Ethical task tracking of operators in agile manufacturing

GRADUATION REPORT

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EXECUTIVE SUMMARY

Diversey BV, a major player of professional hygiene product manufacturing, is facing challenges with agile manufacturing of these hygienic products with changeover process consuming most of production time. They are collaborating with the EU-Horizon 2020 COALA project to develop a cognitive intelligent assistant for the production line. They expect to standardize activities in the production line to reduce the gap in activity performance between experienced and novice operators. In order to set up the cognitive assistant, an operator location tracking system was needed to identify issue hotspots and sequence of activities in the production line. In this project, a suitable motion capture system was explored and deployed at Diversey Enschede 5L/10L production line. A literature study was performed to compare the state of the art motion capture and motion analysis methods. From the literature study results, the project decided to deploy a markerless motion capture method using Zed 2 camera.

The data collection method was tested at Enschede with Zed 2 camera which has in-built object tracking algorithms. The project applied an ethical approach to operator tracking, giving due respect to operators' privacy concerns and anonymity. The Value Sensitive Design method was applied in this project to identify the stakeholders, their values, and the project's future speculation. The data collection, storage and upload to cloud server was conducted using indefinitely running Python codes. The tracking was anonymized by allocating random identification numbers to denote objects and thereby, no personal data that can identify the operator were being stored. The data was captured and stored in spreadsheet format and processed using Python. The project concludes with the implementation of Z-Dash, an interactive tool that visualizes the data in various meaningful representations. Z-Dash offers graphs such as the Spaghetti chart for visualizing operator location and movements, Heat map of operator location concentration and Pareto chart that visualizes time and frequency of visited stations. The tool was evaluated with participants from Diversey to estimate the usability, interactivity and effectiveness for process improvement. The project proposes this tool for identifying the sequence of operator activities during events like changeover or stoppages, identifying issue hotspots and comparing best practices for similar events.

ACKNOWLEDGMENTS

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In addition to my supervisors, I am thankful to Samuel Kernan Freire, PhD candidate at Faculty of Industrial Design Engineering, for his valuable comments and directions to proceed with this project. He helped me with his experience working on similar projects and his constructive criticism on decisions made in this project has made the outcome more concrete. I am also thankful to Adrie Kooijman, Lecturer at Faculty of Industrial Design Engineering and Jered Vroon, Researcher at the Faculty of Industrial Design Engineering for helping me set up the hardware for object tracking.

Last but not the least, I am thankful to my friends and family for their constant support and encouragement throughout this project.

LIST OF ABBREVIATIONS

AI	Artificial Intelligence
AMA	Augmented Manufacturing Analytics
COALA	COgnitive Assisted agile manufacturing for a LAbor force supported by trustworthy Artificial Intelligence
EU	European Union
GDPR	General Data Protection Regulations
ICT	Information and Communications Technology
ID	Identification
IMU	Inertial Measurement Unit
IT	Information Technology
IR	Infrared
KPI	Key Performance Indicator
MAS	Motion Analysis System
MTM	Methods-Time Measurement
ODCE	Overall Data Collection Enschede
OEE	Overall Equipment Efficiency
PC	Personal Computer
PMTS	Predetermined Motion Time System
RFID	Radio-frequency identification
RGB	Red Green Blue
RQ	Research Question
SKU	Stock Keeping Unit
SMED	Single-Minute Exchange of Dies
TU Delft	Delft University of Technology
UTC	Coordinated Universal Time
VSD	Value Sensitive Design

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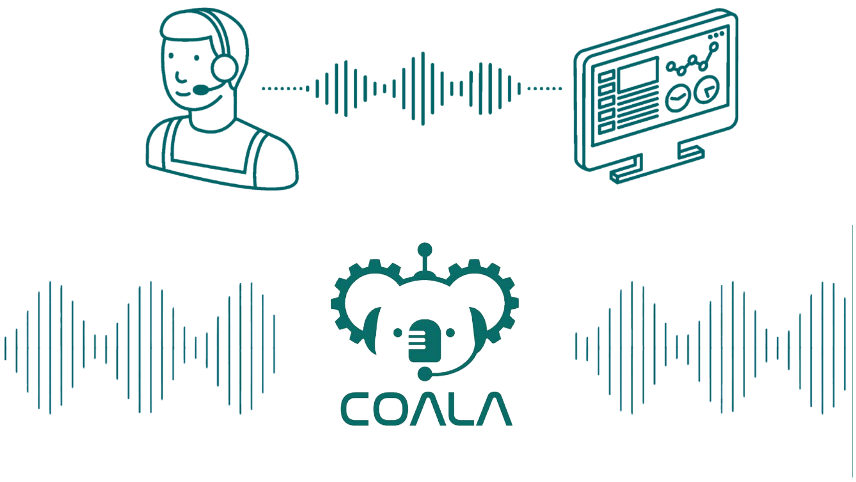
1 INTRODUCTION

The manufacturing industries had been adopting agile and lean manufacturing in its strategy to respond quickly to the customer and market demands. This improves their operational capabilities and inventory management (OptiproERP, n.d.; Cheng et al., 1998). Agile manufacturing involves running different variants of products in small production batches on the same production line depending on its demand. This is usually accompanied by the changeover process in changing the setup for one product to another. As the industries try to minimize the production lot and run a variety of products, it encounters the changeovers and stoppages which significantly contribute to unplanned downtimes, reduce the operational efficiency and contribute to non-value added processes (Van Goubergen & Van Landeghem, 2002). With the increase in variety of products, the configuration process also encounters complexity. This puts a heavy load on operator skill sets to configure production lines differently to manufacture different products. Also, the operators would need to gain expertise in resolving problems within such flexible production lines (Ketelsen et al., 2018).

1.1 COALA project

COALA (COgnitive Assisted agile manufacturing for a LAbor force supported by trustworthy Artificial Intelligence) is an EU H2020 project aimed to create a trustworthy cognitive assistant to upgrade skills of new workers in manufacturing industries. The vision of the COALA project is to develop an Artificial Intelligence (AI) enabled voice assistant, which proactively supports the operators in situations occurring on manufacturing lines, directs best practices to novice operators and provides on-the-job training (Figure 1). This voice assistant is expected to reduce the losses due to downtime and stoppages in the production line and also reduces the time in training the workers (COALA, n.d.; CORDIS Europa, n.d.).

COALA makes use of the open source Mycroft based digital assistant framework to develop the manufacturing-focused voice assistant. Besides the work on quality analytics and on-the-job training, it also initiates "why" questions with the operators to do the root cause of issues. COALA focuses on integrating the assistant into complex manufacturing Information Technology (IT) landscapes to demonstrate effective support. COALA learns from experience and practices of operators and keeps on improving the best practices for each of the events or issues.



Vision
To develop human-centred digital asssitant in manufacturing to shape collaboration between the AI-based asssitant and the human with COALA's AI-focused education and training concept

Figure 1: Vision of COALA project

1.2 About Diversey

Diversey BV is one of the stakeholders of the COALA project. Diversey BV (further in the report called "Diversey'') is a major player of professional hygiene product manufacturing. It is a provider of cleaning, sanitation and maintenance products, systems and services that efficiently integrate chemicals, machines and sustainability programs (Figure 2). Diversey has a market share of approximately 12% of food safety and professional hygiene products where the approximate total EU market is 8 billion euro revenue (COALA, n.d.).

Current challenges

Diversey's manufacturing is facing several challenges related to the agile production of high-quality hygienic products for professional use such as faster line configuration and on-the-job training for line operators. Agile manufacturing has been a long-running practice at Diversey production sites in the Netherlands, Italy, Germany, Spain, and the UK in Europe. It enabled Diversey to offer on-demand supply of multiple types of different products to its customers and to produce them in small batches (5-10 tons). This on-demand service and small batch production, however, requires a frequent reconfiguration of production lines.

With the COALA project, Diversey aims to increase efficiency of production, reduce changeover time and prevent unexpected stoppages by providing best quality training to operators. COALA would capture the best practices and standardize changeover and line handling operations.

SOLUTIONS OFFERED BY DIVESEY

Building care | Food safety | Infection prevention | Floor care

VISION

A healthy and safe world where people can live their lives.

MISSION

Protect and care for people every day through breakthrough, forward-looking cleaning and hygiene technologies.

Figure 2: Portfolio of Diversey BV

1.3 Design Challenge

This MSc project aims to ethically capture operator's activities and tasks in the production line, and then visualize these captured data into meaningful representations. This would serve as a basis for improving the process efficiency and identifying best practices among operators in the detergent packaging lines of Diversey Netherlands Production BV in Enschede and Diversey Italy Productions BV in Bagnolo.

In order to ethically capture these activities, the solution should facilitate the capture of data without direct or indirect identification of the person, yet enabling meaningful insights for the stakeholders. The major stakeholders of the H2020-COALA project are:

- Process improvement team of DIversey
- Diversey BV,
- SMED coordinators,
- Production line operators,
- Delft University of Technology,
- Researchers associated with the COALA project,
- Partnering universities/organizations of the COALA project.

The focus of this MSc project is the location and activity tracking of operators in the manufacturing industry. The design challenge here is to implement a system that collects sufficient data to capture best practices of the operators with an ethical perspective in mind. To tackle this challenge, the following research questions have been formulated:

RQ1: What data need to be collected to provide insights into best practices of operating production lines?

RQ2: What are the privacy issues arising from monitoring operator's activities?

RQ3: What insights required by different stakeholders can be provided using the captured data?

RQ4: How to represent the captured data into intuitive visualizations?

Significance

Through the COALA project, current best practices of changeover and issue handling are expected to be captured by the digital assistant. In order for this digital assistant to be integrated in the production line, supporting means in the ICT framework are necessary. One of these is the position sensing of the operators, which will be used to recognize the activities, the sequence of activities, and the location of the operator with respect to XYZ coordinates. This project facilitates the implementation of the COALA voice assistant in the Diversey production line in Enschede and Bagnolo.

1.4 Project Approach

The project follows a double diamond approach. To tackle the research questions mentioned in the previous section, the project follows the below mentioned four stages. These stages were followed in an iterative manner with research being performed first and the rest of the stages followed in an iterative manner based on the project demands (Figure 3). Analysis and design were iterated several times with data received from client meetings. The list of requirements went through three stages of iteration with first iteration defining the basic project requirement. Second iteration was performed after the co-creation session with COALA project researchers of TU Delft (Section 2.2). The third iteration was done to adjust the requirements to the scope of the project as it changed the emphasis on the data processing. The iterations performed between data processing and data collection stage can be found in Section 4.4.

Research:

This phase focuses on reviewing state-of-the-art tracking methods, understanding the stakeholder needs, privacy concerns and stakeholders values through interviews, site observation and literature research.

Analysis:

The insights from user interviews and stakeholder analysis are processed to identify the relevant data that is required for creating the data representations. This is followed by context mapping, design vision and formulation of a list of requirements.

Design:

This phase involves the design of the position sensing service architecture, setting up and collecting data at site. This is followed by ideating the ways to visualize the tracking data.

Implementation & Evaluation:

The final stage is about implementation for data analytics on collected data, on-site data collection followed by evaluation of the outcome with the stakeholders. Data analytics is applied to identify the locations, activities and postures of the operators with respect to the stations in the production line. From these data, concepts for meaningful data representations will be evaluated.

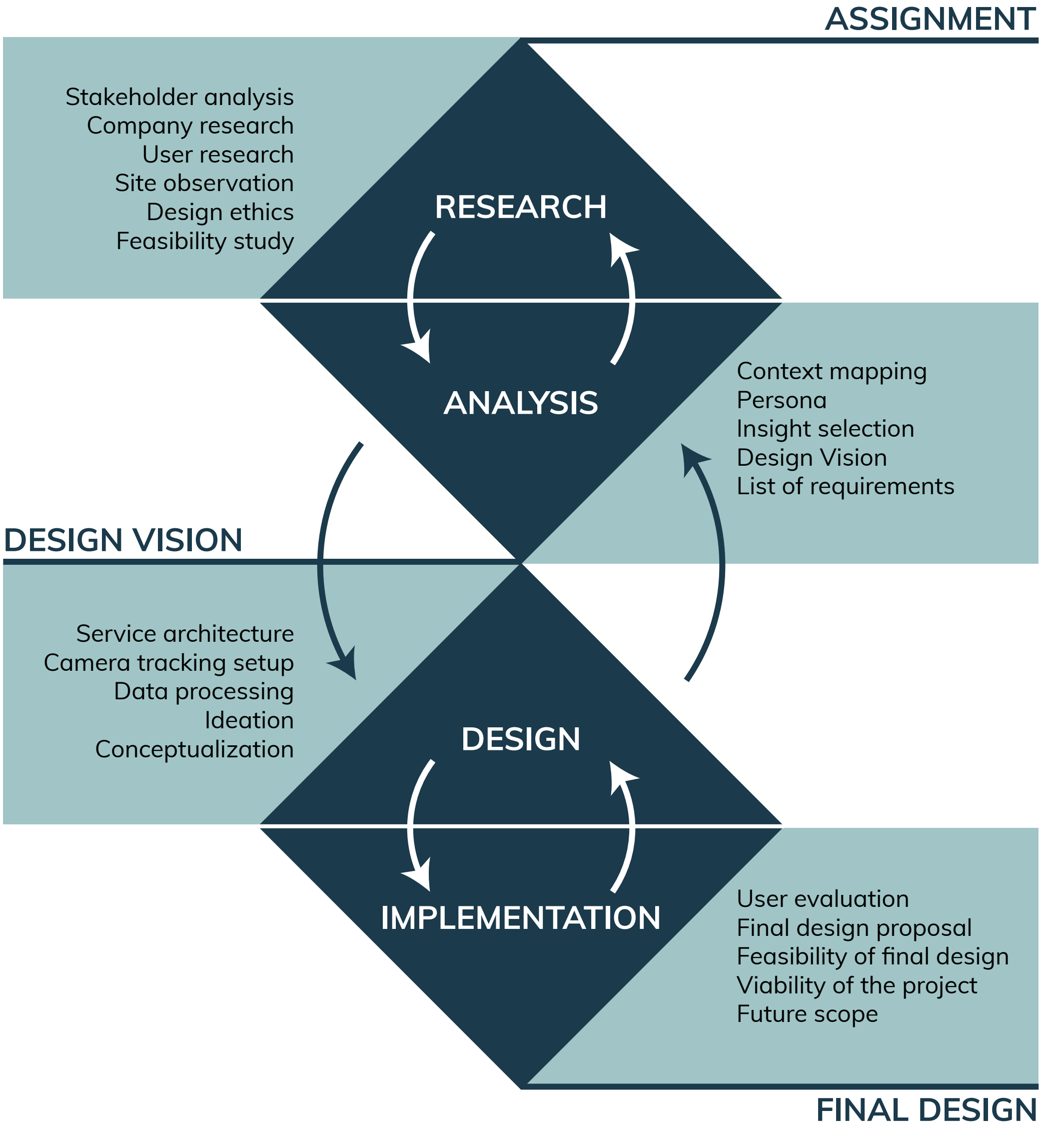


Figure 3: Project approach

2 RESEARCH

2.1 Literature study
2.2 User research
2.3 Ethical design values
2.4 Site observation
2.5 Context mapping
2.6 Zed 2 tracking system - feasibility study

In this chapter, five topics relevant for this MSc project are being investigated. Figure 4 presents these five topics together with their nine pertinent sub-topics.

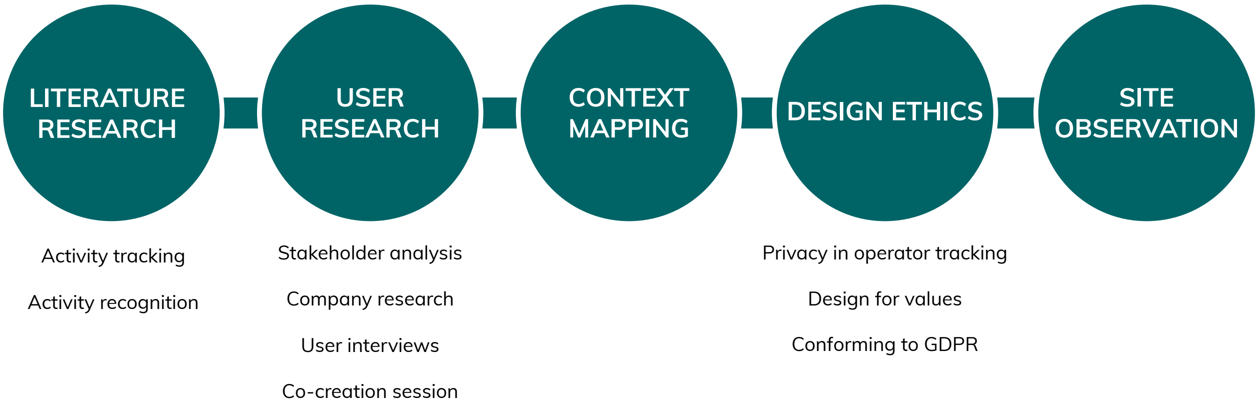


Figure 4: Research methods used in this project

2.1 Literature study

Introduction

This section details the state-of-the-art technologies in work study methodologies and activity tracking currently used in industries.

Research goal

The aim of the literature study was to identify and analyze:

- Current practices of motion and skeleton tracking
- Capabilities of the chosen means of motion tracking

Methods

Literature research was conducted using Google scholar web search engine. The following search terms were used to find relevant scientific papers: "camera based activity tracking", "activity recognition", "motion capture methods", "Zed 2 camera tracking".

