TALLINN UNIVERSITY OF TECHNOLOGY

SCHOOL OF ENGINEERING

Department Of Mechanical And Industrial Engineering

STRUCTURED TRAINING PLAN FOR SURFACE MOUNT ASSEMBLY OPERATORS

STRUKTUREERITUD KOOLITUSKAVA PINDMONTAAŠI OPERAATORITELE

MASTER THESIS

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Tallinn 2024

(*On the reverse side of title page*)

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Department Of Mechanical And Industrial Engineering

THESIS TASK

Student: Elis Aksli, 221933 (name, student code)

Study programme: MARM06/22 Industrial Engineering and Management (code and title)

Main speciality: industrial engineering and management

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Thesis topic:

(in English) *Structured training plan for surface mount assembly operators*

(in Estonian) Struktureeritud koolituskava pindmontaaši operaatoritele

Thesis main objectives:

1. Develop a structured training plan for Surface Mount Assembly operators to ensure consistent skill and knowledge acquisition, enhancing operators' confidence and independence.
2. Establish clear assessment criteria to evaluate the skills and knowledge of first-level operators, ensuring both the company and operators have confidence in their competence.
3. Create a support system within the training program to facilitate quicker adaptation and improved performance of new operators.

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Topic understanding, structure of thesis and planning of activities	11.02.24
2.	Detailed study and literature review about surface mount technology	31.03.24
3.	Choice of training environment	07.04.24
4.	Creation of training plan and materials	28.04.24
5.	Compiling the results and finalizing the thesis writing	18.05.24

Language: English **Deadline for submission of thesis:** 20.05.2024

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PREFACE

This Master’s thesis was initiated and primarily conducted at Comodule OÜ, where the author has the privilege of working. The author is deeply grateful to their employer for their understanding and support. The author would like to thank their team at Comodule OÜ for their inspiration and help throughout this journey. The author also wishes to express appreciation to their supervisor, Mart Saarna, senior lecturer, for his guidance and feedback.

The thesis focuses on developing a structured training plan for SMT (surface mount technology) assembly operators. The primary goal is to equip operators with the essential skills and knowledge required for their roles, enhancing their confidence and independence in executing their tasks. This structured training framework is vital not only for the personal and professional development of the operators but also for improving the operational efficiency and product quality.

Keywords: surface mount technology, training system, knowledge management, operator skills, master thesis

List of abbreviations and symbols

°C – degree Celsius

2D – two-dimensional

3D – three-dimensional

AOI – automated optical inspection

AXI – automated X-ray inspection

BGA – ball grid array

BTC – bottom termination component

CBL – case-based learning

CSP – chip-scale package

DIP – dual in-line package

ESD – electrostatic discharge

HoP – head-on-pillow, a solder joint defect where the solder paste deposit wets the pad, but does not fully wet the ball

IC – integrated circuits

IMC – intermetallic compound

IPC – institute for printed circuit

LMS – learning management system

MBB – moisture barrier bag

N2 – nitrogen

NOK – not okay

OP – operator

PCB – printed circuit board

PLCC – plastic leaded chip carrier

PLiF – personalised learning in focus

PnP – pick and place

PP – paste printer

PWB – printed wiring board

QFJ – quad flat J-leaded

QFN – quad-flat no-lead

QFP – quad flat package

RH – relative humidity

SMA – surface mount assembly

SMC – surface-mounted component

SMD – surface-mounted device

SMT – surface mount technology

SOIC – small outline integrated circuit

SOP – small outline package

SOT – small outline transistor

SPI – solder paste inspection

TAL – time above liquidus

TOL – time on label

TSOP – thin small outline package

1. INTRODUCTION

The quick advancements in technology and the increasing demand for high-quality electronic products have highlighted the importance of skilled surface mount technology (SMT) assembly operators in the electronics manufacturing industry. This thesis focuses on creating a structured training plan for SMT assembly operators, a topic that is highly relevant in today's fast-paced industrial landscape. The goal is to ensure that operators consistently acquire the necessary skills and knowledge, thereby boosting their confidence and independence in performing their tasks. This structured approach is crucial not only for the professional growth of the operators but also for the operational efficiency and product quality of the company.

The electronics manufacturing industry relies heavily on precision and reliability, making a well-structured training program crucial. At the company where this study took place, there was no formal training program for SMT (surface mount technology) operators. Instead, training was informally passed down by senior employees, leading to inconsistencies in the information provided to new operators. As a result, new operators often missed crucial information and struggled to complete tasks independently when faced with unfamiliar situations. The lack of structured training not only impacted the performance of new operators but also affected the overall productivity and quality of the manufacturing process.

In Estonia, there is a need for a structured training program for SMT operators. Companies that require SMT operators typically provide on-site training tailored to their specific machinery and operational needs. This localised training approach is advantageous as it allows for customisation according to the unique requirements of each company's equipment and processes. Therefore, a training program designed to meet the specific needs of the company can significantly enhance the effectiveness of the training and the performance of the operators.

The primary objectives of this thesis are:

1. Develop a standardised training plan for SMT assembly operators that ensures consistent and comprehensive skill and knowledge acquisition.
2. Establish clear assessment criteria to evaluate the competencies of first-level operators, fostering confidence in their abilities for both the operators and the company.

3. Create a support system within the training program to facilitate quicker adaptation and improved performance of new operators.

The main issue addressed in this thesis is the absence of a formalised training program within the company, leading to inconsistencies and inefficiencies in training new SMT operators. The aim of the thesis is to create a structured training plan to address this gap and provide a framework that can be adapted and implemented in similar situations.

The thesis explores surface mount technology (SMT) and the most appropriate educational strategies for adult learners. It starts with an overview of SMT, providing detailed information about the processes, technologies, and essential skills needed for proficient operation. Understanding how adults learn is crucial for designing effective training programs. Therefore, the thesis includes a review of adult learning theories and educational methods applied in this work. These methods include traditional classroom instruction and hands-on practical training.

The main part of the thesis provides an overview of the training program, highlighting the modules designed to cover essential SMT competencies. These modules are organised to provide a comprehensive understanding of SMT operations, from basic principles to advanced troubleshooting techniques. The thesis also discusses the forms and criteria of knowledge assessment meant to evaluate the operators' progress and proficiency. Various assessment methods, including quizzes, practical tests, and performance reviews, are detailed to ensure a well-rounded evaluation of the operators' skills and knowledge.

In conclusion, the main goal of this thesis is to address a critical training gap for SMT assembly operators by developing a well-organized and standardised training program. The proposed training plan aims to enhance overall operational efficiency and product quality in the electronics manufacturing industry by ensuring consistent skill development and providing support systems. This effort not only contributes to the company's expansion but also establishes a model for similar initiatives in other organisations and areas.

2. THEORETICAL BACKGROUND

The theoretical background includes an overview of SMT technology, its nature, technique, and requirements. Additionally, it contains an overview of how adults learn and the content of different learning methods that have been used for this work.

2.1 Surface mount technology

Surface mount technology (SMT) is a cutting-edge technique used in constructing electronic circuits. The method involves mounting Surface Mounted Components (SMCs) directly onto the surface of printed circuit boards (PCBs). This approach has become increasingly popular and has largely replaced the traditional through-hole technology, where components were fitted into holes on the circuit board using wire leads. Thanks to their smaller or absent leads, SMT components are typically more compact than their through-hole counterparts. They may feature short pins or leads of various styles, flat contacts, ball grid arrays (BGAs), or terminations on the body of the component. [1]

2.1.1 History of SMT

Surface mount technology (SMT) has a rich history and has evolved significantly over the years. It originated in the 1950s and found initial applications in military supplies before becoming associated with attaching ceramics to material surfaces. By the 1970s, the Japanese electronics industry capitalised on SMT to produce small, cost-effective portable electronic devices. This reliance on solder joints to secure components to boards resulted in the creation of smaller and lighter surface-mounted devices (SMDs). [1]

The early 1980s saw increased integration of integrated circuits (ICs), leading to more complex electronic circuits with over 100 leads and diminishing the demand for dual in-line package (DIP) ICs due to their larger size. Recent advancements in surface mount technologies and high-speed equipment have enabled the mass production of diverse components at a lower cost compared to traditional products. The evolution of mounting types spans several generations, each characterised by advancements in electronic component technology. Beginning in the 1950s with large high-voltage devices, the first generation transitioned to mobile product parts in the 1960s, and the subsequent generations introduced compact high-density devices and surface mount parts. [2]

Another significant advancement in SMT is attributed to hybrid technology, which gained popularity in the 1960s and continues to be widely used. Hybrid components integrate surface-mount devices within through-hole or surface-mount ceramic package bodies. Despite the differences in substrate sizes between hybrids and traditional SMT, the developmental work in hybrids has significantly contributed to the advancement and profitability of SMT. [1]

2.1.2 Types Of Surface Mounting

Surface mount technology (SMT) involves several assembly types, each with its own equipment requirements and process sequence. There are three primary SMT assemblies referred to as Type I, Type II, and Type III. These categories are determined by the arrangement and presence of through-hole and surface mount components on the assembly. [3]

Type I SMT assembly is a versatile method that utilises surface mount components, allowing for use in both single-sided and double-sided configurations. The process for Type I involves several steps, including screening solder paste, placing components, baking to remove volatiles from the solder paste, and reflow soldering. In the case of double-sided assemblies, this process is repeated for the opposite side. While Type I assemblies are relatively simple, they require precise handling to guarantee adequate component adhesion during reflow soldering. [3]

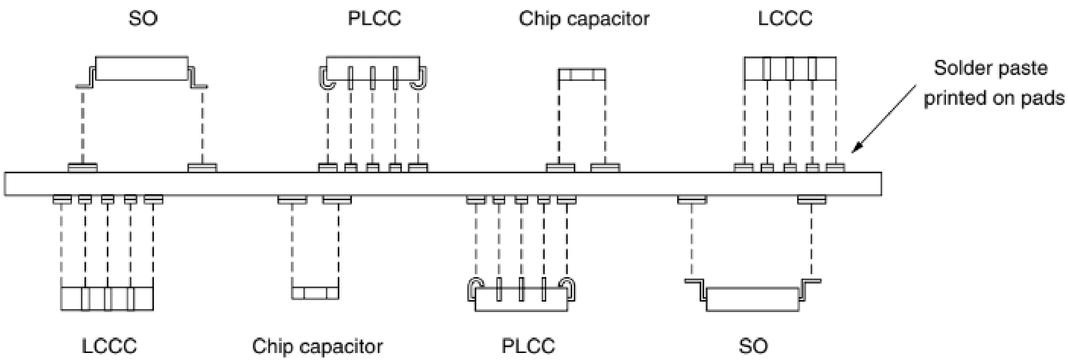


Figure 2.1 Schematic of type I surface mount boards [3]

Type III SMT assembly involves the use of through-hole components or a combination of through-hole and surface-mount components. The assembly process for Type III includes the automated insertion and clinching of through-hole components, application of adhesive, placement of surface mount components, curing of adhesive, and wave soldering. In cases where auto-insertion equipment is not utilised, the sequence is reversed, with adhesive being dispensed first, followed by the manual insertion of through-hole components. [3]

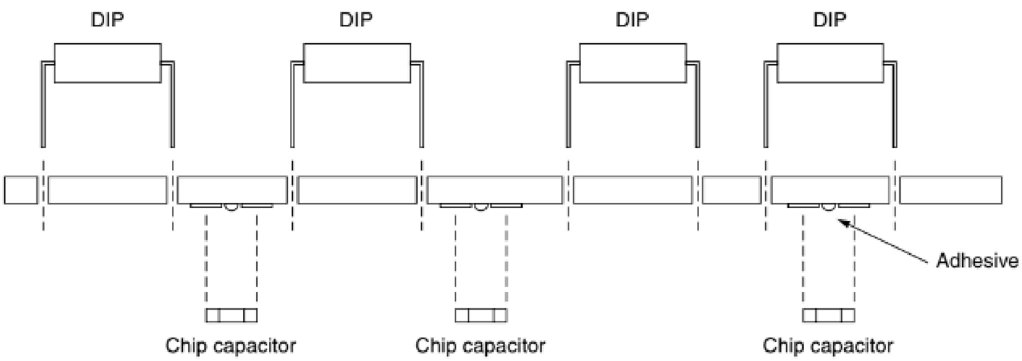


Figure 2.2 Schematic of type III surface mount boards [3]

