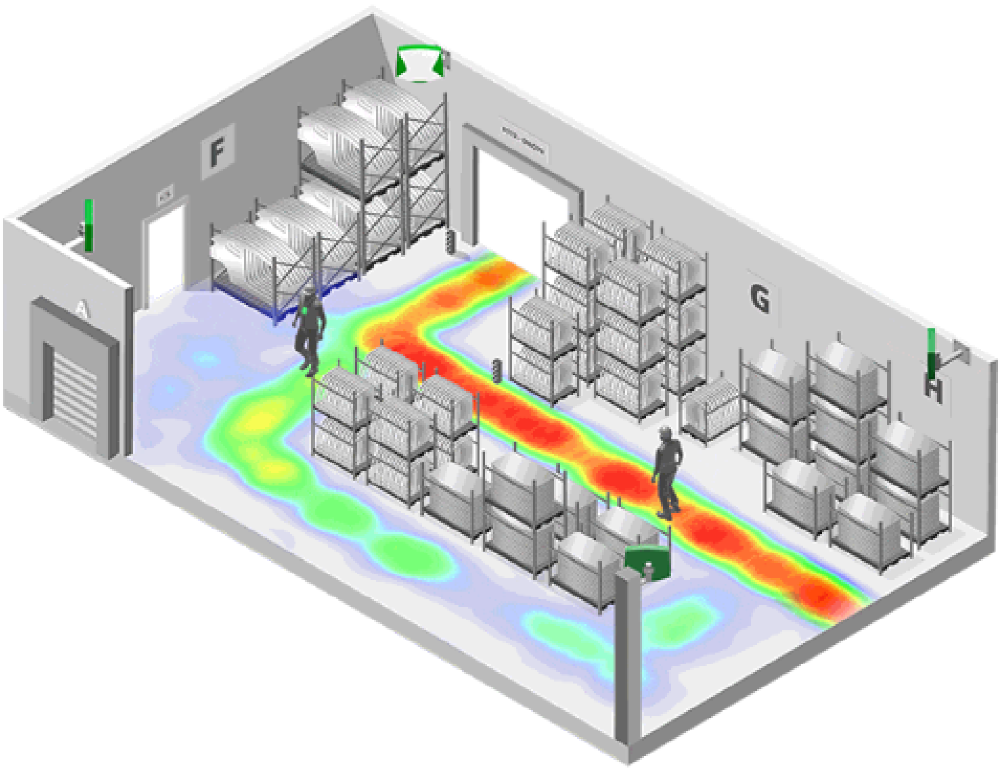

Real-Time Locating System for Changeover Analysis (SMED)

Master's thesis in Production Engineering

PRAJWAL DEVANG HALEPALYA SOMASHEKAR
JAGGDISH PILLAI

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

MASTER'S THESIS 2023

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PRAJWAL DEVANG HALEPALYA SOMASHEKAR
JAGGDISH PILLAI

CHALMERS
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PRAJWAL DEVANG HALEPALYA SOMASHEKAR
JAGGDISH PILLAI

Supervisor: Pontus Rosengren, Virtual Manufacturing Sweden AB
Supervisor: Roland Örtengren, Department of Industrial and Materials Science, Chalmers University of Technology
Examiner: Roland Örtengren, Department of Industrial and Materials Science, Chalmers University of Technology, Department

Master's Thesis 2023
Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 31 772 1000

Cover: Visualisation of spaghetti diagram and heat map using RTLS

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PRAJWAL DEVANG HALEPALYA SOMASHEKAR
JAGGDISH PILLAI
Department of Industrial and Materials Science
Chalmers University of Technology

Abstract

The emergence of novel technologies necessitates innovation to sustain competitiveness. The smart factory concept, which is at the core of the Industrial Internet of Things (IIoT), is a derivative of industry 4.0. Real-time tracking is a crucial component of intelligent manufacturing in this context. The implementation of real-time tracking systems for diverse objects within production and warehouse settings is a crucial control mechanism that facilitates informed decision-making for organisations. In instances where deviations and unforeseen alterations arise, timely and appropriately formatted information can be provided. This thesis project investigates the application of tracking equipment to enhance changeover analysis (SMED) using method study based AviX software in partnership with the consulting firm Virtual Manufacturing Sweden AB (VM). The study yielded a case report demonstrating that the Marvelmind, a technology utilising ultrasonic sound waves and fitted onto the operator, was capable of tracking the operator's walking trajectory during the changeover process. The Gazpacho tracking analysis software was subjected to testing of its tracking data visualisation functions, which included spaghetti diagrams and heat maps. This master's thesis addresses the constraints, areas of growth, and prospects pertaining to Real-Time Locating Systems (RTLS) in the context of manufacturing.

Keywords: changeover analysis, SMED, lean manufacturing, RTLS, Industry 4.0, Marvelmind, ultrasound

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Many thanks!

Prajwal Devang Halepalya Somashekar & Jaggdish Pillai, Gothenburg, June 2023

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis:

SMED	Single Minute Exchange of Die
VM	Virtual Manufacturing Sweden AB
WIP	Work-in-Progress
RTLS	Real-Time Locating Systems
PMTS	Predetermined Motion time Systems
TPS	Toyota Production System
MTM	Renewable-based Energy Sources
SOP	Standard Operating Procedure
CMM	Coordinate-Measuring Machine
KPI	Key Performance Indicator
CSV	Comma Separated Values
VBA	Visual Basic Analysis
PC	Personal Computer
RFID	Radio Frequency Identification
BLE	Bluetooth Low Energy
UWB	Ultra Wideband
US	Ultrasonic
IR	Infrared Radiation

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1 Introduction

Production of smaller lot sizes is a key strategy incorporated by manufacturers to achieve flexible and shorter lead times. Manufacturers choose this strategy to be more responsive to dynamic customer demands and to maintain a competitive edge over others [1]. This is possible only if the changeover is quick and efficient. Single-Minute Exchange of Die (SMED) is a process for reducing the time taken to complete equipment changeover and shorter setups are the way to do it [2]. Setup time can be defined as the stop of production of product A until the start of production of non-defective units of product B [3]. SMED was developed by Japanese Industrial Engineer Shigeo Shingo and his SMED process led to an average changeover time reduction of 94% across multiple industries [4]. SMED is a principle of lean manufacturing and the essence of SMED is to minimize the waste in the changeover process and convert as many changeover activities (internal steps) to external steps and to streamline the remaining steps [2]. Internal steps are those activities that can be performed only if the equipment is stopped, and external steps are activities that can be performed without stopping the equipment [3]. Shorter setups can provide several benefits and they are reduced batch sizes, increased flexibility and capacity, reduced stock and Work-in-Progress (WIP), reduced lead time and manufacturing cost and enhanced productivity and utilization rate [1].

The spaghetti diagram is another lean tool effective in identifying areas where time is wasted by visualizing the movement operators and materials [5]. Conventionally, in industries, work studies are performed to identify value-added and non-value-added activities using a pen-and-paper method of drawing spaghetti diagrams and predetermined motion time systems (PMTS) [6]. Activity tracking has been used in recent times for productivity improvements. With the 4th industrial revolution, many studies are being carried out around the automation of work-study and activity tracking [7]. A key factor to be successful in improving the changeover process is in identifying the waste in the process by monitoring the movement of operators and the materials and standardizing the process.

1.1 Background

Virtual Manufacturing Sweden AB (VM) is an engineering consulting company working with lean-based and Industry 4.0 concepts to improve production processes and internal logistics in manufacturing industries. Their vision is to provide long-term, sustainable solutions to their customers using new technologies to achieve operational excellence in a faster way. At VM, a standardised phase gate-driven methodology is used to carry out improvement projects. In this method, the data is gathered by carrying out an AS-IS state study, which is analysed to create the TO-BE state of the project. VM has invested in tracking equipment to gather data for the AS-IS state and developed Gazpacho software to analyse the tracking data. VM wants to test the readiness of the tracking equipment and the software and standardise the method of using the tools to generate value-adding results for the customers. In this project, the study is carried out only to test and give feedback on the application of the tracking tools and the software in the SMED analysis process.

1.2 Aim

This thesis project is a case study to identify the factors that affect the SMED analysis and how it can be improved with the use of a real-time location system (RTLS) to track the operators in the SMED process. In the AS-IS state of the project, the tracking tool will be used to track the movement of the operators in order to support the decision-making in the TO-BE state. The study was carried out on customers of Virtual Manufacturing. Through the obtained results, the readiness of the tracking equipment and the tracking analysis software developed by Virtual Manufacturing are verified.

1.3 Problem Formulation

With the continuous advancements in the manufacturing industry with Industry 4.0, companies need to be resilient and forge ahead in adapting new technologies in order to be competitive in the market. For VM, it is important to combine lean principles and digital tools to accelerate the identification and mitigation of waste when compared to traditional lean methods. This thesis focuses on using tracking equipment to identify waste in the SMED process. The following questions have been formulated to guide this project:

1. What indoor tracking technologies exist in the market?
2. How to standardise the use of tracking equipment at VM?
3. How to decrease the changeover time using Avix analysis?
4. Test the readiness of the tracking equipment and gazpacho software?

1.4 Limitations

For this master's thesis, the scope is limited with a time constraint of 20 weeks. Thus, only operator movement is included, and the ergonomic assessment during SMED analysis is excluded. Since the operators are tracked and recorded during the study, their behaviour and work pace may vary from normal. Setting up the tracking and recording equipment takes time, so there will be variations in the start and end times of the process while gathering the AS-IS state data. The project is carried out in collaboration with VM and their customers, so the chosen cases are based on the available situations and are not ideal SMED cases. The project aims to only test the SMED analysis with tracking equipment and provide improvement suggestions; it does not include the actual implementation of the results.

2

Literature Review

2.1 Lean - SMED

The rapidly changing environment is forcing companies to increase their competitiveness using various methods and tools that are helpful in quality improvement. Nowadays, companies have to offer the best possible products and services to develop and improve their position in the market. To achieve that, the companies are implementing lean manufacturing. Lean manufacturing is a production process based on the ideology of maximising productivity while simultaneously minimising waste [8]. The goal of lean manufacturing is to be highly responsive to customer demand by reducing waste and producing services and products at the lowest cost and as quickly as possible for the customer [9].

The roots of lean can be found in the Japanese company Toyota, whose production system is called Toyota Production System (TPS). The fathers of this system were Sakichi Toyoda and his sons, Kiichiro Toyoda and Eiji Toyoda, as well as Taiichi Ohno, a manufacturing engineer [10]. Lean manufacturing was coined by James P. Womack, Daniel T. Jones, and Daniel Roos in their book ‘”The Machine That Changed the World”. Lean manufacturing is regarded as the successor to TPS.

Lean manufacturing gives manufacturers a competitive edge by reducing costs and improving productivity and quality. There are several benefits to implementing lean in an organisation [9]. The quantitative benefits include improving production lead time, set-up time, cycle time, inventory, defects, and overall equipment effectiveness. The qualitative benefits include effective communication, team decision-making, standardised work, improved employee morale, and job satisfaction.

There are five principles of lean, and they are as follows [10]:

1. Specify value: The value is determined from the customer’s perspective, and it relates to how much they are willing to pay for products or services.
2. Map the Value Stream: The second principle involves identifying the processes the product undergoes from the beginning of production to delivery to the customer.
3. Create Flow: The third principle is about removing the factors that act as barriers to the production process. These factors are defined as waste and should be eliminated to improve lead times.

4. Establish a Pull System: The fourth principle states that the manufacturing company should start production where there is customer demand.
5. Perfection: The final principle is that the company should strive towards continuous improvement which is also known as 'Kaizen'.

There are 8 types of waste in lean manufacturing, such as unnecessary transportation, excess inventory, unnecessary movement of people, equipment, or machinery, waiting, overproduction of a product, over-processing, defects that require rework, and unused talent [8]. There are several lean tools, such as 5S, Total Production Maintenance, and Single Minute Exchange of Die (SMED), to improve process efficiency and eliminate non-value-added activities.

The development of new technology, sophisticated high-production systems, and assembly lines has ushered in a new era in manufacturing [1]. Competition, productivity, and profitability are the buzzwords associated with these technological advances. High technology costs correspond to higher rates of productivity and flexibility. Productivity can be enhanced by controlling the quantity of resource inputs and increasing outputs with the same or reduced levels of inputs [1]. Set-up time is one of the vital parameters and is a form of necessary input to every machine. Since set-ups are a sequence of changeover activities that are carried out before starting the production of a product, the productivity of a machine can be increased by reducing its set-up time. Set-up activities are a vital part of the production lead-time of any product, as they affect the overall product cost.

Shorter setups can provide several benefits, and they are as follows [1]:

1. Reduced batch sizes
2. Increased flexibility and capacity
3. Reduced stock and Work-in-Progress (WIP)
4. Reduced lead time and manufacturing cost
5. Enhanced productivity and utilisation rate

Setup time does not refer to only the time for changing the moulds or other tooling, but rather the entire time from stopping the production of the previous product until the production of non-defective parts of the next product [3]. With the broad adoption of the Toyota Production System, the single setup technique that was initially used with industrial press equipment was gradually applied to different kinds of equipment such as injection moulding, casting, and forging equipment [3].

There are basic steps for setup time reduction, and they are described briefly in sequence [3]:

Step 1: Analyse the setup operation.
While beginning the setup time reduction, the negative attitude that further time reduction is not possible as the ''setup operations are special" should be relinquished. It is necessary to analyse the setup again with a fresh mind. The first step in

analysing the setup operation is to identify and select the bottleneck equipment in terms of setup time. Next, gather the layout drawing of the area surrounding the equipment, equipment operation manuals, and setup procedure manuals, if any [3]. Then, using a video tape recorder, a time study is conducted. In this thesis, Avix software is used to perform a time study. The recorded video is uploaded to Avix and analysed carefully.

Step 2: Identify the targets for improvements.
The second step is to focus on improvements. Referring to the time study performed in step 1, questions should be asked, such as, ‘’Why must this task be done?” or "Why cannot I do this when the machine is running?" To find ideas for improvement, the following can be used:

Idea Step 1: Eliminate losses in setup operations: Meaningless tasks can be performed within the setup operation [3]. After the time study, tasks that are found to have no particular meaning and are simply a waste of time should be eliminated. For example, walking unnecessarily should be eliminated. A lean tool called the spaghetti diagram should be used to record the walking of the operator during setup time. This will help to identify and eliminate unnecessary walking and decrease the setup time.

Idea Step 2: Separate internal and external setup work: The tasks that can be done only when the equipment is stopped are internal setup, and the tasks that can be done without stopping the equipment are external setup. It is necessary to identify and separate these tasks during the time study. Without this distinction, all the setup tasks can be considered internal setup tasks, thus leading to the equipment being stopped longer than necessary.

Idea Step 3: Covert internal setup tasks to external setup tasks: In this step, setup tasks that are internal setup tasks should be changed and improved so that they can be performed when the equipment is in operation.

Idea Step 4: Shorten internal and external setup tasks: The internal and external setup tasks should be thoroughly analysed and improved.

Step 3: Finalize the improvement plan
After generating improvement ideas, the relevant ones should be assigned to one of the four levels: easy to implement, requires a small investment, requires a medium investment, or is too idealistic [3].

Step 4: Estimate post-improvement setup time
The time that can be reduced after adopting the improvements should be deducted from the current time, and an estimate of the total setup time after the improvements should be calculated. Create a table showing the total improvement time and total setup time. If there are setup tasks that still take a lot of time even after improvements, generate ideas to reduce them.

Step 5: Arrange the actual implementation
The improvements that are classified into easy to implement, require a small investment, require a medium investment, are too idealistic, and are studied and evaluated. Start immediately to implement the ‘’easy to implement” idea and preparatory work is started for the other improvements.

This thesis scope is to perform a study of the setup operation and suggest improvements. It does not involve implementing the suggested improvements.

2.2 Spaghetti Diagram

A Spaghetti diagram is also called a Spaghetti Model or a Spaghetti Chart and it is a visual flow of an activity or process used to identify areas of improvement [11]. A Spaghetti diagram is one of the most widely used lean tools and helps to reduce some of the 8 types of waste in lean manufacturing mentioned previously.

Usually, operators walk around the shop floor, and sometimes they don’t even know how much distance they walk every day to perform an activity, which leads to low productivity. A spaghetti diagram can be used to reduce unnecessary movement of people and decrease non-value-adding time. The basic purpose of a spaghetti diagram is to understand the current process, or AS-IS state, identify the bottlenecks in the process, and increase efficiency by eliminating waste in the process [11]. A spaghetti diagram works best when an operator does repetitive or similar tasks multiple times.

Spaghetti diagrams are most useful for determining the route of an operator performing an activity or a process. For drawing a spaghetti diagram, a pen, the layout of the shopfloor, an operator, and someone observing the operator are required. A stopwatch and a distance estimator can be used to track the movement of the operator [12]. When the operator is performing a process or an activity that needs to be tracked, he or she should be followed by the observer during his or her normal work. When starting this, the time should be noted or the stopwatch switched on. While the operator walks through the shopfloor, the route should be marked with a pen on the layout of the shopfloor. Arrows can be used to indicate the direction of the operator, and if the operator does something worth remembering, for example, searching for a part, making mistakes, or any other non-value-adding activity, make a note on the layout, including the time [12]. The operator’s movement should be tracked until the completion of the process, and none of the parts should be skipped except during breaks. After completion, make a note of the end time and stop the stopwatch. The spaghetti diagram is complete.

After plotting a spaghetti diagram, the results should be analysed, which is often helpful to estimate the total distance walked by the operator. A rough estimation of the distance walked can be done by taking the distances of the layout and multiplying them by the number of times the operator walked. If a distance estimator or a step counter is used, this can be given to the operator, and it will count the number of steps taken. An average step is around 2.5 feet, and this can be used to calculate the total distance.

After analysing the current state, areas of improvement should be identified. There might be a number of ways to improve the situation, for example, moving parts closer to reduce walking time, changing the layout of the shopfloor, simplifying processes, etc., to name a few. To verify the improved state, or TO-BE state, a spaghetti diagram should be plotted to calculate the total walking distance.

The traditional way of mapping the spaghetti diagram is time-consuming, and mistakes can be made while marking the route on the layout manually. Sometimes the operator makes a lot of mistakes, and it might be difficult to record them all simultaneously while mapping the route. Also, it might be difficult to map the route of the operator and observe the processes done by the operator at the same time.

In the conventional method of drawing a spaghetti diagram, the data needs to be collected manually, which includes recording the time data with a stopwatch, noting the workstations, and simultaneously drawing the operator's movements. The traditional method is a time-consuming method, and the unrealistic representation of the operator's movement may result in long-term mistakes that affect the production performance and the safety of the operators [5]. Real-time location systems in the form of wearable technologies and devices are being widely used in field construction, medical facilities, and industrial sectors due to their ability to gather reliable data in real-time [5]. This reliable real-time data is fed into a cyber-physical system for monitoring the process and supporting decision-making. To speed up the data acquisition and visualise the data for the management to effectively analyse the change-over process, the potential of RTLS in SMED analysis, along with tracking tools and software, is studied in this thesis.

2.3 AviX Software

Avix is a process mapping tool that is designed to help companies improve profitability by streamlining their workflows and increasing efficiencies [13]. Avix has different modules of functionality, method, resource balance, failure mode effect analysis (FMEA), SMED, design for excellence (DFX), and ergonomics. For this thesis, method and SMED modules were used. A recorded video of a process or operation should be uploaded to get started with the Avix analysis.

The Avix Method uses MTM-based standard times to perform time study analysis of work operations. This study provides detailed information on individual work operations timings, and these timings can be used for improvement work, line balancing, and work instructions [13]. Avix SMED is used to separate internal and external steps in a changeover process.

