet industry standards, specifications, and customer requirements is a significant challenge. We implement robust quality control processes, including regular testing and inspections throughout the production process. We had to invest in advanced testing equipment and certification programs to guarantee product quality. We have 'BASEC' and 'BSTI' certificates. (i3)

We always keep pace with technological advancements to meet evolving market demands. We invest in research and development to stay at the forefront of technology, upgrade our machinery and production techniques, and train our workforce to handle new cable types and manufacturing processes. (i3)

The biggest challenge is maintaining consistent product quality, which necessitates adherence to industry standards, specifications, and customer requirements. Strong quality control procedures, such as routine testing and inspections, together with investments in cutting-edge testing tools and certification programs (BASEC and BSTI certifications), are used to achieve this.

7. How do you ensure that your cable products meet industry standards and regulations, and what steps do you take to maintain compliance?

We continually evaluate the laws and standards that apply to their goods in the industry. This includes regulations established by organizations like the Federal Communications Commission (FCC), the National Electrical Manufacturers Association (NEMA), and the International Electrotechnical Commission (IEC). (i3)

We create our items to adhere to the established norms and laws. To make sure that these standards are met, we carry out stringent testing during the product development process. We provide safety, signal integrity, and electrical and mechanical testing. (i2)

We have a regular inspections team and audits team to ensure that production processes align with the established standards and regulations. We maintain a robust system for tracking and incorporating any updates into our product development and manufacturing processes. (i3)

We maintain detailed documentation and records related to product design, testing, certification, and compliance. These records serve every week as evidence of compliance and are reviewed during audits or regulatory inspections. (i2)

We engage in continuous improvement efforts to enhance our product quality and compliance. We analyze customer feedback, monitor emerging technologies, and participate in industry forums to stay updated on our best practices. (i1)

The FCC, NEMA, and IEC, among other agencies, determine the regulations and rules that cable companies must abide by. Throughout the product development process, extensive testing is done to guarantee compliance in areas including safety, signal integrity, and electrical/mechanical qualities. A team of inspectors and auditors has been developed to ensure that manufacturing procedures conform to accepted rules.

8. What are your thoughts on the future of cable production, and how do you see this industry evolving in the coming years?

Numerous factors affect how cable manufacturing will develop in the future. We acknowledge the rise in interest in streaming services and the move toward the consumption of digital material. We are thus changing our strategies to be competitive in the developing market. (i1)

Fiber optic cables are anticipated to play a crucial role in meeting the rising need for communication networks that are quicker and more dependable. To advance fiber optic technologies, cable producers are making significant investments in new technology and expanding their capacity for manufacturing. (i3)

The huge demand for data consumption continues to rise. There is a growing demand for cables that can support high-speed data transmission. Cable manufacturers are developing cables with higher bandwidth capacities as per demand and improved signal integrity to meet these requirements. (i2)

The industry is witnessing a trend toward customized cable solutions to meet specific customers' requirements for different applications. Cable companies are offering more flexible and adaptable solutions to cater to the diverse needs of their customers. (i3)

Nowadays, the Internet of Things (IoT) and smart devices have become more prevalent, and cable companies are exploring ways to integrate cables with smart technologies. This includes the development of cables with built-in sensors, enabling real-time monitoring, testing, and diagnostics. (i1)

Cable manufacturing companies are optimistic about the industry's future. They are proactively investing in research, development, technology, and innovation to stay ahead of the changing and growing market demands and deliver cutting-edge cable solutions. (i2)

Several important aspects will influence how cables are made in the future. These include the rising use of streaming services and the consumption of digital material. Companies are altering their methods to stay competitive. The increased need for quicker and more dependable communication networks is anticipated to be met in large part by fiber optic cables. Manufacturers are increasing their fiber optics production capacity while also making large investments in new technology.

There is a greater requirement for connections that can enable high-speed data transmission as data consumption keeps rising. In response, manufacturers are creating cables with increased bandwidth capacity and greater signal integrity. Customized cable solutions, which offer greater flexibility and adaptability and are suited to client applications, are also becoming more popular.

Cable companies are looking at ways to combine cables with smart technologies due to the rise of the Internet of Things (IoT) and smart gadgets. This entails creating cables with integrated sensors for real-time testing, monitoring, and diagnosis. In general, businesses that produce cables are positive about the future of their sector and are aggressively investing in R&D, technology, and innovation to satisfy changing consumer expectations and provide cutting-edge cable solutions.

8 Discussion and recommendations

Implementing lean methodology in power and domestic cable factories increased process performance and production. The findings of this study offer optimism for the quality and the economic aspects of cable production in the future. To increase total industrial efficiency, further steps, norms, and follow-up processes are still needed. The PDCA(planning, doing, checking, and acting) approach has aided in determining dependability and ensuring the system's strong reliability.

This study has clarified the numerous facets of cable manufacture. We have learned a great deal about the complexities of cable production via multiple examinations of the materials, manufacturing procedures, and quality control procedures.

The results of this study show how crucial it is to choose the right materials, optimize manufacturing procedures, and put strict quality assurance protocols in place to produce high-quality cables that satisfy customers' demands and industry standards.