Type II SMT assembly is a combination of Type I and Type III, encompassing both through-hole and surface mount components. This particular assembly undergoes a process that includes the necessary steps for both Type I and Type III assemblies. Nonetheless, depending on the design specifications, Type II assemblies may exclude the adhesive and surface mount components on the bottom side. [3]

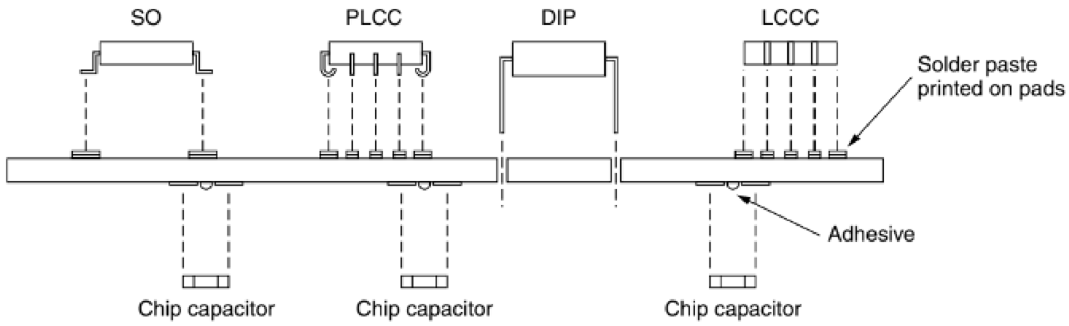


Figure 1.12 Schematic of type II surface mount boards

Figure 2.3 Schematic of type II surface mount boards [3]

2.1.3 Advantages of SMT

Surface mount technology offers numerous advantages over traditional through-hole techniques, such as significant reductions in weight and real estate, enhanced electrical noise reduction, and cost savings in manufacturing processes. SMT facilitates size reduction not only in component dimensions but also in the entire board layout, leading to optimised space, enhanced shock and vibration resistance, and improved overall performance. [1]

In addition to design-related benefits, SMT simplifies assembly processes, reduces the risk of damage during assembly and repair, and contributes to improved manufacturing yields and cost savings over the product lifecycle. Furthermore, it offers intangible advantages such as a quieter work environment, reduced warehouse space requirements, and lower shipping and handling costs, further enhancing cost efficiency. [1]

2.1.4 Challenges of SMT

Surface mount technology offers numerous advantages, but its adoption presents significant challenges at both external and internal levels. Externally, the infrastructure required for SMT implementation, including trained personnel, mature vendor bases, and industry standards, is still evolving. Developing this infrastructure demands collaboration across companies and organisations, with challenges ranging from a lack of experienced engineers to inadequate component standards. [1]

Technical challenges in SMT must be addressed before widespread implementation can occur. While the basic differences between SMT and through-hole technology seem simple, they create complex technical concerns impacting design and assembly processes. For instance, issues like component price, availability, and standardisation affect every aspect of SMT assembly. SMT also introduces design and manufacturing challenges, including solder joint reliability, thermal management, and interconnect design rules. Land pattern design, specific to SMT, is crucial for reliable solder joints and must be carefully considered. [1]

2.1.5 Process flow of SMT

The surface mount technology process flow varies depending on the type of assembly being manufactured. For Type III SMT assembly, the process begins with auto-inserting and clinching through-hole components. The adhesive is then applied to ensure proper fixation of surface mount components, followed by meticulous placement onto the substrate using pick-and-place machines. The adhesive is cured, and both leaded and surface mount components undergo wave soldering in a single operation. [1]

In the absence of autoinsertion equipment, the process sequence is altered. The adhesive is first dispensed, followed by the placement of surface mount components, allowing for manual insertion of through-hole components. The assembly then undergoes a series of rigorous steps, including wave soldering, cleaning, and testing. [1]

Surface mount technology assembly of Type I involves using only surface mount components. The initial step is to screen solder paste onto the substrate, followed by component placement. The assembly is then baked to remove volatiles from the solder paste, and reflow soldering is carried out to bond the components to the substrate. This is followed by solvent cleaning to remove any residue, and for double-sided Type I assemblies, the process is repeated on the opposite side. [1]

2.2 SMT Equipment

The distinctive equipment requirements for through-hole and surface mount assemblies underscore their fundamental differences. Through-hole processes require insertion, wave soldering, and solvent-based cleaning, while surface mount assemblies need specialised machines like component placement and adhesive curing ovens. Type I surface mount assemblies do not require through-hole equipment, while Type III only requires supplementary placement and curing equipment. Type II SMT, on the other hand, includes all equipment, showing its ability to handle through-hole, Type III, and Type I assembly processes. This indicates the unique equipment requirements for each assembly type in manufacturing. [1]

2.2.1 Solder paste printer

The application of solder paste is a crucial step in surface mount assembly, requiring exact deposition to achieve optimal soldering results. Although screen-printing through a stencil remains the primary method, other techniques, such as jet printing, are also employed. Despite the shift to lead-free processes, the printing methods for solder paste have not undergone significant changes, as the same equipment and stencil design guidelines remain applicable. Nonetheless, careful management of factors, including PCB support, squeegee parameters, stencil characteristics, and solder paste composition, is essential to minimise the likelihood of assembly defects. [4]

Effective surface mount assembly processes rely on the careful selection of a screen printer that meets the necessary performance expectations for a given application. There are two main categories of solder paste screen printers available today - laboratory/prototype and production models - each with unique performance characteristics. Depending on the specific requirements of a given application, factors such as mechanical rigidity, registration method, squeegee velocity, and pressure control are all critical to achieving consistent print quality. When selecting a screen printer, it's important to consider variables such as substrate size, maximum boards processed per hour, and print mode to ensure compatibility with production demands. [1]

It is important to ensure proper PCB support during screen-printing to maintain flatness and prevent solder defects such as bridging or insufficient solder. For fine-pitch printing that involves miniature components, dedicated fixtures or vacuum support may be necessary. The squeegee type, pressure, and speed all play critical roles in the screen-printing process. Adjustments are often required to achieve optimal paste deposition. During the initial stages of lead-free conversion, a slower printing speed was common due to the stickier nature of lead-free solder paste. However, modern lead-free pastes often perform well at higher speeds, indicating the constantly evolving dynamics of the process. [4]

The stencil's material, thickness, and aperture size are key factors that heavily influence paste deposition. A wide range of metal stencils, including copper, nickel, bronze, and stainless steel, are used, each with various fabrication techniques. For high-density and fine-pitch components, thinner stencils are preferred, while thicker stencils may be necessary for greater paste volume. Aspect and area ratios are also critical to efficient printing, ensuring proper paste release and deposition onto the pads. [4]

The speed of snap-off and stencil separation can have a great impact on the quality of printed material. To prevent problems like clogging or tailing, it's important to carefully control these factors. Additionally, selecting and handling the right type of solder paste is crucial, taking into account factors such as aperture size and particle size within the paste. Proper storage and handling are also critical to maintain the quality and shelf life of the paste. Manufacturers' recommendations should be followed for these processes. In summary, paying meticulous attention to these factors is vital for achieving effective solder paste printing and enhancing the reliability of surface mount assembly processes. [4]

2.2.2 Pick-and-place

Once the solder paste has been applied with precision, the component placement process commences. It involves meticulous positioning of components on the PCB according to schematics. This multi-step process includes board loading, registration, fiducial vision alignment, component pick-up, inspection, and alignment. Pick and place machines are used to ensure component accuracy and alignment. These machines come in different types, some designed for speed, commonly referred to as "chip shooters," which can place up to 100 000 components per hour. Meanwhile, flexible pick and place machines accommodate a wide range of component sizes, from small chips to larger components like ball grid arrays (BGAs) and connectors, albeit at a slower speed. The appropriate machine selection depends on factors like the component types, sizes, and production volumes, with all machines capable of handling both tin-lead and lead-free components. [4]

The pick and place process involves the use of automated placement machines to carefully position components onto the deposited solder paste. These machines utilise vacuum nozzles to retrieve components from storage, such as paper tapes or plastic trays, and then analyse their location and orientation. Based on this analysis, the machines make adjustments to the positional and rotational offsets to ensure that the components are accurately placed in the designated locations. There are two types of placement machines: pick&place and collect&place heads. Pick&place heads handle components individually, picking up one at a time and placing it accordingly, whereas collect&place heads gather multiple components (usually 4, 8-32) before placing them in their respective positions. While collect&place machines offer higher speeds and are capable of placing several tens of thousands of components per hour, they may exhibit larger positional errors or offsets, reaching up to 20-40 μm, compared to pick&place machines. [5]

The pick-and-place machine is an essential tool in manufacturing, providing reliable and accurate component positioning to meet throughput demands cost-effectively. Typically, 50% of the total capital investment in a medium-volume surface mount manufacturing line, like Type I SMT, is allocated to surface mount pick-and-place equipment. This equipment's importance stems from its ability to precisely place components on PCBs, ensuring efficiency and accuracy throughout the assembly process. As a critical component of the manufacturing line, the pick-and-place machine plays a crucial role in achieving production targets and maintaining quality standards for surface mount technology manufacturing. [1]

To ensure precise placement and optimal productivity, it's crucial to take multiple factors into account. These include selecting the right nozzle for each component, ensuring the vision system is efficient, providing adequate PCB support, accommodating various component sizes and packaging, and ensuring feeder capacity is sufficient. Nozzles are particularly important in achieving accuracy and consistency, and different types are available, often using vacuum technology to hold components securely. Components with non-flat surfaces may require specialised handling, such as gripper nozzles, but this can result in slower placement and wider spacing between components. [4]

The inspection process plays a critical role in ensuring the accuracy of components and detecting any damage before installation. By programming tolerance parameters, the machine is capable of differentiating between correct and incorrect parts, thereby leading to precise assembly. In the case of designs with high component density, it is crucial to provide proper PCB support during placement to prevent misalignment or missing components. To minimise the risk of disturbance and misalignment during assembly, smaller components should be placed before larger ones. This approach can significantly improve the quality of the assembly process. [4]

Various packaging formats are available for surface mount components, such as tape and reel, tubes, and trays. Each format requires a compatible feeder system to ensure efficient delivery to the pick-up mechanism. Tape and reel feeders are often used for small components in large quantities, while matrix tray feeders are more suitable for larger or more expensive components like BGAs or QFN/BTCs. They offer secure component storage without risking damage. However, tray feeding may result in slower pick and place operations compared to tape feeders due to their design differences. [4]

2.2.3 Reflow and wave soldering

Electronic assembly relies on two techniques, wave and reflow soldering, each with unique characteristics and applications. Wave soldering, a revolutionary method introduced in the 1950s, is perfect for mass soldering of through-hole components, utilising a wave of molten solder for both heat supply and application. This process is highly effective for high-volume production. In contrast, reflow soldering, popularised in the 1970s, is ideal for surface mount technology. It involves adding solder paste to component pads before heating the assembly to melt the solder. This method operates at lower temperatures for a longer duration, making it safer for delicate surface mount components. [1]

To achieve optimal results when wave soldering with lead-free solder, it is important to make specific adjustments. This includes maintaining a higher solder pot temperature within the range of 255 to 270°C and carefully optimising flux application methods, amounts, and preheating parameters based on each flux type. Longer preheating times may be necessary to prevent thermal shock, especially for delicate ceramic components like ceramic chip capacitors. The goal is to minimise the temperature difference between preheating and peak temperatures to below 100°C (180°F). Dual wave soldering, which is already well-established for tin-lead soldering, is also a viable technique for lead-free soldering. Inert atmospheres such as nitrogen (N2) can be added to improve soldering quality and yield by reducing issues like bridging and improving wetting and hole filling. While dross formation with SAC and tin-lead solders is comparable under similar conditions, tin-copper solder tends to create significantly more dross. The use of nitrogen (N2) can help mitigate dross formation in lead-free soldering, just as it does in tin-lead soldering processes. [5]

The process of reflow soldering is a critical step in electronic assembly. During this stage, components are passed through an oven, where the solder paste is heated until it liquefies, allowing the solder alloy to reflow. This can be accomplished using a variety of techniques, including infrared radiation, forced convection, or vapour phase soldering. As the solder reaches its molten state, it adheres to the metalised terminals, creating solder joints that secure the components to the printed wiring board (PWB) in a fillet shape. As the assembly cools, the solder solidifies, establishing both mechanical and electrical connections between the components and the PWB. The success of the soldering process is contingent upon factors such as the rheological properties of the solder paste, the precision of stencil printing, and the intricate physical phenomena that occur during the reflow phase as the solder alloy transitions to a molten state. [6]