Activity tracking

Activity tracking has been growing in demand in industry environments for productivity improvements. As the industries are undergoing the fourth revolution of automation and data exchange, there are many studies around automation of work study and activity tracking (Moeslund et al., 2006; Kärcher et al., 2018).

Work study methodologies are used in industries to follow time standards and improve productivity over time. Often, these work studies are performed to estimate the ratio of value-added and non-value added tasks, such as walking to locations. Walk paths are usually estimated using pen-and-paper method of drawing Spaghetti charts and predetermined motion time system (PMTS) method to estimate the time for each activity (Agethen et al., 2016a; Elnekave & Gilad, 2006).

One of the trends seen in automotive assembly is the use of sensor based Mocap technology for virtual training, maintenance and assessment (Han & Song, 2013; Hartel et al., 2011). Stiefmeier et al. (2008) showcased a sensor based method in car assembly by placing sensors on the body of the operator as well as the car to detect assembly steps. They used several sensors, among others Radio-Frequency Identification (RFID) sensors for tool detection and Inertial Measurement Unit (IMU) for hand vibration, to achieve robust activity recognition. Wang et al. (2016) proposed a method to install

RFID tags on all moving objects, and RFID readers throughout the assembly line to get accurate data of real-time object tracking and movement path determination, while Kärcher et al. (2018) presented a similar system using multiple sensors installed on products and tools, but not on the workers. These sensors are integrated through a layer of IT infrastructure and a layer of data analysis and evaluation at the topmost (Figure 5).

Marker based motion capture systems utilize cameras to detect a marker placed on the body in its respective 2D image view, and then later triangulate the position in 3D using multiple cameras (Bortolini et al., 2020). Aminian & Najafi (2004) tested out two different techniques using body-fixed sensors like accelerometers and gyroscopes to effectively identify the postures of the person. They argue that body-fixed sensors offer better quality than the camera based system due to higher frequency sampling.

An assembly planning operation using Virtual Environment has been explained in Bullinger et al. (2000). They used electromagnetic sensors to detect the body postures and hand gloves to determine the orientation of the hand. The resulting image of the body was fed to the system to analyze the MTM (Methods-Time Measurement) basic movements to analyze the assembly planning time. According to Müeller et al. (2016), current developments in tracking based operator guidance are not flexible due to the requirement of additional wearables.

Making a markerless optical capture method that does not interfere with the scene is still a topic of research. The main advantages of such a system are: easy setup and no obstruction in the operators' movement. There are two types of optical motion capture: RGB sensor based and depth camera based. Due to the advancements in 3D depth cameras such as Microsoft Kinect™, motion capture has grown beyond marker based methods. Initially, designed to revolutionize the gaming industry, Kinect™ has expanded beyond its use to find itself useful in object detection, 3D motion capture, facial recognition and voice recognition (Zhang, 2012). Diego-Mas & Alcaide-Marzal (2014) used a Microsoft Kinect™ system to detect the activity and posture of an operator. Their comparison of the results obtained from such low-cost sensors with manual human observed data shows that the low-cost range sensors provide valuable

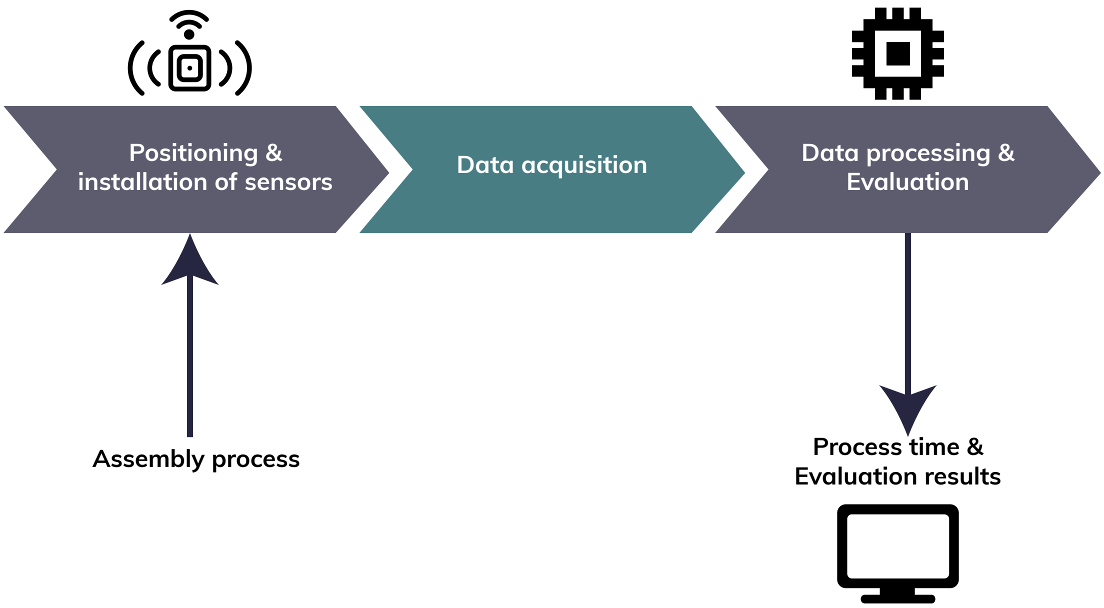


Figure 5: Adapted illustration of steps used by Kärcher et al. (2018) from data collection to analysis

data but are less accurate than the manual method.

In automobile assembly lines, using multiple cameras has become a necessity considering the area that needs to be covered (Berger et al., 2011; Shafaei & Little, 2016; Yeung et al., 2013; Zhang et al., 2012). Bortolini et al. (2020) developed a system called MAS for production and ergonomic assessment using a network of Kinect cameras. The activities recorded in the manufacturing tasks were analyzed with respect to time and space to calculate the work path movements, occupied locations and traveled distances. MAS consists of four depth cameras, each connected to a PC, which are connected together by Wi-Fi and one of the PCs acts as the master which synchronizes the images from all four cameras (Figure 6). Otto et al. (2015) discusses a distributed camera setup using multiple Microsoft Kinect cameras which observe places of interest. Agethen et al. (2016b) presents a similar markerless method of recording walk paths to compare with the planned walk paths. This method uses a distributed camera setup in a manual automobile assembly line.

Activity recognition

One of the main reasons for implementation of motion capture systems in industries is for process optimization. With the tracked data of the worker, the redundant activities or unnecessary work paths can be detected and eliminated (Geiselhart et al., 2016). Several methods used over the past two decades have been reviewed by Aggarwal & Cai (1999), Aggarwal & Ryoo (2011) and Gondo & Miura (2020). These methods for detecting active/inactive workers and problem identification have been reviewed from the perspective of construction sites by Gondo & Miura (2020).

Activity recognition is a two step process: first segmenting the data streams to retrieve meaningful activity and the second step is classifying the segments (Stiefmeier et al., 2008). Peddi et al. (2009) proposed a method to classify the pose of workers as effective, ineffective and contributory tasks. They used two phases to determine productivity: the pose estimation and the productivity classification. In the first phase, image processing algorithms were deployed to estimate the pose followed by deploying neural network algorithms to classify these poses in the second phase.

A few of the marker based methods for activity recognition were using body worn accelerometers to identify the activity based on the accelerometer values placed on the worker's waist (Joshua & Varghese, 2011), RFID based method to identify the state of

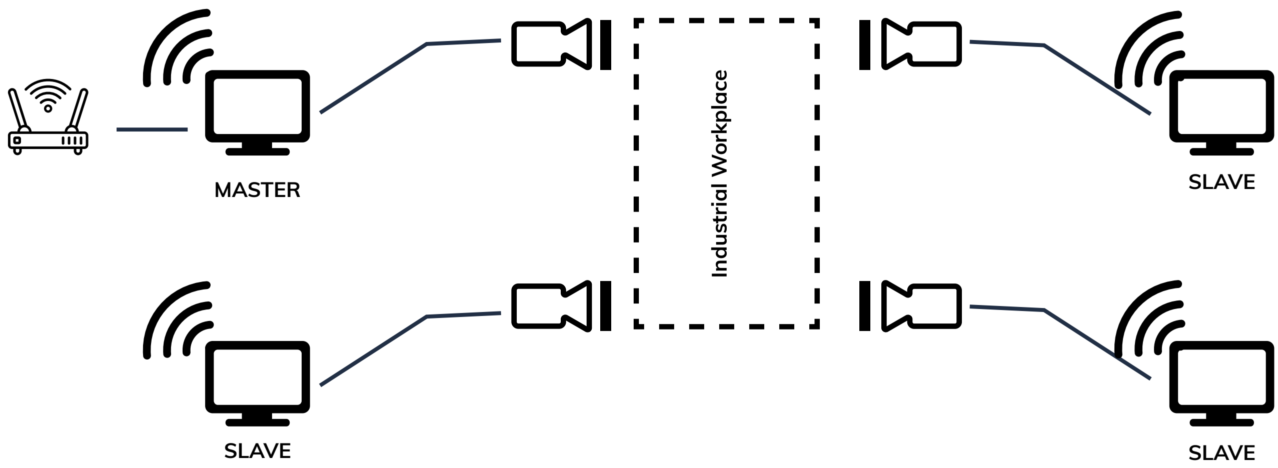


*Figure 6: Adapted illustration of hardware architecture used by Bortolini et al. (2020) in the MAS**

** Reprinted from Computers & Industrial Engineering, 139, Bortolini et al., Motion Analysis System (MAS) for production and ergonomics assessment in the manufacturing processes, p.4, Copyright (2021), with permission from Elsevier.*

the person based on the location (Cheng et al., 2013). Gonsalves & Teizer (2009) used range cameras to develop the skeleton structure of workers, which were further analyzed for activity recognition based on the angles between different segments of the skeleton.

Aggarwal & Ryoo (2011) classified all activity recognition methods as single layered and hierarchical approaches. Single layered approaches detect the activity based on sequence of images, while hierarchical approaches represent complex activities in terms of simpler activities or subevents. Single layered approaches are further subclassified as space-time approaches and sequential approaches. Space-time approaches use video data as XYT volume, while sequential approaches see the video data as a sequence of feature vectors.

Several researches have focused on template matching for activity recognition to keep a record of images of certain activities and match the input data with it to check which activity it matches with. Laptev & Lindeberg (2003) focused on retrieving local interest points that represent certain actions from the 3D-space time volume. Niebles et al. (2008) used a recognition method that states an action as a collection of spatio-temporal feature appearances. Ryoo & Aggarwal (2009) used a pairwise spatio-temporal relationship between local features to identify complex-structured activities.

Results and insights

The studies of the current state of the art activity tracking methods show that there have been several methods for the operator activity and position detection in an industry environment. Activity tracking has been a topic of several years of research spanning from manual PMTS methods to more automated markerless motion capture systems. Most of these studies focused on training and ergonomics of the operators while performing their tasks. From these methods in the studies, all have some positive contributions as well as drawbacks. Body worn sensors offer higher frequency sampling and are cheaper compared to camera based motion capture (Aminian & Najafi, 2004). Marker based motion capture is also relatively cheaper than markerless motion capture. Despite the various methods and their positive contributions from the literature study, the following drawbacks were found in the study as presented in Table 1.

Discussion

As stated in Section 1.3, the proposed MSc project solution should implement a system that collects sufficient data to capture best practices of the operators with an ethical perspective in mind. Moreover, data collection should be done in an unobtrusive way for the operators. Looking at Table 1, markerless optical capture systems seem to be the most suitable option for this project solution, as they provide no obstruction in the operators' movement, are easy to set up, and allow fully automated data collection and analysis. Therefore, it has been chosen to make use of the markeless optical capture system in this MSc project.

This project can be seen as an enhancement of the research conducted by Bortolini et al. (2020), in which they used multiple Kinect cameras to assess the performance and ergonomic factors in a workplace. The aim of their study was to automatically analyze the operator's productivity including walking path movements, added and non-value added tasks, and hand distribution on workspace. One important point to note here is that Bortolini et al. (2020) faced issues with illumination due to the Kinect being a depth camera. To overcome this issue, they had implemented a Neutral Density filter on each of the RGB and IR sensors of the camera. To avoid illumination effects, we are employing a Zed 2 position sensing camera for the same task. Further, this MSc project takes a similar approach to that of Bortolini et al., but makes use of a single Zed 2 camera (Figure 7) instead of multiple Microsoft Kinect. Tracked position and skeleton data of the operators in the production line will be used for comparing and identifying the best practices of operators.

Zed 2 is a 2K* stereo camera with in-built neural networks to reproduce human-like vision. It is capable of detecting objects such as people or vehicles in the spatial context. Zed 2 works based on passive stereo vision the same way as human vision works. The camera captures side by side color images which is used by Zed 2 software to create a depth map of the scene (Figure 8) (StereoLabs, n.d.). Unlike Kinect v2 cameras which are based on Time of Flight sensors, Zed 2 is able to work both indoors and

Table 1: Comparison of activity tracking methods currently used in industry practices

Activity tracking method	Pros	Cons
Computerized Predetermined Motion Time Systems (PMTS) (Elnekave & Gilad, 2006)	• Video recording capability for analysis • Possibility of distance measurements from video	• Still required the analyst to be present on the site for conducting the work study • It was not capable of documenting them automatically • Expensive
Sensor based method (sensors placed on production line or operators or both) (Stiefmeier et al., 2008; Kärcher et al. ,2018; Wang et al., 2016)	• Body-fixed sensors offer better precision than the camera based system due to higher frequency sampling (Aminian & Najafi, 2004)	• Relevant to assembly lines where tools employed for the activities • Some factors such as cables between sensors and real-time processing of data makes this method less suitable for the purpose of this project
Marked based Motion capture (Bullinger et al., 2000; Aminian & Najafi, 2004)	• No need of expensive tracking device • Easy to set up	• Requires additional wearables for motion capture (Müeller et al., 2016) • May hamper the free movement of the operator as well as cause discomfort due to wearing these
Markerless optical capture system (Diego-Mas & Alcaide-Marzal, 2014; Bortolini et al., 2020; Agethen et al., 2016b)	• Easy to set up • No obstruction in the operators' movement (Zhang, 2012)	• Less accurate than the manual method. (Diego-Mas & Alcaide-Marzal, 2014) • Needs multiple camera to cover large area (Berger et al., 2011; Shafaei & Little, 2016; Yeung et al., 2013; Zhang et al., 2012) • Markerless motion capture systems like Microsoft Kinect suffer from challenges due to illumination conditions (Müeller et al., 2016; Bortolini et al., 2020)

** A 2K camera provides a video resolution of 2560x1440*

Figure 7: Zed 2 camera dimensions (Source: stereolabs.com)

outdoors under all illumination conditions (Lun & Zhao, 2015; Peijnenburg et al., n.d.).

Zed 2 camera provides inbuilt functionality for real-time image processing and recording the object parameters such as the object ID, position in XYZ coordinates, skeleton data, velocity, activity (Idle or Moving), etc. Once the activity tracking has been recorded, it needs to be analyzed. For this, the method of activity recognition mentioned by Peddi et al. (2009) would be applied to classify the activity as effective, ineffective and contributory tasks based on the machine running status. The activities that are effective or contributory need to be template matched for activity analysis.

Figure 8: Zed 2 motion capture (Source: stereolabs.com)

2.2 User research

Introduction

The literature study was followed by company research and user research. This section explains the direct and indirect stakeholders, their needs, and expectations relevant to this project. The stakeholders research directed to identify relevant data to be tracked and the ethical concerns associated with that tracking.

Research goal

The company research was focused on the existing methods used by Diversey in process improvement and what the current challenges are. The user research focused on the various needs and expectations of the stakeholders from this project. The goals of the user research were:

- Identifying the direct and indirect stakeholders
- Defining stakeholders' role, needs and expectations

Methods

Literature research on activity tracking and its capabilities provided first insights on defining the goals of the user research in understanding the needs of the stakeholders. The relevant stakeholders of the project were identified and each of their roles and expectations were investigated through user observations, interviews and co-creation sessions.

Results

Stakeholder Analysis

The direct stakeholders identified in this project are: the process improvement team, line operators, SMED coordinator. The indirect stakeholders are: the quality improvement department, TU Delft, Diversey (collectively refers to Operational excellence, Engineering, Technical/Maintenance teams and Site Management) and the COALA project researchers.

The outcome of this project, as mentioned in Section 1.1, is to facilitate a position tracking method for the COALA project and to provide intuitive data visualizations that can provide insights into the working performance of the production line. The operators and the process improvement leads are the ones directly involved in the project. The process improvement team and the SMED coordinators are interested in the collected data and the data visualizations that make it easier to identify problems or bottlenecks at the site. For the operators, however, there is concern for their privacy at work. In consequence, they may not be trustful of the Zed 2 camera being installed at work.

Diversey is an indirect stakeholder related to this project via the process improvement team and SMED coordinators. The potential process improvement could improve Diversey's production throughput as well as the revenue. TU Delft and other COALA researchers could benefit from the outcome of this project for implementing in the COALA project.

Company research

Diversey is interested in the project outcome to implement the COALA voice assistant at Enschede 5L/10L line, and later also in Bagnolo, Italy. A brainstorm session was conducted to determine what the client expects from the COALA project and what all parameters need to be identified (Refer Figure 5). The brainstorm session consisted of three participants from Diversey and three from TU Delft COALA project team.

For Diversey, making use of the Zed 2 camera is beneficial to answer the questions about basic positional and movement data of the operators such as: "Where is/are the operators?", "How long are they in a place?". Through the analysis, Diversey expects to find:

a. Standards by SKU on a production line (from the statistics),

b. Variation based on the statistics,

c. Analytics: find the most effective technique settings, process, change over. Compare them to KPIs (Key Performance Index),

d. Check exceptions: Min/max and escalate (e.g. safety) (Figure 10).