2.4 Tracking Equipment

2.4.1 Real-Time Locating Systems (RTLS)

When compared to conventional lean procedures, the application of digital tools with lean principles offers the potential to speed up the discovery and reduction of waste. The utilisation of indoor positioning systems featuring Real-Time Location Systems (RTLS) presents an opportunity to monitor and record the various operations within a manufacturing environment [14]. Continuous improvement is the foundation of lean manufacturing, and positioning data from RTLS may be used to identify wastes in production processes and eliminate them, as well as standardise jobs and movements to stabilise output quality. RTLS technology enables automated measurement of waste, processing and activity times, and waiting times without the need for laborious and time-consuming manual measurements. The implementation of RTLS in manufacturing settings can yield advantages, as it can furnish data for the generation of dynamic spaghetti and heat map diagrams. These diagrams can subsequently be utilised for the purpose of visualising value streams [14].

RTLS offers a means of monitoring assets within a facility, and when integrated with the Industrial Internet of Things (IIoT), it furnishes technological capabilities for asset management and identification of underlying concerns. Real-time asset tracking can offer numerous advantages in the management of equipment utilisation, inventory levels, and material flow within a manufacturing environment. The information obtained through RTLS can be utilised for process monitoring, thereby furnishing significant insights for process improvement initiatives [15]. RTLS is frequently employed for the purpose of monitoring and locating objects within confined spaces, such as buildings [16]. Indoor tracking systems typically comprise three fundamental components: a tag, reference nodes, and a positioning engine. The tag is affixed to the asset under surveillance and transmits signals to the reference nodes, which are typically stationary in the observed setting [15], [17]. Subsequently, the positioning engine employs a positioning algorithm to approximate the location of the tag [15]. There are multiple RTLSs that employ diverse wireless methodologies in the current market. Most of the RTLSs used in contemporary times employ radio frequency communication as their primary mode of operation. However, alternative technologies such as optical and ultrasound are also viable options. The various methodologies exhibit differences in their precision and responsiveness to the environment. The application of RTLS in industrial settings is subject to certain limitations. This is primarily due to the presence of large machinery, numerous metallic components, wireless equipment, and high levels of ambient noise, all of which can interfere with the signals of the RTLS and lead to inaccurate position estimation [15]. A comparison of different RTLS is shown below in Table 2.1.

The term **Radio Frequency Identification (RFID)** pertains to identification systems that are affixed to objects and employ radio frequency or magnetic fields for communication. RFID technology comprises three primary components, namely the tag, reader, and middleware. The tag refers to the physical apparatus affixed

RTLS technology	Range (m)	Accuracy (m)	Power consumption	Cost
RFID Passive	< 10	Based on configuration	Low	Low
RFID Active	< 100	Based on configuration	Low	Low
BLE	< 10	3-5	Low	Low
UWB	< 30	0.15-0.3	Low	High
US	< 30	0.3	Low	High
IR	< 5	0.5	Low	High

Table 2.1: Comparison of different RTLS

to the object under surveillance, while the reader denotes the equipment capable of identifying tags and retrieving the data encoded therein. Typically, the end-user interacts with the middleware system via software, which subsequently facilitates the transmission of data to various applications. RFID technology enables the retrieval of stored information without the need for direct visual contact. This feature eliminates the need for additional handling or alignment of the objects under surveillance [18]. RFID technology is primarily designed for identification purposes and does not possess an inherent tracking capability. The movement of assets can only be traced through the locations where they are scanned, thereby limiting the real-time tracking capability to specific areas where scanners are installed [15].

RFID tags are classified into three categories based on their functionality: active, passive, and semi-passive. Active RFID tags are energised through an internal power source, commonly a battery that typically has a lifespan of approximately five years. Reflecting a signal from a reader, passive RFID tags function without an internal power source. This feature endows them with an extended lifespan. Semi-passive tags possess an internal power source, which is utilised for specific operations. However, unlike active tags, these tags do not enable communication with readers through their power source. Instead, they rely on the radio signals emitted by the reader, similar to passive tags. The mode of communication between the tag and reader has an impact on the signal's strength and range, as well as the size and cost of the system. Active tags exhibit a greater transmission range of up to 100 metres in contrast to passive tags, which typically have a transmission range of approximately 1-2 metres but are capable of reaching up to 10 metres. Despite the fact that using battery-powered tags entails the use of larger and more expensive tags, it also results in a reduced lifespan for the tags [18], [19].

The **Bluetooth Low Energy (BLE)** protocol is a widely accepted wireless communication standard that employs short-range radio waves to facilitate communication between various devices. The device uses the 2.4 GHz ISM band for its radio signals without the need for a licence. In contrast to traditional Bluetooth, the power consumption of this technology is even lower, enabling the devices to function for an extended period of up to five years prior to necessitating recharging or battery replacement [20]. Bluetooth Low Energy (BLE) is considered a cost-effective option due to its compatibility with a wide range of pre-existing devices, including but not limited to mobile phones. In general, it is observed that BLE technology does not necessitate a line-of-sight (LoS) for signal transmission [20], [21]. This implies that the signal can be transmitted directly from the emitter to the receiver and that communication is not impeded by obstructions such as walls [14]. However, it is crucial to ensure that the beacons are positioned in close proximity to one another within the premises to guarantee optimal accuracy. The maximum transmission range supported by Bluetooth is approximately 100 metres; however, it is commonly used for significantly shorter distances, typically ranging from 5 to 10 metres [20]. The BLE technology has the capability to achieve a tracking precision of approximately 3-5 metres [22].

Ultra Wideband (UWB) is a wireless communication technology that operates over short distances and is capable of transmitting information. The device functions within the frequency range of 0.5 GHz and above; however, in the context of RTLS, it is typically used at a higher frequency of 3 GHz. In general, UWB technology exhibits the capability to traverse through obstructive materials. However, in the context of RTLS that operate at high frequencies, this ability is compromised, necessitating a line-of-sight (LoS) between the tags and reference nodes to achieve a positioning accuracy of a few centimetres. The extent of infrastructure development necessary to address the challenge of non-line-of-sight (NLoS) and achieve the desired level of positioning accuracy is a key determinant of the associated costs and maintenance requirements [15].

Ultrasonic technologies, which rely on the propagation of ultrasound waves and function within the low-frequency spectrum, In contrast to radio frequency technologies, ultrasonic equipment is characterised by distinct nomenclature [23]. Specifically, the ultrasound receivers are denoted as listeners, while the nodes transmitting the signals are referred to as beacons. It is noteworthy that the aforementioned terminology differs from the tags and trackers commonly associated with radio frequency technologies. Typically, the beacons are situated in stationary locations at elevated positions within the vicinity of the tracking zone, while the listeners are affixed to the subject of interest that is undergoing tracking. The beacons emit ultrasonic pulses that are received by the listeners, who subsequently use this information to determine the distances to the beacons and thereby estimate their own position. The ultrasonic systems' architecture can be inverted, whereby the listeners are stationed in stationary locations and the beacons are affixed to the objects that are being monitored [24]. The ultrasonic equipment is deemed more appropriate for applications at room level due to the inability of ultrasound waves to penetrate walls. The precision of the measurements may be influenced by the presence of ultrasound echoes that bounce off various surfaces, including metallic ones [23].

The detection and tracking of objects are accomplished via **Infrared Radiation (IR)** technologies, which employ electromagnetic waves in the infrared spectrum area. The proper functioning of the equipment necessitates an unobstructed line of sight between the transmitter and receiver [25]. This technology is most appropriate for applications at the room level, as it lacks the ability to penetrate walls [23]. In comparison to radio frequency technologies, IR technology overcomes several interference issues. However, it is susceptible to interference caused by objects obstructing the line of sight and intense light sources like fluorescent light and sunlight. Various system architectures exist for IR positioning, with varying levels of precision. Certain architectures offer accuracy up to the millimetre level, while others are limited to providing only a rough accuracy of a few metres [23].

2.4.2 Tracking at Virtual Manufacturing

2.4.2.1 Marvelmind

The Marvelmind System employs ISM band technology in conjunction with ultrasonic beacons that are offered at various frequencies. Various models of beacons are accessible, and the design of both the beacons and listeners can be modified to suit diverse environments and use cases. It is necessary to instal multiple beacons or listeners on the walls or ceiling of the premises in order to establish the systems. The Marvelmind system is also suitable for outdoor applications [26].

The Marvelmind indoor navigation system consists of a network of stationary ultrasonic beacons that are interconnected via a radio interface in a license-free band, one or more mobile beacons installed on objects to be tracked, and a modem connected to a PC to provide a gateway to the system [26]. The location of the mobile beacon is calculated based on the propagation delay of ultrasonic pulses between the stationary and mobile beacons using a trilateration algorithm [26].

The stationary beacons are mounted on walls or ceilings with the ultrasonic sensors facing down. The position and orientation of the beacons should be chosen in a way that provides maximum ultrasonic signal coverage. These beacons emit and receive ultrasound. The diagram of the transmitting and receiving of ultrasound is shown below in Fig. 2.1.

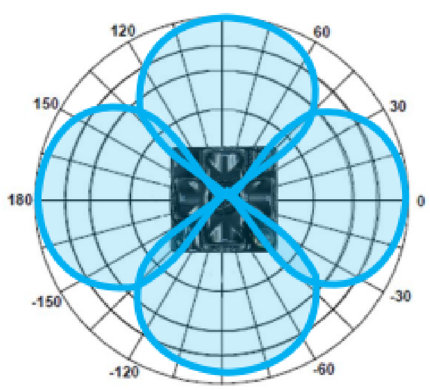


Figure 2.1: Transmitting and receiving of ultrasound

The mobile beacons are placed on the object that needs to be tracked, for example, on the helmet of an operator. The sensors of the mobile beacon should not be covered with anything, as this might reduce the strength of the ultrasonic signal. The mobile beacon can only receive ultrasound signals and cannot transmit them. The receiving diagram is shown below in Fig. 2.2.

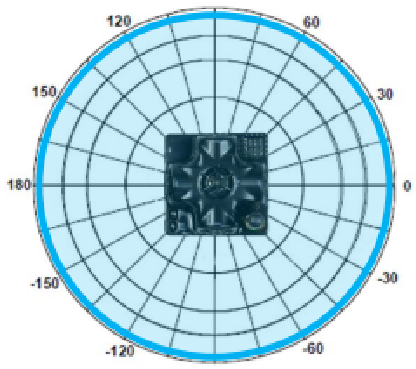


Figure 2.2: Receiving of ultrasound

The modem is the central controller of the system and should always be powered when using the navigation system. The modem is used to set up and monitor the system and can be placed anywhere within radio coverage. A picture of the Marvelmind system with four stationary beacons, one mobile beacon and one modem is shown below in Fig. 2.3. The Marvelmind tracking devices used for this thesis is shown below in Fig. 2.4 where the cap and the vest are the moible beacons.

Figure 2.3: Marvelmind tracking devices

Gazpacho software with its analysis features such as spaghetti and heat map visualisation, geofencing, defined work areas and KPIs on the dashboard, defined standard paths, comparing data sets, MTM and sequence integration. According to VM, the above-mentioned features of Gazpacho help in identifying the following values: 1. Evaluate if the operator is working on pace with the standard task time 2. Evaluate if the operator is following the standard sequence of the operations 3. Evaluate if the forklifts are following the time schedules/takted logistics and standard routes over time 4. Evaluate the capacity requirements from the operators and resources'

Figure 2.4: Marvelmind tracking devices

points of view 5. Follow the lead time and logistics pick-up time between different workstations or buffer stations 6. Evaluate the lead time between operator sign-off and logistics pickup 7. Evaluate the time takted line where the operators are doing the sign-offs and the last sign-off that's used to take 8. Human interactions with forklift movements area i.e important for analysing safety 15 2
The main requirement for optimal performance of the navigation system is that there should be an unobstructed line of sight (hearing) between a mobile beacon and 3 or more stationary beacons within 30 metres. The Dashboard app is used for setting up and tuning the system. This app allows you to get tracking data. The steps for setting up the Marvelmind indoor navigation system are shown below in the appendix 1.

2.4.2.2 Gazpacho

Gazpacho is a tracking analysis software based on Virtual Twin. The development of the Gazpacho Tracking analysis tool was initiated by VM in November 2020 in collaboration with Scania. The software uses positioning and tracking-based inputs to bring out the issues and challenges in the system. Gazpacho allows the population of in-data from the manufacturing systems such as Siemens Teamcenter, Delmia 3DExperience, PTC MPM Link, AviX, ERP data or Microsoft Excel, Microsoft Project etc. Gazpacho has integrated partnerships with some tracking and positioning hardware service providers like Quuppa, Eliko, Marvelmind, and Zozio. Marvelmind also has a manual feature where you can draw, and it will do the calculations in metres and time in zones.

The positional data collected from the tracking equipment can be processed in the Gazpacho software with its analysis features such as spaghetti and heat map visualisation, geofencing, defined work areas and KPIs on the dashboard, defined standard paths, comparing data sets, MTM and sequence integration. According to VM, the above-mentioned features of Gazpacho help in identifying the following values:

1. Evaluate if the operator is working on pace with the standard task time
2. Evaluate if the operator is following the standard sequence of the operations
3. Evaluate if the forklifts are following the time schedules/takted logistics and standard routes over time
4. Evaluate the capacity requirements from the operators and resources' points of view
5. Follow the lead time and logistics pick-up time between different workstations or buffer stations
6. Evaluate the lead time between operator sign-off and logistics pickup
7. Evaluate the time takted line where the operators are doing the sign-offs and the last sign-off that's used to take
8. Human interactions with forklift movements area i.e important for analysing safety

3
Method

For learning how to use the Marvelmind beacons, the operating manual provided by Marvelmind was studied. The operating manual was used to create a document called ''How to Get Started with Marvelmind" for easier use by the employees at Virtual Manufacturing. The document simplifies the instructions in the operating manual and helps to start tracking without any previous knowledge of the device. The steps in the document can be found in the appendix.

The tracking equipment was initially set up at VM to learn how to efficiently track movement. First, the stationary beacons were set up to track in a small area with two stationary beacons and a mobile beacon to test the equipment. After achieving good tracking results, the area was expanded to the entire office using several stationary beacons. After several trials, goods tracking was achieved for the entire office. Fig. 3.1 shows the tracking of the VM office layout.

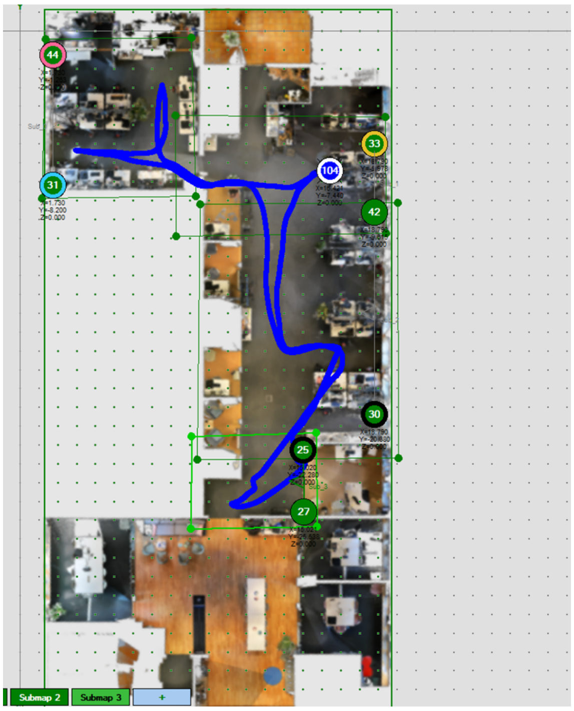


Figure 3.1: Tracking at VM office

For testing the Marvelmind devices, consent was needed from the union and the operators. A detailed presentation was made to all the stakeholders involved to explain how and why the test was being conducted. The work for testing the method was started, and the visit was planned after consent was approved by the union and the operators.

For testing the Marvelmind beacons in an industry, Haglund Industri AB was chosen. The press break machine in the factory was used to test if the beacons functioned properly. This press-break machine can be considered an environment with mild noise. The stationary beacons were set up on the walls. Setting up the beacons takes some time as the place to set them up needs to be decided, we need to observe the movement of the worker to decide the places to track, and we need to put the beacons up on an elevated area. Also, the Marvelmind beacons were tested in an extremely noisy environment in Haglund, which is the sheet metal punch machine. During the test, the results were not accurate due to noise disturbances. The reading from the Marvelmind cap was random due to these noises. When the distance between the stationary beacons was reduced, the readings from the mobile beacon were fairly accurate. During our testing, it was found that the Marvelmind beacons do not function properly in an extremely noisy environment. First, tracking was done by us by wearing the Marvelmind cap to test if the tracking is functioning and if there is a smooth transfer between the handover zones. Once the tracking results were accurate, the operator wore the Marvelmind cap and performed the changeover process. Simultaneously, the operator was recorded using a video camera for analysis later in Avix. Permission was obtained from the operator before using the tracking device and video camera.

As explained above, the Marvelmind tracking equipment relies on ultrasonic technology to collect the movement data of the operators. However, this technology has many drawbacks related to independence and accuracy. So, the proposed methodology shall overcome these gaps to get a reliable spaghetti diagram and heat map on the Gazpacho software from the tracked data. The automatic data acquisition of the operator's movement during the changeover processes relies mainly on the positioning of Marvelmind stationary beacons and a good line of sight between the wearable mobile beacons without any noise disturbance.

Transferring the data starts with stationary beacons installed on the shop floor and the ultrasound connection between the mobile beacons attached to the body of the operator that detects the movements during the changeover process. Then, this data (which refers to the identified place or position) gets transferred through ISM band technology to the Marvelmind modem, which is connected to a PC through the USB port. The position, status, and activity of the stationary beacons and the mobile beacons can be viewed and monitored through the Marvelmind dashboard software. Once the tracking session is completed, the tracking data is saved and stored on the PC in a .csv format file. The tracked data from Marvelmind is inserted into the Gazpacho software to obtain interactive spaghetti and heat map diagrams. The whole framework of the tracking method is shown in Fig. 3.2.

This tracking system provides the practitioners with informative data that can sup-

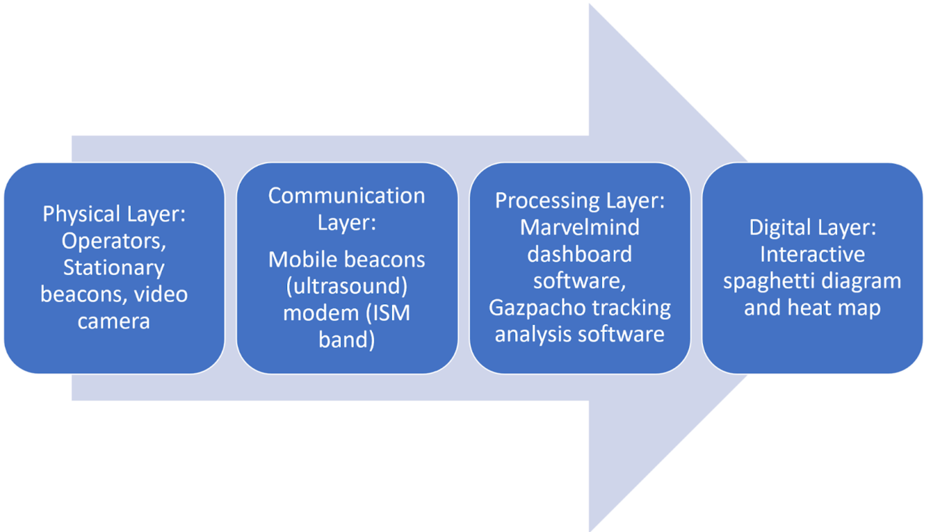


Figure 3.2: Framework of the tracking method

port the analysis process that deals with the movement of the operator and the time spent on each movement with high accuracy and independence. For the system to work well in the industrial shopfloor and environment, the following reflective practice and experimental procedure must be followed:

1. Identifying the facility layout, including the equipment, machines, stores, workstations, etc
2. Identifying the changeover activities, including manual material handling, manufacturing processes, and other most important operations during the changeover
3. Installing stationary beacons in the right locations on the shopfloor such that the operators' movements during the changeover are fully tracked
4. Make the operator wear the mobile beacon cap on his or her head or a mobile beacon vest. Each mobile beacon has an identified code to facilitate data acquisition and analysis
5. Connecting the Marvelmind modem to the PC to configure the connectivity and ensuring there is good connectivity and synchronisation between stationary and mobile beacons on the Marvelmind dashboard software
6. As soon as the worker starts the activities, the tracking is started on the Marvelmind dashboard software, and the operator is recorded with a video camera
7. Acquire and analyse the tracking data in the Gazpacho software to generate a spaghetti diagram and heat map.