The process of reflow soldering is critical in the assembly of electronics and requires careful management of temperature profiles to guarantee quality and reliability. The reflow soldering profile is represented as a temperature curve throughout the duration of the soldering process and has a significant impact on the formation of intermetallic compounds (IMCs) and solder defects. Two main types of profiles exist: the linear profile, which has a delta shape, and the soak profile, which resembles a trapezoid. The soak profile includes several phases, such as ramp, soak, reflow, and cooling, and is meticulously designed to activate flux, ensure even temperature distribution, and encourage optimal peak temperatures for solder reflow. This process results in proper alloy melting and joint formation. [6]

To produce high-quality electronic assemblies, it is essential to calibrate an array of parameters within the reflow profile. If ramp rates are inadequate, solder paste may slump or flux may boil, resulting in solder bridges or short circuits. Improper soak durations can also lead to insufficient flux activation, causing oxidation and poor solder wetting. Careful control of peak temperatures is necessary to prevent cold joints or component damage, while optimal time above liquidus (TAL) ensures proper joint formation without excessive oxidation. Cooling rates post-reflow also significantly affect joint structure and reliability, highlighting the multifaceted considerations inherent in reflow soldering profiles. [6]

2.2.4 Inspection equipment

Ensuring the quality and reliability of PCB solder joints is crucial, as many defects can arise from the solder paste printing process. In the past, manual inspection methods mainly focused on monitoring solder paste height. However, as the correlation between paste volume and joint quality became more apparent, more comprehensive inspection techniques became necessary. As a result, automated solder paste inspection systems were developed to allow manufacturers to closely monitor paste alignment and volume during printing. These systems utilise either 2D or 3D inspection methods, with 3D Solder Paste Inspection (SPI) becoming a popular approach due to its ability to accurately measure both paste height and total volume. This method provides precise control over the printing process and enables early detection of defects. [4]

To ensure the quality and reliability of the overall assembly, it is essential to conduct a thorough examination of the solder joints in addition to solder paste inspection. Visual inspection methods are commonly used to assess visible joints, aided by human observation or optical devices such as magnifying glasses or microscopes. However, for concealed joints lying beneath components like BGA or BTC components, X-ray inspection is necessary to identify potential defects. In manufacturing environments, automated optical inspection (AOI) and automated X-ray inspection (AXI) systems are frequently deployed to examine carefully solder joint quality and detect various anomalies, including misalignments, missing components, or solder bridging. [4]

Automated Optical Inspection (AOI) systems are a critical component of the surface-mount technology (SMT) process. These systems can identify various quality defects and failures, such as component misplacements and soldering irregularities. AOI systems use camera and machine vision technologies to capture images of the board surface, which are then processed and compared with known standards to detect any deviations and generate reports. On the other hand, X-ray inspection, notably automated X-ray inspection (AXI), is essential for inspecting hidden solder joints beneath components such as BGA or CSP, where visual inspection is impractical. X-ray inspection can identify defects such as voids or head-on-pillow (HoP), and it also ensures a thorough assessment of solder joint integrity in multiple surface finishes. Overall, X-ray inspection contributes to enhancing the quality and reliability of the assembly. [4]

2.3 SMT environment

In surface mount technology (SMT) assembly, temperature and humidity are crucial factors in ensuring the integrity of the manufacturing process and the quality of the final products. IPC standards provide guidelines and standards for maintaining appropriate conditions in SMT assembly areas to prevent electrostatic discharge (ESD) damage and ensure optimal soldering and assembly performance. IPC J-STD-001E-2010 outlines the significance of humidity in SMT assembly, highlighting that when humidity levels drop below 30%, the risk of electrostatic discharge increases, potentially jeopardising the integrity of electronic components. Maintaining a temperature range between 18°C and 30°C for operator comfort and to sustain solderability is recommended, while relative humidity should not exceed 70% to prevent moisture-related issues and ensure optimal process performance. [7]

According to IPC-A-610G, effective prevention of ESD damage involves a combination of static charge prevention and elimination. Static charges can originate from various sources present in SMT assembly environments, such as friction between materials or human activities. Insulating materials, like plastic bags or Styrofoam containers, are particularly problematic as they can concentrate static energy and lead to ESD damage if brought into processing areas. For instance, peeling adhesive tape or using compressed air nozzles over insulating surfaces can generate significant static charges, posing a risk to electronic components. The impact of humidity on static voltage generation further emphasises the importance of controlling environmental conditions in SMT assembly areas. At lower humidity levels (10-20%), activities like walking on carpet or using plastic bags can generate substantially higher static voltages compared to conditions with higher humidity (65-90%). These differences underscore the need for stringent humidity control measures to mitigate the risk of ESD damage in SMT assembly environments. [8]

The machines used in the factory have manuals that specify the ideal operating conditions. For instance, the Desen Navigator paste printer manual suggests that the temperature should be maintained at 23±5°C, and the humidity level should remain between 20% and 95% [9]. On the other hand, the AOI NVI-G300 Standard Specification states that the temperature of use must be between 10 - 35°C and the humidity between 35% and 95% [10]. Finally, the Reflow operating manual recommends that the temperature of the operating environment be between 5-40°C and that the humidity be between 20% and 95% [11].

In conclusion, maintaining precise temperature and humidity levels is essential in surface mount technology (SMT) assembly, serving as a critical factor in preventing electrostatic discharge (ESD) damage, ensuring the proper functionality of soldering and assembly materials, and preserving operator comfort. Adhering to established industry standards and implementing robust ESD protection measures are pivotal in safeguarding the quality and reliability of electronic products. Therefore, for optimal performance and minimal risk, an SMT assembly room should maintain a temperature range of 18°C to 28°C and a relative humidity range of 35% to 70%. These controlled environmental conditions not only enhance the efficiency of the assembly process but also contribute significantly to the overall integrity of electronic components and assemblies.

2.4 Surface mount components and materials

Surface mount components (SMCs) are a significant advancement in electronic packaging technology. They offer higher packaging density and improved electrical performance compared to traditional through-hole components. While the design and electrical function of internal devices remain unchanged, the packaging of surface mount devices (SMDs) is crucial for optimising board space and enhancing assembly efficiency. SMDs not only reduce parasitic losses like capacitance and inductance but also provide additional functionalities such as environmental protection, heat dissipation, communication links, and handling capabilities. Despite challenges related to component availability, cost, and standardisation, the surface mount technology (SMT) industry is continuously evolving due to user demand and advancements in package configurations. In this chapter, we explore the diverse landscape of commonly used passive and active surface mount components, as well as considerations for packaging, shipping, handling, and procurement specifications, reflecting the dynamic nature of SMT in modern electronics manufacturing. [1]

2.4.1 SMC packages

Melfs and chips are two types of SMD components. Melfs are cylindrical with solderable design and metal endcaps, while chips have small square bodies with metallised endfaces. Resistors and capacitors provide mounting flexibility. In 1990, resistors dominated passive SMD usage globally. Chips and melfs are distinguished by sizing conventions, reflecting advancements in miniaturisation. The trend in miniaturisation has posed challenges for automatic component placement equipment manufacturers. [12]

Small Outline Package (SOP) components, such as Small Outline Transistors (SOTs), Small Outline Integrated Circuits (SOICs), and Plastic Leaded Chip Carriers (PLCCs), are crucial in nonmilitary electronic applications due to their cost-effectiveness and reliable interconnection. However, plastic packages, while preferred for commercial electronics, have challenges such as susceptibility to moisture-induced cracking during reflow soldering. Factors such as plastic thickness, moisture content, and die size must be carefully considered to ensure reliability. [1]

Quad Flat Package (QFP) and Quad Flat J-leaded (QFJ), also known as Plastic Leaded Chip Carriers (PLCC), are essential components in modern electronics manufacturing, offering versatility and reliability in various applications. These packages feature gull-wing leads on all four sides, providing high pin density and accommodating complex, high lead-count chips. They are commonly used in commercial, industrial, and military electronics due to their compact form factor and high-density packaging capabilities. Additionally, they are often used in memory card applications alongside Thin Small Outline Packages (TSOP), highlighting their importance in memory storage technology. These components adhere to stringent standards outlined in the IPC-SM-782 standard, ensuring uniformity and reliability across manufacturing processes. [13]

Ball Grid Array (BGA) components are a high-density interconnection solution for modern electronics. They feature square or rectangular package configurations and diverse mounting structures for attaching the die. BGA components may employ flip-chip or wire bond technologies for signal routing, ensuring efficient connectivity. They are widely used in various applications due to their compact form factor and high-density packaging capabilities, enabling advanced electronic devices with enhanced performance and reliability. [13]

2.4.2 Soldering paste

Soldering paste plays a crucial role in reflow soldering processes, particularly in mounting electronic components onto a PCB. It is made up of a mixture of flux and solder powder, which serves as an adhesive medium to bond electronic components securely to the board. The flux in the paste is made up of a combination of solvents, agents, and rosin resin, which ensures optimal adhesion and flow during the soldering process. It is worth noting that recent trends in electronics manufacturing have shifted towards lead-free solder powders, indicating a commitment to environmental sustainability. [14]

To achieve the best printing quality on printed circuit boards (PCBs), it is crucial to ensure that the right conditions are met when using soldering paste. The way in which the paste is stored and handled is crucial since it can cause detrimental changes in viscosity over time due to reactions between the solder powder and the activator. These changes can lead to issues such as a "skinned surface" or loss of viscosity, which can result in poor wetting and joint failures during the reflow process. To prevent such quality degradation, it is essential to maintain stable storage conditions and carefully monitor viscosity transitions. [14]

Achieving effective soldering paste during the printing process depends critically on temperature control. Research studies have revealed that temperature variations have a significant impact on the filling areas and viscosity of solder paste. Higher temperatures result in decreased viscosity and poor wetting, which can be further worsened by the oxidation of solder alloys at excessive temperatures. Extensive experimentation and analysis have conclusively determined that the optimal temperature range for solder paste during SMT printing is between 23°C and 33°C. Within this temperature range, viscosity remains consistent, and wetting is maximised. It is crucial to maintain strict temperature control in manufacturing environments to uphold printing quality and prevent the degradation of solder paste performance. [15]

2.4.3 Moisture-sensitive components

Moisture sensitivity is a significant challenge in microelectronic packages. It often results in various failure mechanisms, such as "popcorn failure," which causes pressure within the package and leads to delamination. Another problem is the long-term reliability of electronic packages during their service life. Moisture can facilitate electrochemical migration, resulting in anode-cathode short failures. These diverse failure mechanisms underscore the critical importance of moisture management strategies in preserving the reliability and functionality of microelectronic packages. [16]

The lifespan of Surface Mount Devices (SMDs) on the floor is affected by the surrounding environmental conditions. According to Table 2.1, when the temperature exceeds 30°C/60% RH, the lifespan of these SMDs will be shortened. If only a part of the SMDs is used, it's crucial to reseal or store the remaining packages safely within an hour of opening the bag. This step is necessary to avoid moisture absorption. If these guidelines are not followed, it may be necessary to refer to the table specified in the IPC J-STD-033D standard to determine the maximum allowable time before rebake is required. [17]

Table 2.1 Moisture Classification Level (MSL) and Floor Life per J-STD-020 [18]

Level	Floor life
MSL 1	Floor Life (out of bag) is Unlimited
Other MSLs	Floor Life (out of bag) at factory ambient ≤ 30 oC/60% RH
2	1 year
2a	4 weeks
3	168 hours
4	72 hours
5	48 hours
5a	24 hours
6	Mandatory bake before use. After bake, it must be reflowed within the time limit specified on the label (TOL - Time on label)

Safe storage practices are important for keeping moisture-sensitive components in good condition, particularly SMD packages, which are classified from Level 2 through

5a. These packages need to be stored in controlled humidity conditions to maintain their floor-life clock at zero. Intact moisture barrier bags (MBBs) can be used for storage, as well as dry atmosphere cabinets maintained at specific relative humidity levels that do not exceed 10% RH or 5% RH. [17]