Diversey together with the process improvement team would like to visualize the distance moved, number of visits and time spent on specific stations. These data could enable them to, for example, analyze issue handling methods of operators, sequence of activities, identify fine tuning and bottlenecks during a shift. Diversey also expressed interest in automating the (Single-Minute Exchange of Dies) SMED process, which is currently implemented manually at the site. Through the SMED process, they record the time taken for each of the activities and categorize each of the activities as internal (performed when the machine is stopped) or external (performed without stopping the machine). The SMED process aims to reduce the time taken for the internal activities, convert internal to external activities and improve changeover efficiency of the line. The SMED process trials new sequences of activities and checks the improvement in the time taken for the activities. Diversey is interested in finding out the best practices of activity sequence for changeovers.

During the brainstorm session with Diversey (Figure 10), the data parameters to be collected using Zed 2 were defined. These data to be collected are based on the state

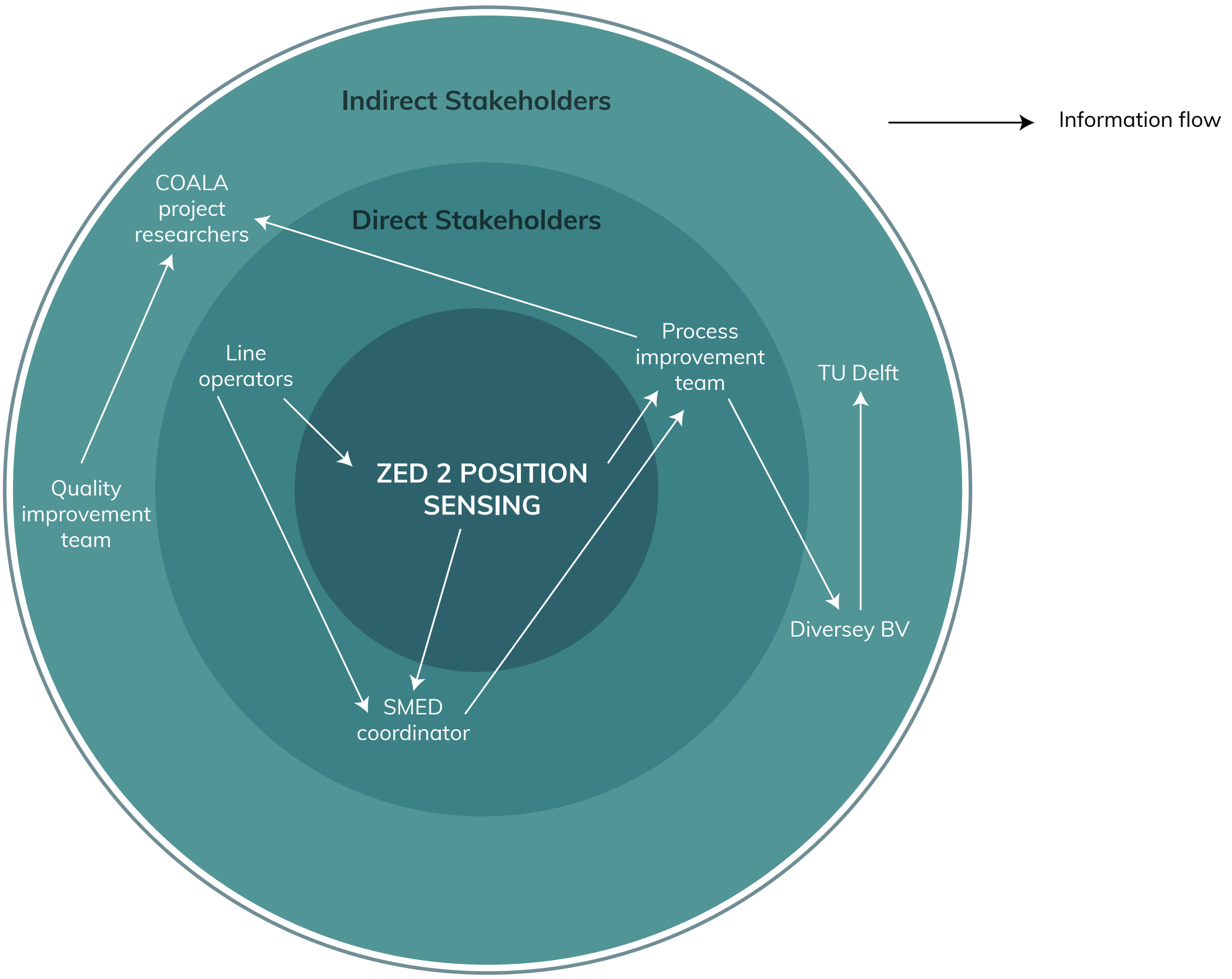


Figure 9: Stakeholder map

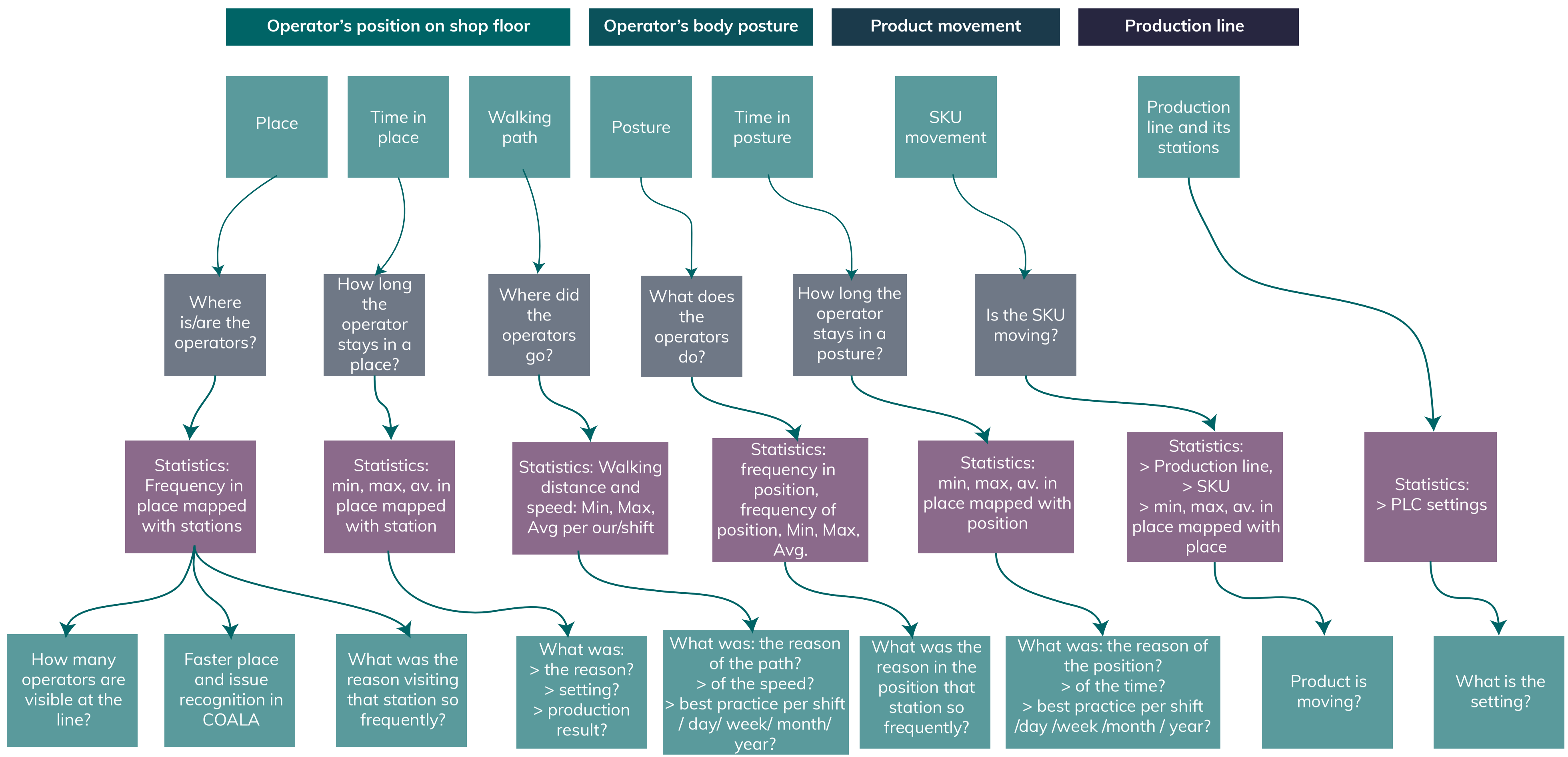


Figure 10: Summary of brainstorm session with Diversey (full version in Appendix D)

of the person in 3D coordinates with respect to time such as:

- Timestamp
- Anonymous ID
- Location of object - XYZ
- 18 point skeleton data - XYZ
- Station proximity
- Velocity of the object
- Distance from camera

From these parameters, various data can be inferred which are relevant to visualize the performance of the production line (Figure 11). In order to calculate the time spent on specific stations, the data collected with respect to timestamps are compared with the proximity to stations. Activity is marked as “idle” or “moving” or as working on specific stations based on the XYZ coordinates comparison. Behavioral patterns or seriousness of events are inferred through change in a person’s walking pace. Besides these data, the machine data from the ODCE server of Diversey, would also be merged with the object data for connecting with machine running status.

User Interviews

In order to get insights into the needs of the process improvement team, an interview was conducted with the process improvement team leader and also with a personnel from the quality improvement team. It was found that the current process improvement measurements are performed manually using timed activities. The data is then being reported in tabular form to the daily meetings with the team.

The adoption of the Zed 2 camera in the production line is expected to change manual problem analysis (such as verbally inquiring to the operators and analyzing the root cause) to a more refined automatic visual analysis of performance data. The process improvement team is expected to benefit from data visualization proposed from this project. The team showed interest in applying Machine Learning algorithms to find patterns in the performance. Currently, the comparison of data from different shifts is not yet done or might be done manually. This is a missed opportunity in identifying patterns in the line. If there could be a method to compare the data from different shifts or of the same SKU another day can provide insights about the error/fault patterns in the line depending on the shift, SKU or other such parameter.

One of the scenarios where operator knowledge plays an important part in performance is the sequence of activities to be performed for different issues. The experienced operators work the sequence from their memory but the inexperienced or novice operators make mistakes, for example, by being too confident to refer to this sequence. From the visualization, if the sequence of activities performed can be analyzed, it would help the process improvement team to identify at what step and time the mistake happened. Another experience factor governing the operators is setting the right speed for the SKU. Different liquids have different rated speeds and the operators usually start at 35% rated speed and perform stepwise increment to the 100% rated speed. It takes some fine tuning before novice operators can get it running efficiently. The camera data along with the machine data could facilitate the process department with an improved way to standardize these settings.

The most events are usually occurring at the depalletizer and filler station. The labeler is partially resolved as the machine has been fixed recently and is not expected to cause as many faults as other stations would. With this, a good point of setting the camera would be close to the conveyor covering area encapsulating the filling station, box loader and PC. Appendix B and C provides details about user interviews.

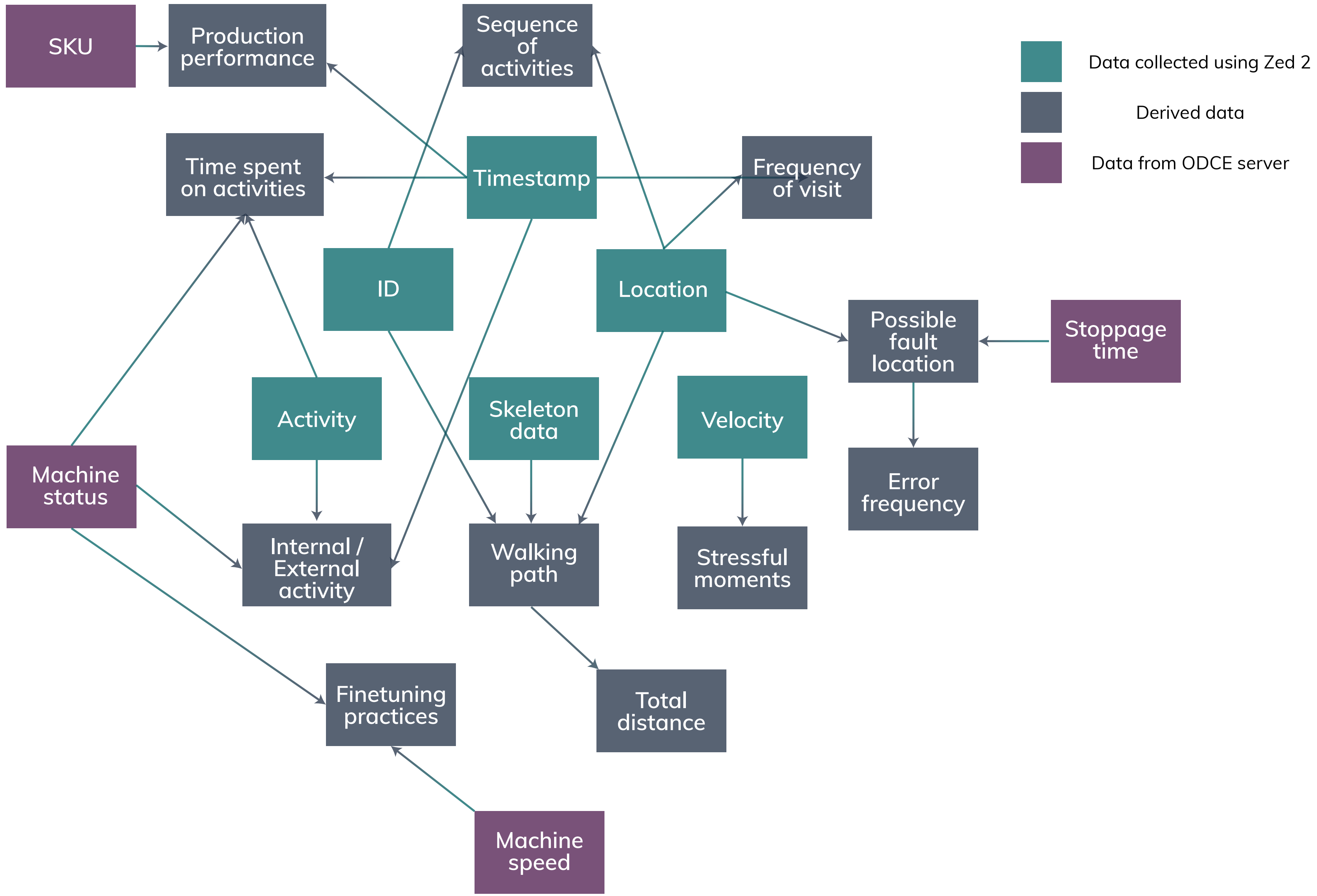


Figure 11: Parameters for data collection

Co-creation session with COALA researchers at TU Delft

The session was aimed at exploring the expectations of the TU Delft COALA team using the Zed 2 camera at Diversey. The session was attended by three participants from the TU Delft COALA team. The session started with exploring their understanding of the bigger COALA project and what they expect the final outcome to be. With this result in mind, they were asked to think of what Zed 2 camera can do to produce that outcome. The problem statement for the brainstorm session was: "What can Zed 2 camera contribute to COALA voice assistant?" The issues at Diversey and what can be solved with the Zed 2 camera were explored in this session. A few of the ideas that came out were about "Assist issue handling", "Inform COALA where the

Table 2: Clustering of ideas

Cluster	Ideas
OBJECT TRACKING	• Track skeleton to identify issues with machine • Track operators to identify if the activity is internal / external • Identify operator's sequence of actions • Track operators position to monitor sequence of configurations • Sense if the operator is at the production line • Sense what the operator is performing • Sense if the operator is working on a machine/station • Identify the operator position • Capture the movement of operator's hands • Sense if operator is standing / walking/ running, etc. • Inform COALA of the operator's location.
OUTCOMES OF TRACKING	• Assist changeover • Assist issue handling • Provide contextual data to adapt the COALA recommendations • Sense how many people are standing together • Track idle time for engaging operators in issue reporting • Assist root cause analysis • Sense if a operator is stuck with an issue
LINE PARAMETERS	• Track when issue handling starts and ends • Track when configuration starts and ends
SAFETY	• Track if operator is lying motionless on floor • Sense if there is a dangerous scenario
STATE OF BEHAVIOR	• Track if consultation with COALA is disturbing the activity flow • Sense if the operator is drowsy • Sense the stress level of operator • Track posture to see if operator is actively interacting with machine

** Appendix can be found in a separate file along with this report* operator is standing along the production line", "Sense if there is a safety issue", etc.

The ideas generated in the brainstorm session were clustered based on their similarity into five clusters: object tracking, outcomes of tracking, line parameters, safety, and state of behavior. The clusters of ideas from the session are as shown here in Table 2.

a. Line parameters: Ideas related to the production line running status.

b. Object tracking: Ideas related to the object tracking and the data related to it such as the skeleton tracking, operator's sequence of actions, sensing motion of operators (walking, running, standing), tasks performed.

c. Outcomes of tracking: Ideas related to the outcomes that can be inferred from the object tracking such as assisting changeover or root cause analysis, sense if operator is stuck with an issue or whether multiple people are present at the same station.

d. State of behavior: Ideas related to the activity of the operator such as whether the COALA voice assistant is disturbing operator activity, sense if operator is actively interacting with machine, sense if operator is stressed or relaxed.

e. Safety: Ideas related to safety in the production line.