The research has also highlighted and recognized new developments in cable production, including the use of modern technologies and the integration of sustainable materials.

With the potential to increase productivity, lessen environmental impact, and improve overall product performance, these advances might change the cable production business.

By increasing our expertise and understanding in this area, we can promote greater innovation and help with continued development and progress.

1. Improvements of flame-retardant cable

The FR cable discussed in Chapter 2.2 is very important nowadays in the cable industry. Utilize modern, naturally fire-resistant insulation materials. In comparison to conventional PVC insulation, materials including cross-linked polyethylene (XLPE), silicone rubber, and mineral-insulated cables offer better fire performance.

Modern infrastructure must have fire-resistant cables to maintain functionality and safety in case of a fire. These specialist cables are a crucial option for critical applications where the continued transfer of power, data, or signals is paramount since they are designed to withstand intense temperatures and flames.

Advanced materials and creative design go hand in hand when making fire-resistant cables. These cables are typically covered with fire-resistant materials such as silicone rubber, mica tapes, ceramic, or mineral-based compounds. Even when exposed to extreme heat, these materials' excellent thermal insulation levels prevent the spread of fire.

The capacity of fire-resistant cables to keep their integrity and operate amid a fire is one of its essential characteristics. When exposed to flames, ordinary wires may melt or burn, causing short circuits or even electrical failures. Contrarily, fire-resistant cables are created to withstand the heat of the fire while maintaining their structural integrity, guaranteeing the continued operation of vital services like emergency lights, fire alarms, communication systems, and power distribution.

Numerous businesses use fire-resistant cables extensively. They are frequently utilized in business structures, manufacturing facilities, tunnels, airports, data centers, and crucial production procedures.

2. Economic factors and cost-effectiveness

Production of cables, which are vital components in a variety of industries, including telecommunications, energy transmission, manufacturing, and more, is heavily influenced by economic variables and cost-effectiveness. Complex factors that affect both the producer of the cables and the final consumers must be taken into account during the production process. Let's examine several important economic aspects and how they affect cable production.

The choice of raw materials, including conductors, insulation, shielding, and jackets, has a big impact on how much a cable costs to produce overall. Higher-quality materials may improve performance but also increase costs, so manufacturers frequently try to find a compromise between both. Innovations in material science can result in the creation of more affordable substitutes without sacrificing performance.

Manufacturers can obtain economies of scale by producing more cables because the production of cables is frequently capital-intensive. Fixed expenses can be distributed over more units when manufacturing volume rises, lowering unit costs. This theory accentuates the need for effective resource optimization and production planning.

3. Productivity and timeline improvements

Cable production must increase productivity and timeliness to increase effectiveness, cut costs, and satisfy the needs of an increasingly competitive market. Cable production must increase productivity and timeliness. Cable producers can use a variety of tactics and best practices to accomplish these aims.

By locating bottlenecks, duplications, and inefficiencies, the manufacturing process can be made more efficient. Review and improve the production flow on a regular basis to reduce waste and maximize resource use.

Utilize lean concepts like the 5S (Sort, set in order, Shine, Standardize, Sustain) and Kaizen (continuous improvement) to foster an efficient workplace culture where each employee actively participates in finding and removing waste.

Invest in cutting-edge equipment and automation technology to complete complicated procedures and repetitive activities faster and more correctly. This not only speeds up production but also lowers the possibility of mistakes.

Provide staff members with the chance to receive training and upskilling so they may improve their technical know-how. A trained staff is better able to perform jobs and contribute to quicker production cycles.

Overall, this study report is an invaluable resource for stakeholders, customers, and industry experts looking to improve cable production methods and satisfy the market's changing demands.

8.1 Conclusion

This research focused on the complex and multidimensional world of cables, illuminating their crucial function in contemporary technology and communication networks. The study has demonstrated the importance of cables across industries and sectors by a thorough investigation of various cable types, construction materials, transmission capacities, and applications.

According to the study, cables have evolved from simple copper wires to sophisticated fiber-optic networks, underscoring the constant quest for quicker data transmission, better signal quality, and higher economy. In a time when environmental responsibility and technological growth are inextricably connected, the exploration of the environmental impact and sustainability factors involved with cable manufacture and disposal has also highlighted the necessity for eco-conscious solutions.

The study has also revealed the mutually beneficial relationship between innovation and cables, showing how advancements in cable technology have continuously opened the door for game-changing innovations in industries like telecommunications, internet connectivity, power transfer, and more. The importance of changing cable infrastructure to meet the rising demands of a digitally linked world has also been highlighted in the report.

This research report is an important tool for experts in the field, decision-makers in government policy, researchers, and enthusiasts alike as we stand on the verge of additional technical advancements. It highlights the significance of ongoing research and development in cable design, production, and application, encouraging a future where dependable, high-speed, and environmentally friendly connectivity stays at the fore of technological advancement.

In essence, this research has shed light on the complex network of cables that supports contemporary civilization, and it is hoped that its findings will advance discussion and research in this important area of study.