It is crucial to follow proper drying procedures when handling moisture-sensitive components to ensure they last longer. The drying methods to be used depend on the level of sensitivity to moisture and the exposure to ambient humidity. Industry tables provide specific conditions for different drying options. For example, SMD packages in MBBs can be dried and sealed with fresh desiccant to reset their shelf life. It is also important for suppliers and distributors to communicate with each other to convey information about the maximum allowable storage time for products before rebaking becomes necessary. It highlights the significance of adhering to standardised handling protocols to prevent moisture-induced failures in sensitive components. [17]

2.5 Learning methods

Learning is a transformative process by which organisms adapt to their environment. In humans, this innate capacity for learning is genetically encoded, enabling rapid assimilation of information and response to changing conditions. Through generations, individuals with heightened adaptability passed on their learning abilities, driving human evolution. Today, humans stand as unparalleled learning organisms, excelling in the ability to absorb, process, and apply knowledge. Our evolutionary success hinges on this remarkable trait, shaping our survival and advancement as a species. [19]

Adult learning is driven by intrinsic motivation, which typically comes from personal desires or practical needs. Unlike children, whose learning is often guided by external sources such as teachers or curriculum, adults tend to seek out knowledge because they want to or have to. Traditional teaching methods, rooted in didactic models focused on content delivery, have long dominated education. However, contemporary understanding suggests that effective adult learning requires a departure from this passive instructional style. Instead, trainers must recognise the importance of learner autonomy, engaging adults as active participants in their own learning journey. By acknowledging and harnessing the intrinsic motivations of adults, trainers can foster more meaningful and effective learning experiences. [20]

2.5.1 70-20-10 learning framework

The 70-20-10 learning framework was developed by McCall Jr. in 1988. This framework proposes that there are three primary ways to develop professional skills: experiential, social, and formal learning. According to this approach, 70% of learning occurs through challenging work experiences, 20% through interactions with peers and senior managers, and the remaining 10% through formal training programs. The framework aims to promote comprehensive capability development by incorporating different forms of learning. It emphasises the importance of aligning learning with real-world tasks to facilitate effective skill transfer. [21]

Trainers and talent development professionals can gain valuable insights into crafting effective learning strategies by understanding the 70-20-10 framework. While formal training sessions make up only 10% of the learning process, they are crucial for introducing new concepts and ideas. However, equal attention must be given to social learning, which relies on peer collaboration, mentoring relationships, and feedback mechanisms. Additionally, prioritising on-the-job assignments, where employees can apply their skills in real-world scenarios, enhances their competence and confidence, ultimately driving organisational performance. [20]

As the landscape of work evolves, incorporating the principles of the 70-20-10 framework becomes increasingly essential. By embracing a holistic approach to learning and development, organisations can empower employees to thrive in an ever-changing environment. By recognising the interconnectivity of formal training, social interactions, and on-the-job experiences, trainers can foster a culture of continuous learning, ensuring that individual development contributes to organisational success. [20]

2.5.2 Case Based Learning (CBL)

Case-based learning (CBL) has been shown to effectively encourage critical reflection and develop students' learning capabilities. According to research by Williams, it has the potential to boost self-motivation, encourage group collaboration, and promote independent learning [22]. Additionally, a study by Li, Ye and Chen suggests that students involved in CBL experienced significantly improved exam results [23]. CBL operates within a constructivist-oriented learning framework, involving students in selecting and modifying information, forming ideas, and making decisions based on their existing knowledge, thereby facilitating the development of personalised understanding. [24]

CBL involves several stages. It starts with presenting students with real-life cases related to the material to be studied, which stimulates active thinking and interest. The next stage involves analysing the problem in groups, identifying important information and core problems in the cases presented. Students then gather information, make plans for completion, and draw conclusions. This process trains them to integrate the information and skills they have learned to achieve a deeper understanding of a problem. [24]

The main goal of the study was to evaluate the impact of CBL on students' problem-solving abilities related to buffer solutions. The results show a significant increase in the average scores of students from the pretest to the posttest, indicating that CBL effectively improves students' problem-solving skills in this area. This is consistent with previous research, which has also shown the effectiveness of CBL in enhancing students' problem-solving abilities [25]. These findings suggest that CBL holds great promise for improving students' problem-solving skills. [24]

2.5.3 Personalized Learning Interaction Framework (PLiF)

The Personalized Learning Interaction Framework (PLiF) emphasises the learner-driven nature of personalised learning. Experts have identified key themes such as flexible resource utilisation, competency mapping, assessment, community involvement, and mentorship. These findings closely align with the principles of andragogy, which focuses on adult education. Andragogy asserts that adults should be involved in planning and evaluating their instruction, learning from their experiences, focusing on immediately relevant subjects, and engaging in problem-centred learning rather than content-oriented approaches. [26]

The research shows that personalised learning effectively addresses these principles, promoting learner agency and self-sustaining interactions to support ongoing learning and development. It encourages learners to define expectations, determine assessment methods, formulate their learning plans, and tackle meaningful projects, all of which are central tenets of andragogy. However, it is acknowledged that tensions may arise between the efficiency and return on investment of training programs and the imperative to maintain learner agency and relevance, particularly in industry or higher education settings. [26]

The personalised learning approach emphasises the importance of learner agency and relevance in the learning process. It aligns adult learning principles with personalised learning aims, tailoring the learning experience to the diverse backgrounds, experiences, and learning styles of adult learners. This empowers them to take ownership of their educational journey. The PLiF (Personalized Learning in Focus) research provides a robust framework for effectively engaging and empowering adult learners. The framework advocates for a learner-centered approach that fosters a sense of ownership and autonomy in the learning process, encourages active participation and self-directed learning, and acknowledges the unique needs, motivations, and prior experiences of adult learners. The goal is to create an inclusive and supportive learning environment conducive to ongoing learning and development, ultimately promoting a more impactful and adaptive learning experience for adult learners. [26]

2.3.4 Knowledge testing

The process of testing and examination plays a crucial role in the learning process. It serves as a natural checkpoint to confirm performance objectives and provide corrective feedback. Successful learners experience intrinsic rewards, leading to feelings of competence and confidence in their abilities. This sense of accomplishment not only enhances the probability of reusing knowledge on the job but also positively impacts the learner's overall perception of the learning experience. However, viewing testing as threatening can lead to increased anxiety and hinder the learning process. It is essential to see testing as an opportunity to verify learning rather than an examination of personal worth. [19]

Assessing adult learning encompasses various types of assessments, each serving distinct purposes and posing unique challenges. Formative assessments, which occur throughout a course, allow instructors to gauge and improve students' learning by providing regular feedback through exams, quizzes, or written assignments. These assessments not only enable educators to adjust their teaching methods and course content but also help reduce learners' anxiety and identify areas where additional support may be needed. In contrast, summative assessments, conducted at the end of a learning unit, evaluate a learner's overall understanding of the material. Examples include final examinations. [27]

Authentic assessment is a powerful method that requires students to apply their acquired knowledge and skills to real-world tasks. This mirrors the challenges they may face as adult citizens or professionals. By engaging students in meaningful tasks such as community service, internships, demonstrations, and portfolios, authentic assessment not only motivates students but also provides instructors with valuable insights into students' capabilities. [28]

In contrast, traditional testing, which is commonly used in both classroom and adult education settings, includes various forms such as diagnostic tests, pre-test and post-test comparisons, and summative assessments. These tests, which can range from multiple-choice to essay questions, are designed to measure students' knowledge, skills, and performance. Developing open-ended questions requires detailed answer keys, and by emphasising analysis and critical thinking in test responses, the quality of assessment can be enhanced. It is important for instructors to differentiate between criterion-referenced and norm-referenced testing. Criterion-referenced testing is closely aligned with learning outcomes or objectives, while norm-referenced testing is primarily used to classify students based on their achievement levels. [28]

The purpose of the diagnostic assessments carried out at the beginning of the course is to identify learning problems, areas that need development, and learners' suitability. They enable instructors to recommend early interventions or support services to enhance learners' success. Additionally, assessments can be classified as traditional, alternative, and performance-based, each measuring learning at different cognitive or psychomotor levels. Assessments can also be categorised based on learning style, with teacher-directed formats focusing on lower-level cognitive skills, while self-directed formats allow learners to determine their evidence of learning and its evaluation. [27]

Both authentic assessment and traditional testing are important for evaluating student learning and performance. Authentic assessment encourages the application of knowledge and skills in real-world scenarios, while traditional testing provides a structured approach to measure student progress and achievement. Understanding the strengths and limitations of each assessment method enables educators to create a balanced and effective evaluation system that supports student learning and development. [28]

3. MAIN PART

The SMA Operator Level 1 training program integrates the 70-20-10, personalised learning and Case-Based Learning (CBL) frameworks to increase learning outcomes. It emphasises practical, on-the-job experiences over traditional classroom instruction. The program provides a comprehensive overview of the organisation's machinery, operational processes, and work environment, with a focus on company-specific examples to ensure relevance to the learners' roles. Additionally, the addition of CBL principles enhances the program by offering materials and assessments designed to improve operators' problem-solving abilities. These materials are based on real work situations and examples within the company, allowing learners to directly apply theoretical knowledge to practical challenges they may encounter.

3.1 Choice of training environment

After conducting research, four different environments have been identified that can serve as comparable training environments. These four environments are ProProfs Training, Sakai LMS, Google Classroom, and 360Learning.
ProProfs Training is a comprehensive platform that offers a wide range of features like course creation, assessments, reporting, and integration with other tools. It is suitable for organisations that need a versatile platform that can cater to their diverse training needs. [29]

Sakai LMS is an open-source learning management system that is designed for educational institutions. It offers features like content management, collaboration tools, and assessment capabilities. This platform is suitable for organisations that prefer open-source solutions and need a platform that can cater to the needs of an academic environment.[30]

Google Classroom is an intuitive and straightforward platform that provides educators with an easy-to-use interface to create and manage classes, distribute assignments, and provide feedback to students. It integrates seamlessly with other Google services, such as Google Drive and Google Docs. This platform is ideal for organisations that are already using other Google services and want to have a consistent experience across their tools. [31]

360Learning is a collaborative learning platform that provides social learning tools, collaborative learning features, and analytics for tracking learner progress. This platform is suitable for organisations that prioritise collaboration and social learning in their training programs. [32]

Google Classroom stands out for its user-friendly interface and tight integration with other Google services. It is designed to be intuitive for both educators and students, making it easy to use even for those who are not tech-savvy. Furthermore, Google Classroom is often provided for free as part of Google's suite of education tools, making it a cost-effective option for organisations of all sizes.

Google Classroom is highly scalable and can accommodate classes of various sizes, making it suitable for both small classrooms and large educational institutions. It also benefits from Google's extensive support resources and a large user community, making it easy to find help and resources online.

Taking all these factors into account, Google Classroom appears to be the optimal choice, especially for organisations that already use other Google services. Its ease of use, seamless integration, cost-effectiveness, scalability, and a strong support community make it a strong contender for managing training and educational activities.

3.2 Structure of the training

The goal is to standardise the training period for all trainees. In the past, operators took varying amounts of time to learn their work, with some taking a month and others taking six months. This depended on their individual confidence, access to information, and opportunity to practice. The aim of the new training program is to boost operators' confidence and knowledge, leading to quicker independence. This will be achieved through a structured training program, regular access to materials, and tests to confirm learning, giving operators confidence in their knowledge.

Each operator will be assigned a supervisor for support, fostering a sense of belonging and aiding in quicker integration. The focus is on need-based learning, meaning the operators themselves are motivated to complete the training program. The curriculum encompasses theoretical learning, job shadowing as working side-by-side with a supervisor, on the job practice, and case-based learning to learn about different situations and improve problem-solving skills (see Figure 3.2). The estimated volume of the training program is 320 hours, the training schedule is shown on Figure 3.1.