Discussion

From the interactions with the stakeholders of the project, the direction of what needs to be tracked and the location of tracking was identified. From the interview with process improvement lead, it was understood that the filling station and the depalletizer are the most error prone locations and the site setup location should cover those. The requirements of data collection mostly circled around the time-based object tracking of the operators in an XYZ world coordinate system. The questions which Diversey would like to get answers such as "Where are the operators?", "How frequently are they visiting station A?", etc. can be derived from the data collected. COALA team of TU Delft also had similar requirements as the Diversey requirements. The data they required were such as the object tracking parameters, behavior state of the operator, safety issues, production line parameters and derived data from outcomes of tracking. The complete details about stakeholders and their expectations can be found in Appendix E. With the requirements identified, it was decided that ethical aspects of the data capture needed to be brought into the picture before starting the actual data collection. This is explained in detail in the next section.

2.3 *Ethical design values*

Introduction

Camera tracking of an operator's activity may raise a negative association whether it is going to be performed ethically or whether it would lead to covert operator surveillance using tracked videos. Therefore, it is important to define ethical guidelines for any activity tracking. In this project, the operator tracking is done anonymously and is used only for the intention of process improvement.

Research goal

The goals of the ethics study were to:

- Define ethical guidelines in tracking personnel in production lines
- Identify the values for direct and indirect stakeholders
- Tackle the challenges arising from the future use of the Zed 2 camera position sensing

Methods

The literature as found in Section 2.1 has been used to find out how others tackled ethical considerations when tracking human activities, and what kind of regulations handling privacy issues should be taken into account. Further ahead, the Value Sensitive Design method was applied to identify the values associated to this project by the stakeholders. A poster addressing these values and what will be captured was presented at the site. Before starting the data capture, the operators working in the shift were explained about the project and their consent for the data capture was recorded.

Process

Privacy in operator tracking

One of the major issues of establishing a camera based position sensor in this project was the privacy concerns from the operators being tracked. Solove (2008) proposes a taxonomy that identifies the various privacy violations, and which consists of four main activities: "(1) information collection, (2) information processing, (3) information dissemination, and (4) invasion".

Clarke (1997) outlines four types of privacy. These four types were extended by Gutwirth et al. (2011) to include seven types of privacy: privacy of the person, privacy of behavior and action, privacy of personal communication, privacy of data and image, privacy of thoughts and feelings, privacy of location and space and privacy of association. In this MSc project, the privacy types that are relevant are:

- Privacy of behavior and action - the observation systematic or casual of a person and their actions,
- Privacy of data and image - issues related to data being available to other individuals or organizations,
- Privacy of location and space - right to move around without being identified or monitored.

Senior et al. (2005) outlined six questions in their "Model for Video Privacy" that need to be answered to ensure privacy in video surveillance systems:

1. What data is present?
2. Has the subject given consent?
3. What form does the data take?
4. Who sees the data?
5. How long is the data kept?
6. How raw is the data?

These questions help in defining the architecture of the motion capture system, its implications and drawing up preventive measures.

Besides the video privacy model, necessary privacy guidelines provided by the General Data Protection Regulations (Regulation EU

2016/679, 2016) also need to be followed for ethical tracking in industries. Rights of the data subject enacted under Articles 12-23 describes the rights of the data subjects in the data collection process. Also, Article 25 dealing with the "Data protection by design and by default" states that the responsibility of the controller to implement appropriate measures to ensure only necessary personal data are processed. Bortolini et al. (2020) had taken into account three major principles to follow the privacy guidelines in an industry under GDPR (Regulation EU 2016/679, 2016). First, the "privacy by design principle" was implemented during the development of the MAS to ensure personal data protection. Secondly, "right to be forgotten" for removal of data upon request from any worker and, thirdly, the "principle of transparency" of data agreed mutually between employer and the operators. The agreement consisted of information regarding the purpose of the MAS adoption, anonymity of the data, non-identifiable data to any specific employee, who has the data, duration of the data storage and camera specifications. If the operators at work are not identifiable, major privacy issues can be eliminated. Agethen et al. (2016b) implemented a method to close out the RGB sensors using a physical cap placed in front of it and utilized only the depth camera to track anonymized skeleton data.

Design for Values

Design for Values integrates human values into design and facilitates technological development in the direction of values for its stakeholders. Design for Values is a design approach used at TU Delft with the vision to address the interaction between design and values (Design for Values, 2019).

Design for Values originated from VSD approach which was originally developed to address the role of human values in the field of IT (van den Hoven et al., 2015, p. 1-7). Since its origin in the early 1990s, VSD has become an approach that weaves together the human values in design from its early phase development, implementation, use and evaluation (Davis & Nathan, 2015). In this MSc study, VSD methodology will be used to define the connection between the technology and the values.

VSD is a way to include the human and moral values in emerging technologies, design and development. It takes into account the values imparted by the technology to the stakeholders and also reflects in advance on how it changes over time and with widespread use (Davis & Nathan, 2015; van den Hoven, 2007). According to Friedman (2002), VSD employs an iterative tripartite methodology that integrates conceptual, technological and empirical investigations on the design. Conceptual investigations involve analytical or theoretical explorations of the issues and questions of what and whose values to support, how to deal with value conflicts, etc. Empirical investigations involve the context of human activity where technology is used and they involve questions like how stakeholders prioritize individual values and usability, trade-offs between competing values, etc. Technological investigations focus on how the technological properties influence human values.

Results and insights

The following three methods serve as a framework for ethical guidelines for this MSc project.

Model for Video Privacy (Senior et al., 2005)

To handle privacy related issues due to video motion capture, the method outlined by Senior et al. (2005) is used for this study. The insights from this study can be found in Table 2.

Table 3: Model for Privacy (Senior et al., 2005) solutions

Privacy question	Solution
What data is present?	Operator object and skeleton data with respect to three-dimensional coordinate over time.
Has the subject given consent?	Consent forms were signed by the plant manager on behalf of all the operators after discussing with them about the project.
What form does the data take?	.csv or .xlsx format of the data containing anonymous ID of person, object XYZ data, velocity, activity and 18 point skeleton coordinate data.
Who sees the data?	The data is used by the TU Delft researchers working on COALA as well as the process improvement team of Diversey BV.
How long is the data kept?	The data will be stored for a maximum of 6 months.
How raw is the data?	Spreadsheet of the data specified above with filenames representing the time and date

From these data, the data collection architecture of the system was created as shown in Figure 12.

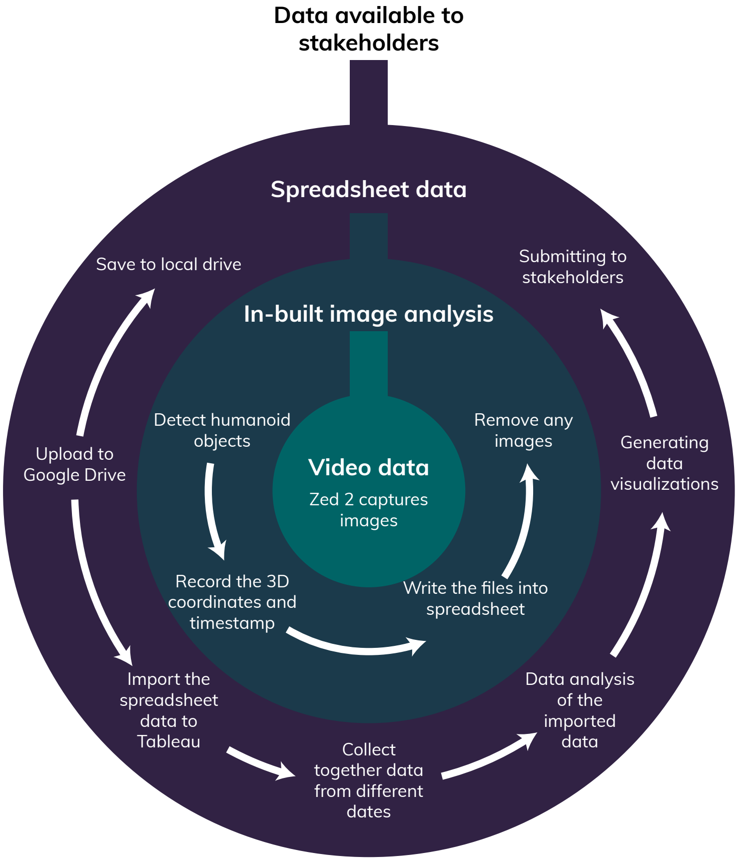


Figure 12: Data collection architecture

Conforming to GDPR

The collected data had to be handled as per the GDPR (Regulation EU 2016/679, 2016). The relevant articles for this project and the solutions are given in Table 4.

Table 4: Actions taken to conform to GDPR regulations

Article	Description (European Commission, 2016)	Action
Art. 12 - Transparent information, communication and modalities for the exercise of the rights of the data subject	Principle of transparency of the data collected and shall be provided to data subjects in concise, intelligible and easily accessible form upon request.	The data shall be made available for the data subjects to visualize.
Art. 13 - Information to be provided where personal data are collected from the data subject	When personal data of subjects are collected, the subjects should be provided with contact details of the controller, purpose and processing information of data.	Data collected shall be anonymous. The consent forms and poster specifying the research with the data subjects should be shared with them.
Art. 14 - Information to be provided where personal data have not been obtained from the data subject	When personal data of subjects are collected from another source, the subjects should be provided with contact details of the controller as well as the representative, purpose and processing information of data.	Data collected shall be anonymous and no data of subjects shall be collected from other sources.
Art. 15 - Right of access by the data subject	The right of data subject to ask for the purpose of the processed data, recipients of the data, right to lodge a complaint.	The data collected shall be made available to the data subjects in visualization form. As the data is anonymous, it is not possible to identify and erase a specific person's data.
Art. 16 - Right to rectification	Right to obtain from the controller without undue delay the rectification of inaccurate personal data concerning him or her.	All data is anonymous and no intervention in the normal working mode. So, no rectification would be required in this study.
Art. 17 - Right to erasure ('right to be forgotten')	Right to obtain from the controller the erasure of personal data concerning him or her without undue delay and the controller shall have the obligation to erase personal data without undue delay	The data collected need to be complete and continuous for meaningful representations for process improvement.

Article	Description (European Commission, 2016)	Action
Art. 21 - Right to object	Right to object, on grounds relating to his or her particular situation, at any time to processing of personal data concerning him or her	The data collected need to be complete and continuous for meaningful representations for process improvement. Data subjects are given the facility to inform their concerns about data collection to the process improvement team.
Art. 25 - Data protection by design and by default	The controller shall implement appropriate technical and organizational measures for ensuring that, by default, only personal data which are necessary for each specific purpose of the processing are processed.	Position sensing cameras are instructed to only collect the required data in spreadsheet format and no image or video is captured even though it is capable of doing so. The code for Zed 2 should be encrypted for any future tampering with this format.

Value Sensitive Design

There are several ways to methods developed with VSD principles, of which the Envisioning cards method will be used here. Envisioning cards is a versatile toolkit, developed in University of Washington, consisting of 32-cards based on four criteria - Stakeholders, Time, Values and Pervasiveness (Friedman et al., 2011; Friedman & Hendry, 2012). Of the four criteria, three relevant cards will be worked out as shown below. Pervasiveness has not been taken into account here as it is presumed that it would have very little importance due to the project focusing just on Diversey production lines. The analysis of the questions from the VSD cards are based on previous known events or speculations. Some of the speculations may or may not be true and need to be verified further during the implementation.

The result of the cards will be used to identify the implications of the design. Relevant solutions from literature will be applied to mitigate the implications. In the next step, these values will be translated into a list of requirements.

◊ STAKEHOLDERS

Non-targeted use:

- Identifying and evaluating the performance of the operator from the camera captured images.
- If it is set up in a particular area, the operators would stop using that area for the idle position. This can increase the walking path towards the stations during events.
- Operators' may try to perform their work from blind spots of the camera (for instance the direction) due to their lack of trust in the Zed 2 camera.
- Lack of proactiveness in the process improvement as they over trust the Zed 2 would capture everything.

Direct stakeholders:

Table 5 shows the preliminary direct stakeholder study and the pros and cons of this project related to each of the stakeholder.

Table 5: Values of direct stakeholders

Stakeholders	Pros	Cons
Operators	• Easy fault identification • Easy documentation • Visualization of overall performance	• Privacy concerns (Honovich, 2008) • Lack of data transparency • Tracking their work causes work anxiety. (Aalto University, 2012)
Process improvement leads	• Easy analysis of production line • Identifying the bottlenecks in the process • Best practices of the changeover procedures	• Reduction of workload of process improvement team, may lead to redundancy of many roles. • Change in working style may be struggling for a few
Diversey	• Best practices of the changeover procedures • Process improvements • Comparison of data from different shifts	• Non-cooperation of operators

Indirect stakeholders:

Table 6 shows the preliminary indirect stakeholder study and the pros and cons of this project related to each of the stakeholder.

Table 6: Values of indirect stakeholders

Stakeholders	Pros	Cons
COALA researchers	• Identify operator's position at the line • Recognize the activities for operators • Identify events based on behavioral cues from operators • Identify safety issues on site	• Accuracy of the data
TU Delft	• More opportunities for COALA project	• Privacy concerns of the research output

◊ VALUES

Elicit stakeholder views and values:

The Zed 2 camera system will make it easier for the operators to solve complex problems and easier for the leads to analyze the problem. The changeover procedures differ between operators and with a comparison of various methods, the process improvement team can guide the operators on more efficient methods. Also, as mentioned by the process improvement lead, the speed of running various SKU is different and usually they operate in trial and error based on stepwise increment of speeds till the 100% rated speed. With the data collection integrated with Zed 2 and the PLC the operators can be guided to go directly at the identified best speeds (Appendix C - Interview with Process Improvement Lead) which reduces the time spent on fine tuning.

Value tensions:

Technology vs privacy - The main value struggle in establishing the position tracking using Zed 2 camera is the fine line that demarcates the point where technology trespasses the privacy of the operators. The camera should be regulated from collecting any image or such visually identifiable data in order to satisfy this dilemma.

Tracking best practices vs tracking performance - With the establishment of the position sensor there may arise a need for process leads to classify the operators based on their performance. This ideology does not match with what COALA intends to do and such classification does not in no way assist the COALA project nor Diversey. So a definite plan for what data will be captured in the Zed 2 camera and what will be stored should be clearly addressed to both the process improvement team and the operators.

Ease of data collection vs accuracy - With the technology in automatic data collection, it is not unprecedented to have skepticism on accuracy of the technology (Engler, 2020; Fisher & Brown, 2020). The accuracy of data was tested in a pilot test conducted in the IO main hall but the same should be verified on-site nonetheless. The Zed 2 datasheet specifies the depth accuracy of < 1% up to 3m and < 5% up to 15m (StereoLabs, 2019).

◊ TIME

Work of the future:

With the implementation of Zed 2 cameras on the site, COALA project is facilitated with an easy way to identify the position of the operator as well as the various information about sequence of activities performed, the time spent etc. With the voice-assistant operational on the line, the operators would no longer require the training and experience to handle complex problems on the site. The knowledge transfer happens effectively through the voice assistant and the knowledge gap between the novice and experienced operators have been drastically reduced. Diversey would not need to spend long time and capital on training new operators.

The process improvement analysis would take a shift towards more automated data gathering. The team becomes more technology driven and is capable of identifying more unforeseen patterns in the production runs. Intuitive visualization of performance helps in reflecting on the best practices for respective SKUs and changeovers.

Apart from the positive impacts of the COALA technology, it is accompanied with negative impacts too. (1) Process leads might utilize the technology to identify the operators' performance which could create a mistrust with the technology among operators, (2) Operators may not gain the knowledge of the production lines and may rely totally on the COALA voice assistant. This could have a negative impact on the production efficiency as it might be worsened due to operators waiting for help from COALA, (3) No new tacit knowledge might be created if the operators always rely on COALA and the work turns into fully standard procedures.

In order for Diversey and COALA to ensure smooth installation and execution of Zed 2 cameras, the operators need to be assured the reason for its installation. The data should be made transparent to them and detailed information on what is being done with the collected data.

Adaptation:

The positional tracking and error documentation being automated could reduce the usage of paper in process improvement departments. The department would be supported by intuitive visualizations that enhance the process improvement procedures and root cause analysis.

Some of the adverse adaptations speculated from this technology are the operators who are mistrustful of the camera standing outside its vision to avoid idle time detection. This can increase the work path movement in case of events. And for the operators working with the COALA voice assistant, they may grow overconfident of the technology and become less responsible for their actions.

The translation of design values to design requirements are done in two steps. First step is translation of general value into general norms and then the latter into more specific design requirements (van de Poel, 2013) as shown in Figure 13.