Fig. 3.3 below explains the reflective practice procedure that can be applied for tracking the operators during the changeover process to generate an interactive spaghetti and heat map diagram.

Upon gathering all the necessary data during AS-IS state tracking, the data is anal-

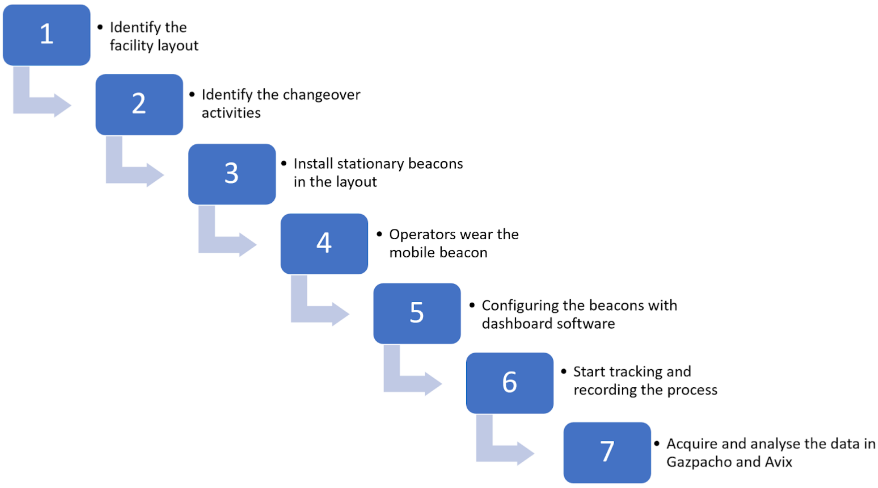


Figure 3.3: Reflective practice procedure to generate spaghetti and heat map diagram

ysed in Gazpacho and Avix. In Gazpacho, the log file is imported to generate a spaghetti diagram, and in Avix, a breakdown of activities is done. Both results are compared against each other to identify improvements.

4
Results

4.1 IAC Group

The first company where the designed method was tested was IAC Group, Sweden. IAC Group is a leading global supplier of powertrain-agnostic automotive interior components and solutions to all major OEMs.

The tracking of the operator's movement was carried out for an injection moulding machine. Initially, a semi-structured interview was conducted with the Continuous Improvement Engineer at IAC Group. The questions and answers can be found in the appendix 3. A two-day visit to the facility was planned, where on the first day, the changeover process was observed, the location of the stationary beacons was decided, and the beacons were set up and tested. On the second day, the actual tracking data was gathered, where the operator's movements were recorded using a camera and the location of the operator was obtained by the mobile beacons worn by the operator to track their movement. This was done simultaneously by starting the camera and Marvelmind beacons at nearly the same time. A picture of the Marvelmind tracking data can be found below in Fig. 4.1.

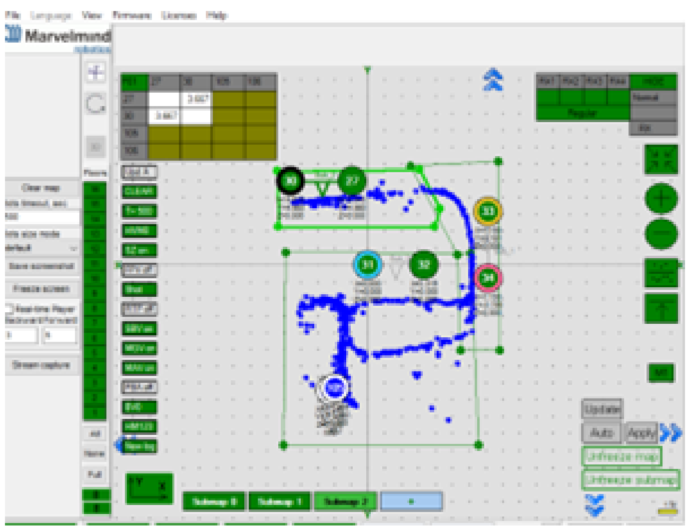


Figure 4.1: IAC marvelmind tracking data

Tracking was done for the changeover process at IAC Group involving an injection moulding machine. The products produced by this machine are instrument panel carriers, door panel main carriers, door panel frames, and door pocket carriers. In the changeover process recorded, the moulding die was producing the door panel main carrier.

For this changeover, there were two setters involved. A summary of the activities involved in the changeover process is as follows:

1. Machine module – Last piece operation, open door, tool detaching
2. Releasing all the fluid connections - compressed air, hot and cold water and hydraulics
3. Unpluging all the connections and hoses
4. Attaching the ends of the die and disconnecting the electromagnet
5. Bringing down the crane hook, aligning and attaching to the tool
6. Crane operation
7. Lifting the next tool, aligning and placing inside the machine
8. Connecting all the hoses and connections
9. Heating and fluid supply checking
10. Changing the grippers of the robotic arm
11. Waiting for heating of the die
12. Checking for issues (usual are electrical signal, fluid supply, heating, plastic injection, gripper pneumatic error)
13. Trial runs

4.1.1 AS-IS State

In the AS-IS state of Avix analysis, the recorded video of the operators' movements was broken down into smaller activities and classified into loss, waiting, or required tasks in Avix. During the classification, notes were written down in Avix. The notes included comments, suggestions, and problems that would help in decision-making while classifying the TO-BE state. Also, in the SMED module, the tasks were classified into internal and external activities depending on the current changeover process.

Two setters, operator 1 and operator 2, were involved in the changeover process. The changeover time was 58.5 minutes, and the total changeover time considering both operators was 116.85 minutes. The tasks classified as "loss" time were 15.82 minutes, which takes up 14% of the total time; "waiting" time was 34.19 minutes, which was 29% of the total time; and "required" time was 66.83 minutes, which takes up the remaining 57% of the total time. The Avix AS-IS result of both operators is shown below in Fig. 4.2. Considering operator 1, the "loss" time was 7.57 minutes, the "waiting" time was 18.79 minutes,and the "required" time was 31.99 minutes. The total non-value-adding tasks add up to 58.35 minutes. Operator 1's AS-IS result is shown below in Fig. 4.3. The second operator's "loss" time was 8.26

minutes, the "waiting" time was 15.41 minutes, and the "required" time was 34.84 minutes. Operator 2's AS-IS result is shown below in Fig. 4.4. Both operators worked simultaneously, so the total changeover time was 58.50 minutes.

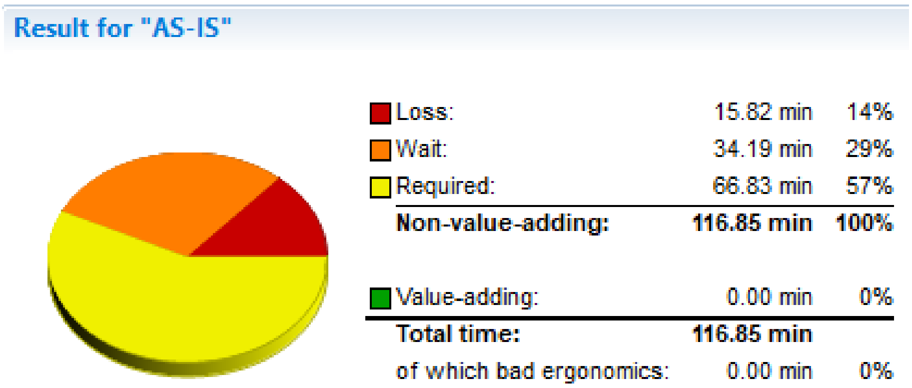


Figure 4.2: Avix AS-IS results

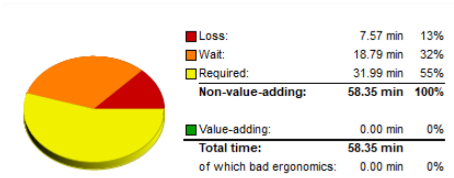


Figure 4.3: IAC Avix operator 1 AS-IS results

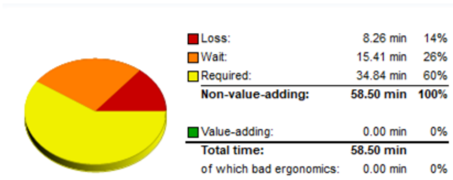


Figure 4.4: IAC Avix operator 2 AS-IS results

4.1.1.1 Loss

Most of the time classified as "loss" was due to the walking of the operators. The total walking time of both operators was 15.26 minutes, and the walking was classified into three categories: walking for locking, walking inside the machine, and general walking. Walking for locking took a lot of time because both operators needed to lock their keys before entering the machine. This was due to safety reasons. General walking took around 10.30 minutes as the operators walked during crane operation, and for connecting and disconnecting the hoses, the operators needed to walk to the back of the machine. The remaining "loss" time of 0.24 minutes was spent on searching for tools and parts and personal time.

"Walking for locking" was when the operator walked to lock their key before entering the machine. "Walking inside the machine" was when the operator walked inside the machine and "general walking" was the remaining walking where the operator walked to operate the crane, pick up the checklist, etc.

4.1.1.2 Wait

The total “waiting time” in the AS-IS state of Avix analysis was 34.19 minutes, as shown above in Fig. 4.3. Most of the “waiting time” was due to the heating up of the die, which took around 30 minutes. The remaining “waiting time” was when one operator waited for the other operator while he was operating the crane.

4.1.1.3 Required

The required time was 66.83 minutes, and the tasks involved were module operation, plugging and unplugging the hoses, crane operation, cleaning the moulds, and performing trail runs.

4.1.2 AS-IS State Tracking Results

As discussed previously, the movements of the two operators involved in the changeover process were tracked. In order to track the movement, the stationary beacons were set up as shown in Fig. 4.5. In this process, six stationary beacons and two mobile beacons were used to track the operators. The tracking area was divided into three zones, with two stationary beacons in each zone. The division of tracking areas and the stationary beacon placement can be seen in Fig. 4.5. Several challenges were faced while tracking the movements of the operators during the process, which prevented the complete tracking of the operators movements. The operators’ movements inside the machine couldn’t be tracked as the stationary beacons couldn’t be set up there because of the strong magnetic field of the dies. Also, there was no clear line of sight from the beacons set up outside the machine. The second challenge was tracking in the robotic cell area, where access was denied for safety reasons. The third challenge was no clear line of sight while operating the crane as the large moulding die blocked the line of sight path between the mobile beacons on the operators and the stationary beacons. Considering all these challenges, the stationary beacons and the zones were set up to obtain the maximum tracking data possible.

The tracked data from the Marvelmind dashboard was obtained in the form of a .csv log file, which was further analysed using the Gazpacho tracking analysis software. Even though the floor plan of the changeover area was used in the Marvelmind dashboard software for creating the tracking and the handover zones, the movement of the operators, which is the spaghetti diagram obtained by processing the tracked data in the Gazpacho software, was not aligned and oriented. The orientation of the spaghetti diagram was done manually by adjusting the X and Y coordinates and rescaling the size of the obtained spaghetti diagram to fit the floor plan. Heat map along with spaghetti diagram of both the operators during the changeover is shown in the Fig 4.6.

With several analysis features available in the Gazpacho software, the total time

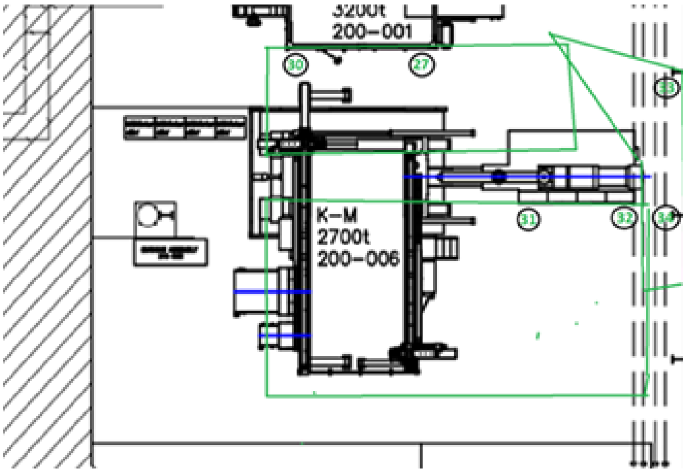


Figure 4.5: Marvelmind stationary beacon placement at IAC

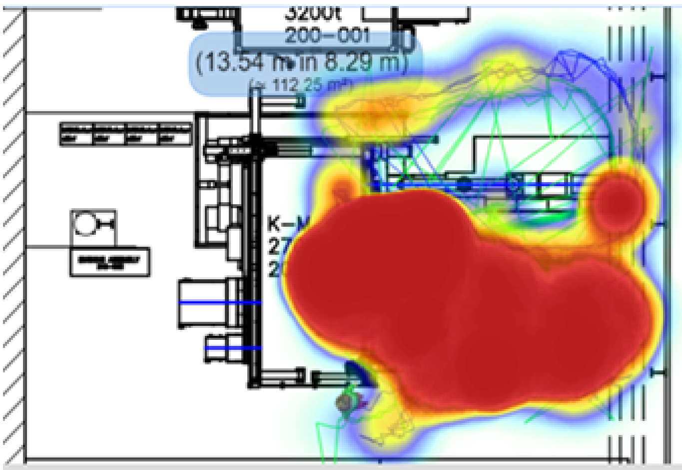


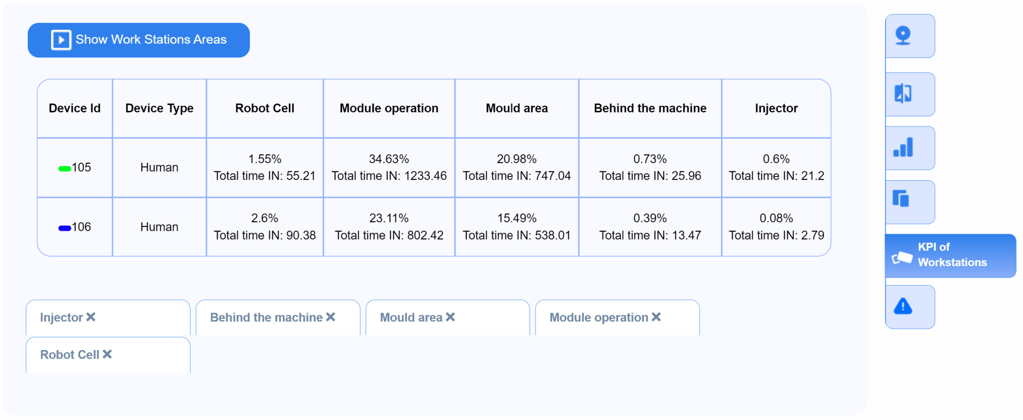
Figure 4.6: Gazpacho heat map with spaghetti

spent by the operators was classified into standing-still time, sleeping time, and moving time based on the tracking data. Also, the total distance travelled by the operators during the changeover was measured. Table 4.1 shows the comparison of the time spent and distance travelled by the two operators during the changeover.

Tracking results IAC		
Device ID	Beacon 105	Beacon 106
Device Type	Human	Human
Standing still time	21.22 min = 35.75%	20.33 min = 35.12%
Sleeping times	18.21 min 32.08 %	19.25 min 32.44%
Moving time	19.07 min 32.12 %	18.77 min 32.44%
Distance	1149.95 m	974.16 m
Distance/hour	1.162 km/hr	1.01 km/hr

Table 4.1: Comparison of time spent and distance travelled by the operators

The Gazpacho software allows you to divide the spaghetti diagram into areas of interest to obtain KPIs. In order to test the functionality of this feature, the tracked data in the floor plan was divided into different zones. The different zones and the time spent by the operators in these zones are shown in Fig. 4.7. This feature was helpful in identifying where the operator spent the most time during the changeover process, which was valuable input while prioritising the areas and considering the improvements. As shown in Fig. 4.8, operator 1 with ID 105 and operator 2 with ID 106 spent the most time near the machine module, followed by the mould area.



Device Id	Device Type	Robot Cell	Module operation	Mould area	Behind the machine	Injector
105	Human	1.55% Total time IN: 55.21	34.63% Total time IN: 1233.46	20.98% Total time IN: 747.04	0.73% Total time IN: 25.96	0.6% Total time IN: 21.2
106	Human	2.6% Total time IN: 90.38	23.11% Total time IN: 802.42	15.49% Total time IN: 538.01	0.39% Total time IN: 13.47	0.08% Total time IN: 2.79

Figure 4.7: KPI of workstations

To test the MTM and sequence integration features of the Gazpacho software, the AS-IS state analysis file where the tasks of the operators were classified as required, loss, and waiting in the Avix software was imported to the Gazpacho software. This feature of the Gazpacho software visualises the animation of the movement of the operators in the spaghetti diagram while highlighting if the task is required, loss or waiting. The visualisation included an animation of the sequence of tasks carried out by the operators. Figs. 4.8 and 4.9 show the animation panel with the task timeline and the task with the Gantt view, respectively. Method studies with spaghetti to show where the activities are being performed and visualising waste in geographical locations help in highlighting the waste in the process easily and help in decision-making for improving the process. In this case, a complete synchronisation between the movement of the operators and the method study data in the animation panel could not be achieved as the tracking data did not include the complete movement of the operators and also included a lot of outliers.