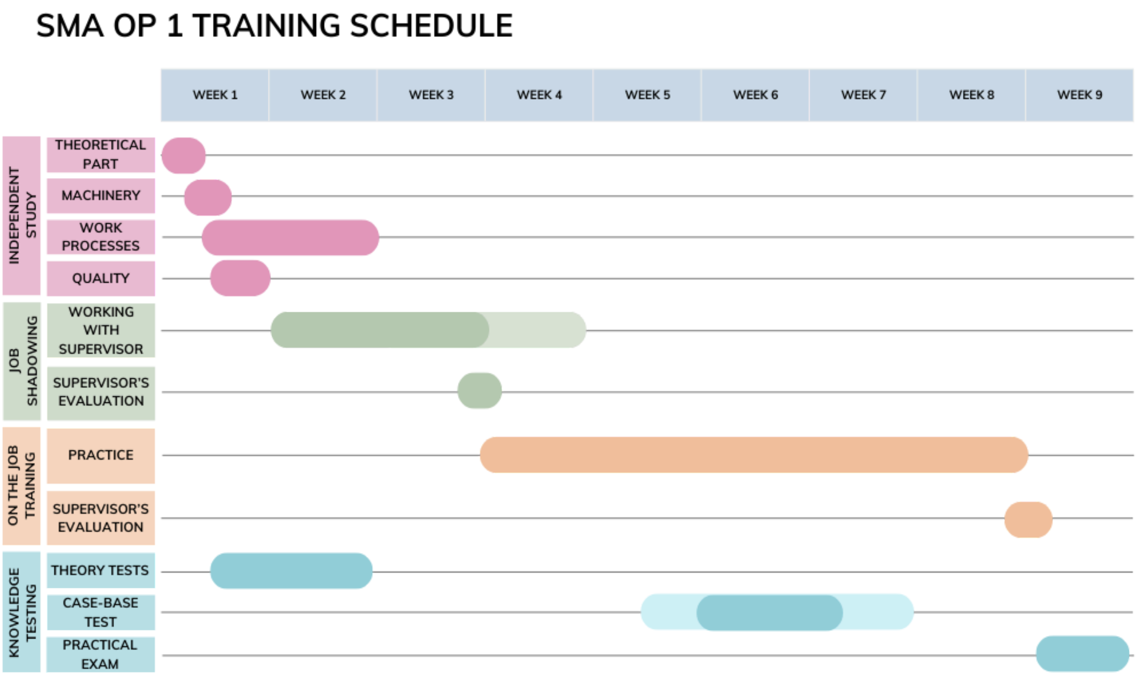


Figure 3.1 SMA operator level 1 training schedule

3.2.1 Independent study

The independent study module is designed to allow operators to engage with learning materials at their own pace, ensuring they gain a comprehensive understanding of the topic. This initial stage is crucial as it establishes the foundation for subsequent modules, ensuring that operators possess a strong theoretical base, which is essential for grasping the practical aspects of their work.

During this phase, operators are expected to thoroughly study the provided materials, which cover key concepts and theories relevant to their roles. The module's self-paced nature allows operators to manage their time effectively, accommodating their individual learning styles and schedules.

To support operators in this independent study, individual meetings are scheduled with them. These sessions review the materials covered, address any questions or concerns, and provide additional explanations if necessary. The personalised nature of these meetings allows for tailored instruction that meets the operator's unique learning needs, enhancing their understanding and retention of the material.

These individual meetings are a vital component of the independent study module. They ensure that operators receive the necessary guidance and clarification, preventing any potential misunderstandings and reinforcing their knowledge base. This personalised approach helps to identify and address specific areas where an operator might need additional support, thereby facilitating a more effective learning experience.

Overall, the independent study module is designed to be a flexible and supportive learning environment. By allowing operators to learn at their own pace and providing individualised support through scheduled meetings, the module aims to build a robust theoretical foundation. This ensures that operators are well-prepared for the practical modules that follow, contributing to their overall success in the training program.

3.2.2 Job shadowing

During the job shadowing phase of the program, the operator will engage in a minimum of 80 hours of close collaboration with a supervisor. This hands-on experience is a critical component of the curriculum, providing the operator with practical knowledge and skills under the guidance of an experienced employee. To facilitate effective monitoring and progress tracking, an Instructor's Checklist has been developed (see Appendix 1). This checklist assists the supervisor in overseeing the completion of specific chapters and tasks, ensuring that the operator gains comprehensive exposure to necessary competencies.

Throughout the job shadowing process, the operator will actively participate in the duties of a first-level operator while working alongside a supervisor. This immersive experience is designed to equip the operator with the essential skills and confidence needed for independent practice. By engaging in real-world tasks and responsibilities, the operator will gain a deeper understanding of their role and the operational environment.

The supervisor plays a crucial role in mentoring and evaluating the operator during this phase. Using the Instructor's Checklist, the supervisor can systematically track the operator's progress, provide feedback, and identify areas for improvement. This structured approach ensures that the operator is meeting the program's objectives and acquiring the necessary competencies.

At the conclusion of the job shadowing period, the supervisor will conduct a thorough evaluation of the operator's readiness to transition to on-the-job practice. This assessment will consider the operator's performance, skill acquisition, and overall preparedness for independent duties. If the supervisor determines that the operator requires additional support, the shadowing period may be extended to provide further development opportunities.

The extension of the shadowing period, if necessary, ensures that the operator receives adequate preparation and training. This flexibility allows for a tailored approach to each operator's learning needs, promoting confidence and competence in their role. The ultimate goal of the job shadowing phase is to ensure that the operator is fully prepared for the responsibilities of their position, contributing to a smooth transition to independent practice.

3.2.3 On-the-job training

The On-the-job module provides operators with a critical opportunity to apply their theoretical knowledge and the skills they have learned under the guidance of a supervisor. This practical training is designed to foster independence and enhance problem-solving abilities. Operators are encouraged to tackle tasks on their own to gain real-world experience and build proficiency. During this phase, they will address current challenges and gain experience in problem-solving and critical thinking. While the goal is for operators to solve problems autonomously, instructors are available to offer advice and support when dealing with complex or unfamiliar issues.

The module spans a duration of 200 working hours, ensuring that operators are exposed to a diverse range of real-world situations. This extensive training period is essential for accumulating invaluable hands-on experience. Throughout this comprehensive training, operators are expected to confront and effectively navigate various scenarios, which helps them develop a deep understanding of the practical aspects of their role.

During the On the Job module, operators will perform tasks independently while under the observation of their supervisor. This real-time practice allows them to apply their knowledge in real-world contexts, solidifying their skills and enhancing their problem-solving capabilities. The experience gained during this period is vital for developing the confidence and competence needed for their roles.

Throughout the module, the supervisor provides ongoing feedback and support, ensuring that operators stay on track and address any challenges effectively. This support is crucial for guiding operators through complex tasks and helping them refine their skills. The supervisor's role is to mentor and evaluate the operator's progress, providing insights and adjustments as needed.

At the end of the practical training, the supervisor conducts a thorough evaluation of the operator's performance. This assessment focuses on the operator's ability to apply acquired knowledge and skills in challenging situations. The evaluation is crucial for determining whether the operator has developed the necessary competencies to pass the practical exam. This final assessment ensures that operators are fully prepared to carry out their responsibilities confidently and competently.

3.2.4 Case-based study

The case study is designed as a test to evaluate the operator's practical skills and problem-solving abilities. To pass the test, the operator needs to have substantial hands-on experience working on the production line and addressing various problems and situations. It's recommended that the test be administered towards the end of the practice period to ensure the operator has encountered a wide range of scenarios.

If the operator hasn't experienced a specific topic included in the test, it provides valuable feedback for the supervisor, indicating that this topic needs to be addressed in future training sessions. Nonetheless, the operator is encouraged to respond to these unfamiliar scenarios based on their existing knowledge and understanding. This approach not only tests their practical skills but also evaluates their logical thinking and analytical abilities, providing a comprehensive assessment of their capability to handle unexpected challenges. More about the content of the test is discussed in chapter 3.4.2 Case-based test.

3.3 Content of the training

This chapter is dedicated to the level one operator training plan, which is designed to provide operators with the necessary skills and knowledge to perform their duties effectively and efficiently. The chapter offers a comprehensive overview of the topics that will be covered during the first-level operator training, including safety protocols, equipment handling, material handling, processes, quality topics, and more. Figure 3.2 illustrates the structure of the training. Upon completion of this training, operators will have a thorough understanding of their roles and responsibilities. They will also have acquired the tools and techniques required to perform their tasks confidently and proficiently.

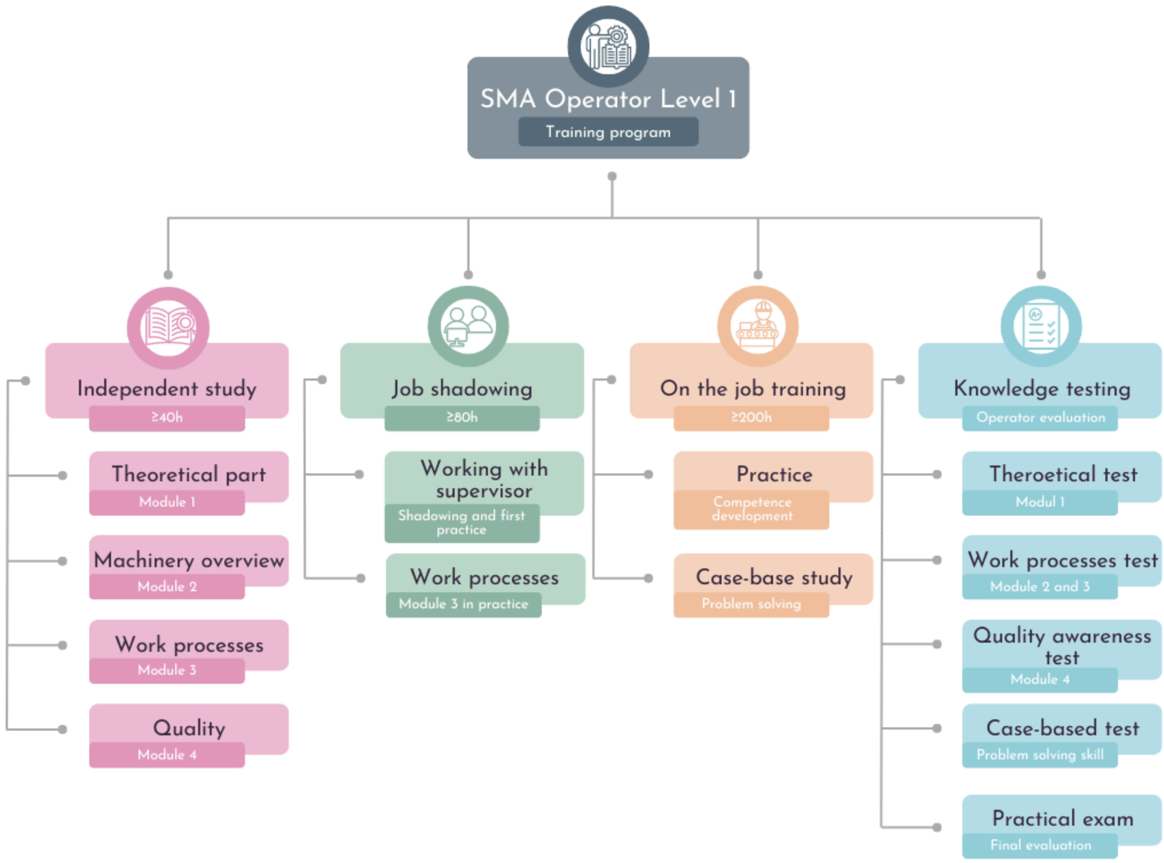


Figure 3.2 Structure of the SMA OP 1 training plan

3.3.1 Theoretical part

The course on SMA level 1 operator training covers a detailed theoretical part that encompasses all the essential aspects of SMT. The theoretical part starts with an introduction to SMT, its history, and how it has evolved over the years. It is crucial to understand the history of SMT to gain perspective on how it has developed and become an integral part of modern electronics.

The section on SMT further includes an explanation of various abbreviations used in the field of SMT to ensure that the operator understands the terminology used. Since SMT has a vast array of technical terms and abbreviations, it is essential to have a thorough understanding of them to work efficiently.

In addition, the theoretical part also briefly compares through-hole technology to SMT. The module explains the advantages of SMT, such as its design-related benefits, manufacturing process benefits, and other advantages. It also outlines the challenges faced by SMT, such as infrastructure and standards, technical concerns, and design and manufacturing challenges. This comparison helps operators understand why SMT is a better approach than through-hole technology.

Module 1 of the course describes three different types of surface mounting: Type 1, Type 2, and Type 3. The module explains the differences between them and their special features. It also describes how they are made and what processes are used. This section is crucial for operators to understand the types of surface mountings and the process involved in making them.