The main values that the stakeholders impart to this was found to be privacy, data transparency, work simplification, accuracy, safety and identifying best practices. The corresponding values were analyzed to generate multiple norms connected with the value and from them the design requirements

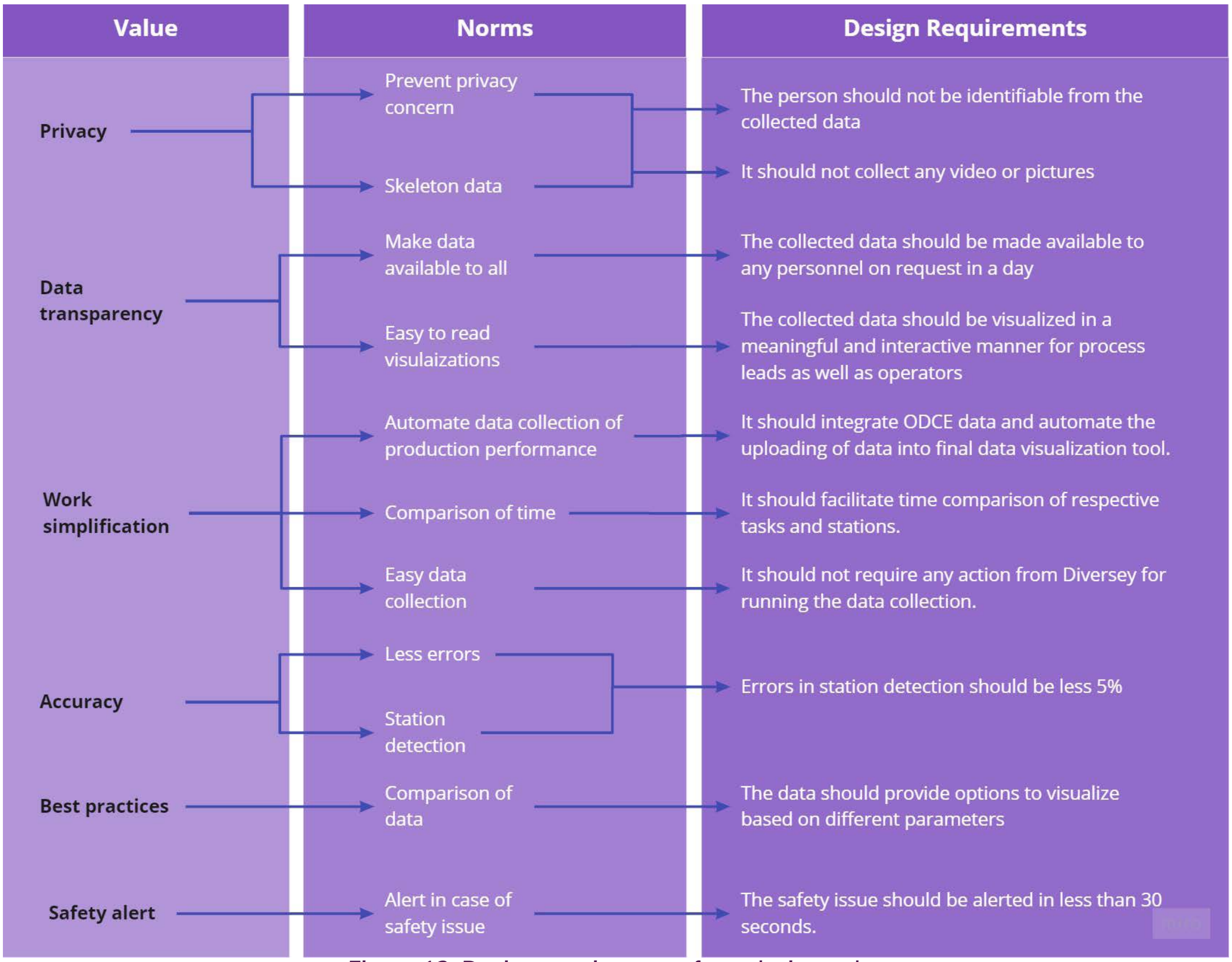


Figure 13: Design requirements from design values

to make this project outcome more aligned with the stakeholder values. More details about the choice of these values can be found in Appendix F.

Discussion

Application of ethical approach in design came at the cost of sacrificing some of the major capabilities of Zed 2 camera. Since the video identification is turned off and only anonymous object data is used, it is not able to distinguish between tracked objects whether they are operators or maintenance team or process improvement team. Also, objects exiting the camera view and reentering may not be recognized as the same. Thus, it results in different ID numbers assigned to them.

Another important point of discussion is the balance between usability for process improvement and anonymity of operators. Even though operators are not being tracked through video, it is still possible to estimate who the person is based on the list of operators assigned work on that particular day / shift. To anonymized even further, the date of data collection could be redacted but then the data would be rendered less useful to visualize.

For the operators, privacy and data transparency are usually the main aspects that cause mistrust with new technology. The operators would require an assurance that they will not be identifiable through this camera and only their position would be tracked. It should be made clear and transparent to them and the most convenient way to do so is to make the data (collected data as well as the visualizations) available to the operators for their own reference. This reference has double effects - firstly, seeing what data is being captured and secondly, visualizing their own performance and adapting their work to the best practices. To get the operators on board with the project, they were presented a poster outlining the main goals and sample outcomes of the project as shown in Figure 14.

For the process improvement department, Zed 2 camera facilitates the data collection, generating visualizations and identifying earlier unforeseen patterns in production performance. This is expected to be beneficial for them to improve the performance way better and easier than what could have been when done through manual data collection. Also, the timestamps of changeover activities would help them identify the best practice for the corresponding SKUs and enable them to guide the operators with optimal settings.

What we do?

We use a Zed 2 position sensor to collect the XYZ coordinates of those working in the view. In this process, we do not collect any image, video or any data that can identify you. This data collection is done purely for process improvement.

Activity cal...	Date Time	ID	Time	Timestamp	Velocity	X-Axis	X calculated	Y-Axis	Z-Axis
MOVING	20-05-2021 14:35:32	0	20-05-2021 1...	14:35:32	1.00	-6.7966	-7.6604	-1.91297	-5.9666
MOVING	20-05-2021 14:35:32	0	20-05-2021 1...	14:35:32	0.34	-6.7376	-7.6038	-1.92890	-5.9767
MOVING	20-05-2021 14:35:32	0	20-05-2021 1...	14:35:32	0.40	-6.7330	-7.6056	-1.91579	-6.0172
MOVING	20-05-2021 14:35:32	0	20-05-2021 1...	14:35:32	0.50	-6.6913	-7.5646	-1.88502	-6.0178
MOVING	20-05-2021 14:35:32	0	20-05-2021 1...	14:35:32	0.74	-6.8198	-7.7175	-1.89291	-6.1813
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.47	-6.8826	-7.7904	-1.91624	-6.2495
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.51	-6.9307	-7.8485	-1.91159	-6.3161
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.49	-7.0109	-7.9439	-1.92362	-6.4183
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.36	-6.8726	-7.7941	-1.89337	-6.3351
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.45	-6.8527	-7.7809	-1.88430	-6.3750
MOVING	20-05-2021 14:35:33	0	20-05-2021 1...	14:35:33	0.40	-6.8536	-7.7949	-1.90484	-6.4575

What we collect?

The data collected includes the XYZ coordinates of the person, posture of the person represented by 18 skeleton points of the body, velocity and proximity to any station.

What we get?

From the collected data we try to visualize the process in the 5L/10L line. We get the walking path of the person, number of visits to a particular station, heat map of location.

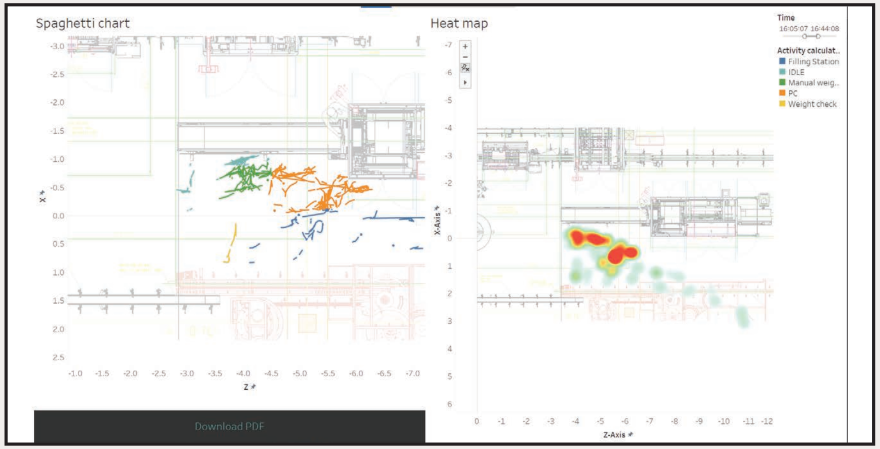


Figure 14: Project poster for operators

2.4 Site observation

Introduction

The previous sections defined the requirements and ethical aspects of the data collection. This was followed by site observation and interacting with operators. This section explains about the various stations on the 5L/10L and the major issues that were observed during the visit. The complete findings of site observation can be found in Appendix G.

Research goal:

The site observation was done to answer the following questions:

- To identify various activities performed by operators
- To identify the frequent activity location
- To understand how operators interact with various stations and how they react to events
- To estimate the area for Zed 2 camera setting

Methods

The observation was performed non-intrusively, observing the activities and locations of frequent operator visits. When there were major issues such as unplanned stoppages for more than 5 minutes or reoccurring issues at the same station, the operators were inquired about the details of the issue.

Results

Diversey plans to implement this project specifically in the 5L/10L line at Enschede site. For this the site plan was studied to understand the various stations of the line (Figure 15).

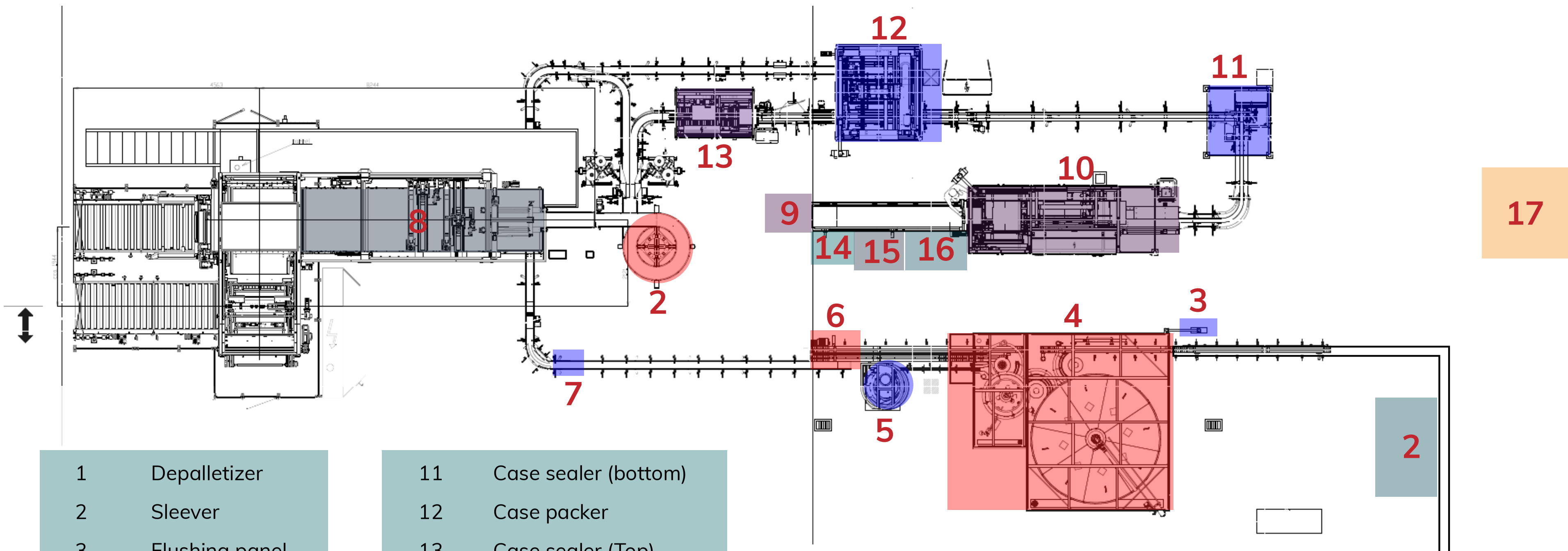
The site runs in three shifts of 8 hours each starting at 6 am in the morning. In each shift, there can be multiple SKU runs based on demand. At a time, there are two operators on the 5L/10L line and maybe a technician if in case of any issues. At the start of the production run, one operator handles the cleaning/ flushing process (Figure 16 (a)) and the other inputs the details into the system. Before the start of the run, they have to perform a 4-eyes check of quality of the liquid (Figure 16 (b)). Here another operator from a different line would be observing while the operator in the 5L/10L line takes the liquid. This liquid will be pH tested to detect any contamination.

The run of a single type of SKU took around one hour that day but varies depending on the desired batch quantity. After the run,

(a)

(b)

Figure 16: (a) Quality check before the production run; (b) quality check sample from nozzle 17 of filling station



1	Depalletizer	11	Case sealer (bottom)
2	Sleever	12	Case packer
3	Flushing panel	13	Case sealer (Top)
4	Filling station	14	Manual weigher
5	Capper	15	Workstation
6	Weight check	16	PC
7	Labeler	17	Waste water discharge
8	Box arrangement		
9	Box stack		
10	Case erector		

Figure 15: Site layout of 5L/10L line in Enschede, The Netherlands

the changeover process is performed which approximately takes around 20 mins. Few of the activities during changeover process are as shown below:

- Flushing the filling tank nozzles (Figure 17(a))
- Capper change
- Sleever roll change
- Labeler roll change
- Inputting production run data into system
- Loading 10L canisters onto the line (Figure 17(b))

Most of the time errors were occurring and operators were constantly on issue resolving activity. The person who worked on the stoppage will take care of inputting the error report into the system. The operators are most of their time on the run as one station or the other would be having errors. The major points of operator attention during the site visit was on the sleever machine (Figure 15) which often caused crushing of cans or tearing of sleeves. Another issue that was reported on the day was spilling of liquid in the filling station causing the final product to slip down the spiral conveyor.

During events or stoppages the operators were quick to find the location of issue but the frequency of events were still high. This may be partly due to temporary resolving of issues rather than understanding the root cause of the errors. If the Zed 2 camera is able to detect the high frequency of events at the same place, the process improvement lead can guide them in identifying the root cause of the problem.

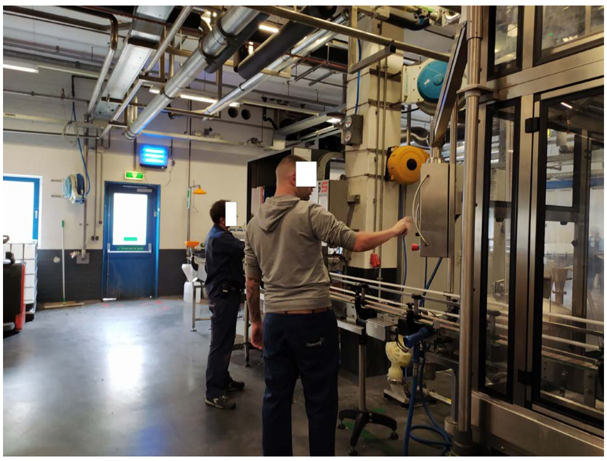
The best locations for camera setting were found to be:

Option A: (Figure 19) Close to the spiral conveyor. This can cover the box loading area as well as the filling station. Mixing station and the box loading area can be tracked from the at position. Labeler will be missed in this view.

Option B: (Figure 20) Above the waste water discharge. This gives a view of the flushing panel, filling station up till the weight checker.

Discussion

The site visit helped to locate the potential positions for Zed 2 camera at the site. The frequency of faults were high at the sleever machine but the location of errors were mostly dependent on the SKU. Setting the camera to capture the sleever machine area



(a)

(b)

Figure 17: (a) Flushing filling station nozzles; (b) Loading 10L canisters

would have to leave out all the other areas and so was not found ideal. The options provided in Figure 21 were based on the largest favorable area of coverage of the line. Option A seems more feasible as the area is capable of getting a power and LAN connection. Option B gives a better angle of view of the filling station activities which may not be possible in Option A. The final position would be determined by testing out each of the positions and their data capture capability.

Figure 18: Operator working on the sleever machine during a stoppage

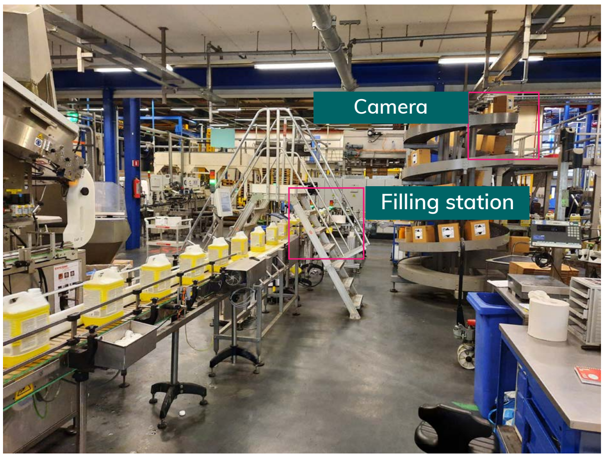


Figure 19: Option A: Atop the spiral conveyor (facing towards as shown in picture).