As discussed previously, there were several challenges while tracking the data from Marvelmind, such as beacon placement and poor line of sight, which resulted in poor tracking accuracy. As a result, the gazpacho software's spaghetti diagram also included a random representation of the operators' movements in addition to their complete movements. The reason for the random representation of operator movement was because of the outliers in the collected data when the operators moved from one tracking zone to the other and the latency in connection between the mobile beacon and the stationary beacons. To have a better understanding of the

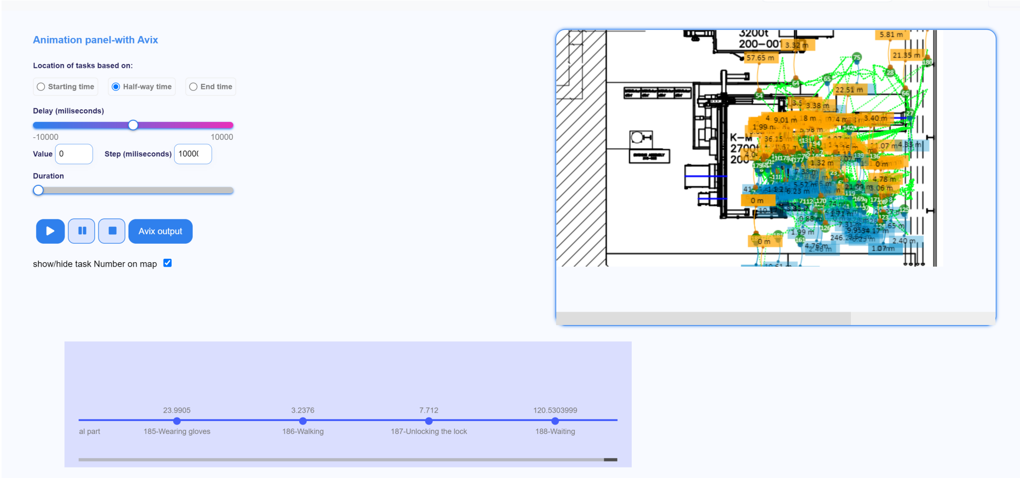


Figure 4.8: Avix animation panel with task timeline

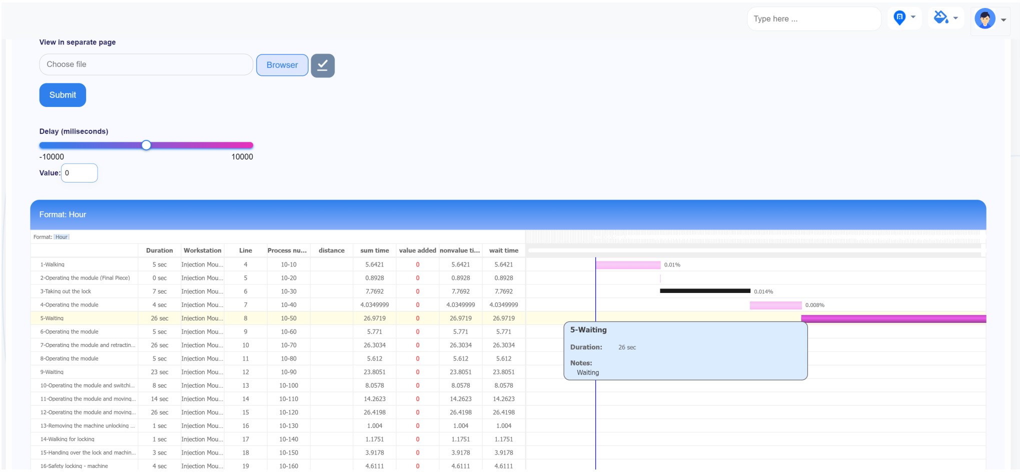


Figure 4.9: Tasks and Gantt view

operators' movements, the manual spaghetti drawing options of the gazpacho software were used. The manually drawn spaghetti diagram and heat map are shown in Figs. 4.10 and 4.11. The manual spaghetti diagram was drawn on the Gazpacho software by referring to the movements of the operators recorded for the Avix analysis. The manual drawing function has interactive features where the time can be entered for the task performed by the operators and the estimated distance walked by the operators.

A comparison of the results obtained from Gazpacho and Avix analysis was done for better identification of the waste in the process, which is mainly operator walking. In Avix analysis, the walking distance is calculated by multiplying the steps taken by the operator by 0.7 metres. This calculation is according to the MTM standards, according to which the average distance of a human step is 0.7 metres. The comparison of the results is shown in Table 4.2. A big difference in distance travelled and moving time by the operators was found between Gazpacho results and Avix results. The Marvelmind tracking device has an accuracy of +/- 2cm and is worn on the

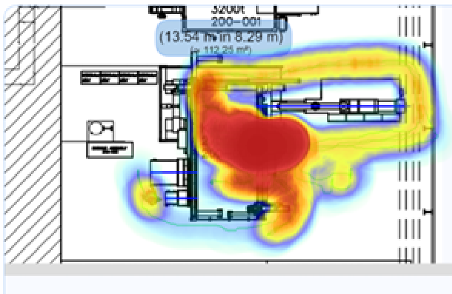


Figure 4.10: Manual spaghetti with heat map of operator 1

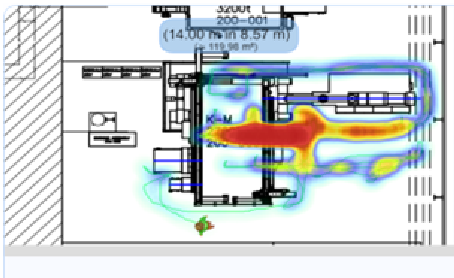


Figure 4.11: Manual spaghetti with heat map of operator 2

head of the operator. Every small head movement was considered for the distance travelled and moving time. Thus, the distance travelled data from the Gazpacho results cannot be considered for method studies and process improvement without filtering out the unnecessary movements. A suggestion was given to the Gazpacho software development team to filter the movements that were less than 0.5 metres.

Gazpacho Results		
	Moving time	Distance
Operator 1	19.07 min	1149.95 m
Operator 2	18.77 min	974.77 m

Avix Results		
	Moving time (walk)	Distance (walk)
Operator 1	8.02 min	336.84 m
Operator 2	7.07 min	296.4 m

Table 4.2: Comparison of Gazpacho and Avix results

4.1.3 TO-BE Improvements

While analysing the AS-IS state of IAC Group, several improvements were found. The improvements were divided into TO-BE Improvement 1, Improvement 2, and Improvement 3.

4.1.3.1 TO-BE Improvement 1

While working on the Avix analysis, it was found that the operator waits for the other operator to complete his task, and then both operators perform the same operation together. For example, when plugging out the connections and changing the robot grippers, both operators did these operations together, and this took a lot of time. So, changing the task sequence and doing these tasks in parallel can reduce the changeover time. If one operator completes plugging out the connections, the other operator should change the robot grippers.

Moreover, the operators spent some time locking the machine key for safety reasons. They used a traditional lock and key for this operation, and sometimes the operator had a hard time finding the correct key. The lockbox was situated at the side of the machine, as shown under appendix 2, and some time was spent walking to it. So, to reduce the changeover time, the safety lockbox position should be changed to a position right below the module so that the machine key can be removed and placed inside the lockbox quickly. Also, an RFID-based lockbox could be used to avoid spending time searching for the lock or the key. The operator can open the box quickly and easily by using this, and a picture of the RFID lockbox is shown under appendix 2.

The connectors used for the machine had some wear and tear as they were plugged in and out quite a lot. During the changeover, there was a connection issue, and the operator had to plug out and plug in to correct this. This may be due to the fact that the connectors were not parked properly after unplugging. So, using single-action multi-coupling connectors could help solve the connection issue and the wear and tear issue. A figure of the single-action multi-coupling connectors is shown under appendix 2.

The last improvement in Improvement 1 is to use laser guidance for faster crane operation. Quite a lot of time was spent by both operators aligning and placing the die inside the machine. So, a laser guide could be attached at the bottom of the die, and that can indicate if the alignment is correct. An example of laser guide for aligning is shown under appendix 2.

4.1.3.2 TO-BE Improvement 1 Results

After considering the above-mentioned suggestions for the TO-BE state, the changeover time decreases to 42.63 minutes, which is 15.87 minutes less than the AS-IS state. This is a 27% reduction in the changeover time when compared to the AS-IS state. The Avix TO-BE Improvement 1 results are shown below in Fig. 4.12. Improvement 1 results for operator 1 and operator 2 are shown in Figs. 4.13 and 4.14 respectively. The tasks involving “loss” time are 5.75 minutes, which is the total walking time of the operators and is 9.51 minutes less than the AS-IS state. "Walking for locking” is 2.02 minutes; “walking inside the machine” is 2.94 minutes; and “general walking” is 10.30 minutes. The total “wait” time is 33.1 minutes, of which the majority is due to the heat-up of the die, and the “required ”time is 46.22 minutes.

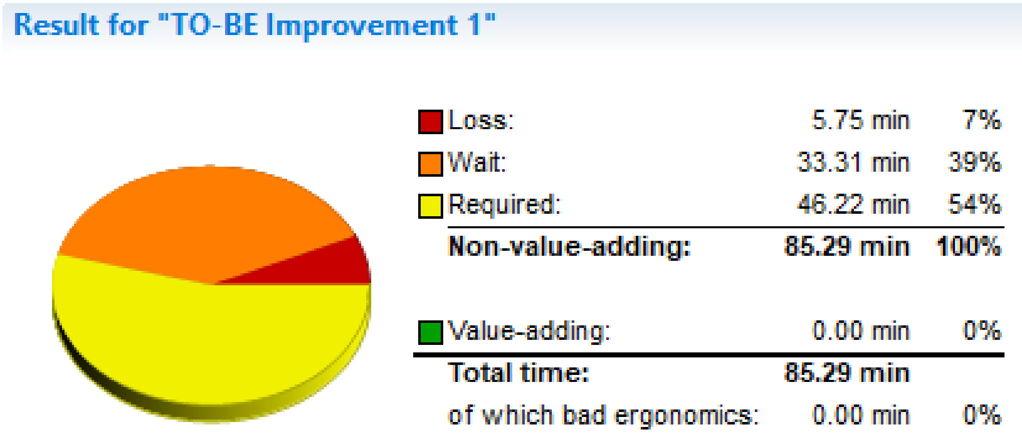


Figure 4.12: IAC Avix TO-BE Improvement 1 results

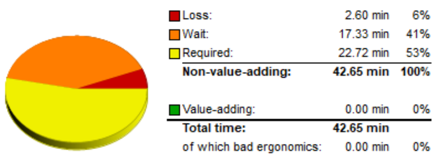


Figure 4.13: IAC Avix operator 1 TO-BE improvement 1 results

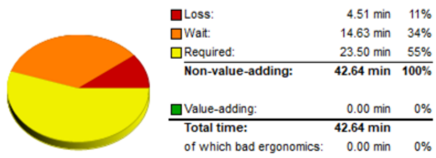


Figure 4.14: IAC Avix operator 2 TO-BE improvement 1 results

4.1.3.3 TO-BE Improvement 2

As observed in the Avix analysis, plugging in and plugging out of the connectors takes a lot of time, and if this is reduced, a lot of time could be saved during the changeover. To reduce the amount of time spent plugging in and out the connectors, automated plugging in and out of the hoses could be used. The picture of the automated connector connection is shown under appendix 2.

4.1.3.4 TO-BE Improvement 2 Results

After considering the suggested improvements for Improvement 2, the changeover time decreases to 38.15 minutes, which is a 35% time reduction compared to the AS-IS state. The total “loss” time is 3.35 minutes, which is again only the walking. The “wait” time is 33 minutes, which is again the time for heating up the die and the “required” time reduces to 39.96 minutes. The Avix To-Be Improvement 2 results are shown below in Fig. 4.15. Figs. 4.16 and 4.17 shows the TO-BE Improvement 2 for operator 1 and 2 respectively.

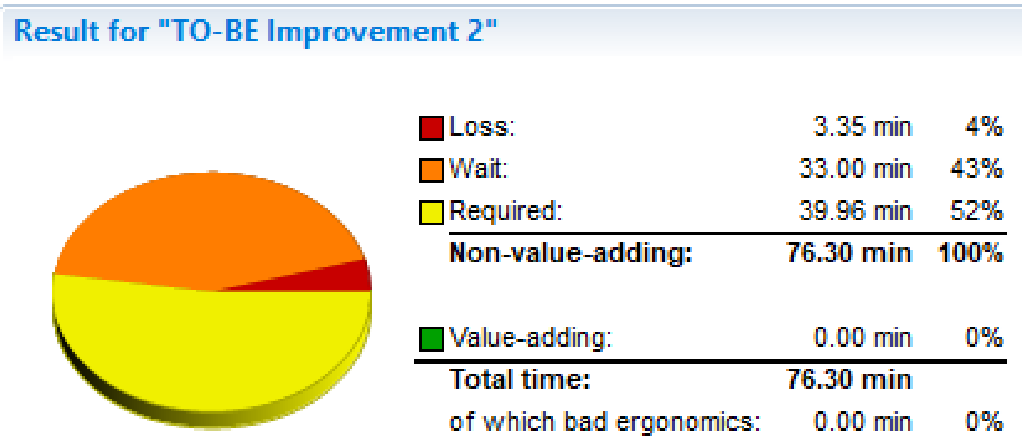


Figure 4.15: IAC Avix TO-BE Improvement 2 results

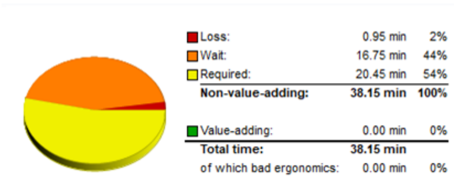


Figure 4.16: IAC Avix operator 1 TO-BE improvement 2 results

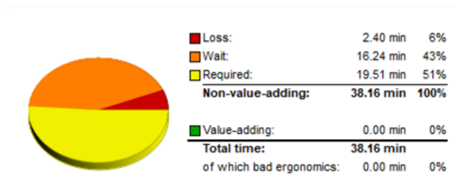


Figure 4.17: IAC Avix operator 2 TO-BE improvement 2 results

4.1.3.5 TO-BE Improvement 3

Still, the ”wait” time is quite long and needs to be decreased. Since the majority of this “wait” time was due to the operator waiting for the die to heat up, an external pre-heating tool could be used. This reduces the “wait” time by over 17 minutes, thus reducing the changeover time.

4.1.3.6 TO-BE Improvement 3 Results

The changeover time decreases to 28.12 minutes after considering the TO-BE Improvement 3 suggestions, which is a 52% time reduction compared to the AS-IS state. The total “loss” remains 3.35 minutes, the “wait” time decreases to 15.41 minutes and the “required” time is 37.52 minutes. The Avix results are shown below in Fig. 4.18. Figs. 4.19 and 4.20 shows the TO-BE Improvement 3 for operator 1 and 2 respectively.

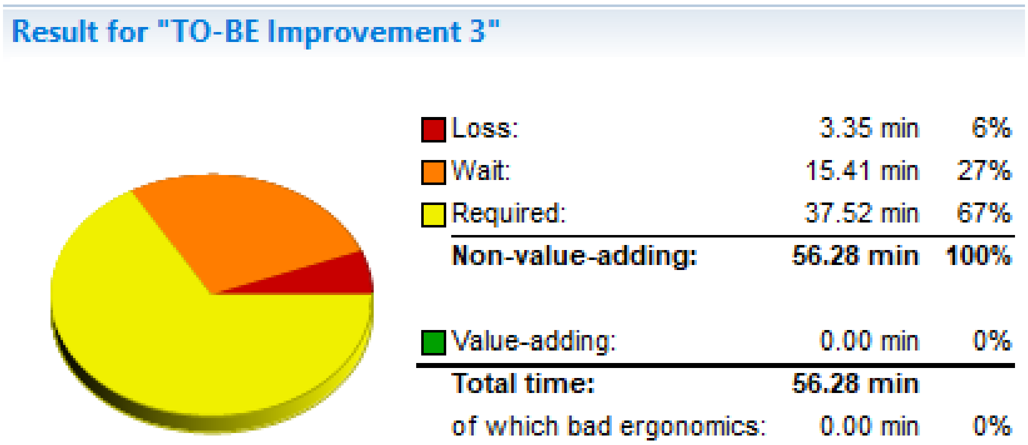


Figure 4.18: IAC Avix TO-BE Improvement 3 results

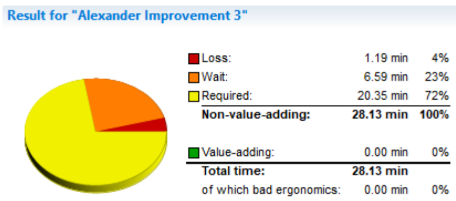


Figure 4.19: IAC Avix operator 1 TO-BE improvement 3 results

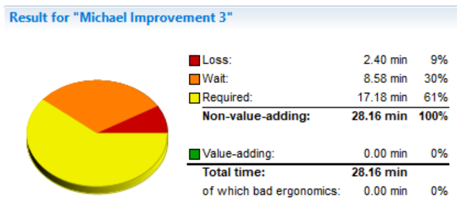


Figure 4.20: IAC Avix operator 2 TO-BE improvement 3 results

The SMED chart showing all the AS-IS and TO-BE states with all the improvements is shown in the appendix 2.

4.1.3.7 Financial Impact

The financial impact of all the improvements is shown below in Table 4.3. Detailed calculations are shown under appendix 3.

	AS-IS state	Improvement 1	Improvement 2	Improvement 3
Single changeover time (min)	58.50	42.65	38.16	28.16
Changeover time/year (hr)	202.80	147.33	132.28	97.62
Increased capacity time (hr)	-	55.47	70.52	105.18
Additional products (no.)	-	3618	4599	6860
Annual savings (SEK)	-	90,450	114,975	171,500

Table 4.3: IAC financial impact of all improvememts

4.2 Bror Tonsjö

The second company to test the method was Bror Tonsjö. Bror Tonsjö is a full-service supplier for all machining and processing needs. The same procedure as mentioned above for the IAC Group was followed. A semi-structured meeting was conducted with the production supervisors, and the information gathered can be found in the appendix 3. The machine that was used for tracking was not under regular production as it was stopped for a few weeks due to a breakdown and was repaired a few days prior to the changeover, which was recorded and analysed.

For the AS-IS state, the recorded video of the operator's movement and the tracking data were analysed using Avix and Gazpacho software. In Avix, all the tasks were classified as loss, waiting, or required. Similar to the IAC group, notes were written down in Avix during classification.

A summary of the changeover procedure at Bror Tonsjö as observed during the visit was as follows:

1. Removal of previous process raw material from the conveyor
2. Getting the next process raw materials
3. Changing of turret tools and chuck jaws
4. Changing robot grippers
5. Loading part fixture and raw material on the conveyor
6. Trial runs
7. Quality inspection with CMM

4.2.1 AS-IS State

The total changeover time as analysed in Avix was 239.24 minutes, but this includes an error time of 61.23 minutes. The Avix AS-IS result with error is shown below in Fig. 4.21. This was because the machine had a breakdown and was repaired. The error involved machine referencing, and this error-fixing time was eliminated in the analysis. In the Avix AS-IS result with error, tasks involving loss time was 77.40 minutes, 61.23 minutes was error fixing time, waiting time was 95.31 minutes, and required time was 66.53 minutes.

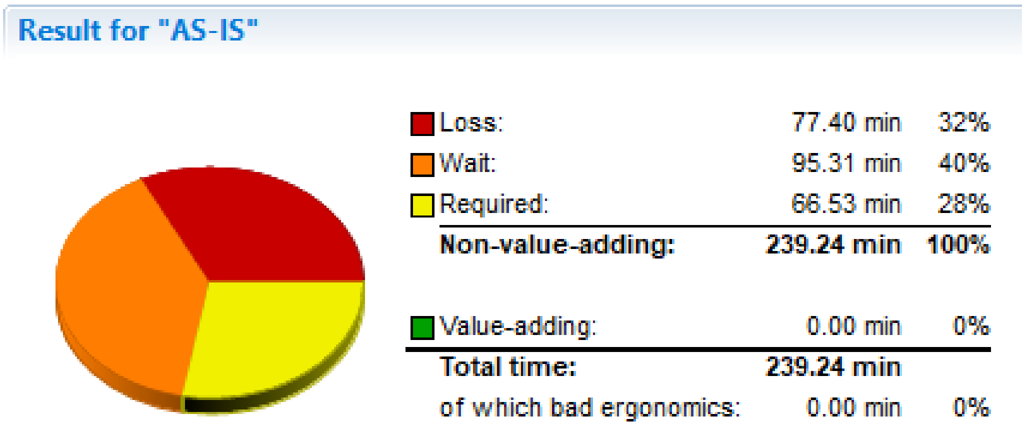


Figure 4.21: Bror Avix AS-IS results

So, the total changeover time was 178.01 minutes. The tasks classified as “loss” time were 16.17 minutes, which takes up 9% of the total time; “wait” time was 95.31 minutes which was 54% of the total time; and the required time was 66.53 minutes which takes up the remaining 37% of the total time. The Avix AS-IS result without error is shown below in Fig. 4.22.