Module 1 is focused on surface mount devices, which include various types of components such as Melfs, chips, SOPs, SOTs, QFPs, and BGAs. This section is important for the operator to set up the machine and programs, as well as to check the quality and compliance of components. It is crucial for the operator to identify and understand the differences between component packages and their variations to ensure their correct usage. Having a thorough understanding of surface mount devices is essential for working efficiently with them. Additionally, the handling and storage requirements of MSL components are also covered in this module. It is essential for the operator to understand why it is important to monitor MSL components to prevent quality problems.

The environment of the SMA room is discussed as well, including the ideal temperature and humidity levels that should be maintained within the room. Its importance and various quality problems that may arise due to it are explained. These issues include equipment malfunction, reduced printing quality, problems with component placement and other problems that can negatively impact the overall success of the SMA room operations. By understanding the significance of maintaining proper temperature and humidity levels, the optimal functioning of the SMA room can be ensured, and the desired outcomes of experiments can be achieved.

Safety is a crucial aspect of this work. Since the operator works in an ESD environment with various materials, it is essential to have appropriate clothing and knowledge to work safely with machines. The operator is also exposed to various chemicals, and it's important to understand how to protect themselves and their health. The course covers all the necessary safety measures that an operator needs to take while working in an SMT room.

3.3.2 Introduction and setup of the machinery

The loaders paragraph provides detailed instructions on the proper usage of the loader and unloader. It outlines step-by-step guidelines to help operators effectively operate the equipment. Additionally, the chapter also includes comprehensive magazine loading instructions that aim to assist operators in efficiently loading the magazine.

The paste printer DESEN Navigator is used in the factory to print tin paste on printed circuit boards (PCBs). It requires proper calibration for accurate and consistent application of the tin paste. The quality of the product depends on the machine's setting. Calibration issues can lead to significant production problems, so it's vital to set up the machine correctly from the beginning.

This chapter provides a comprehensive tutorial on how to set up a paste printer in a step-by-step manner. The guide covers everything from installing the support block, stencil, and squeegees in detail to adjusting the settings for optimal performance. By the end of this chapter, one will have a clear understanding of the paste printer setup process and the confidence to execute it successfully.

Solder paste inspection machine DJTECH is used in the factory. It is used to check paste printing quality and set up the paste printer in the factory. Its advanced features provide precise control over the printing process, enabling early defect detection and ensuring high-quality final products. Additionally, the machine helps in monitoring paste printing quality during production and facilitates easy setup of the paste printer by showing solder misalignment on the panel. This makes the setup process faster, easier, and more accurate.

The pick and place machine Kulicke&Soffa iX-302 is used in the factory. It is mainly intended to stack chip package components. This machine has three feeder carts, one of which is equipped with 27 feeder slots. It has eight robot heads, among which seven have laser side-view cameras. To stack larger components with precision, one head has both a laser side-view camera and a bottom-view camera. [33]

The pick and place machine is the main machine with which the operator works during production. The operator works closely with this machine to splice components, change feeders, monitor quality and make necessary adjustments throughout the production cycle. In addition, the operator is responsible for resolving any ongoing issues that may arise, such as component reading issues or problems with feeders. This requires a keen eye for detail and a deep understanding of the workings of the machine, as well as the ability to quickly identify and troubleshoot any technical issues that may arise.

In order to better understand the preparation of the pick and place machine, a PNP setup flowchart (see Figure 3.3) has been created. This chapter clearly explains the steps of the PNP setup process and provides step-by-step instructions for the operator. The ability to quickly and efficiently prepare the machine for production helps to save preparation time and prevent problems at the beginning of production.

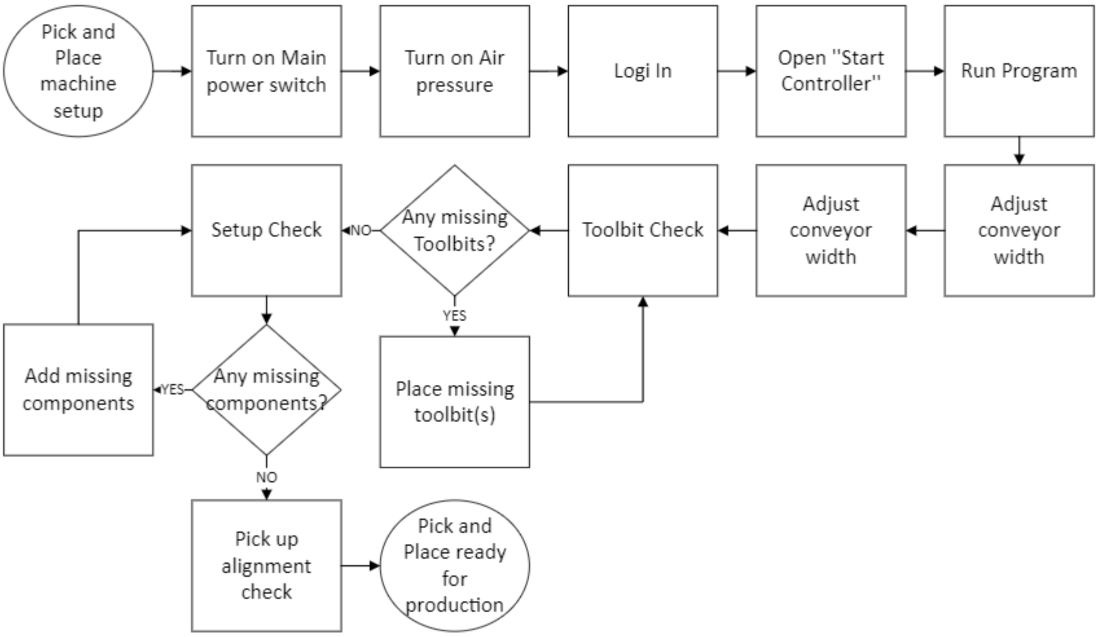


Figure 3.3 PnP Setup Process

Reflow oven HTS Series is used in the factory. It has a chain conveyor system. The oven has eight separate top and bottom heating chambers that can be independently controlled, providing flexibility in creating a reflow profile that is made to the product's specific needs. Additionally, the oven has two cooling chambers, which help to prevent thermal shock and ensure a consistent and high-quality solder joint. [11]

In this chapter, the operator will be instructed on the steps to prepare the reflow oven for production. This includes setting the conveyor width, adjusting the mid-support position, and using the oven interface to access important information. Additionally, there will be a guide on how to effectively monitor and adjust the N2 level in the furnace.

An automated optical inspection machine, the NVI-G300 Inspection System, is used in the factory to evaluate the quality of PCBA after reflow soldering. This system is designed to detect various defects in quality, such as component presence, misalignment, rotation, tilting, polarity, character (text), solder joint, bridging, and foreign materials. The NVI-G300 has both 2D and 3D inspection capabilities. [10]

This chapter provides a tutorial on how to set up an AOI in a step-by-step manner. The guide covers everything from installing the support block, stencil, and squeegees in detail to adjusting the settings for optimal performance. By the end of this chapter, one will have a clear understanding of the paste printer setup process and the confidence to execute it successfully.

3.3.3 Work processes

The Processes chapter is designed to provide operators with a comprehensive understanding of their responsibilities and the steps required to perform their tasks effectively. It offers an overview of what is expected from them, preparing them for job shadowing and on-the-job practice by explaining the background and details of each process.

All processes are illustrated with a process flow diagram, as shown in Figure 3.4. This diagram provides operators with a visual and clear overview of each process, making it easier to grasp the content and sequence of operations. Additionally, the chapter includes detailed explanations of each stage and step-by-step instructions, ensuring that operators have the necessary information to execute their tasks accurately and efficiently. This combination of visual aids and detailed descriptions enhances the learning experience, helping operators to confidently apply their knowledge in practical settings.

The Kitting and Preparation chapter provides a detailed guide to the kitting process, as shown in Figure 3.4. This chapter covers several key aspects essential for operators. It explains how to efficiently locate materials within the warehouse using the warehouse address system. This system is crucial for maintaining organisation and ensuring quick retrieval of needed items. Operators learn how to obtain and interpret a list of materials required for a production order. This ensures that all necessary components are gathered before the production process begins.

The chapter teaches operators to differentiate between various types of feeders, which is important for the correct handling and loading of materials. Detailed instructions are provided on how to properly load these feeders to ensure smooth operation. Operators are instructed on how to register the loaded materials into the machine. This step is crucial for maintaining accurate inventory records and ensuring that the machine is set up correctly for production.

Lastly, the chapter includes a tutorial on splicing components. This skill is essential for maintaining continuous production without unnecessary downtime. By covering these topics comprehensively, the Kitting and Preparation chapter ensures that operators are well-prepared to handle the kitting process efficiently and accurately.

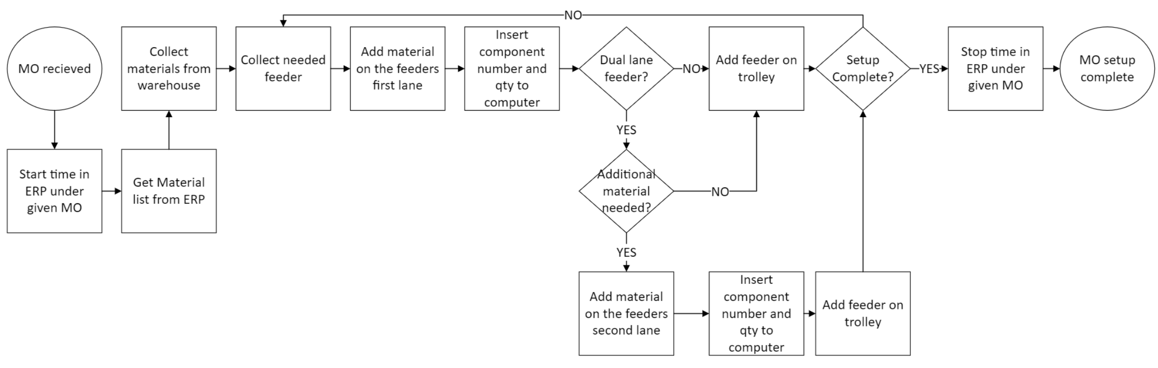


Figure 3.4 Kitting and preparation process

The Line Startup chapter provides detailed instructions for initiating the production line and the correct sequence of steps involved. It includes a step-by-step guide designed to help operators start the line quickly and effectively, taking into account factors such as the time needed for the tin paste to warm up and the reflow oven to reach the appropriate temperature. This chapter emphasises efficient and swift line startup procedures, as any unnecessary delays can negatively impact overall productivity. Operators are taught best practices to minimise downtime and ensure a smooth commencement of production.

Key components of the chapter include instructions on preparing all necessary materials and equipment before starting the line to avoid any last-minute issues, a clear, chronological sequence of steps to follow, ensuring that each part of the line is started in the correct order for optimal performance and guidelines on the required warm-up times for the tin paste and reflow oven to help operators plan and synchronise these steps efficiently. Practical tips and strategies are provided to help operators reduce startup times and avoid common problems that can cause delays.
By mastering the content of the Line Startup chapter, operators will be equipped to start the production line efficiently, thereby enhancing overall productivity and minimising any potential drawbacks associated with delays.

The Line Shutdown chapter is divided into two essential parts. The first section provides a comprehensive description and a step-by-step tutorial on performing a complete shutdown of the production line. A total shutdown is necessary when production will not resume the following morning, requiring the entire machine park to be turned off.

Key elements covered include instructions on how to properly prepare the line for a complete shutdown and ensuring all ongoing processes are safely concluded. Detailed steps for turning off each component of the machine park systematically, ensuring no equipment is damaged or left in an unsafe state. Guidelines for verifying that all machinery is completely powered down and safely secured, preventing any issues during the non-operational period.

The second section focuses on how to pause the production line overnight, allowing for a quick and efficient restart the next morning. This is crucial for maintaining productivity while ensuring safety and readiness.

Topics covered include instructions on how to bring the machine park to a safe state for an overnight pause, ensuring that no processes are left in a hazardous condition. A detailed guide on how to pause each piece of equipment, maintaining their readiness for the next production cycle. Tips and strategies for setting up the line to ensure a rapid and smooth restart the next morning, minimising downtime and ensuring production efficiency.

By following the procedures outlined in the Line Shutdown chapter, operators will be able to perform both total shutdowns and overnight pauses effectively. This ensures the safety of the equipment and readiness for subsequent production activities, thereby enhancing overall operational efficiency.