Figure 20: Option B: Camera view

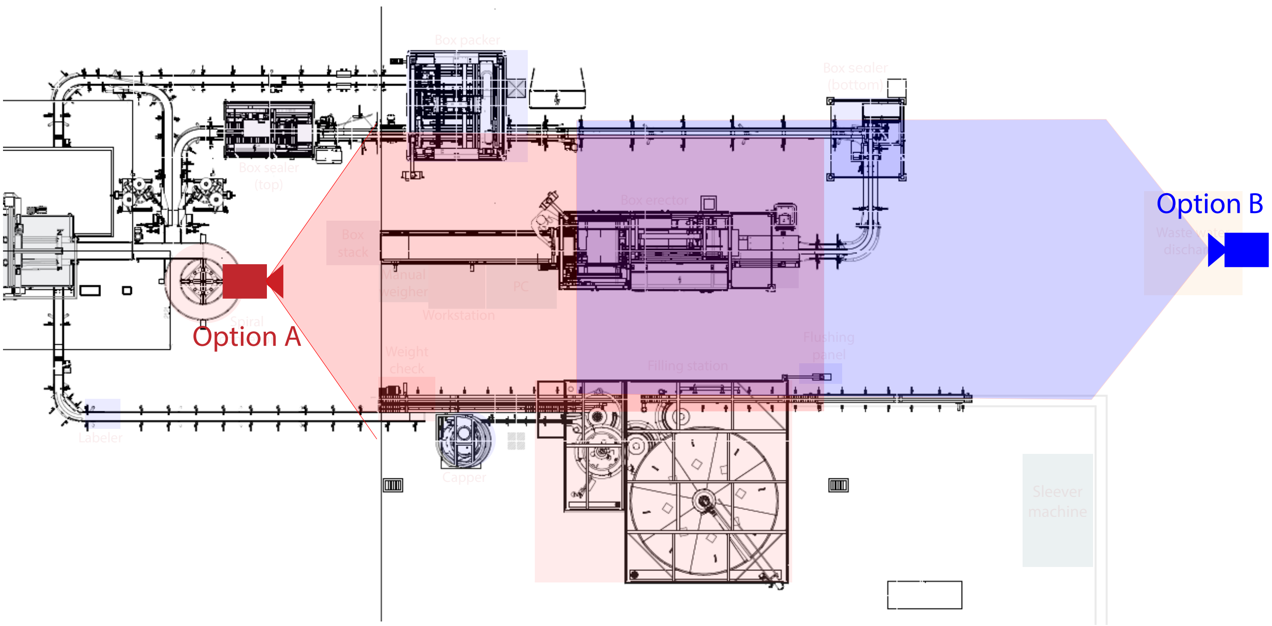


Figure 21: Choices of camera placement location

2.5 Context mapping

From the information received from stakeholder interviews and site visit, the characteristics and pain points of the directly involved stakeholders were clearly defined.

Here, persona was used to define their characteristics and needs. First, a persona of the process improvement leads was defined as shown in Figure 23. Later, another persona of a line operator was also defined as shown in Figure 22.

Discussion

The main stakeholder out of these two is the process improvement lead. The project outcome is desired to make it easier for them to understand the performance of the production line. Their user journey map shows the current process of retrieving data and identifying issues of the previous day. Besides the process lead, the project also would like to explore what can be the benefits (direct or indirect) to the operators.

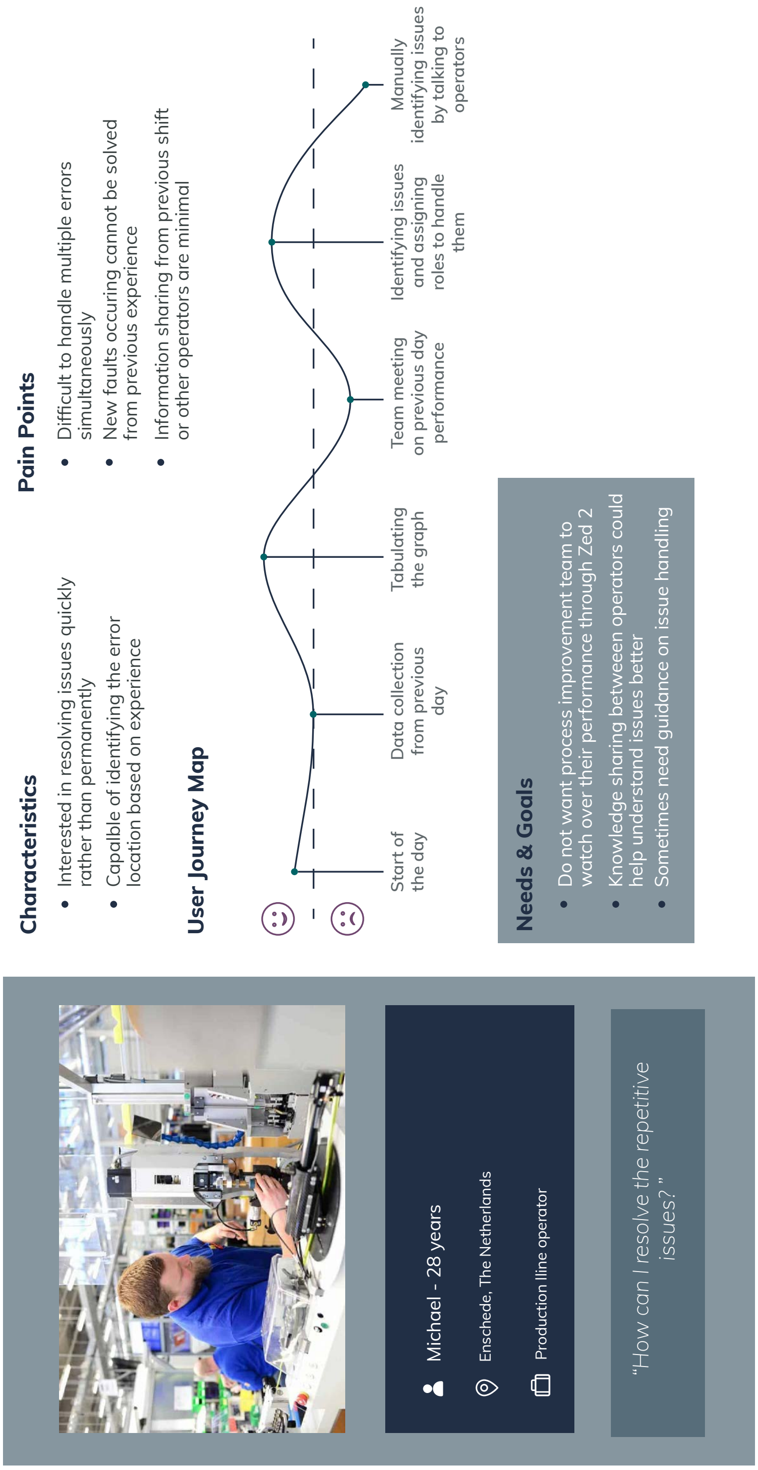


Figure 22: Persona of line operator

Manon - 40 years

Enschede, The Netherlands

Process Improvement Lead

“ How can I easily identify patterns of events in the production line?”

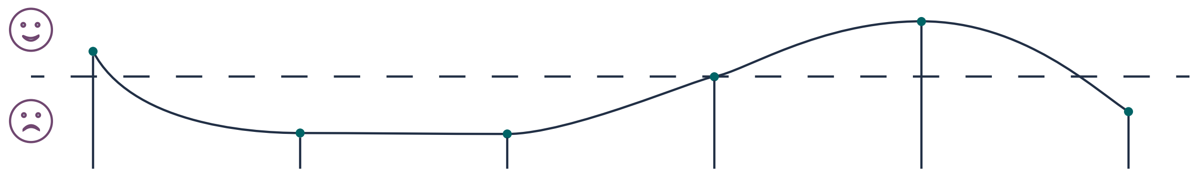
Characteristics

- Interested in seeing the patterns of errors in the line
- Striving for reduction in ocuurenc-es of stoppages

Pain Points

- Data collection is tedious
- Have to manually talk to operators for issue understanding
- Operators do not do proper root cause analysis

User Journey Map



Needs & Goals

- Data visualizations of operator movements and activity sequences
- Easy identification of errors and their frequency
- Finding average of changeover for an operator
- Finding if there are similar issues occuring with same SKU another day

Figure 23: Persona of process improvement lead

2.6 Zed 2 tracking system - feasibility study

Introduction

Before its deployment at the production line, the Zed 2 camera needed to be tested for its feasibility. The feasibility study was performed at main hall of the Faculty of Industrial Design Engineering, TU Delft. It focused on identifying capabilities and shortcomings of the Zed 2 camera regarding tracking positions and movements of a person with respect to objects (e.g. station) and camera placement. The complete details of pilot test can be found in Appendix H.

Research goal

Feasibility study of the Zed 2 camera has been done keeping the following goals of the study in mind:

- To identify best height of camera setting from the floor
- To check the requirement of coordinate transformation
- To identify the limits of the camera (range, obstruction)
- To identify the consistency in captured operator skeleton data while performing the same task in a large area similar to the production floor
- To identify the hand movements and interactions at different angles to camera (facing forward, back facing, sideways)
- To detect the position of person with respect to a station

Methods

The test setup (Figure 24) consisted of Zed 2 camera powered by Nvidia Jetson, containing the Python code for data collection, which would be connected to the power socket available in the setup areas, peripherals such as mouse and keyboard for operation and running the code, a PC screen for visualizing and real-time validating the captured data. Masking tape and markers used for designating the imaginary station points on the floor. Tripod stands will be used to set the Zed 2 camera at required heights. The test was performed with one participant who would be performing the test procedure

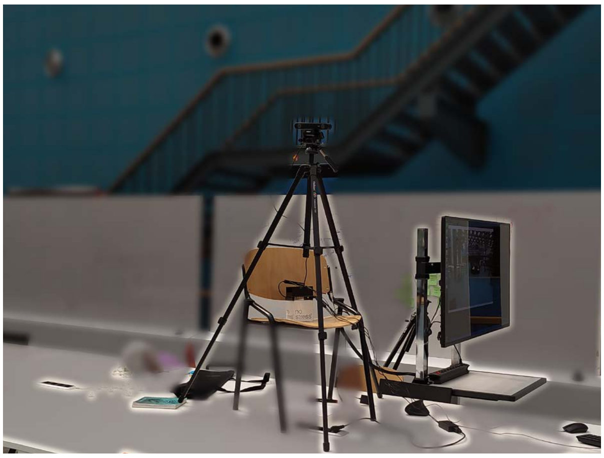


Figure 24: Setup used to perform feasibility study of the Zed 2 camera

while the researcher recorded the data in spreadsheet as well as in screen recording.

Process

The feasibility study consisted of six tests to answer each research goal. Here are the tests and the steps followed in performing the tests.

Test 1: Identify the best positions for camera height

1. Mark point of camera with masking tape. Note down the height of the camera set up from the floor.
2. The participant will be asked to move towards the camera starting from a 5 meter distance in the vision of the camera..
3. Note down the nearest point where the object detection starts to flicker.
4. Check if object detection and skeleton detection are proper or not on the screen. Note down the distance from the camera where the object is lost from tracking.
5. Repeat above steps at different heights of the tripod.
6. Determine the best camera height for

better range of detection.

7. Note down any other points that affect the tracking.

Test 2: Checking the XYZ direction of the camera kept facing at an angle. (Determining quaternion transformation requirement)

1. Keep the camera tilted 45degrees to the horizontal in the best height chosen.
2. Mark two points anywhere in the vision of the camera with a distance of 2 meters measured perpendicular to the camera.
3. Ask the participant to stand at point X and then at point Y.
4. Note down the XYZ coordinates when the participant stands at both points.
5. Repeat steps 3 and 4 thrice.
6. Find the difference in the coordinates here.

Test 3: Consistency in skeleton tracking

1. Keep the camera in the normal angle facing the widest area at the best position chosen in the first test.
2. Mark two points in the vision of camera A and B which are at the opposite sides of the camera view.
3. The participant will be asked to walk towards from a random point outside the camera view and stand still at Point A.
4. Three recordings will be noted as well as saved in excel sheets.
5. XYZ values of the point will be noted. The consistency of the XYZ values will be tested by comparing the values from excel sheets.
6. Repeat for point B.
7. The participant will be asked to perform a "lifting bag" interaction at every 45 deg angle on point A. The accuracy of skeleton data and the object XYZ data will be evaluated in real-time on the screen.
8. Note down any other points that affect the tracking.

Test 4: Finding the limits at best camera position

1. Stand at the nearest point marked earlier in the first test.
2. Walk to the left of the camera.
3. Find the spot where the object detection is lost. Mark with masking tape.
4. Do the same for the right side of the camera.
5. Repeat steps 1 to 4 thrice.
6. Choose the innermost points for final area marking.
7. Stand at the farthest point marked in the first test.
8. Walk to the left of the camera.
9. Find the spot where the object detection is lost. Mark with masking tape.
10. Do the same for the right side of the camera.
11. Repeat steps 7 to 10 thrice.
12. Choose the innermost points for final area marking.
13. Measure the boundary lengths with measuring tape.
14. Place an obstructing object in front of point A and ask the participant to stand directly behind it. Note down if the detection is proper.
15. Perform the lifting bag operation behind the object at every 45deg angle to see if the detection is proper.
16. The accuracy of skeleton data and the object XYZ data will be evaluated in real-time on the screen. Note down in the checklist.

Test 5: Detection of proximity to station

1. Mark with tape on the floor, two random station areas in the scene at point A and B.
2. Calibrate the coordinates with the participant and put it in the code.

3. Place a bag in the station area A
4. Rerun the code to switch off and on the camera.
5. Ask the participant to walk towards station A from another random point away from the station and stop next to it.
6. Ask the participant to lift the bag and place it down.
7. See if the participant activity is detected as “Station A” (or B). Mark in the checklist.
8. Check if the skeleton data is detected correctly.
9. Repeat steps 4 to 8 thrice starting from different starting points. Repeat for station B.

Results and insights

Test 1: Identify the best positions for camera height (Figure 25)

From the test for best height from floor, two heights first at 2.35m and 2m were tested out and found that the latter had a better range of view. The nearest point of detection at this height was 1.44m and the farthest was at 13.4m.

Test 2: Checking the XYZ direction of the camera kept facing at an angle. (Determining quaternion transformation requirement)

The camera coordinate system are as shown in Figure 26. The intended value from point A to B should have been only 2m in the Z axis alone. Since considerable difference is found in the Y axis also, a coordinate transformation may need to be applied for getting the coordinate system corrected to the world frame.

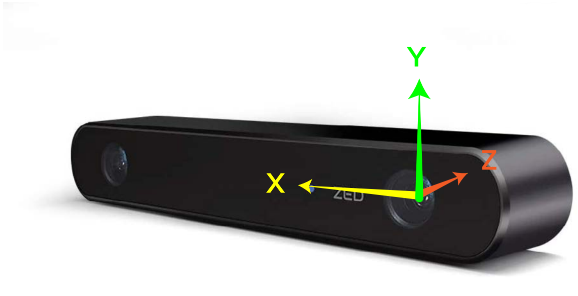


Figure 26: Camera coordinate frame

Test 3: Consistency in skeleton tracking

Point A was found consistent while point B was inconsistent for both object and skeleton detection. The values from first and third recording at point B were found to fluctuate by approximately 1.5m while the values from second recording showed considerably stable values. This must have been due to some slight error in the recording.

The object detection data was found to be consistent (Figure 27) while the skeleton data was limited to shorter angles of -45º to 45º from the camera.

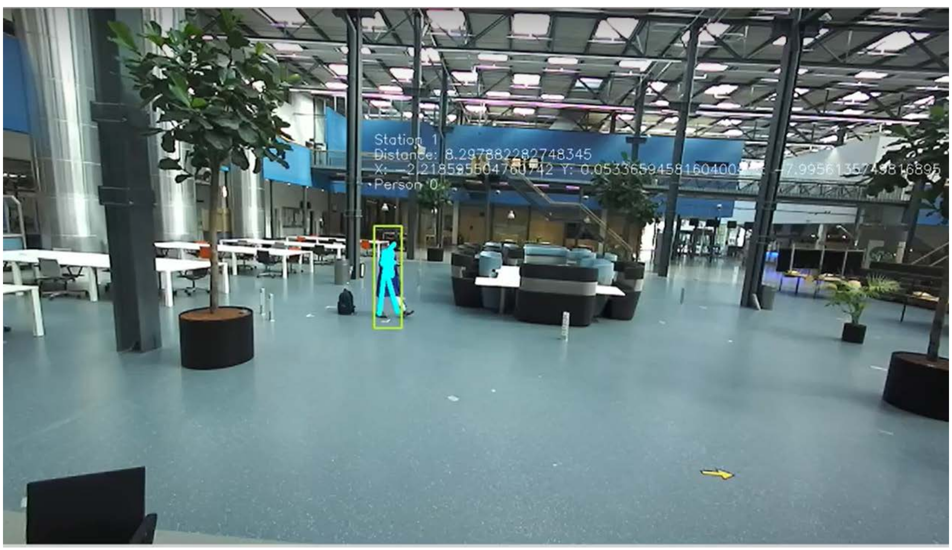


Figure 25: Maximum distance of object detection with camera height 2.35m from floor

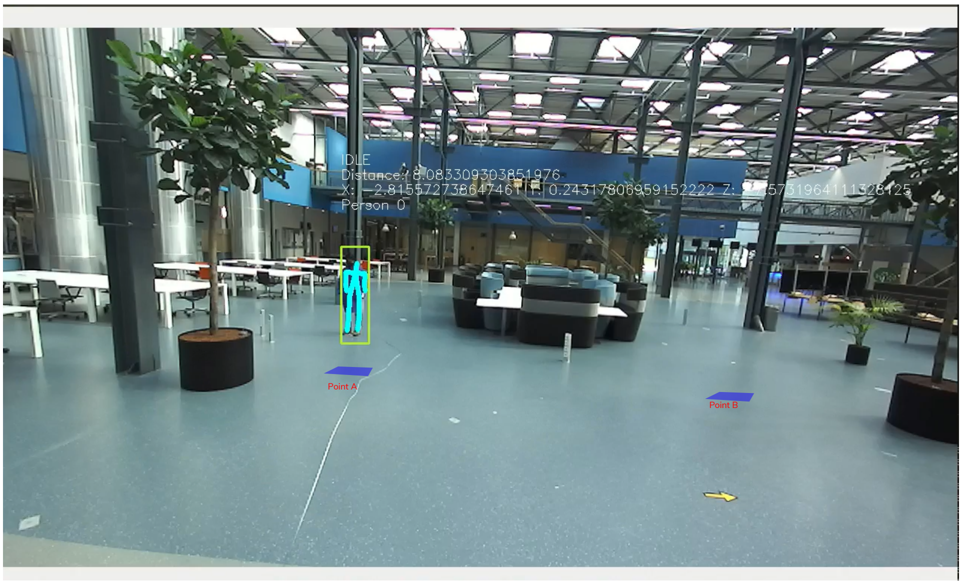


Figure 27: Object and skeleton detection at point A

Test 4: Finding the limits at best camera position

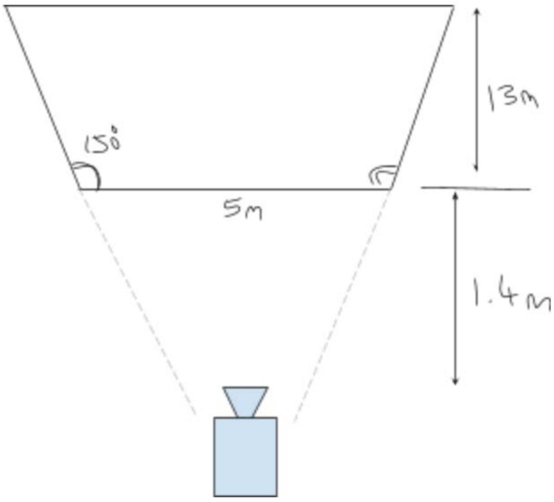


Figure 28: Dimensions of area of detection

The camera was able to cover the area as shown here in Figure 28.