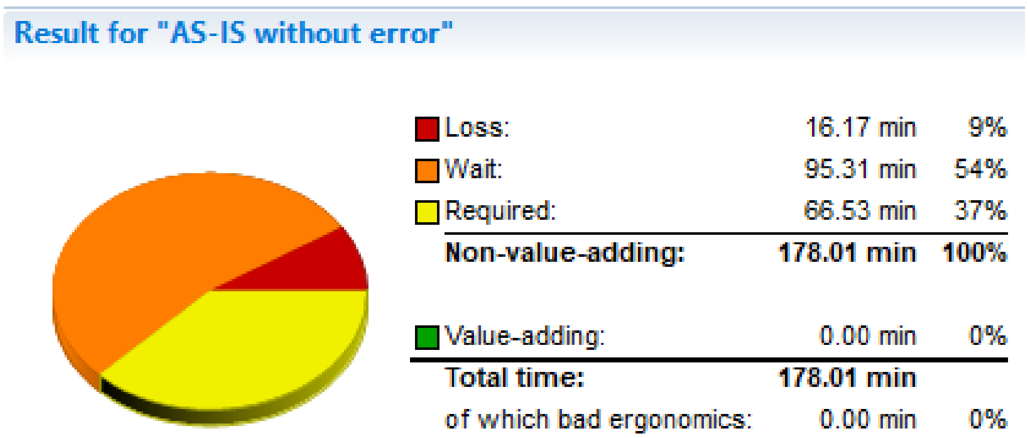


Figure 4.22: Bror Avix AS-IS without error results

4.2.1.1 Loss

The majority of the lost time was due to the operator walking. The total "walking" time was 8.69 minutes, and the walking was classified into four categories: walking for materials, walking for machine tools, walking near the machine, and general walking. Walking for materials, walking for machine tools, and walking near the machine are repeated walks that took a lot of time, whereas general walking was performed only two or three times in the entire changeover process.

"Walking for materials" is when the operator walks to pick up raw materials and remove previous process raw materials. "Walking for machine tools" was when the operator walked to pick measurement tools, gauges, and fastening tools required for the changeover. "Walking near the machine" was when the operator walked to pick up turret blocks and tools and to measure the trial part on the measurement trolley, which was placed near the machine module. Lastly, "general walking" was the remaining walking where the operator walked to pick up the checklist, measure the final product, perform finishing operations like grinding, and drop off the final product for measuring in a coordinate measuring machine (CMM).

The remaining loss time was spent on searching for tools and parts and other losses such as rework, adjusting, retightening, and break time. The searching for tools and parts takes 1.90 minutes and other losses took 5.58 minutes.

4.2.1.2 Wait

The total waiting time in the AS-IS state of Avix analysis was 95.31 minutes, as shown above in Fig. 4.22. Most of the waiting time was due to the CMM and it took around 90 minutes. The final trial part should be inspected in a CMM for quality conformance before the product is mass produced. The CMM took 40 minutes to measure the final trial part, and the remaining 50 minuntes were spent waiting for the part to be measured. This was because there was only one CMM machine in the whole factory for final and daily inspection of the parts produced from different machines, and the dropped-off parts needed to wait until the previous parts were completed. The remaining 5.31 minutes in the total waiting time were due to the operator waiting when the machine and the robot were running.

4.2.1.3 Required

The required time was 66.53 minutes and tasks involved were removing previous process raw materials from the conveyor, operating the machine and robot module, changing turret tools, chuck jaws, and robot grippers, loading part fixtures and raw materials on the conveyor, and performing trial runs.

4.2.2 AS-IS State Tracking Results

At Bror Tonsjö, the tracking setup was similar to that at the IAC Group. The movement of the operator involved in the changeover process was tracked with a mobile beacon with ID 106, and the stationary beacons were positioned as shown in Fig. 4.23. The setup involved two tracking zones and four stationary beacons. The challenges faced for tracking were minimal compared to the IAC Group. The only major challenge was that the mobile beacon lost connection with the stationary beacon when the operator used an air spray gun with a loud noise. The loud noise from the air spray gun exceeded the ultrasonic signal strength between the stationary and mobile beacons, resulting in some outliers in the tracked data. Along with the noise, there was some disturbance with the line of sight between the mobile and the stationary beacon, which influenced the tracking accuracy.

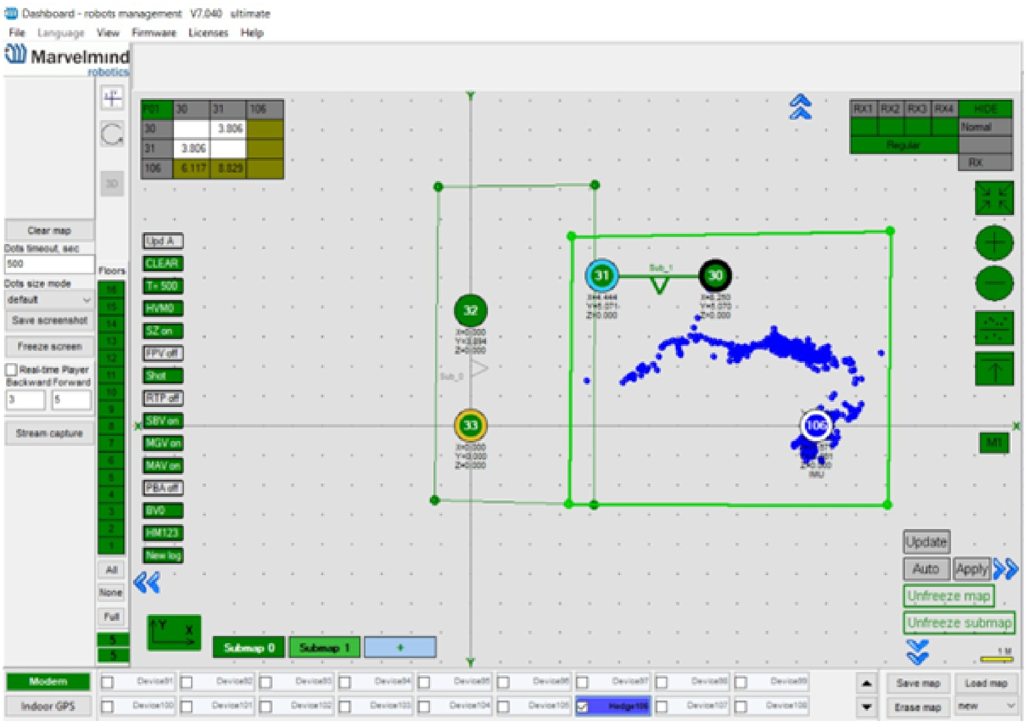


Figure 4.23: Bror beacons positioning

The tracked data from the Marvelmind dashboard was obtained in the form of a .csv log file, which was further analysed using the Gazpacho tracking analysis software. Since the changeover process involved the operator taking breaks, the tracking process had to be stopped and restarted again, which resulted in .csv tracking log files. The Gazpacho software was capable of reading several log files. The several log files data were compiled into a single large log file of tracking data with the help of Excel VBA. The Gazpacho software could not handle the large tracking data file, and the obtained spaghetti diagram did not have smooth operator movement. This issue was fixed with the help of the software development team. The orientation of the tracked data to the floor plan had to be done manually, like in the case of IAC Group. The spaghetti diagram and heat map of the operator during the changeover are shown in Figs. 4.24 and 4.25 respectively.

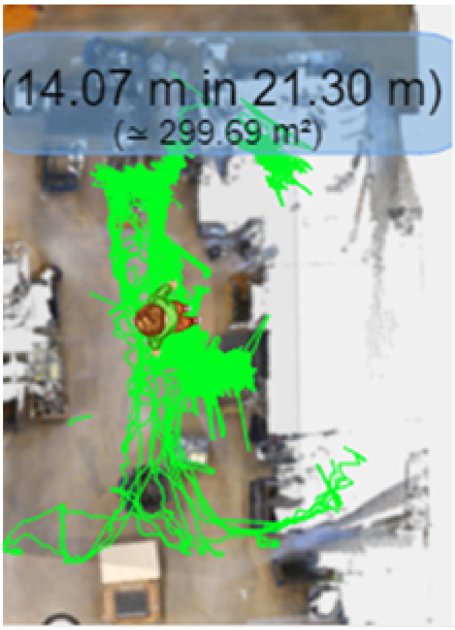


Figure 4.24: Spaghetti diagram of operator

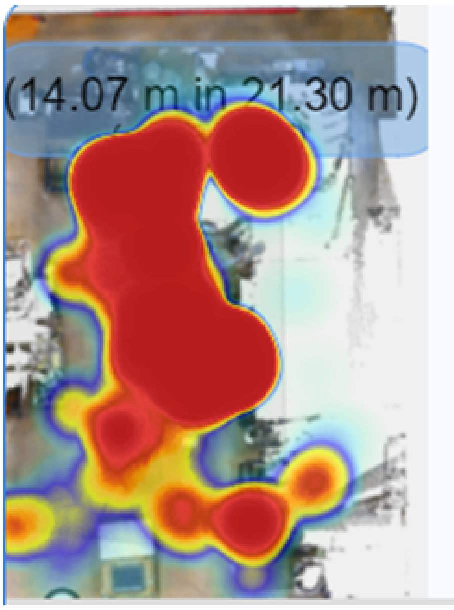


Figure 4.25: Heat map of operator

The tracked data in the floor plan was divided into different areas of interest to obtain KPIs. The different zones and the time spent by the operators in these zones are shown in Fig. 4.26. This feature was helpful in identifying where the operator spent the most time during the changeover process, which was valuable input while prioritising the areas and considering the improvements. As shown in Fig. 4.26, operator 1 with ID 106 spent the most time near the machine module.

Figure 4.26: KPI of workstations

In this case, the MTM and sequence integration features of the Gazpacho software did not work as they could not handle the large log data file. The comparison of the Gazpacho and Avix analysis results is shown in Table 4.4.

In the case of Bror Tonsjö, outliers in the tracked data were lower compared to the tracked data of the IAC Group. A smooth spaghetti diagram representing the

Gazpacho Results		Avix Results	
Moving time	Distance	Moving time (walk)	Distance (walk)
197.20 min	3874.10 m	10.39 min	794 m

Table 4.4: Comparison of Gazpacho and Avix results

operator's movement was obtained after some backend software adjustments from the software development team. The interactive spaghetti diagram obtained from the Gazpacho software visualised the movement of the operator, which helped in identifying unnecessary movements and waste in the process.

4.2.3 TO-BE Improvements

While analysing the AS-IS state of Bror Tonsjo, a lot of improvement suggestions were found. The improvements are divided into TO-BE Improvement 1, Improvement 2, and Improvement 3.

4.2.3.1 TO-BE Improvement 1

While working on the Avix analysis, it was found that the operator spends a lot of time picking up the tools required for the changeover. The tools include fastening tools, turret tools, chuck jaws, insert tools, and machining tools. All these tools were not kept at one location, and the operator had to walk to pick them up from different locations. Sometimes the operator does not remember where those were placed and searches for them as well. Also, the operator cleaned the previous turret tools and chuck jaws right after removing them from the machine and then attached the new turret tools and chuck jaws.

Moreover, the operator picks up and arranges the required measurement gauges when the machine is stopped. Sometimes, the operator forgot the gauge and walked to get it. The operator also searched for the measurement gauges and tools, as they were not readily available. A few of the measurement gauges were not calibrated, and the operator had to calibrate them to measure the trial part. The operator also walked to get the masterpiece for setting the parameters in the machine module.

The operator checks the inserts of every tool used in the turret. He removed them if not required, checked them under the table light, cleaned them, and then placed them in the box. This took up some time. Also, the operator spent some time searching for new inserts if the old ones were worn out.

All the above tasks can be converted into external tasks which can save a lot of time and decrease the total changeover time. The external tasks have been divided as follows:

1. 20 mins before the machine stops
2. 10 mins before the machine starts
3. 5 mins before the machine starts
4. After the machine starts

Tasks to be completed 20 minutes before the machine stops: A checklist could be provided where all the required fastening tools, turret tools, chuck jaws, insert tools, and machining tools are mentioned, and the operator picks them up accordingly and arranges them on the tool tray. Since it was observed in the AS-IS state that the operator picks the parts from different locations, a tool tray could be used containing all the parts required for the changeover. A tool tray was designed on Autodesk, and it is shown under appendix 2. The tool tray can be divided into three separate areas and includes space for placing the fastening tools, previous process tools, and next process tools.

To arrange the inserts and tools, an example of an insert box as shown in appendix 2 could be used. The insert box can be divided into two parts: one for placing the previous process inserts and tools and the other for placing the new inserts and tools. The operator has to pick the inserts and tools required according to the checklist and place them in their respective positions. So, 20 minutes before the changeover, the operator has to pick up all the required tools mentioned in the checklist and arrange them on the tool tray and the insert box. The cleaning of the previous process parts has to be done only after the changeover is completed. The tool tray has to be placed on the table below the machine module, and the insert box has to be placed on the yellow desk. A picture is shown under appendix 2.

10 minutes before the machine starts: The raw material has to be prepared 10 minutes before the machine is started. During this time, the raw material from the previous process has to be removed, and the new process has to be brought and unloaded near the conveyor. The final products of the previous process have to be removed from the conveyor, cleaned, and arranged in a bin. Also, the fixtures used in the previous process have to be removed from the conveyor. Moreover, the operator should bring the masterpiece and place it near the insert box.

5 minutes before the machine starts: The standard operating procedure (SOP) has to be arranged and attached to the machine 5 minutes before it is started. An SOP holder is used to hold the SOP. During this time, the SOP of the previous process should be removed, and the new SOP should be picked up from the rack and attached to the side of the machine module. An example of a SOP holder is shown below in the appendix 2.

After the machine starts: As observed in the Avix analysis, the operator cleans the previous process tools and inserts while the machine is idle. This increases the changeover time. So, these activities have to be avoided and completed after the machine is started. When the final product is measured using the CMM machine and quality approved, the machine can be started. Since the raw material is loaded into the conveyor fixtures, the operator can use this time to clean up and place all the tools in their respective positions while the machine is running and producing products. The tasks include cleaning the previous process inserts, machine tools like chuck jaws and turret blocks, fastening tools, and placing them in their respective positions. This allows the operator to have only the required tools around him and reduces the time needed for preparation during the next changeover process.

Internal tasks: During the Avix analysis, it was seen that the operator used an allen key to loosen and tighten the screws of the robot grippers. Also, the operator had to kneel to reach the bottom screws, which was not good from an ergonomic perspective. So, a suggestion is to use a battery-operated angled nutrunner to correct the posture of the operator and reduce the time taken for loosening and tightening the screws. An example of an angled nutrunner is shown in the appendix 2.

As mentioned before, the machine had a breakdown and was repaired recently. So, there was a machine referencing issue that caused a lot of delay in the changeover process. This error time has been removed from the Avix analysis. As observed in the Avix video, there were simultaneous tasks involving changeover and error. So, a detailed calculation of the tasks involving the changeover was done, and a total of 20 minutes have been given for performing the trial run in the TO-BE state.

The measurement in CMM takes approximately 90 minutes, which includes a total of 50 minutes of waiting time. This is because the company has only one CMM machine, and the products are measured on a first-come, first-served basis. To decrease this waiting time, a CMM reservation system was suggested. For instance, if a changeover is scheduled in the coming week, the CMM department has to be informed about the changeover, and the CMM machine has to be kept ready for measuring the product as soon as it arrives for quality inspection. This reduces the waiting time by 50 minutes.

Also, the operator is free during the measurement and waits for 40 minutes after dropping off the final product for quality inspection. So, during this time, the operator can complete a few required activities. These activities include filling out the checklist and arranging all the required documents.

4.2.3.2 TO-BE Improvement 1 Results

After implementing the above-mentioned suggestions, the total changeover time decreases to 124.42 minutes, in which the internal time is 104.69 minutes, which is 73.32 minutes less than the AS-IS state, and the external time is 19.73 minutes. This is a 41.03% decrease in the changeover time when compared to the AS-IS state. The Avix TO-BE Improvement 1 results are shown below in Fig. 4.27. The tasks involving loss time are 5.44 minutes, which is the total walking time of the operator and is 3.25 minutes less than the AS-IS state. This walking time is further classified into internal and external walking. Internal walking is the walking time of the operator when the machine is stopped, and external walking is the walking time of the operator when the machine is running. The total internal walking time is 3.70 minutes, and the total external walking time is 1.74 minutes.

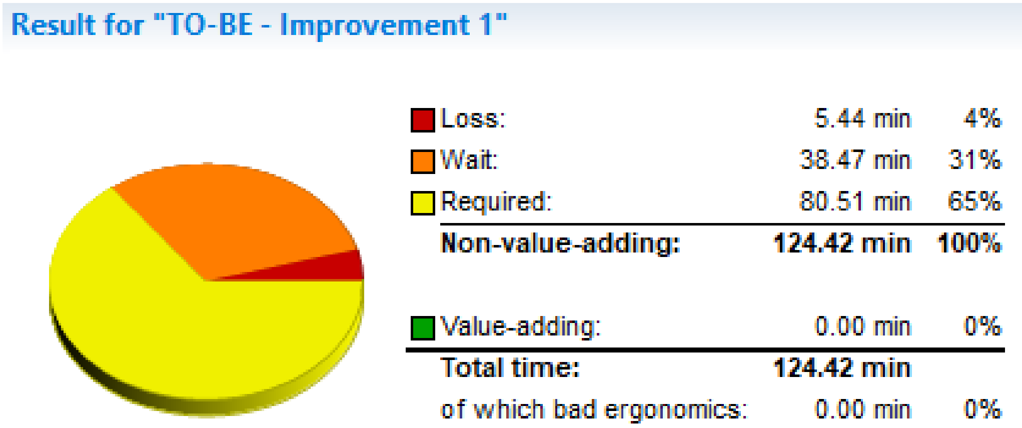


Figure 4.27: Bror TO-BE improvement 1 results

Moreover, the different types of walking mentioned above in the AS-IS state are further classified into internal and external walking. The total walking time for materials is 1.76 minutes, in which the internal walking time is 0.56 minutes and the external walking time is 1.20 minutes; the total walking time for machine tools is 0.53 minutes, in which the internal walking time is 0.00 minutes as the operator arranges all the required parts before the machine is stopped; and the external walking time is 0.53 minutes. Total walking time near the machine is 0.50 minutes, which is only the internal walking time and is less compared to the AS-IS state because all the required parts are placed closer to the machine module. The total general walking time is 2.65 minutes, which is only the internal walking time.
The total waiting time is 38.47 minutes, of which the majority is due to the measuring of the trial part in CMM, which takes 37.93 minutes, and the remaining 0.54 minutes are spent waiting while the machine and the robot are running. The total required time is 80.51 min.

4.2.3.3 TO-BE Improvement 2

In the Avix analysis, it was observed that the tasks involving the robot were done before dropping off the final product for quality inspection in CMM. The tasks involved attaching new fixtures and loading raw materials to the conveyor, operating the robot module to bring the robot to the reference position for changing the grippers, removing the previous process front and bottom robot grippers, attaching the next process robot grippers, adjusting the sensor position, and operating the robot module to get the robot started. The waiting time after implementing Improvement 1 suggestions was 38.47 minutes, which is very high, and a solution had to be found to decrease this. So, here comes Improvement 2, which is to change the sequence of tasks performed during the changeover. The suggestion was to complete all the tasks involving the robot as mentioned above after the final product was dropped off for quality inspection in CMM. If this is done after dropping off the final product for measuring, 8.14 minutes can be saved, thus decreasing the waiting time. The sequence of the activities involving the robot is shown below in appendix 2.