The Production with Paste Printer chapter is divided into two distinct processes, both crucial for efficient and accurate printing operations. The first section provides detailed instructions for executing the print testing process. It focuses on ensuring that the machine is correctly set up and calibrated before production begins. Key components of this process include clear guidelines on configuring the paste printer, making adjustments to ensure optimal print position and alignment, and conducting print tests to verify accuracy and consistency. This helps to identify and rectify any issues with print position or alignment before actual production begins.

The second part of the chapter delves into the use of the paste printer during production activities. It covers various essential aspects for maintaining efficiency and quality throughout the printing process. This includes detailed explanations on how to operate the paste printer effectively during production, ensuring smooth and uninterrupted workflow. It also provides instructions on cleaning the stencil and squeegees after printing to prevent buildup and maintain print quality, as well as guidance on changing the cleaning paper within the machine to ensure continued effectiveness in removing excess paste and debris.

By providing comprehensive guidance on both the print testing process and the production printing process, this chapter equips operators with the knowledge and skills necessary for efficient and high-quality printing operations. From initial setup and testing to ongoing maintenance during production, operators will be able to execute their tasks with precision and confidence, contributing to overall manufacturing excellence.

The Production with SPI (Solder Paste Inspection) chapter serves as a comprehensive guide for operators, covering essential aspects of effectively using the machine to enhance quality control in the manufacturing process.

The machine operation section provides detailed instructions on operating the SPI machine, ensuring operators understand how to use its functionalities efficiently. Key components of this guide include clear guidelines on properly configuring the SPI machine, including calibration and alignment, to ensure accurate inspection results. Step-by-step procedures for running inspections, including loading boards, initiating scans, and interpreting the generated data.

Operators are equipped with the knowledge and skills needed to interpret the results obtained from SPI inspections accurately. This involves guidance on identifying and categorising defects detected by the SPI machine, such as insufficient or excess solder paste, bridging, or misalignment. Strategies for assessing the quality of solder paste application based on inspection results allow operators to determine whether adjustments are necessary.

The adjustment and improvement section emphasises the importance of making necessary adjustments based on SPI inspection results to enhance quality and minimise risks. It includes techniques for diagnosing common issues identified during SPI inspections and implementing corrective actions to address them effectively. The section also includes recommendations for making process adjustments to improve solder paste application quality, such as fine-tuning printing parameters.

Operators can effectively use the guidance provided in the "Production with SPI" chapter to make the most of the capabilities of the SPI machine. This helps in reducing quality risks and identifying potential issues with paste printing. Such proactive quality control approach ensures consistency and reliability in the manufacturing process, ultimately leading to the production of high-quality electronic assemblies.

The Production with a Pick and Place (PnP) Machine chapter is a comprehensive guide designed to equip operators with the necessary skills to operate and troubleshoot the PnP machine effectively. As previously mentioned, the PnP machine is the primary machine that operators work with most frequently.

Operators are provided with clear instructions on how to operate the PnP machine efficiently during production. Key aspects covered include detailed guidance on configuring the PnP machine for specific production requirements, including panel or feeder skipping as needed. Instructions on monitoring material requirements during production to ensure uninterrupted operation, including timely addition of materials to prevent downtime, are also provided.

Operators learn essential troubleshooting techniques to minimise production downtime and address issues promptly. This includes a tutorial on identifying common errors that may occur during PnP machine operation and implementing appropriate solutions. This empowers operators to quickly resolve issues and maintain smooth production flow. Strategies for diagnosing and resolving issues related to machine operation, component placement, or material handling, ensuring efficient troubleshooting and minimal disruption to production.

By following the guidance provided in the Production with PnP Machine chapter, operators can effectively utilise the capabilities of the PnP machine to maintain continuous production, troubleshoot issues efficiently, and contribute to overall manufacturing success. This proactive approach helps minimise downtime, improve productivity, and optimise production processes.

The Production with a Reflow Oven chapter is an essential resource for operators to manage the reflow oven during production. It provides comprehensive guidance on effectively handling the oven, ensuring smooth operation, and addressing potential issues that may arise.

Operators receive clear instructions on how to handle the reflow oven during production, covering important considerations and best practices. Key aspects include detailed guidelines on operating the reflow oven, such as setting temperature profiles and monitoring the production process for optimal results. It also includes the identification of critical indicators to monitor during oven operation, such as temperature consistency, conveyor speed and nitrogen levels.

Operators are provided with specific guidance on how to manage the reflow oven in the event of a power outage, which is critical for maintaining product quality and safety. This includes instructions for safely managing panels inside the oven during a power outage to prevent damage or overheating, as well as a protocol for safely cooling down the oven and removing panels if a power outage occurs, minimising the risk of thermal damage to components.

By following the procedures outlined in the "Production with Reflow Oven" chapter, operators can effectively manage the reflow oven during production, mitigate potential issues, and respond appropriately to emergencies. This ensures consistent product quality, minimises downtime, and supports the overall efficiency of the manufacturing process.

The Production with Automated Optical Inspection (AOI) chapter is crucial for ensuring the quality and integrity of products during the manufacturing process. It provides operators with detailed instructions on how to effectively use the AOI machine and emphasises their critical role in the inspection and decision-making process.

Operators receive comprehensive guidance on operating the AOI machine during production. This includes instructions on configuring and calibrating the AOI machine to ensure accurate inspection results and clear guidelines on initiating and conducting inspections, such as loading boards, selecting programs, and interpreting results.

Operators are trained to accurately identify and classify errors detected by the AOI machine, distinguishing between false errors and genuine quality issues. They are also provided with guidance on interpreting inspection results and images obtained by the AOI machine to make informed decisions regarding product quality. Operators are expected to make critical decisions based on AOI inspection results, such as determining whether detected errors need repair or if the product can proceed to the next production stage without further intervention.

Operators are encouraged to provide feedback on AOI performance and to participate in ongoing training to enhance their skills in result interpretation and decision-making. Collaboration with engineers and supervisors is necessary to optimise AOI inspection processes and improve overall efficiency and effectiveness.

By following the procedures outlined in the Production with AOI chapter, operators can effectively utilise the AOI machine to maintain product quality, minimise defects, and uphold the standards of the manufacturing process. This proactive approach contributes to customer satisfaction and the overall success of the production operation.

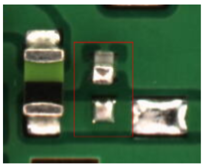
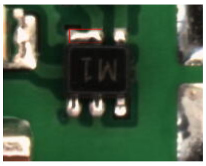
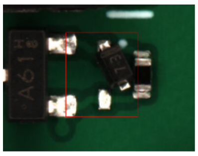
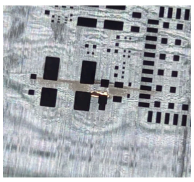
3.3.4 Quality

Quality is a critical aspect of an operator's responsibilities. It is essential for the operator to identify quality issues and make necessary adjustments to the production line to resolve them. This training program focuses on the skills required of a

first-level operator. Therefore, it is strongly recommended that the operator seek assistance from an engineer or supervisor for more complex issues.
To support the operator's learning and problem-solving process, a reference table has been created (part of this table is shown in Table 3.1), outlining various quality issues and their corresponding solutions. This table serves as a valuable resource for identifying and addressing common problems that may arise during production.

The operator plays a key role in quality control. They must assess alarms from the automated optical inspection system to determine if they indicate genuine quality issues that require correction or if they are false alarms. The operator's ability to accurately interpret these alarms and take appropriate action is vital to maintaining the overall quality of the production process.

Table 3.1 Quality problem action list

Error title	**Photo**	**Description**	**Possible location**	**Decision (OK/NOK)**	**Action**
...					
Manhattan		Component standing on one pad	PP,PnP,Reflow	NOK	Check printing and component placement quality; check N2 level
Bridge		Short circuit between two legs	PP	NOK	Check printing quality and PP area temperature and humidity
Tilt		Component incorrect position	PnP	NOK	Check nozzle cleanliness, component placement quality
Damaged stencil		Stencil has damage, resulting to bad printing quality	PP	-	Notify an SMA engineer or your supervisor immediately, do not continue production
Wrong polarity		Polarity 180deg	PnP	NOK	Check component placement quality, check program values (component placement position degree)
...					

3.4 Tests and practical exam

The training program includes three types of knowledge control forms, which are theoretical tests, case-based test and practical exam.

3.4.1 Theoretical tests

Theoretical tests are a crucial component of the independent study modules. These short tests contain questions based on the provided study materials and are intended to keep operators engaged with the content. They also provide valuable feedback to help operators identify their strengths and areas requiring further review.

There are a total of three small tests:
1. **Theoretical Knowledge Test**: This test focuses on theoretical aspects, including questions about surface mount technology (SMT), component handling, and SMT room environmental requirements.

2. **Work Processes Test**: This test evaluates the operator's understanding of work processes by asking questions related to various processes and their sequential steps.

3. **Quality Awareness Test**: This test focuses on quality control. Operators must recognise quality-related issues and identify appropriate actions to resolve them.
These tests are designed not only to assess the operator's knowledge but also to reinforce their learning and ensure they are well-prepared for their roles.

3.4.2 Case-based test

The case-based test aims to improve the operator's critical and logical thinking, as well as enhance their problem-solving skills. It presents real-world scenarios that the operator may encounter, requiring them to analyse the situation, explain the underlying issues, and propose suitable solutions. This approach not only assesses their understanding of specific problems but also evaluates their ability to respond effectively.

Operators should explain the reasons for problems and outline their solutions. For example:
Example Question 1: "In Automated Optical Inspection (AOI), there is a consistent error with the same component being placed upside down. Please describe where and why this problem might occur and what steps you would take to resolve it."

Expected possible response: The operator should identify potential problems in the component placement process, such as feeder setup or programming errors, and suggest solutions, such as checking the feeder mechanism, reprogramming needs on the placement machine, or checking component orientation instructions.

Example Question 2: "The reflow oven has stopped accepting panels and the yellow light is on. Describe what you would look for and check, identify possible causes, and outline how you would solve them."

Expected possible response: The operator should check the error codes of the reflow oven and investigate possible blockages or malfunctions in the conveyor system and the nitrogen level in the reflow oven. Solutions may include removing obstructions, relocating sensors, or adjusting nitrogen levels.

Operators must answer these questions using their own words, offering insights into their understanding of the topic, their analytical abilities, and their problem-solving experience. Their responses will help evaluate whether they have encountered similar situations before and can propose effective solutions, demonstrating their readiness to handle real-world challenges on the production line.

3.4.3 Practical exam

The practical exam evaluates the operator's ability to independently run the production line. This ensures they are prepared to work without supervision. The operator's task is to operate the production line for a specific period or within the scope of order fulfillment. This exam assesses key areas including the operator's sense of responsibility, adherence to work processes, machine handling skills, and the overall quality of their work.

An evaluation sheet (Appendix 2) has been created to standardise this assessment. The examiner will offer comprehensive feedback and suggestions for improvement based on the operator's performance. If the operator does not pass the exam, they are permitted one retake within the probationary period, which lasts for four months.

Evaluation Criteria (Scale 1 to 5)

1. The operator needs constant supervision and has inadequate skills and a negative attitude.
    - They frequently require assistance and guidance, struggle with operating machinery, and often deviate from standard operating procedures. Additionally, the operator consistently displays a negative attitude, is resistant to feedback, and disrupts the workflow.

2. The operator often needs assistance and occasionally can be uncooperative.
    - They sometimes require help to complete tasks and may not always follow procedures correctly, needing correction. While they can handle machinery, they often need assistance, and at times, they show resistance to feedback, which can affect team dynamics.

3. Can manage most tasks independently, competent with occasional help, and generally positive.
    - The operator manages machinery adequately with some support. The operator generally works independently but might need occasional support. The operator maintains a positive attitude most of the time, is open to feedback, and contributes to a good work environment.

4. The operator rarely needs supervision and is proficient, rarely requiring help.
    - They produce high-quality work with few errors and operate machinery effectively with minimal assistance. The operator consistently shows a positive attitude, actively seeks feedback, and fosters a positive team environment.

5. The operator is completely reliable, highly skilled, and independent, with an exemplary attitude.
    - They consistently manage tasks independently and efficiently, excel in machinery operation and maintenance without needing help, demonstrate an outstandingly positive attitude, welcome feedback, encourage others, and significantly enhance team morale.