Test 5: Detection of proximity to station

The random station coordinates were calibrated using the participant and inserted into the code. In the next run of the test, when the participant approached the area, the camera was recording the activity at the station (Figure 29).

Discussion

The reason for the choice of 2m height from floor in first test was that the nearest point of detection was reduced while keeping at a higher position. This could be rectified by

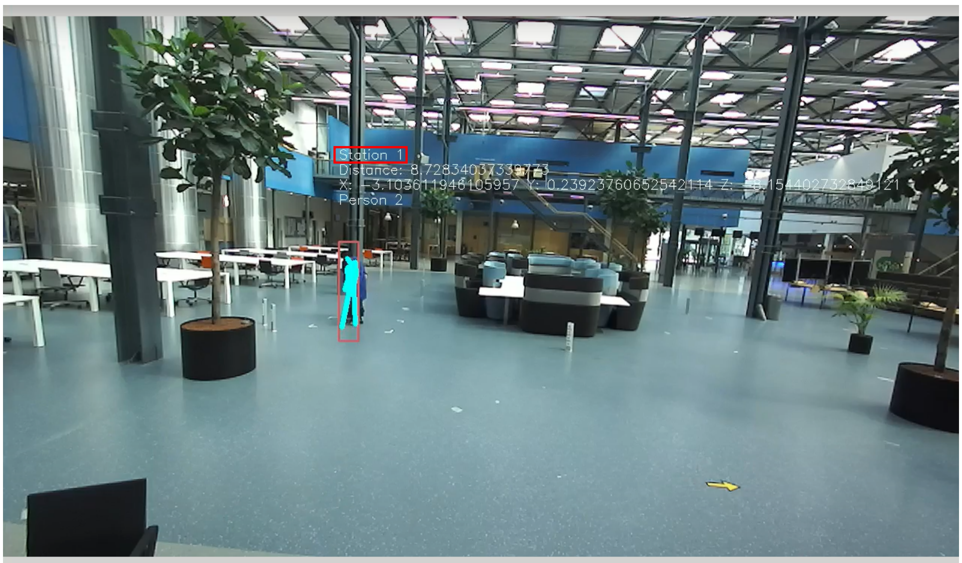


Figure 29: Station detection when in proximity

correcting the camera angle but that was found to sacrifice the farthest point of object detection. In the second test, when the camera was tilted downwards to test the above issue, it was found that the camera is working on camera coordinate system and requires quaternion transformation of coordinates either in pre-processing or post processing.

The inconsistency of data and the restriction of angle of detection to -45° to 45° from the camera greatly reduces the capability of activity tracking. Activity tracking may not be too accurate to provide insights if such higher angels are used. So the camera deployment at site needed a better angle of view to the main stations.

Problems detected during the feasibility study:

- Occasional flickering on video - no data issues found in the recorded data (Figure 30 (a))
- Sometimes an imaginary object with ID 4294967295 found on screen. When such an object is detected, the distance from the camera of the main object gets reduced by a value same as that shown on the imaginary object (Figure 30 (b)). This issue was rectified by increasing the object detection threshold to 60 from 20 and making the code ignore the specific noisy ID object.

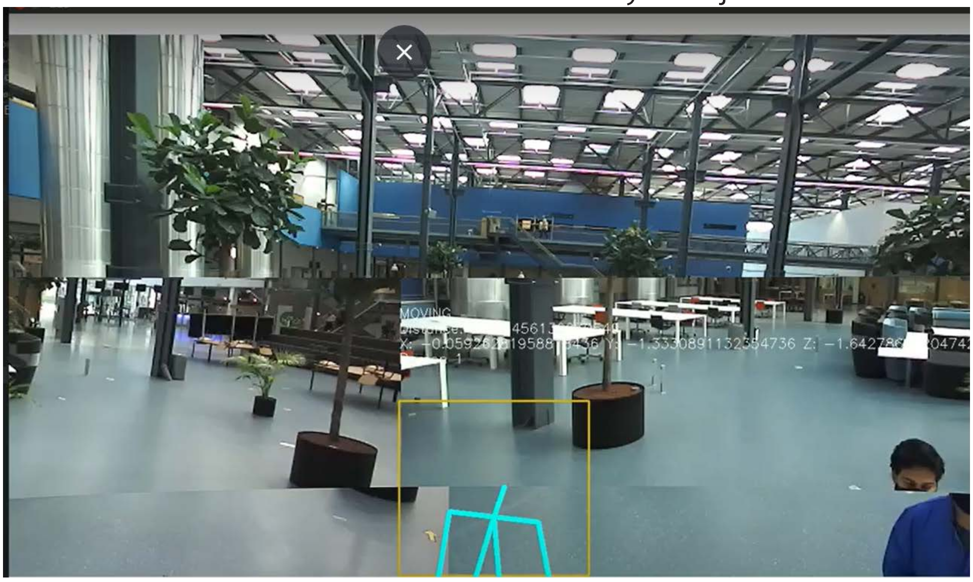


Figure 30 (a): Flickering in the video

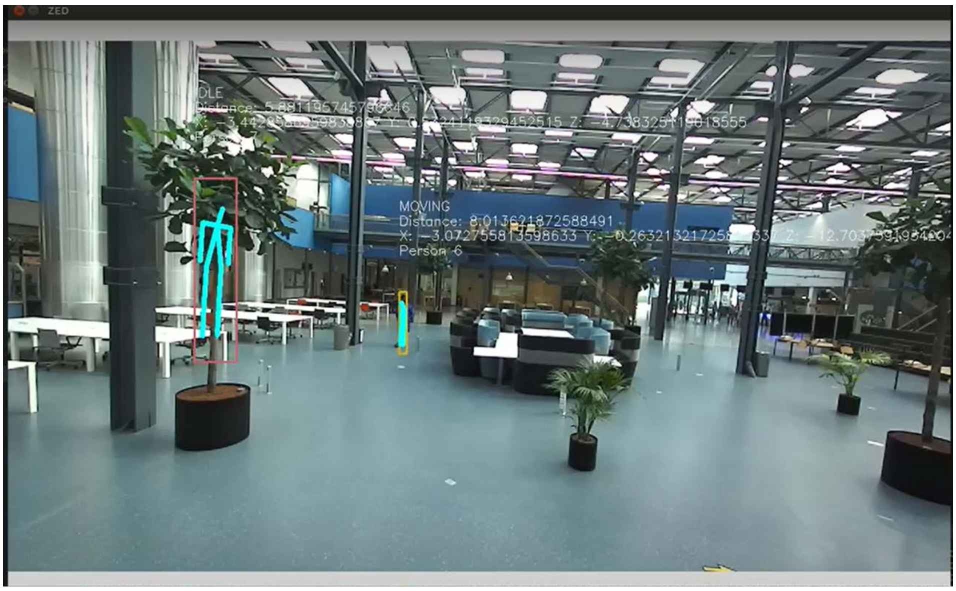


Figure 30 (b): Wrong objects detected

3 ENVISIONING

3.1 Insight selection
3.2 Design vision
3.3 Design requirements

3.1 Insight selection

After deep understanding of the user research and ethics research, a list of insights which were relevant for the project outcome were chosen to develop the list of requirements.

Given below are some of the quotes from the users during the user research:

"Error prone areas would be mostly depalletizer and the filler"

"What I will do is to make the numbers visible by printing the numbers and I will go by each and every operator and ask if this has happened in the last 24 hours."

"For instance, rinsing the whole process from mixing to filling each and every operator has a different kind of rinsing the machine . So there must be a best practice for all the operators"

"Identify by how they do it by looking at it. Do a time measurement, collect them, write them down and compare with each other"

"It can find if it is a changeover or a problem or module on a certain machine. If that is recorded, any indication of where the operator has spent most of his time."

"What would be the average time for changeover for an operator or what would be the downtime for a specific module that can find the same problem as the week before and the one before."

"Would anyone from the company watch us through the camera? If so then it would be a Big Brother situation."

With the insights from user interviews and ethics research, a clustering method (as shown in Figure 32) was necessary to order these into a list of requirements. In the insight selection process, the information received from the research phase was distributed on post-its and relevant ones were filtered. The chosen insights were clustered into five categories- line parameters, object tracking, outcomes of tracking, post processing and data visualizations. These categories determined the different steps of the project:

- Outcomes of tracking - expectations and requirements for the data collection method.
- Object tracking - preprocessing steps for the data collection including the python code for calling the Zed 2 image capture functions and storing the data into readable format.
- Line parameters - data from ODCE that needs to be integrated with the Zed 2 data.
- Post processing - refining the collected data into meaningful form
- Data visualizations - expectations from users about data visualizations

Figure 31: Insight selection from research

Safety is not considered in this clustering as the later research showed that safety is not a major issue and has frequency very minimal to none throughout a year at Enschede production lines.

Following the co-creation session with TU Delft COALA team of researchers, the expected outcome of tracking was defined. The tracking method is beneficial to provide contextual information to the COALA digital assistant in turn making it able to provide a better location refined recommendation, provide better assistance to operators in changeovers and issue handling. Further on, it was decided that the relevant data such as operator position, activity, proximity to station and skeleton data needs to be captured using Zed 2.

The camera placement was most important to capture the relevant stations. After consultation with process improvement lead, it was planned that the filling station would be the best place for object and events tracking.

3.2 Design vision

With the user research and the insight selection process, the design vision was ready to be set for the project.

"

To design an intuitive data visualization dashboard from ethical operator tracking for the process improvement team at Diversey using temporal location data to assist process improvement in the 5L/10L line. "

The final visualization tool should provide an intuitive understanding of the operator location data to the process improvement team at Diversey. The visualizations would be also used in the future cognitive assistant interface.

3.3 Design requirements

Object tracking

T.1 The object tracking should be able to identify the contextual data (position, location, time, etc.).

T.2 Object tracking should sense what and where the task/activity the operator is performing.

Ethics

E.1 The person should not be identifiable from the data.

E.2 It should not store any data in videos or picture format.

Data processing

P.1 The processed data should be able to determine the duration of activities.

P.2 It should be able to distinguish internal and external activities.

P.3 It should be able to identify the operator's sequence of actions.

Outcomes

O.1 The tracking system should be able to help in easy documentation of errors.

O.2 It should be able to sense if the operator is stuck with an issue / thinking.

O.3 The object tracking should assist in SMED analysis.

Data visualizations

V.1 The processed data should be visualized in a meaningful and interactive manner for process leads as well as operators.

V.2 It should provide options to visualize based on different parameters of the dataset.

Wishes

1. The object tracking should be able to track their behavioral state.
2. The collected data should be made available to any personnel on request in a day.
3. The tracking system should be able to detect activities during technical issues like fine tuning.
4. The processed data should be able to identify patterns in issues.
5. The visualized data shall provide an opportunity of self reflection of performance for the operators.
6. The processed data should be able to predict future issues at the line.

4 DATA COLLECTION

4.1 Execution of data collection
4.2 Pre-processing
4.3 Camera tracking setup
4.4 Post processing

4.1 Execution of data collection

Service architecture

From the list of requirements, the service architecture of the data collection was decided with the Zed 2 camera as shown in Figure 32. The Zed 2 camera's in-built capabilities include 3D object detection, spatial mapping and skeleton mapping which can be utilized to trace the time based XYZ coordinates of the human objects in the scene. The collected data will be visualized in appropriate representations that provide insights on the data that can be inferred from them.

4.2 Pre-processing

In the preprocessing stage, the Python code for the data collection was set to collect data for indefinite time with each hour data being stored separately as a csv file. The Zed camera SDK and Google Authentication libraries were the main libraries used for this process. Zed SDK enables the camera for object detection, skeleton tracking and various other parameters of the camera such as object detection threshold, image resolution and reference frame.

The data tracked by the camera was directly written to a csv file at a frequency of 6-8Hz. This frequency was preferred as it would give continuous data of the skeleton movement. The data mentioned in Figure 32 were recorded and stored in separate columns in an easily readable format for Python data handler.

Pre-processing also had gone through several iterations before the camera tracking was working. Some of the iterations overlapped with post processing which can be found in Section 4.4.

One of the challenges in the Preprocessing stage was simultaneous recording and uploading the file into Google Drive. Since the internet connection was unstable, sometimes the code crashed. This was handled using the "try-except" method in Python which skipped the code block when there was an issue with internet connection. Even then there was a memory leakage happening due to the Google Drive authentication libraries.

Takeaways

The code was split into two - one for data collection and another for uploading to Google Drive all the collected data at every hour mark. These two codes were running simultaneously and were faster than the previous code.

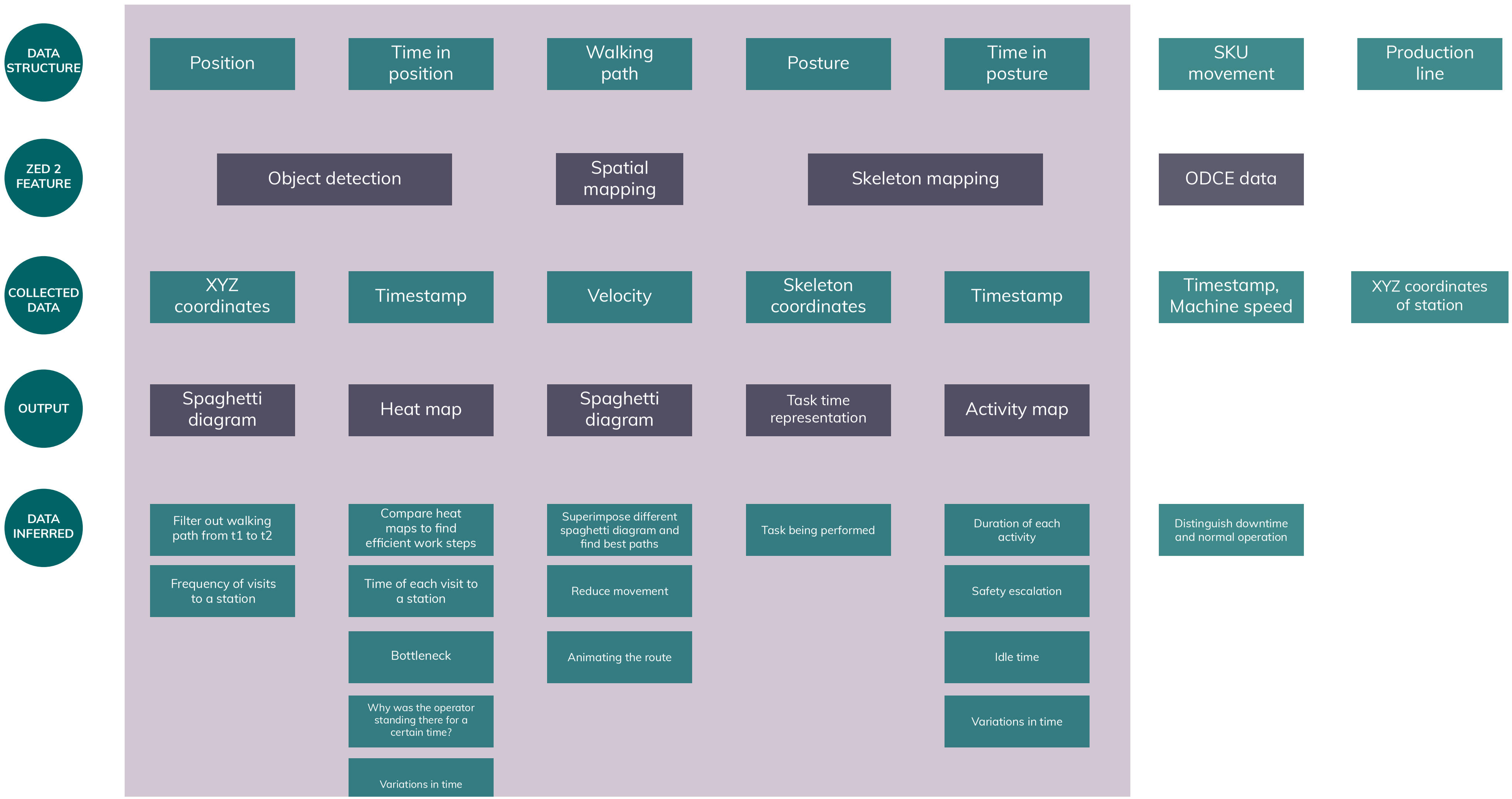


Figure 32: Service architecture of data collection

4.3 Camera tracking setup

Camera tracking setup

The setup consists of a Zed 2 camera (Figure 33) powered by a HP Omen 25L desktop with Nvidia GeForce GTX 3070, a CUDA enabled video card. The data collection is performed using an infinitely running Python code which captures and stores this data into a spreadsheet. The recorded data will be used offline for the analysis of patterns using another Python code.