After implementing the above-mentioned suggestion and the suggestions from Improvement 1, the total changeover time decreases to 116.31 minutes, in which the internal time is 96.58 minutes, which is 81.43 minutes less than the AS-IS state, and the external time is 19.73 minutes. This is a 45.74% decrease in the changeover time when compared to the AS-IS state. The Avix TO-BE Improvement 2 results are shown below in Fig. 4.28. The tasks involving loss time took 5.41 minutes, which was the total walking time and was 0.03 minutes less compared to Improvement 1 results. The total internal walking time was 3.67 min and external walking time was 1.74 min.

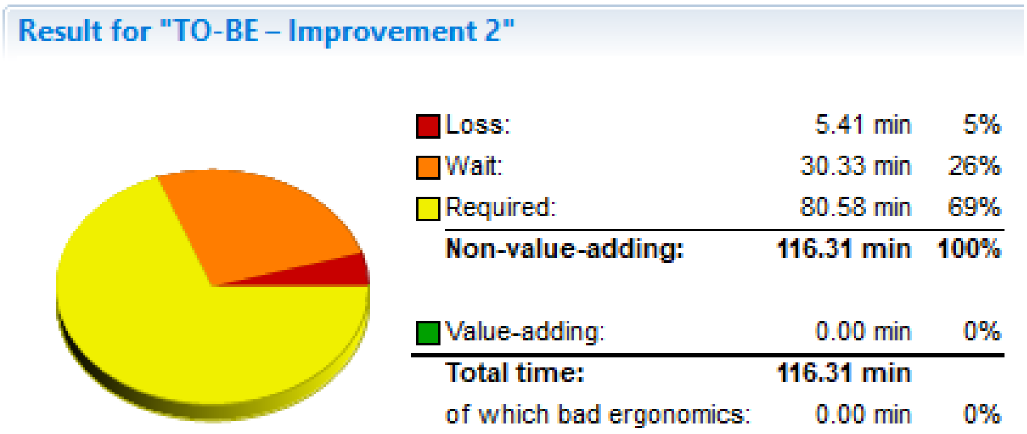


Figure 4.28: Bror TO-BE improvement 2 results

The total walking time for materials is 1.86 minutes, of which the internal walking time is 0.56 minutes and the external walking time is 1.30 minutes. The total walking time for machine tools is 0.44 minutes, which is only the external walking time, and the total walking time near the machine is 0.50 minutes, which is only the internal walking time. The total general walking time is 2.61 minutes, which is only the internal walking time.

The total waiting time decreases to 30.33 minutes, which is 8.14 minutes less than the Improvement 1 results. The majority of the waiting time is due to measuring in CMM, which will decrease to 29.79 minutes compared to the Improvement 1 result, and the remaining 0.54 minutes are due to the operator waiting while the machine and the robot are running. The total required time is 80.58 min.

4.2.3.4 TO-BE Improvement 3

After implementing both Improvement 1 and Improvement 2 suggestions, the waiting time was still 30.33 min. To decrease this waiting time, a metrology-grade 3D scanner was suggested. The suggestion is to reserve the CMM for inspections of high-tolerance features, and the metrology 3D scanner could be used to inspect all the other features. The 3D scanner can be used for inspecting all machined parts and accelerates simple and daily inspections.

Using the metrology 3D scanner for inspection along with the Improvement 1 and Improvement 2 suggestions, the total changeover time will decrease to 87.95 min in which the internal time is 68.22 min, which is 109.79 min lesser than AS-IS state, and the external time is 19.73 min. This is a 61.67% decrease in the changeover time when compared to the AS-IS state. The Avix TO-BE Improvement 3 results are shown below in Fig. 4.29.

The SMED chart of the AS-IS state and all the TO-BE Improvement states is shown below in appendix 2. The chart shows the difference in the total changeover time and the internal and external times of both states.

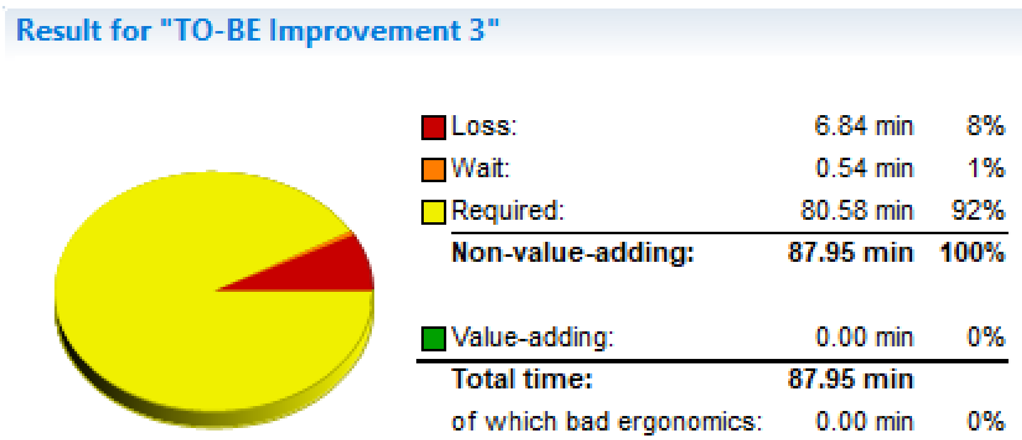


Figure 4.29: Bror TO-BE improvement 3 results

4.2.3.5 Financial Impact

The financial impact of all the improvements is shown below in Table 4.5. Detailed calculations are shown under appendix 3.

	AS-IS state	Improvement 1	Improvement 2	Improvement 3
Single changeover time (hr)	2.97	1.74	1.60	1.13
Changeover time/year (hr)	463.32	271.44	249.60	176.28
Increased capacity time (hr)	-	191.88	213.72	287.04
Additional products (no.)	-	2487	2770	3720
Annual savings (SEK)	-	472,530	526,300	706,800

Table 4.5: Bror financial impact of all improvememts

4.3 IMI Hydronic

The third company for testing was IMI Hydronic in Sweden. IMI Hydronic is an HVAC company. An interview was carried out with the workshop manager during the visit and the questions and answers can be found under appendix 3. Only one operator was involved in this changeover process.

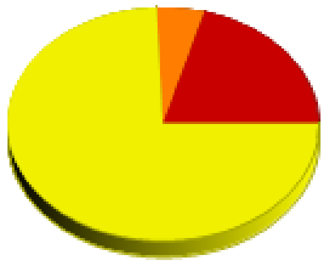
4.3.1 AS-IS State

The total changeover time as analysed in Avix was 396.72 minutes. The Avix AS-IS result is shown below in a pie chart in Fig. 4.30. The tasks involving loss time was 82.07 minutes, waiting time was 19.53 minutes, and required time was 295.13 minutes.

From Fig. 4.30, it was seen that the tasks classified as loss time take up 21%, waiting time takes up 5%, and required time takes up 74% of the total changeover time.

4.3.1.1 Loss

The total walking time was 82.07 minutes, and most of the loss time was due to the operator's walking. The total walking time of the operator was 47.03 minutes. The remaining loss time was due to searching for tools and personal time like drinking water, break time, etc. The searching time was 8.84 minutes, and the personal time was 10.97 minutes.
The walking time was classified into two categories: walking with a trolley and



Loss:	82.07 min	21%
Wait:	19.53 min	5%
Required:	295.13 min	74%
Non-value-adding:	**396.72 min**	**100%**
Value-adding:	0.00 min	0%
Total time:	**396.72 min**	
of which bad ergonomics:	0.00 min	0%

Figure 4.30: IMI Avix AS-IS results

general walking. Walking with trolley was when the operator walks along with the trolley carrying the tools and general walking was when the operator walks to perform all the other tasks such as, operating the module, measuring the trial part, operating bar feeder module, etc. The total walking time was high because the machine is a multi-spindle machine and there are two machine modules present in the machine, and the operator has to walk to each of them when performing a task on the machine. For instance, to rotate the spindle to replace a machine part with a new one, the operator must close both doors of the machine and operate the module to rotate the spindle. This walking between the machine modules takes up a lot of time.

4.3.1.2 Waiting time

The total waiting time was 19.53 minutes. The majority of the waiting time was due to the operator waiting for the machine to complete the operation after making some adjustments.

4.3.1.3 Required time

The total required time was 295.13 minutes. The main tasks involved during this time were operating the machine module, operating the bar feeder module, working on the bar feeder, replacing previous process machine parts with next process machine parts, and measuring the trial and final parts using measurement tools and an optical measurement machine.

4.3.2 AS-IS State Tracking Results

At IMI Hydronic, the tracking setup was similar to the other two cases. The complete movement of the operator during the changeover process could not be tracked as the area to be tracked was too large to be tracked with the available Marvelmind tracking equipment. The operator's movement around the machine was only tracked, and the movement of the operator to the tool room and other movements were not included in the tracked area. The positioning of the stationary and mobile beacons is shown in Fig. 4.31.

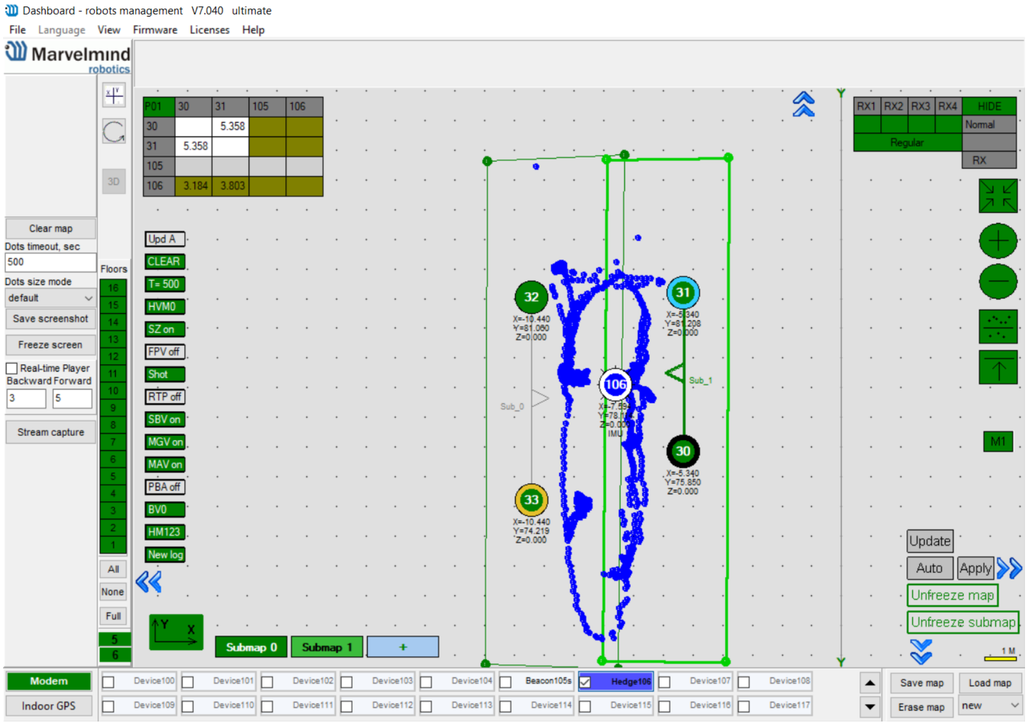


Figure 4.31: The positioning of the stationary and mobile beacons

The challenges faced during the tracking of this changeover process were noise from the air spray guns, blind spots due to line of sight issues between the stationary and mobile beacons, and limited tracking area coverage from the available equipment.

The tracked data from the Marvelmind dashboard was obtained in the form of a .csv log file, which was further analysed using the Gazpacho tracking analysis software. Similar to the case at Bror Tonsjö, the changeover process involved the operator taking breaks and lasted for around 9 hours. The tracking process had to be stopped and restarted again, which resulted in .csv tracking log files. The Gazpacho software was not capable of reading several log files. The several log files data were compiled into a single large log file of tracking data with the help of Excel VBA. The Gazpacho software could not handle the large tracking data file. Thus, Gazpacho analysis could not be carried out for this case.

4.3.3 TO-BE Improvement

While analysing the AS-IS state, a few improvements were found. In the AS-IS state, all the operations during the changeover were treated as internal activities. There were several operations that could be converted into external activities. The operator picks up the checklist, which contains the tools required, and picks them up after the machine is stopped. This takes a lot of time because the tools were not placed at one location; the operator had to walk to several locations to pick up the tools. Moreover, the operator did not know where the tool was placed and had to search for the tool box. A tool trolley is used to place all the tools picked up, and the trolley was not cleared before the changeover. The operator had to remove unwanted parts first before placing the tools required for the changeover. Also, sometimes the operator has to stop working on the machine and walk to pick up the tool. This was because the tool was not available in the tool trolley. All of these can be eliminated by arranging the required tools in the trolley before the machine stops and placing the trolley near the machine.

During the measurement of the trial parts, the operator searches for the document containing the tool drawing. Also, the operator writes down the information required for measuring and does calculations for the setting. Moreover, the operator removes the tools from the machine and cleans them before placing them in the trolley. These activities could be done after the machine is started. All of these activities can be converted into external steps. This saves a lot of time and decreases the changeover time.

There were several instances where the operator was not sure what to do. The operator checks the same dimensions of the trial part several times by simultaneously looking at the drawing. So, a procedure to carry out sequential checks could be provided. Sometimes the operator picks up the wrong tool and tries attaching it to the machine, but realises that it's wrong and uses another tool. The operator could be provided with a checklist containing the right tools, and proper training could be provided to avoid these mistakes.

4.3.3.1 TO-BE Improvement Results

After implementing the above-mentioned suggestions, the total changeover time will decrease to 321.85 minutes, in which the internal time is 307.89 minutes, which is 88.83 minutes less than the AS-IS state, and the external time is 13.96 minutes. This is a 22.39% decrease in the changeover time. The Avix TO-BE Improvement results are shown below in a pie chart in Fig. 4.32.

The tasks involving loss time are 26.70 minutes, in which the total walking time is 26.09 minutes and the personal time for drinking water is 0.61 minutes. The loss time decreases by 55.37 minutes when compared to the AS-IS state. The walking is further classified into internal and external walking. Out of the total walking time of 26.09 minutes, the internal walking time is 23.14 minutes, and the remaining 2.95 minutes are external walking time. Moreover, the different types of walking, walking with trolley time, and general walking time are 3.95 minutes and 22.14 minutes, respectively. In the total walking time with the trolley, the internal walking time is 2.02 minutes, and the external walking time is 1.93 minutes. In the total general walking time, the internal walking time is 21.11 minutes, and the external walking

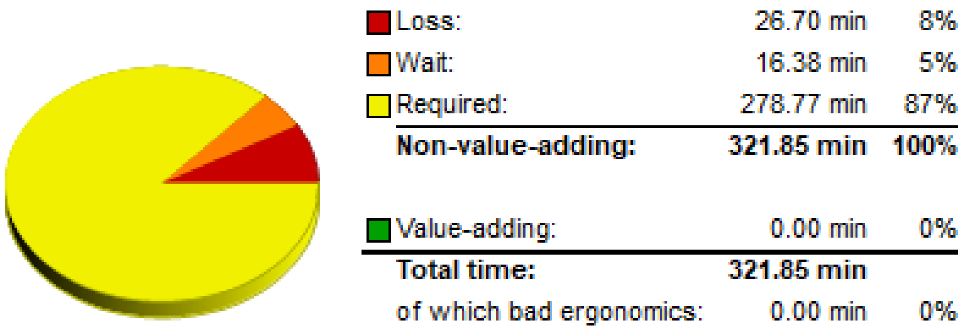


Figure 4.32: IMI Avix TO-BE Improvement results

time is 1.03 minutes.The waiting time decreases to 16.38 minutes, which is 3.15 minutes less compared to the AS-IS state, and the total required time is 278.70 minutes.

The SMED chart of the AS-IS state and the TO-BE Improvement state is shown in appendix 2. The chart shows the difference in the changeover time between the two states. It also indicates the internal and external tasks in the TO-BE state.

4.3.3.2 Financial Impact

The financial impact of improvement 1 is shown below in Table 4.6. Detailed calculations are shown under appendix 3.

	AS-IS state	TO-BE state
Single changeover time (hr)	6.61	5.36
Changeover time/year (hr)	343.82	278.94
Increased capacity time (hr)	-	64.88
Additional products (no.)	-	19,464
Annual savings (SEK)	-	194,640

Table 4.6: IMI financial impact of TO-BE state

5
Discussion

Numerous tracking systems are available on the market and have shown to be successfully utilised in manufacturing settings, as was indicated in the literature study. Marvelmind indoor positioning systems based on ultrasound technology were deemed to be the most appropriate for tracking the operators throughout a changeover procedure for the various types of scenarios that were investigated during this study. Other tracking devices, on the other hand, might be more appropriate in some circumstances. Marvelmind technology was a purchase made by VM, and it was combined with the Gazpacho tracking and analysis programme. These elements contributed to the decision to use ultrasound-based Marvelmind technology rather than other tracking technologies.

In this study, the first question aimed to identify what tracking devices are available on the market, how they differ from one another, and how developed the technologies are for use. To choose the tracking equipment to be used for the case studies, various types of tracking equipment that are suitable for operator tracking were investigated. Their benefits and drawbacks were then compared. Other tracking devices might have been bought if preferred, however the Marvelmind's features were appropriate for the case studies. It is challenging to gauge the technology's level of development. While conducting testing at the VM office, we were able to get correct movement data; nevertheless, there were some problems when tracking the industrial activities at the case companies. The industrial installations' loud noises and the walls, which block ultrasound signals, contributed to the poor tracking accuracy. That is not to suggest that the technology is not developed enough, as the difficulties encountered were undoubtedly exacerbated by a lack of expertise, inadequate hardware, and the readiness of the Gazpacho tracking analysis programme.

How to standardise the usage of tracking equipment for the changeover analysis process was the second research issue. VM wants to commercialise the tracking system alongside its customers, who receive lean-based production and logistics solutions from them. As of right now, tracking is not a typical offering from VM. A consistent work technique was required because previous experiments with various pieces of equipment had yielded unsatisfactory results. A guidebook for best practises for tracking with Marvelmind has been created, however additional research should be done to expand it and address some of the problems that haven't been answered.

Using Avix analysis, the third research question tried to ascertain ways to shorten the transition time. By optimising their workflows and boosting productivity, VM employs the Avix software as a tool to map the processes of its clients. In order to analyse the SMED cases with the Avix programme, training was obtained from the VM colleagues. The SMED analysis was conducted in three separate industry scenarios as a result of the lessons learned, and the changeover time was decreased by 30 to 50%.

In the study's last question, the tracking technology and the Gazpacho software were put to the test. There were a number of difficulties encountered while tracking the operators during the investigation, despite the Marvelmind company's claims that the equipment could be used in industrial instances with loud noises and a broad tracking area. The operators' tracked data had outliers as a result of the loud noise and the poor line of sight, which affected the poor tracking accuracy. The Gazpacho software was able to build and display dynamic spaghetti and heat maps using the tracked data. The Gazpacho software's tracking and analytic features were tried during the trial as well. In two of the three case studies, the Gazpacho programme was unable to handle the huge tracking data files. The software team has created a first improvement concept for how the data will be displayed in Gazpacho to ensure that the spaghetti diagrams are appropriately displayed in the programme. The features, however, were added in the very end of the project and will probably need extra testing to catch issues and enhance usability.

6
Conclusion

Finding out how tracking equipment may be used for SMED analysis using Avix analysis at Virtual Manufacturing Sweden AB was the main objective of the current investigation. The findings of this study indicate that ultrasound-based Marvelmind technology may be a useful tracking tool that is suitable for both one-time usage in smaller improvement projects and for use as a regular business solution. In a number of industrial contexts, the Marvelmind equipment was able to produce tracking data, but there were also problems with it in operation. A standardised work approach has been created for some of the concerns, but further research is still needed for others because the causes are not entirely understood.