8.2 Recommendations and Future Research

Based on the conclusion, some recommendations and future research discussions.

8.2.1 Recommendations

The outcomes of using Lean methods are noticeably superior to our initial predictions. The team is equipped to apply lean methods to additional machines due to its skills and the real-world knowledge learned through using the pilot machine. The team has seen the improved potential of lean methods according to the proof of concept. As a result, management must keep up with the program and assist the team as they apply lean principles in other parts of the production. Additionally, the following is advised:

- Assist the auditing system in adhering to the standards set out in the operations (AM & PM) meetings.
- Make extra time for training and clearly define the duties and responsibilities of the TPM team.
- Introduce top problem analysis and solutions as the first step in weekly OEE reporting.

8.2.2 Future research

The demand for effective and dependable cable infrastructure has increased substantially as technology continues to change the globe. From data centers and transportation to telecommunications and electricity transfer, cables are essential parts of many different sectors. Future issues, such as escalating data quantities, climate change, and the need for sustainability, however, will place additional demands on cable production methods. The sustainability, performance, and adaptability of cable production are highlighted in this report as prospective future research paths.

Recycled materials and sustainable materials:

To reduce the environmental effect, future cable production studies should examine the incorporation of sustainable materials. Lowering carbon footprints and reducing the exploitation of natural resources may be achieved by looking into environmentally acceptable substitutes for standard cable insulation, shielding, and conductor materials. Further supporting sustainability in the cable business will be the development of effective recycling procedures for end-of-life cables.

High data rate applications with improved performance:

Cables that can handle greater data speeds are needed to meet the rising demand for faster data transmission. In order to ensure low signal attenuation and little interference at ultra-high frequencies, future research should concentrate on creating unique cable designs and cutting-edge materials. This would make it possible for applications like 5G, data centers, and high-definition video streaming to use dependable data transfer.

Biodegradable cable:

Future studies should investigate the creation of biodegradable wires appropriate for transient applications as environmental concerns continue to rise. These cables might be used in situations when temporary infrastructure is needed, such as disaster relief operations and temporary installations, decreasing waste and the impact on the environment.

REFERENCES

[1] Utsho A Arefín. (2015). Analysis of Conductive Materials, Wires, and Cables for Using in a Commercial Complex.

[2] Haddi, A.; Imad, A.; Vega, G. Analysis of temperature and speed effects on the drawing stress for improvment.

[3] the wire drawing process. Mater. Des. 2011, 32, 4310–4315.

[4] Zhou, C., Yi, H., & Dong, X. (n.d.). Review of Recent Research towards Power Cable Life Cycle Management.

[5] Angalane, S. K., & Kasinathan, E. (2022). Influence of nanofiller concentration on polypropylene nanocomposites for high voltage cables. Journal of Electrical Engineering, 73(3), 174–181. https://doi.org/10.2478/jee-2022-0023

[6] Chen, X., & Ye, W. (2023). Analysis of Factors Affecting Strand Tension in Cable-Twisting Equipment and Method for Equilibrated Control. Applied Sciences (Switzerland), 13(8). https://doi.org/10.3390/app13084690

[7] Jack Shannon. (n.d.). Manufacturing Variance Analysis: How & Why to Run One.

[8] Paradise Cables Ltd. Technical catalog book. Design and R&D section (2021)

[9] Martinez, G. A. S., Qian, W. L., Kabayama, L. K., & Prisco, U. (2020). Effect of process parameters in copper-wire drawing. *Metals*, *10*(1). https://doi.org/10.3390/met10010105

[10] Fossey E, Harvey C, Mcdermott F, Davidson L. Understanding and Evaluating Qualitative Research. Australian & New Zealand Journal of Psychiatry. 2002;36(6):717-732. doi:10.1046/j.1440-1614.2002.01100.x

[11] Alamoudi, M., & Alamoudi, R. H. (2019). Implementing Lean Methodology in a Power Cable Factory: A Case Study of a Low Voltage Cable. *American Journal of Industrial and Business Management*, *09*(12), 2083–2097. https://doi.org/10.4236/ajibm.2019.912138

[12] Pritha Bhandari. (2020). What Is Qualitative Research? | Methods & Examples.

[13] Uma Sekaran Roger Bougie. (n.d.). Elements of research design.

[14] Rachaelle Lynn. (n.d.). Lean methodology https://www.planview.com/resources/articles/lean-methodology/

Appendices 1

1. What is your experience with the cable industry?

2. What types of cables are produced by your company, and what are the primary applications for these cables?

3. What are the key manufacturing processes involved in cable production, and how does your company ensure quality control throughout the process?

4. How does your company source raw materials for cable production, and what factors influence your selection of suppliers?

5. How does your company stay up to date with the latest technological advancements in cable production, and how do you incorporate new technologies into your manufacturing processes?

6. What are some of the biggest challenges that your company has faced in cable production, and how have you overcome these challenges?

7. How do you ensure that your cable products meet industry standards and regulations, and what steps do you take to maintain compliance?

8. What are your thoughts on the future of cable production, and how do you see this industry evolving in the coming years?