The standardised evaluation system ensures that all operators are assessed fairly and consistently, providing clear insights into their readiness for independent work and areas needing improvement. This is crucial for maintaining a positive and productive work environment.

SUMMARY

Summary in English:

This Master’s thesis focused on creating a structured training plan for SMT (surface mount technology) assembly operators, which is highly relevant in today's fast-paced industrial landscape. The goal is to ensure that operators consistently acquire the necessary skills and knowledge, thereby boosting their confidence and independence in performing their tasks. This structured approach is crucial not only for the professional growth of the operators but also for the operational efficiency and product quality of the company.

The development and implementation of a structured training program for SMT assembly operators represent an advancement for the given company. The program's design addresses the critical need for standardised training, ensuring that new operators acquire the necessary skills and knowledge efficiently and consistently. The training program is composed of four main modules: Independent Study, Job Shadowing, On-the-Job Training, and Knowledge Testing. Each module is designed to create a comprehensive learning experience that combines theoretical knowledge with practical application.

The Independent Study Module consists of four sub-modules that cover theoretical aspects, machinery overview, work processes, and quality. This allows operators to learn at their own pace, with individual meetings scheduled to review material, address questions, and provide additional explanations. This personalised approach ensures a solid theoretical foundation essential for practical training.

During the Job Shadowing Module, operators spend a minimum of 80 hours working closely with a supervisor. This hands-on experience is crucial for gaining practical knowledge and skills. The Instructor's Checklist helps supervisors track progress and ensure comprehensive competency development. Continuous feedback and guidance from the supervisor help operators refine their skills and address areas needing improvement.

In the On-the-Job Training Module, operators apply their theoretical knowledge and skills under supervisory guidance. This module focuses on fostering independence and enhancing problem-solving abilities. Operators tackle real-world tasks, gaining

experience and building proficiency. Supervisors provide ongoing support and feedback, helping operators navigate complex tasks and refine their skills.

The Knowledge Testing Module includes three theoretical tests, a case-based test, and a practical exam. The theoretical tests cover key areas such as surface mount technology, work processes, and quality control, reinforcing learning and ensuring preparedness. The case-based test evaluates critical thinking and problem-solving skills through real-world scenarios. The practical exam assesses the operator's ability to run the production line independently, ensuring readiness for unsupervised work. A practical exam evaluation sheet standardises this assessment, providing comprehensive feedback and recommendations for improvement.

The structured training program developed through this thesis offers several significant benefits. Standardising the training process ensures consistent skill acquisition among all operators, reducing the variability found in informal training methods. This comprehensive training boosts operator confidence and independence, leading to higher job satisfaction and performance. Additionally, well-trained operators can perform their duties more efficiently and accurately, resulting in improved operational efficiency, increased productivity, and reduced error rates.

To further improve the effectiveness of the training program, it is recommended that the training materials and methods be regularly updated based on feedback from operators and instructors, as well as advances in SMT technology. In addition, after the initial training period, periodic evaluations should be conducted to ensure ongoing competence and to identify areas for further development. Consideration should also be given to expanding the training program to include other roles within the company or similar positions in different companies in order to use a structured approach for wider benefit.

The development of a structured training program for SMT assembly operators represents an important step forward for the company. By addressing existing training gaps and providing a comprehensive, standardised approach, the program increases operator competence, confidence and independence. This, in turn, leads to better operational efficiency and product quality, which benefits both the company and its employees. The success of this program sets a good example for similar initiatives, contributing to the overall advancement of training practices in the electronics industry.

Summary in Estonian:

See magistri lõputöö keskendub SMT (*surface mount technology* - pindmontaaži tehnoloogia) operaatorite struktureeritud koolituskava loomisele, mis on tänapäeva kiirel tööstusmaastikul väga asjakohane. Eesmärk on tagada, et operaatorid omandaksid järjepidevalt vajalikke oskusi ja teadmisi, suurendades seeläbi nende enesekindlust ja sõltumatust oma ülesannete täitmisel. See struktureeritud lähenemine on ülioluline mitte ainult operaatorite professionaalseks kasvuks vaid ka ettevõtte tegevuse tõhususe ja tootekvaliteedi jaoks.

SMT operaatorite struktureeritud koolitusprogrammi väljatöötamine ja rakendamine on antud ettevõtte jaoks edasiminek. Programmi ülesehitus käsitleb kriitilist vajadust standardiseeritud koolituse järele, tagades, et uued operaatorid omandavad vajalikud oskused ja teadmised tõhusalt ning järjepidevalt. Koolitusprogramm koosneb neljast põhimoodulist: iseseisev õpe, töövarjutamine, töökohapõhine koolitus ja teadmiste kontrollimine. Iga moodul on loodud tervikliku õppekogemuse loomiseks, mis ühendab teoreetilised teadmised praktilise rakendusega.

Iseseisva õppe moodul koosneb neljast alammoodulist, mis hõlmavad teoreetilisi aspekte, masinate ülevaadet, tööprotsesse ja kvaliteeti. See võimaldab operaatoritel õppida omas tempos. Individuaalsed koosolekud on planeeritud materjalide ülevaatamiseks, tekkinud küsimustele lahendamiseks ja täiendavate selgituste andmiseks. See isikupärastatud lähenemine tagab praktilise treeningu jaoks olulise teoreetilise aluse.

Töövarju mooduli ajal veedavad operaatorid juhendajaga tihedat koostööd tehes vähemalt 80 tundi. See praktiline kogemus on praktiliste teadmiste ja oskuste omandamiseks ülioluline. Töö käigus loodud Instruktori kontroll-list aitab juhendajatel jälgida edusamme ja tagada igakülgse pädevuse arendamise. Juhendaja pidev tagasiside ja juhised aitavad operaatoritel täiustada oma oskusi ja tegeleda täiustamist vajavate valdkondadega.

Töökohapõhise koolituse moodulis rakendavad operaatorid oma teoreetilisi teadmisi ja oskusi juhendaja valvsa pilgu all. See moodul keskendub iseseisvuse edendamisele ja probleemide lahendamise oskuse parandamisele. Operaatorid täidavad reaalseid ülesandeid, omandades kogemusi ja arendades oskusi. Juhendajad pakuvad pidevat tuge ja tagasisidet, aidates operaatoritel keerulistes ülesannetes navigeerida ja oma oskusi täiustada.

Teadmiste testimise moodul sisaldab kolme testi vormi: teoreetili teste, juhtumipõhist testi ja praktilist eksamit. Teoreetilised testid hõlmavad põhivaldkondi, nagu pindmontaažitehnoloogia, tööprotsessid ja kvaliteedikontroll, mis tugevdab õppimist ja tagab valmisoleku. Juhtumipõhise testiga hinnatakse kriitilist mõtlemist ja probleemide lahendamise oskusi reaalsete stsenaariumide kaudu. Praktilisel eksamil hinnatakse operaatori oskust tootmisliini iseseisvalt opereerida, tagades valmisoleku iseseisvaks tööks. Töö käigus loodud eksami hindamisleht aitab operaatoreid ausalt hinnata, pakkudes igakülgset tagasisidet ja soovitusi parenduseks.

Selle lõputöö kaudu välja töötatud struktureeritud koolitusprogramm pakub mitmeid olulisi eeliseid. Koolitusprotsessi standardiseerimine tagab järjepideva oskuste omandamise kõigi operaatorite vahel, vähendades mitteametlike koolitusmeetodite varieeruvust. See põhjalik koolitus suurendab operaatori usaldust ja iseseisvust, mis suurendab tööga rahulolu ja töötulemusi. Lisaks saavad hästi koolitatud operaatorid oma ülesannete täitmisega tõhusamalt ja täpsemalt hakkama, mille tulemuseks on parem töötõhusus, suurem tootlikkus ja väiksem veamäär.

Koolitusprogrammi tõhususe edasiseks parandamiseks on soovitatav koolitusmaterjale ja -meetodeid regulaarselt uuendada, lähtudes operaatoritelt ja juhendajatelt saadud tagasisidest ning SMT-tehnoloogia edusiarengust. Lisaks tuleks pärast esialgset koolitusperioodi läbi viia perioodilisi hindamisi, et tagada jätkuv pädevus ja selgitada välja valdkonnad, mida edasi arendada. Kaaluda tuleks ka koolitusprogrammi laiendamist, et see hõlmaks ka teisi rolle ettevõtte sees või sarnaseid ametikohti erinevates ettevõtetes, et kasutada struktureeritud lähenemist laiema kasu saamiseks.

SMT operaatorite struktureeritud koolitusprogrammi väljatöötamine on ettevõtte jaoks oluline samm edasi. Kaasates olemasolevaid koolituslünki ja pakkudes kõikehõlmavat standardiseeritud lähenemisviisi, suurendab programm operaatori pädevust, enesekindlust ja sõltumatust. See omakorda toob kaasa parema töö efektiivsuse ja tootekvaliteedi, millest on kasu nii ettevõttele kui ka operaatoritele. Selle programmi edu on heaks eeskujuks sarnastele algatustele, aidates kaasa elektroonikatööstuse koolitustavade üldisele edendamisele.

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APPENDICES

Appendix 1 Supervisor's checklist

Supervisor's Checklist for SMA first-level operator training

Operator name: ______________________ Supervisor: ______________________

Start date: ______________________ Practice start date: ______________________

End date: ______________________

Setup preparation

- [ ] Material finding
- [ ] ITF 8mm feeder loading
- [ ] TTF 8mm feeder loading
- [ ] ITF 12-...mm feeder loading
- [ ] Material registering to machine
- [ ] Kitting station usage
- [ ] Trolley changes
- [ ] Material unloading

Work procedures

- [ ] Humidifiers handling
- [ ] UH washer handling
- [ ] Solder paste handling
- [ ] Waste handling
- [ ] Loaders and conveiors handling
- [ ] MSL components handling
- [ ] Evocon handling
- [ ] MRP handling

Notes

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Paste printer

- [ ] PP setup and shutdown
- [ ] Support block and pins placement
- [ ] Stencil placement
- [ ] Print position adjusting
- [ ] PCB cleaning
- [ ] Stencil and squeege cleaning
- [ ] Clean paper replacing

SPI

- [ ] SPI setup and shutdown
- [ ] Using SPI results for PP print adjustment

Pick and Place

- [ ] PnP setup and shutdown
- [ ] Toolbit check and changes
- [ ] Splicing
- [ ] Pickup position adjustment
- [ ] Lazer cleaning
- [ ] Skipping board
- [ ] Error handling
- [ ] Patterns and feeders skipping
- [ ] Machine cleanup

Reflow oven

- [ ] Reflow conveior adjustment
- [ ] Reflow startup and cooldown
- [ ] N2 level adjustment
- [ ] Reflow ventilation
- [ ] Power outage scenario
- [ ] Power outage scenario

AOI

- [ ] AOI setup and shutdown
- [ ] Error handling
- [ ] More than one PCBA in machine scenario

General

- [ ] SMA room environment requirements
- [ ] ESD requirements

Supervisor's evaluation notes

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Operator ready for On-the-job practice [ ] YES [ ] NO

To be completed after completion of the practice period

Supervisor's evaluation for operator

[ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

Supervisor's evaluation notes for practice

____

Operator ready for practical exam [ ] YES [ ] NO

Appendix 2 Practical exam evaluation sheet

SMA OP 1 Practical *Exam* evaluation sheet

Operator name: ____________________ Supervisor: ____________________

Date: ____________________ Examiner: ____________________

Evaluation criteria		Score (1-5)	Comment
Safety	Follow safety precautions and rules		
Responsibility and attitude	Able to identify and report irregularities at work place		
	Is punctual, detail oriented, initiative, reliable		
	Keeps the workplace tidy		
	Willingness to learn		
Work processes	Kitting and preparation		
	Splicing		
	Line startup		
	Line shutdown		
	PP and SPI		
	PnP		
	Reflow oven		
	AOI		
Quality of work	Able to match line speed		
	Work completion/target achievement		
	Understands tools/equipment functions		
	Able to perform the job independently		
	Problem solving ability		
	Skill acquired during "On job training"		
	Correct validation of quality errors		
	Total score:		

Examiner's evaluation notes and development proposals

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Examiner's evaluation for operator

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Exam completion ☐ PASS ☐ FAIL

Operator's signature: ____________________

Examiner's signature: ____________________