Since it was not possible to evaluate the usability of every tracking technology, it is unknown whether another technology would be more suitable for use. However, before to choosing to use Marvelmind, study was conducted on the pros and downsides of the available tracking technologies. Despite the limited technologies tested, this work provides insightful information about important factors to take into account when standardising the use of tracking devices at Virtual Manufacturing Sweden AB.

Some suggestions for streamlining the work when visiting a customer to perform monitoring were made during the study, but more work has to be done to make the tracking more accessible to all staff. The manuals from the developer did not address all of the issues that came up when conducting tracking at client locations, thus a manual of best practises was created. With the help of the training received from the VM colleagues, the SMED cases were analysed using the Avix tool. As a result of the lessons learned, the SMED study was performed in three different industrial scenarios, and the changeover time was reduced by 30 to 50 %. The operator has privacy concerns due to the continuous monitoring and recording of them during the operation.

How to convey the gathered data so that it may be enhanced was a significant consideration as well. Spaghetti diagrams can be used to display waste in the changeover process and to indicate the routes that tracked operators have travelled. A lot of work has gone into making the tracking in the Gazpacho software from Virtual Manufacturing as user-friendly as possible in order to ensure that it is value-adding. This was accomplished by making suggestions for enhancements to the software development team. Other visualisation options were suggested in addition to the spaghetti and heat map, including an activity map, a comparison of the activity times, timestamps for each activity, and the frequency of trips to various areas.

The tracking hardware characteristics have a significant impact on the accuracy of the results. With improvements to the hardware system for tracking and the use of process mining tools in the Gazpacho software to get rid of tracking faults, tracking accuracy might be increased. In order for the diagrams to display the proper paths on the layout when data is submitted, the analysis capabilities for the Gazpacho programme must be built in order to handle the massive output data from Marvelmind.

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A

Appendix 1

A.1 Marvelmind Steps

Tracking a single room with Single Submap

Step 1: Install the Marvelmind Dashboard software

- Download and install the latest version of SW pack software from Marvelmind's website (https://marvelmind.com/download/)

Step 2: Attach the stationary beacons on the wall

- Attach stationary beacons on the wall and the number of beacons depends on the size of the tracking area.
- The maximum distance between two stationary beacons must be within 30 meters.
- Make sure there is a direct line of sight between the stationary beacons without any obstructions.
- A minimum of 2 beacons and a maximum of 4 beacons should be used in each submap.
- For inverse architecture (suitable for noisy environment), make sure the ultrasonic frequencies of the stationary beacons are different.
- The stationary beacons should be attached in a same orientation. For example, as shown in Figure A.1, all the beacons should be attached in an orientation where the antenna is in the top right corner.

Step 3: Open the Dashboard Software

- Start the Dashboard software and plug in the modem.
- Click on erase map present at the bottom right corner of the software as shown in Figure A.2 below to remove the previous layout if any.
- Wake up the stationary beacons by double-clicking on the respective device number. The devices can be found at the bottom as shown in Figure A.3. The device number is attached to the beacon along with the ultrasonic frequency. In the figure A.4, 31 represents the device number and 25K represents 25000 Hz ultrasonic frequency.
- Align the beacons on the floor plan according to their position on the wall. Hold the Ctrl button and use the Scroll button on the mouse to rotate the stationary beacons. Use the submap mirroring option present at the right side of the workspace to change the direction of the tracking area. The triangle

Figure A.1: Orientation of the stationary beacon

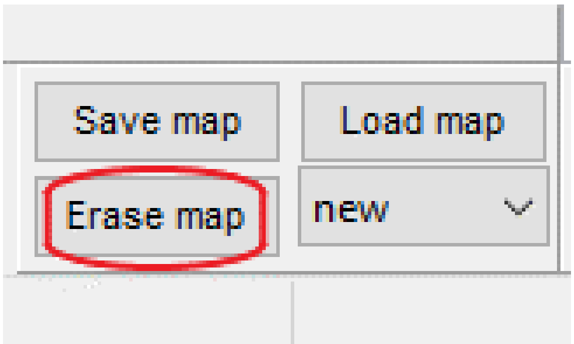

Figure A.2: Erase previous layout

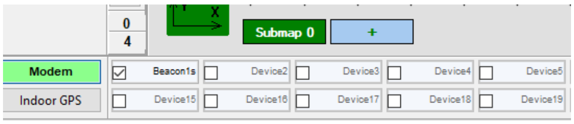

Figure A.3: Waking up the beacons

should be pointed in the direction where tracking is required. An example of the LMP area at Virtual Manufacturing AB is shown below in Figure A.5.

- Load the floorplan for better reference of tracking path. The floorplan can be added by right clicking on the desired floor, selecting load floorplan, and choosing a picture. This is shown below in Figure A.6. Similarly, the floorplan can be removed by right clicking on the floor which contains the picture and selecting remove floorplan.
- Align the stationary beacons on the floorplan, right click on the beacons and select "Nail to floorplan" to fix the location of the stationary beacons. Before nailing the beacon to the floorplan, make sure that the fields in the matrix indicating the measured distance between the beacons are coloured white. The matrix is present at the top left corner of the workspace and is shown below in Figure A.7.

Figure A.4: Device number and ultrasonic frequency

Figure A.5: Beacon positioning

- If the fields are red, it means that the measurements are inaccurate. This might be due to obstacles present between the line of sight of the beacons. So, try placing the beacons where there are no objects interfering between them. If the problem persists, measure the distance between them and enter manually by right clicking on the field and selecting enter distance for pair. This is shown below in Figure A.8.
- Create a service zone to indicate the area where tracking is required. Service zone is an area which serves the submap. Service zone helps to divide tracking between different submaps and outlines the area to be tracked for every submap. To create a service zone, click on the submap and use Shift + Left click to create an area on the map. A service zone is shown below in Figure

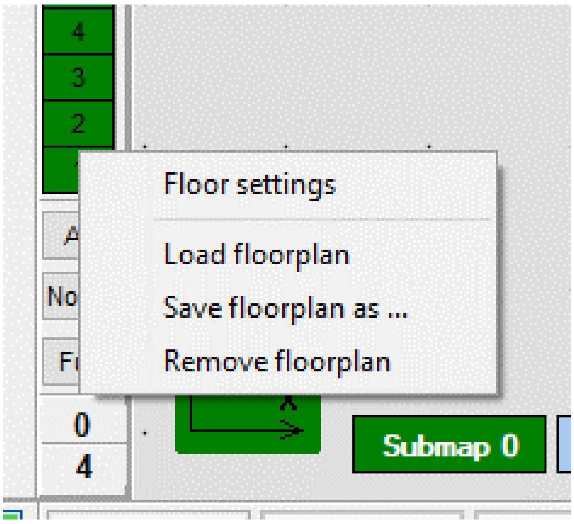

Figure A.6: Loading and removing floorplan

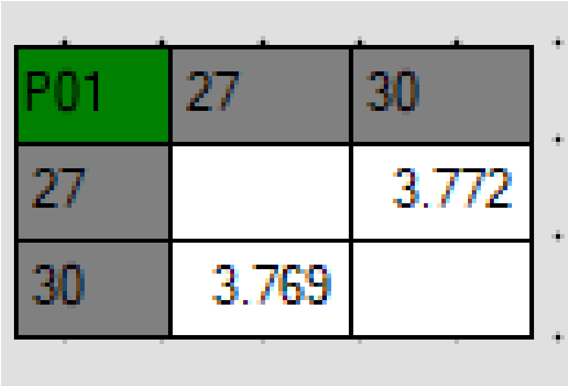

Figure A.7: Matrix indicating distance between beacons

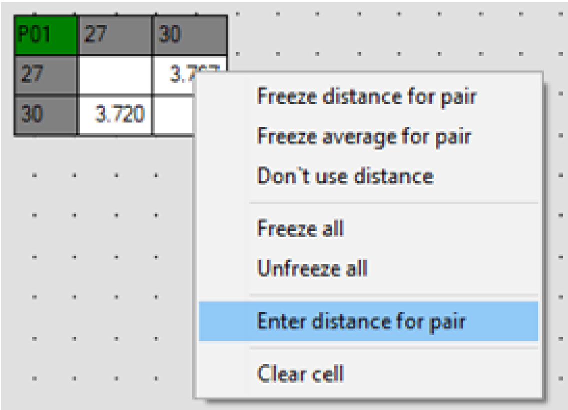

Figure A.8: Entering distance manually

A.9.

- Right click on the service zone and go to "Zones setup" and change the option to service zone as shown in Figure A.10. Freeze the submap by clicking on the Freeze submap option present at the bottom right corner. And is shown in Figure A.11. Similarly, the service zone can be removed by using Shift + Left clicking on the nodes of the service zone.

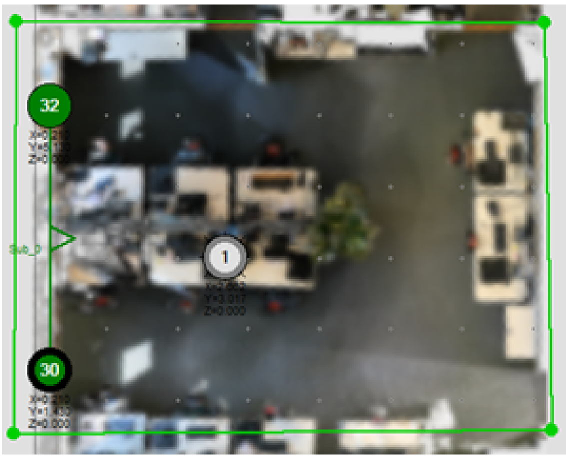

Figure A.9: Service zone

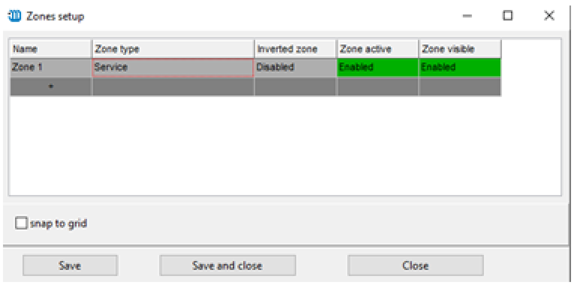

Figure A.10: Zone setup

Step 4: Record the tracking data

- Wake up the mobile beacon(s) or hedgehog by double clicking on the respective device number as shown in Figure 3 and freeze the map. The freeze map option can be found at the right bottom of the workspace.
- For the mobile beacon to track accurately, the map should be frozen. Sometimes the mobile beacon will not show up on the workspace, if so, try unfreezing the map and freeze it again. If this does not work, put the mobile beacon to sleep by double clicking on the device, wake it up again and freeze the map.
- Now, you can track the movement of the workers. The tracking data will be recorded and saved in a .txt file and can be found in the folder C/Marvelmind/dashboard/logs
- Once the tracking is done, make sure to put both the stationary and mobile beacons to sleep. The beacons can be put to sleep by double clicking on the respective device number. Also, all the beacons can be put to sleep together by selecting one beacon device, holding Ctrl, and clicking on sleep as shown below in Figure A.12.

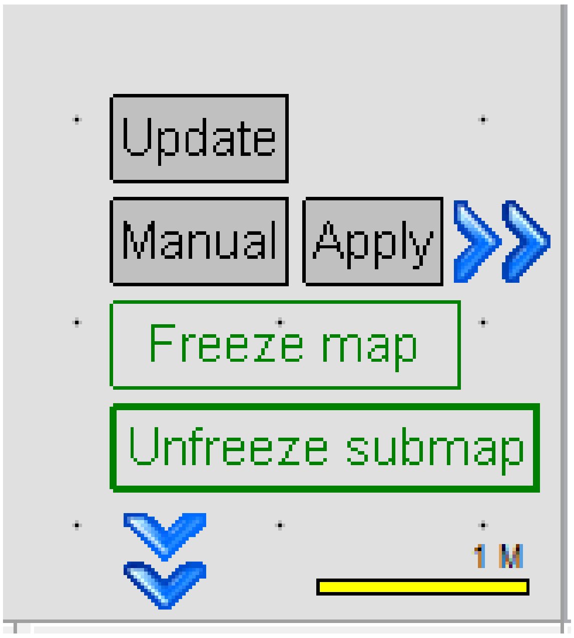

Figure A.11: Freeze, unfreeze submap and map

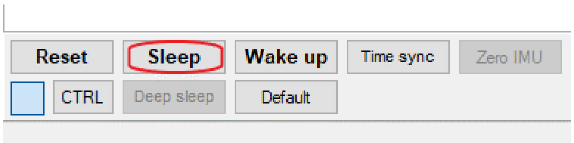

Figure A.12: Put all beacons to sleep

Multiple Submaps for tracking several rooms

Step 1: Follow the steps mentioned above from Step 1 to Step 3
Step 2: Create multiple submap

- Create a new submap by clicking on "+" sign next to the submap icon as shown in Figure A.13. Wake up the beacons and make sure that the beacons from one submap are not present in the other submap unless the two submaps must be created in one room. You can add and remove the beacons in each submap by right clicking and selecting add to current map or remove from current submap map as shown in Figure A.14.

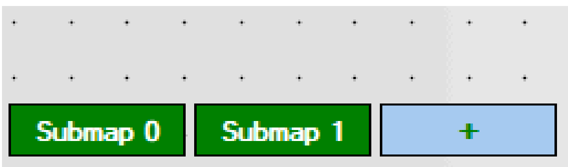

Figure A.13: Adding submap

Step 3: Create service zones

- Freeze the submaps and create service zones. Service zones should be created

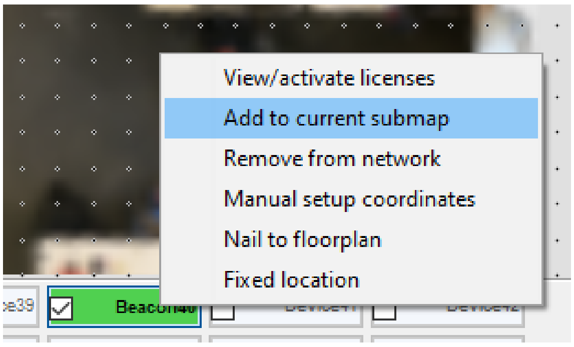

Figure A.14: Adding and removing beacons from submap

for each submap. This can be done by selecting one submap and following the same steps as mentioned above for single submap. This should be done for both the submaps, and the service zones should overlap each other to create a handover. The overlap is shown below in Figure A.15.

Figure A.15: Overlapping of service zones

Step 4: Create handover zones

- After creating service zones, handover over zone should be created. Handover zone is the overlapping area between service zones when they cross. Handover zone helps the mobile beacon to transfer smoothly between service zone of one submap to another. Handover zone can be created by holding Alt and clicking on the border of the neighbouring submap. By doing this, the neighbouring submap colour changes from light green to dark green. This indicates that the handover zone is created.

Step 5: Aligning the mobile beacon

- Now freeze the map and wake up the mobile beacon. Move the mobile beacon to the border between the two submaps and click on M1 present at the right side of the workspace as shown in Figure A.16. This is done to align the mobile beacon to get a smooth tracking between submaps.

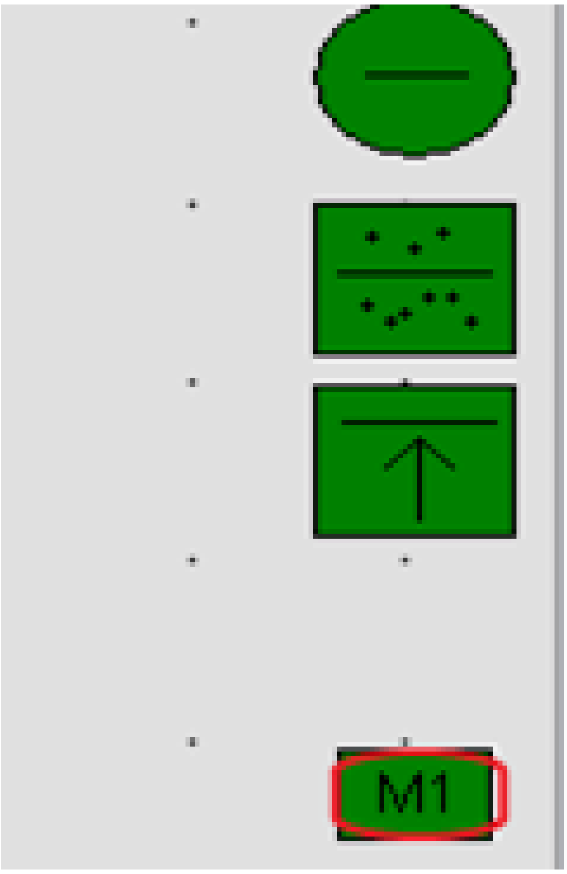

Figure A.16: M1 for aligning the mobile beacon

- On clicking M1, two orange-coloured mobile beacon icons will appear. This is shown below in Figure A.17. Two icons of mobile beacon appear because the stationary beacons in both the submaps detect the mobile beacon, and these should be made to overlap each other to ensure smooth tracking. This can be done by unfreezing the map and moving the stationary beacons in X or Y direction. After moving the beacons, the map and submap should be frozen to check if the orange icons overlap. This should be repeated until the icons overlap completely. The workspace can be zoomed in by using Scroll and the two orange-coloured mobile beacon should be made to completely overlap each other to ensure smooth tracking in the handover zone. This is shown below in Figure A.18.
- Sometimes, even after moving the stationary beacons, the position of the orange icons will not change. This can be corrected by unfreezing and freezing the map.
- While aligning the mobile beacons, all the beacons should have direct line of sight to the mobile beacon when placed near the boundary of both submaps.

Figure A.17: Mobile beacons in two submaps

Figure A.18: Overlapping of two orange coloured mobile beacons

For example, when the mobile beacon is placed near the entrance to the LMP room, beacons 28 and 40 have direct line of the sight from the LMP room and beacons 27 and 30 have direct line of sight from the office main area. It can be clearly understood from the Figure A.17 and A.18.

Step 6: Record the tracing data

- Once the mobile beacon is aligned, the movement of the worker moving between different submaps can be tracked.

B
Appendix 2

B.1 Improvement suggestion examples

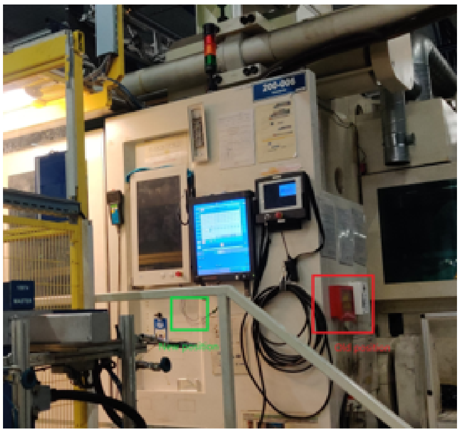

Figure B.1: IAC lockbox position

Figure B.2: IAC RFID based lockbox

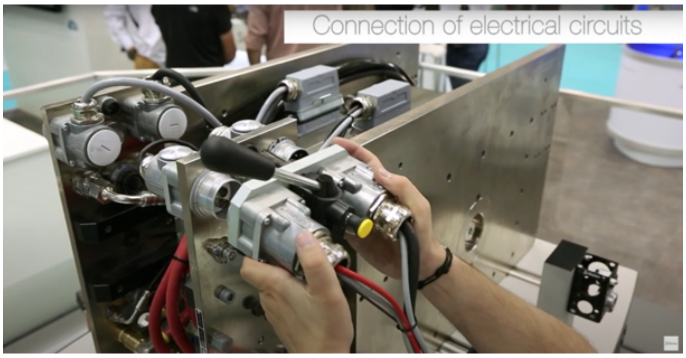

Figure B.3: IAC single action multi coupling connectors

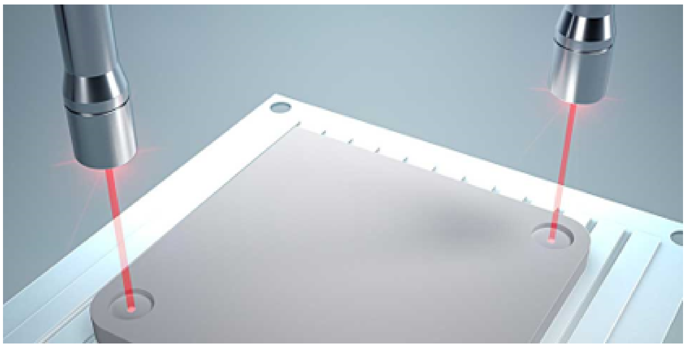

Figure B.4: IAC laser guidance for faster crane operation

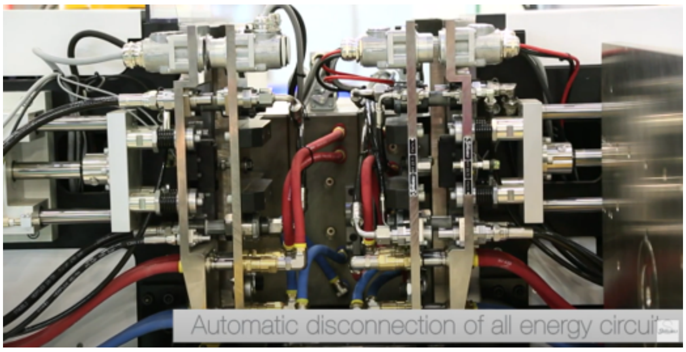

Figure B.5: IAC automatic connection and disconnection of connectors

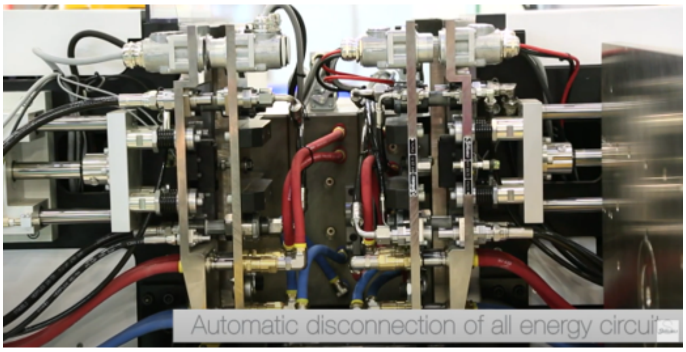

Figure B.6: IAC automatic connection and disconnection of connectors

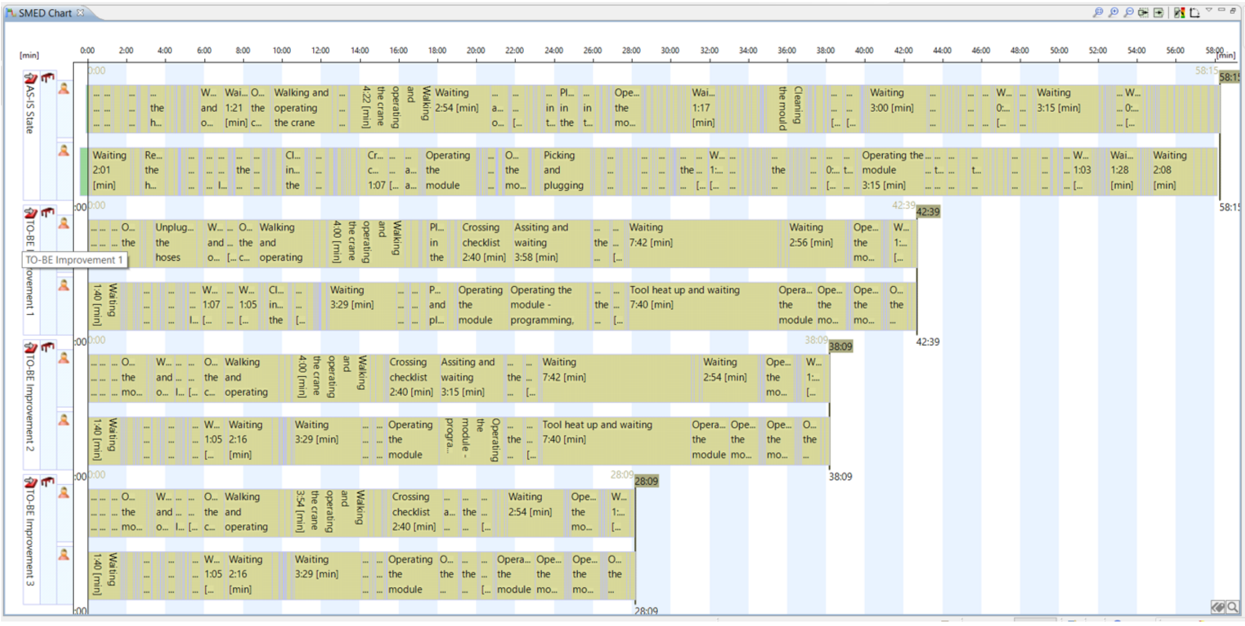

Figure B.7: IAC SMED chart

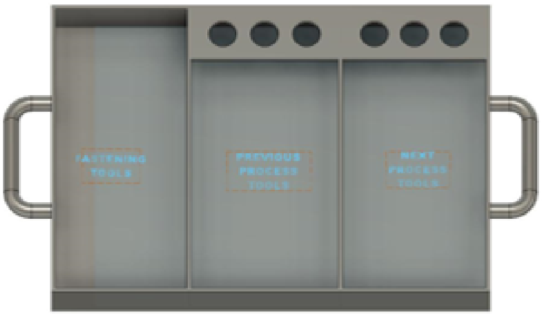

Figure B.8: Bror Tonsjö tool tray

Figure B.9: Bror Tonsjö insert box

Figure B.10: Bror Tonsjö tool tray position

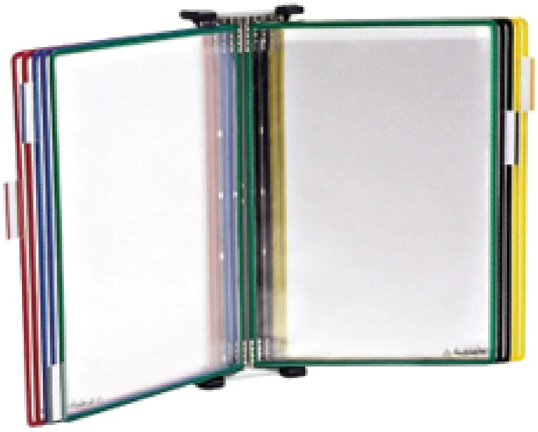

Figure B.11: Bror Tonsjö SOP holder

Figure B.12: Bror Tonsjö angled nutrunner

[10-1630] Drop off finished product - measuring start
[10-1640] Walk
[10-1650] Pick SOP
[10-1660] Walk (material)
[10-1670] Place the document on the shelf
[10-1680] Walk (material) to pick checklist
[10-1690] Fill checklist
[10-1700] Walk (material)
[10-1710] Attach the new fixtures and load the raw materials on the conveyor
[10-1720] Walk
[10-1730] Operate the robot module
[10-1740] Walk
[10-1750] Wait
[10-1760] Open the robot cell
[10-1770] Pick bin and power tool
[10-1780] Remove the previous process front robot grippers
[10-1790] Remove the previous process bottom robot grippers
[10-1800] Place the bin below the conveyor
[10-1810] Pick the bin with grippers for the next process
[10-1820] Pick and attach grippers
[10-1830] Place bin below the conveyor and pick bin with bottom grippers
[10-1840] Pick and attach bottom grippers
[10-1850] Place power tool and pick screwdriver
[10-1860] Adjust sensor position and check
[10-1870] Place screwdriver
[10-1880] Walk
[10-1890] Close the robot cell door
[10-1900] Walk
[10-1910] Operate robot module
[10-1920] Wait
[10-1930] Walk (material)
[10-1940] Wait for measuring in CMM

Figure B.13: Bror Tonsjö sequence of activities involving robot

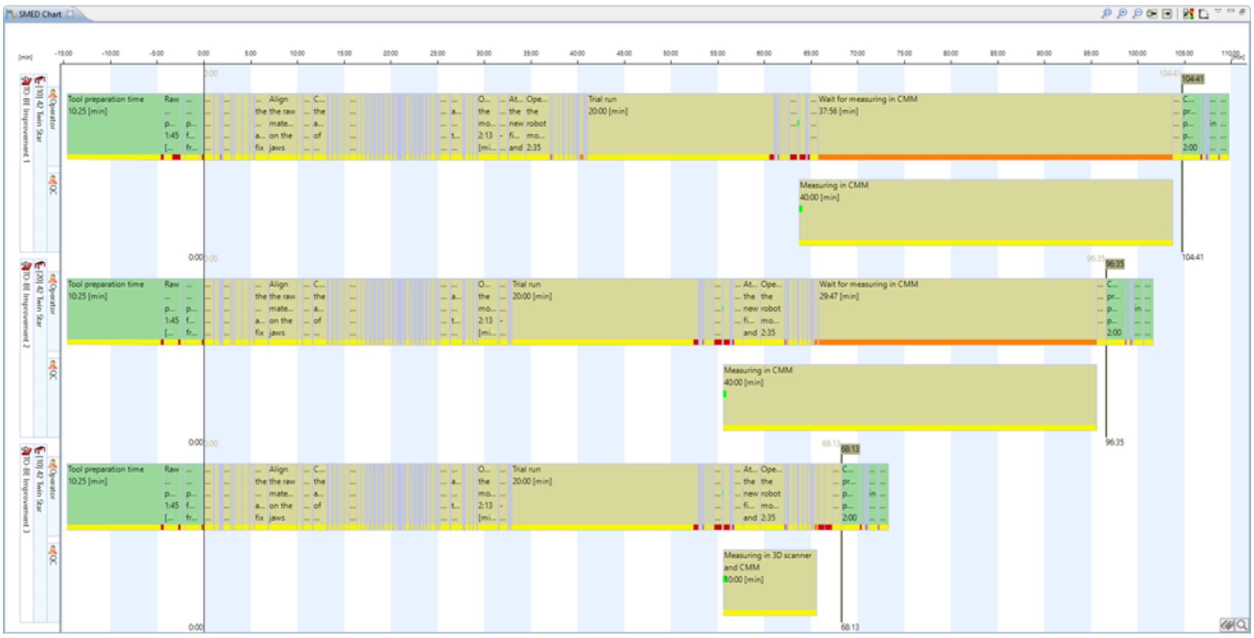

Figure B.14: Bror Tonsjö SMED chart

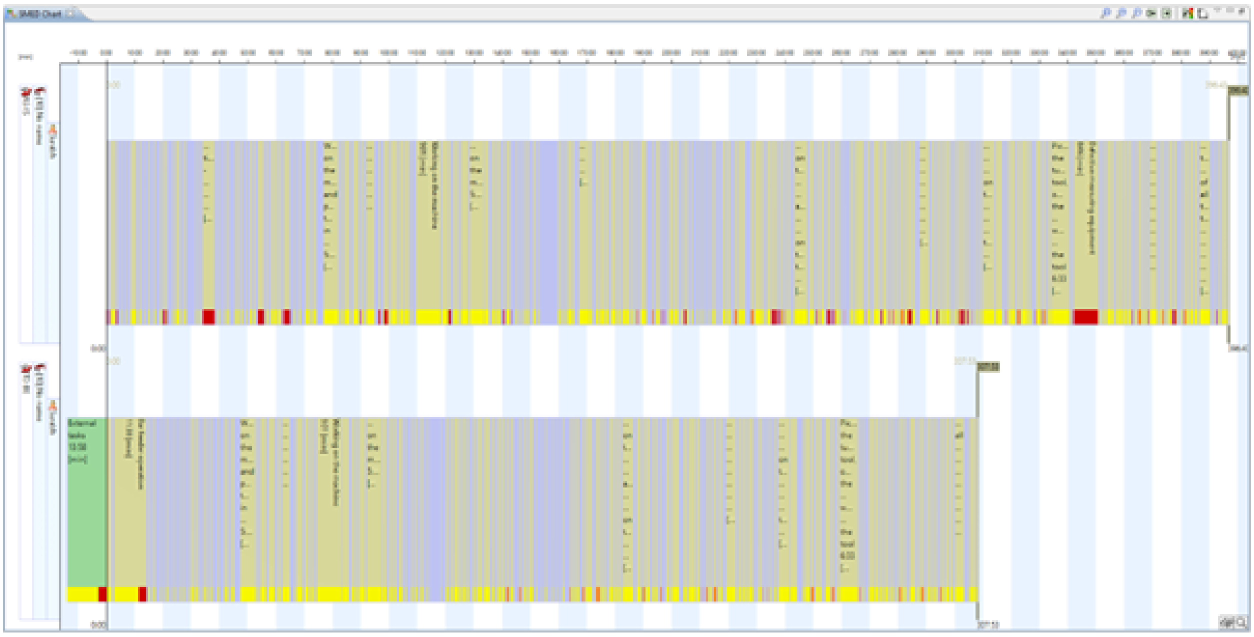

Figure B.15: IMI SMED chart

C
Appendix 3

C.1 Financial Impact IAC Group

To calculate the financial impact of the improvements suggested, a questionnaire was sent via email to the Continuous Improvement Engineer at Bror Tonsjo. The questions and answers are as follows:

1. Consent from the union and the management to track and record the process? - Yes
2. How often this changeover takes place in a day/week/month? - 4
3. Total working hours in a year? - 4000 hr
4. Cycle time of product? - 0.82 min
5. Cost of one product? - 25 SEK
6. How many operators/setters are involved? - 2
7. Do you have the layout of the machine? - Yes
8. Single station/machine or multiple involved during the changeover? - Multiple
9. Is there a checklist or clear work instructions for carrying out the changeover process? - Work instructions are provided
10. During the setup, will the operator take any breaks? - No
11. Any critical processes or tasks which needs to be performed at a particular pace? Any other limitations? - No

From the above information, the number of changeovers per year was calculated.

Number of changeovers per year = number of weeks per year * changeovers per week = 52*4 = 208

C.1.1 Improvement 1

For the AS-IS state, the single changeover time = 58.50 min, which gives the changeover time per year,

Changeover time per year = Single changeover time * number of changeovers per year = 58.50 * 208 = 12168 min = 202.80 hr

After implementing improvement 1 suggestions, the single changeover time decreases to 42.65 min.

So, the changeover time per year = (42.65 * 208)/60
= 147.33 hr

This gives an increased capacity time per year = changeover time per year (AS-IS state) – changeover time per year (improvement 1) = 202.80 – 147.33 = 55.47 hr

This increased capacity time per year allows to produce additional products of, Number of additional products = (Increased capacity time per year * 60) / Cycle time of product = 3618 products

Annual savings from these additional products = No. of additional products * Cost of one product = 3618 * 25 = 90 450 SEK

The return of investment was not calculated for this case. Similarly, the financial impact of improvement 2 and improvement 3 suggestions were calculated.

C.1.2 Improvement 2

Single changeover time = 38.16 min

Changeover time per year = (38.16 * 208)/60 = 132.28 hr

Increased capacity time per year = 202.80 – 132.28 = 70.52 hr

Additional products = 4599

Annual savings = 4599 * 25 = 114,975 SEK

C.1.3 Improvement 3

Single changeover time = 28.16 min

Changeover time per year = (28.16 * 208)/60 = 97.62 hr

Increased capacity time per year = 202.80 – 97.62 = 105.18 hr

Additional products = 6860

Annual savings = 6860 * 25 = 171,500 SEK

C.2 Financial Impact Bror Tonsjö

To calculate the financial impact of the improvements suggested, a questionnaire was sent via email to the production supervisor at Bror Tonsjo. The questions and answers are as follows:

1. Consent from the union and the management to track and record the process? - Yes
2. How often this changeover takes place in a day/week/month? - 3
3. Total working hours in a year? - 1080 hr
4. Cycle time of product? - 4.63 min
5. Cost of one product? - 190 SEK
6. How many operators/setters are involved? - 1
7. Do you have the layout of the machine? - Yes
8. Single station/machine or multiple involved during the changeover? - Multiple
9. Is there a checklist or clear work instructions for carrying out the changeover process? - Work instructions are provided
10. During the setup, will the operator take any breaks? - Yes
11. Any critical processes or tasks which needs to be performed at a particular pace? Any other limitations? - No

From the above information, the number of changeovers per year was calculated. Number of changeovers per year = number of weeks per year * changeovers per week = 52*3 = 156

C.2.1 Improvement 1

For the AS-IS state, the single changeover time = 178.01 min = 2.97 hr which gives the changeover time per year,

Changeover time per year = Single changeover time * number of changeovers per year = 2.97 * 156 = 463.32 hr

After implementing improvement 1 suggestions, the single changeover time decreases to 104.69 min which equals to 1.74 hr.

So, the changeover time per year = 1.74 * 156 = 271.44 hr

This gives an increased capacity time per year = changeover time per year (AS-IS state) – changeover time per year (improvement 1) = 463.32 – 271.44 = 191.88 hr

This increased capacity time per year allows to produce additional products of, Number of additional products = (Increased capacity time per year * 60) / Cycle time of product = 2487 products

Annual savings from these additional products = No. of additional products * Cost of one product = 2487 * 190 = 472,530 SEK

Similarly, the financial impact of improvement 2 and improvement 3 suggestions were calculated.

C.2.2 Imrprovement 2

Single changeover time = 96.58 min = 1.60 hr

Changeover time per year = 1.60 * 156 = 249.60 hr

Increased capacity time per year = 463.32 – 249.60 = 213.72 hr

Additional products = 2487

Annual savings = 2487 * 190 = 526,300 SEK

C.2.3 Improvement 3

Single changeover time = 68.22 min = 1.13 hr

Changeover time per year = 1.13 * 156 = 176.28 hr

Increased capacity time per year = 463.32 – 176.28 = 287.04 hr

Additional products = 3720

Annual savings = 3720 * 190 = 706,800 SEK

C.3 Financial Impact IMI Hydronic

To calculate the financial impact of the improvements suggested, questions were asked to the workshop manager during the visit to IMI Hydronic. The questions and answers are as follows:

1. Consent from the union and the management to track and record the process? - Yes
2. How often this changeover takes place in a day/week/month? - 1
3. Total working hours in a year? - 1080 hr
4. Cycle time of product? - 0.2 min
5. Cost of one product? - 10 SEK
6. How many operators/setters are involved? - 1

7. Do you have the layout of the machine? - Yes
8. Single station/machine or multiple involved during the changeover? - Multiple
9. Is there a checklist or clear work instructions for carrying out the changeover process? - No
10. During the setup, will the operator take any breaks? - Yes
11. Any critical processes or tasks which needs to be performed at a particular pace? Any other limitations? - No

From the above information, the number of changeovers per year was calculated.
Number of changeovers = 52 * 1 = 52

For the AS-IS state, the single changeover time = 396.72 min = 6.61 hr.

Changeover time per year = 6.61 hr = 343.82 hr

After implementing the improvement 1 suggestions, the single changeover time decreases to 321.85 min which equals to 5.36 hr.

So, the changeover time per year = 5.36 * 52 = 278.94 hr

This gives an increased capacity per year = 343.82 - 278.94 = 64.88 hr

This increased capacity allows to produce additional products of, Number of additional products = (64.88*60) / 0.2 = 19,464 products

Annual savings from these additional products = 19,464 * 10 = 194,640 SEK

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