The camera was set at a position next to the spiral conveyor from the top as shown in the Figure 40. The camera was initially placed horizontal to the ground at the same position. 3D printed sleeves were used with velcro straps for attaching the camera firmly in position (Figure 34). But the view of the camera was very limited as shown in Figure 36.

The camera angle was then adjusted with the help of Diversey maintenance team to slightly downwards at an angle of 23° in the X-axis using an attachment shown in Figure 35. (See coordinate system in Figure 26 for X-axis direction). The view of the camera and the hardware setup is as shown in Figure 37 and Figure 38 respectively.

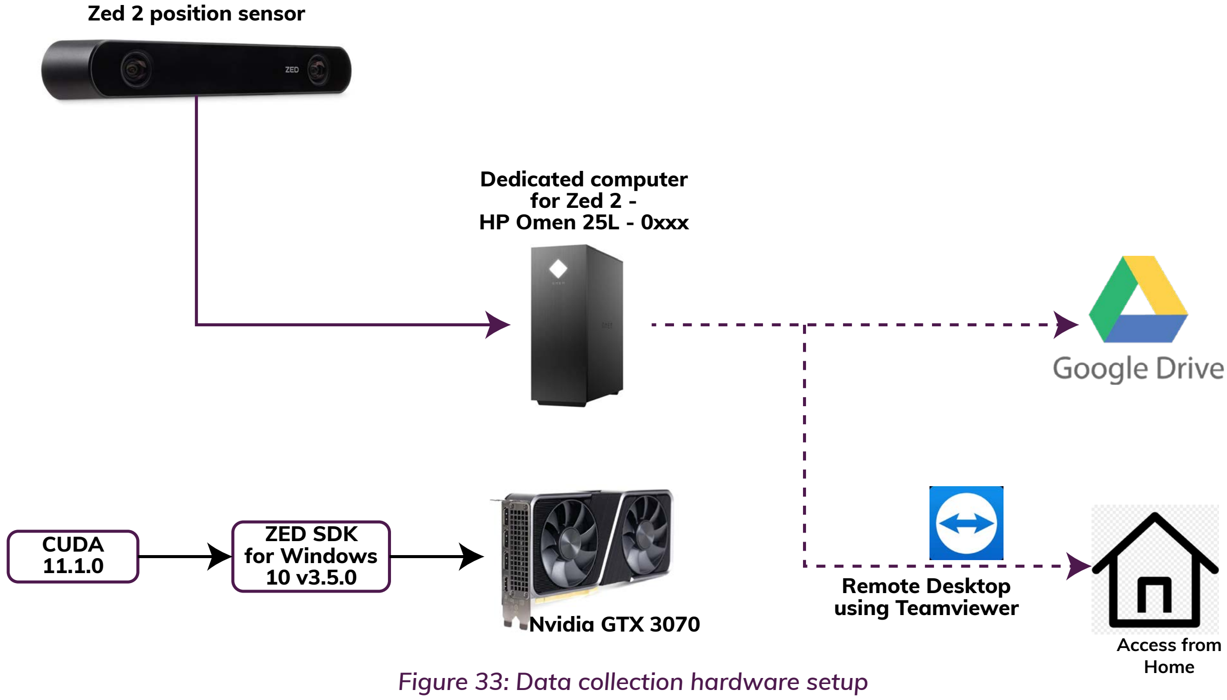


Figure 33: Data collection hardware setup

Figure 34: Velcro and sleeve for attaching camera

Figure 35: Attachment for angular placement of camera

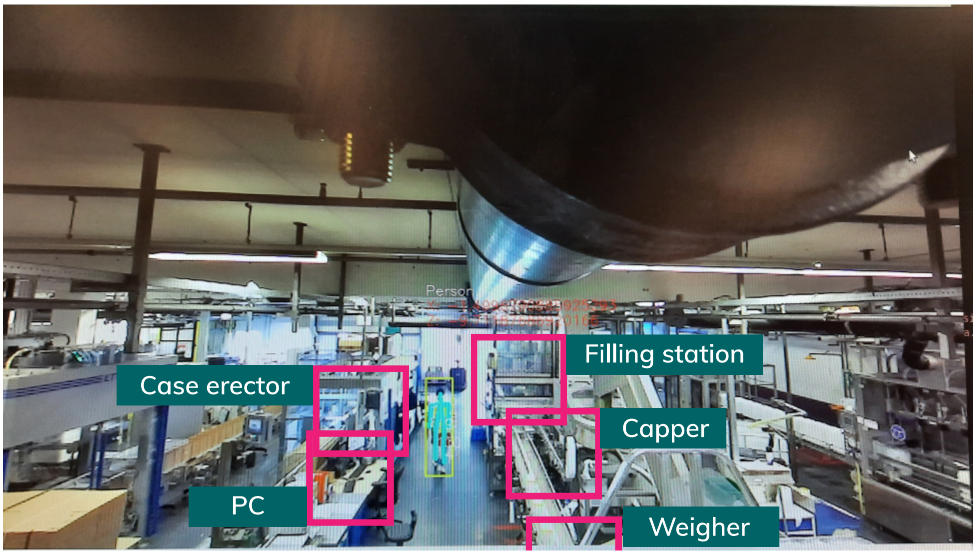


Figure 36: View from camera when placed horizontal to ground

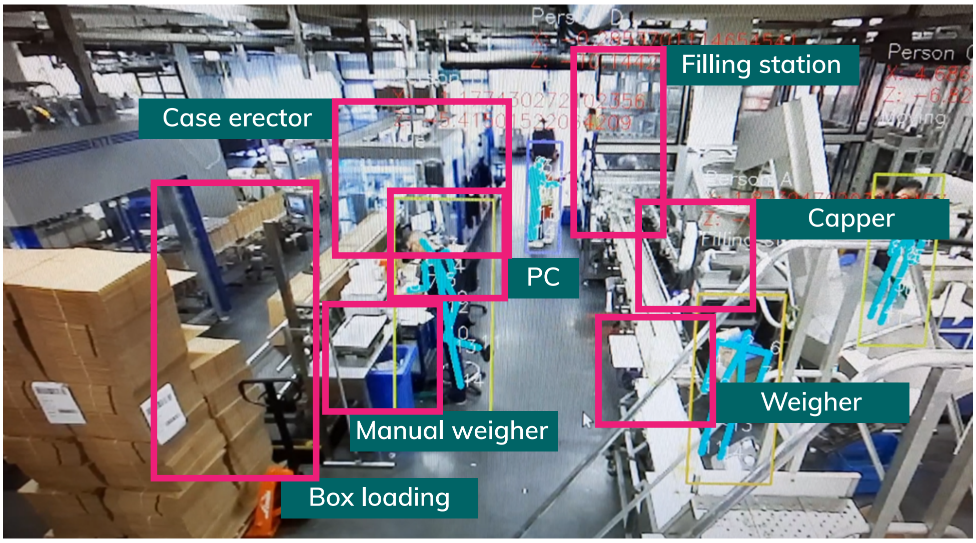


Figure 37: View from camera placed at 23° angle

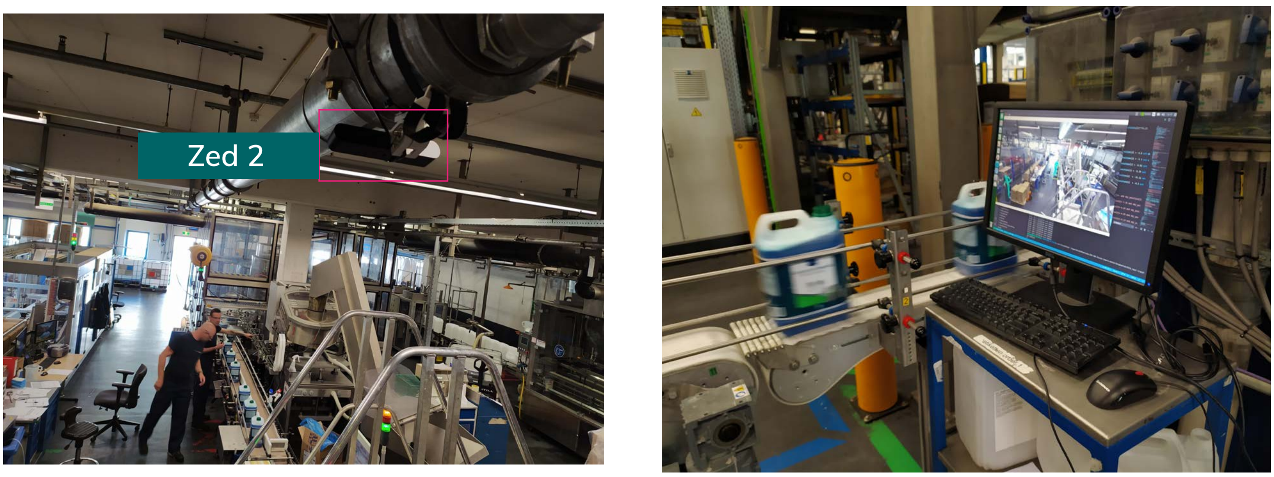
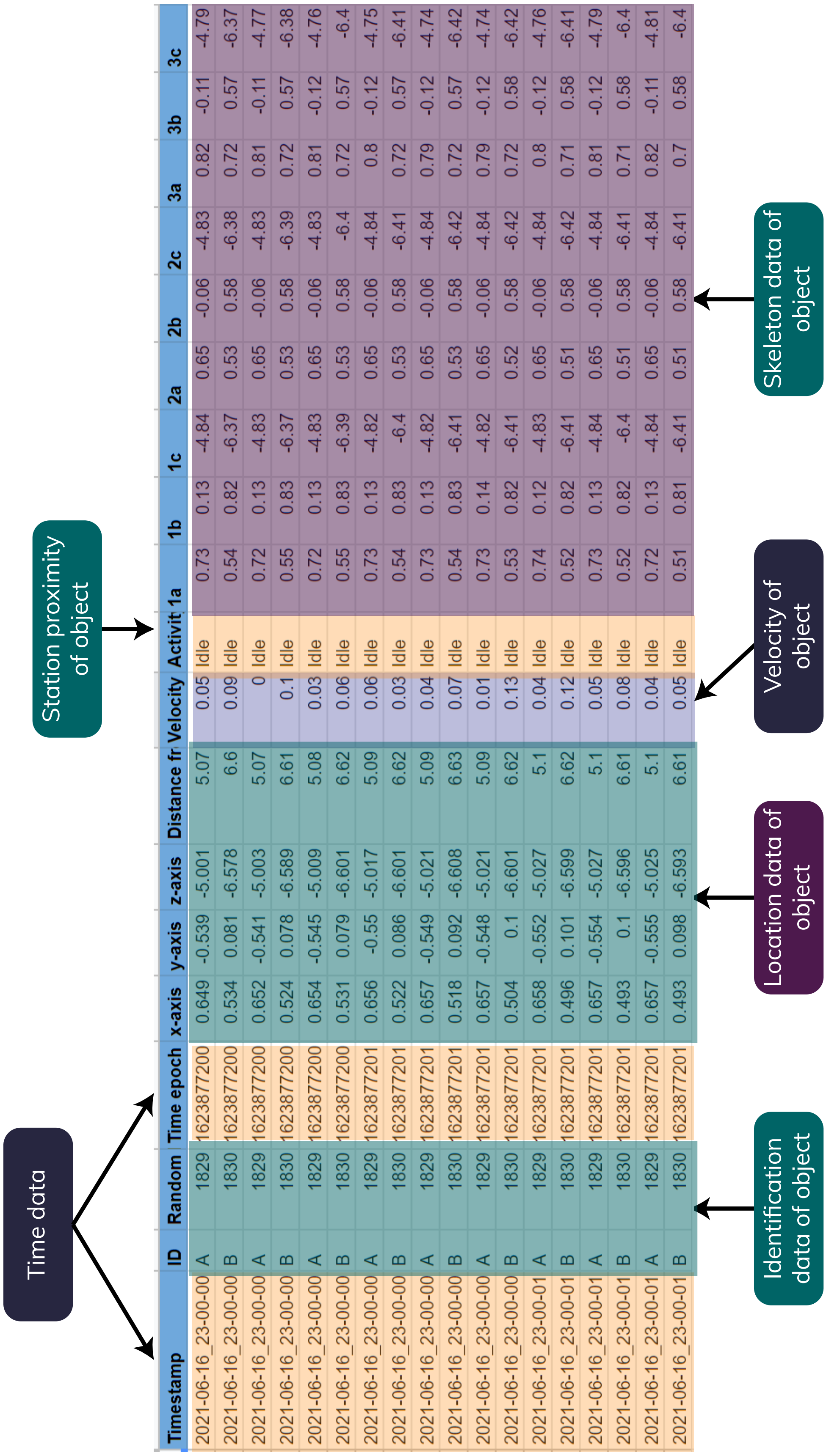


Figure 38: Camera (left) and other hardware placement (right) at site

Data collection

The data was initially collected for three continuous days. The collected data was stored as a spreadsheet every hour and automatically uploaded to the cloud server.

The collected data consisted of time, location data, velocity, identification data and skeleton coordinate data (Figure 39).



Timestamp	ID	Random	Time epoch	x-axis	y-axis	z-axis	Distance fr	Velocity	Activit	1a	1b	1c	2a	2b	2c	3a	3b	3c
2021-06-16_23-00-00	A	1829	1623877200	0.649	-0.539	-5.001	5.07	0.05	Idle	0.73	0.13	-4.84	0.65	-0.06	-4.83	0.82	-0.11	-4.79
2021-06-16_23-00-00	B	1830	1623877200	0.534	0.081	-6.578	6.6	0.09	Idle	0.54	0.82	-6.37	0.53	0.58	-6.38	0.72	0.57	-6.37
2021-06-16_23-00-00	A	1829	1623877200	0.652	-0.541	-5.003	5.07	0	Idle	0.72	0.13	-4.83	0.65	-0.06	-4.83	0.81	-0.11	-4.77
2021-06-16_23-00-00	B	1830	1623877200	0.524	0.078	-6.589	6.61	0.1	Idle	0.55	0.83	-6.37	0.53	0.58	-6.39	0.72	0.57	-6.38
2021-06-16_23-00-00	A	1829	1623877200	0.654	-0.545	-5.009	5.08	0.03	Idle	0.72	0.13	-4.83	0.65	-0.06	-4.83	0.81	-0.12	-4.76
2021-06-16_23-00-00	B	1830	1623877200	0.531	0.079	-6.601	6.62	0.06	Idle	0.55	0.83	-6.39	0.53	0.58	-6.4	0.72	0.57	-6.4
2021-06-16_23-00-00	A	1829	1623877201	0.656	-0.55	-5.017	5.09	0.06	Idle	0.73	0.13	-4.82	0.65	-0.06	-4.84	0.8	-0.12	-4.75
2021-06-16_23-00-00	B	1830	1623877201	0.522	0.086	-6.601	6.62	0.03	Idle	0.54	0.83	-6.4	0.53	0.58	-6.41	0.72	0.57	-6.41
2021-06-16_23-00-00	A	1829	1623877201	0.657	-0.549	-5.021	5.09	0.04	Idle	0.73	0.13	-4.82	0.65	-0.06	-4.84	0.79	-0.12	-4.74
2021-06-16_23-00-00	B	1830	1623877201	0.518	0.092	-6.608	6.63	0.07	Idle	0.54	0.83	-6.41	0.53	0.58	-6.42	0.72	0.57	-6.42
2021-06-16_23-00-00	A	1829	1623877201	0.657	-0.548	-5.021	5.09	0.01	Idle	0.73	0.14	-4.82	0.65	-0.06	-4.84	0.79	-0.12	-4.74
2021-06-16_23-00-00	B	1830	1623877201	0.504	0.1	-6.601	6.62	0.13	Idle	0.53	0.82	-6.41	0.52	0.58	-6.42	0.72	0.58	-6.42
2021-06-16_23-00-01	A	1829	1623877201	0.658	-0.552	-5.027	5.1	0.04	Idle	0.74	0.12	-4.83	0.65	-0.06	-4.84	0.8	-0.12	-4.76
2021-06-16_23-00-01	B	1830	1623877201	0.496	0.101	-6.599	6.62	0.12	Idle	0.52	0.82	-6.41	0.51	0.58	-6.42	0.71	0.58	-6.41
2021-06-16_23-00-01	A	1829	1623877201	0.657	-0.554	-5.027	5.1	0.05	Idle	0.73	0.13	-4.84	0.65	-0.06	-4.84	0.81	-0.12	-4.79
2021-06-16_23-00-01	B	1830	1623877201	0.493	0.1	-6.596	6.61	0.08	Idle	0.52	0.82	-6.4	0.51	0.58	-6.41	0.71	0.58	-6.4
2021-06-16_23-00-01	A	1829	1623877201	0.657	-0.555	-5.025	5.1	0.04	Idle	0.72	0.13	-4.84	0.65	-0.06	-4.84	0.82	-0.11	-4.81
2021-06-16_23-00-01	B	1830	1623877201	0.493	0.098	-6.593	6.61	0.05	Idle	0.51	0.81	-6.41	0.51	0.58	-6.41	0.7	0.58	-6.4

Figure 39: Example of collected data in spreadsheet

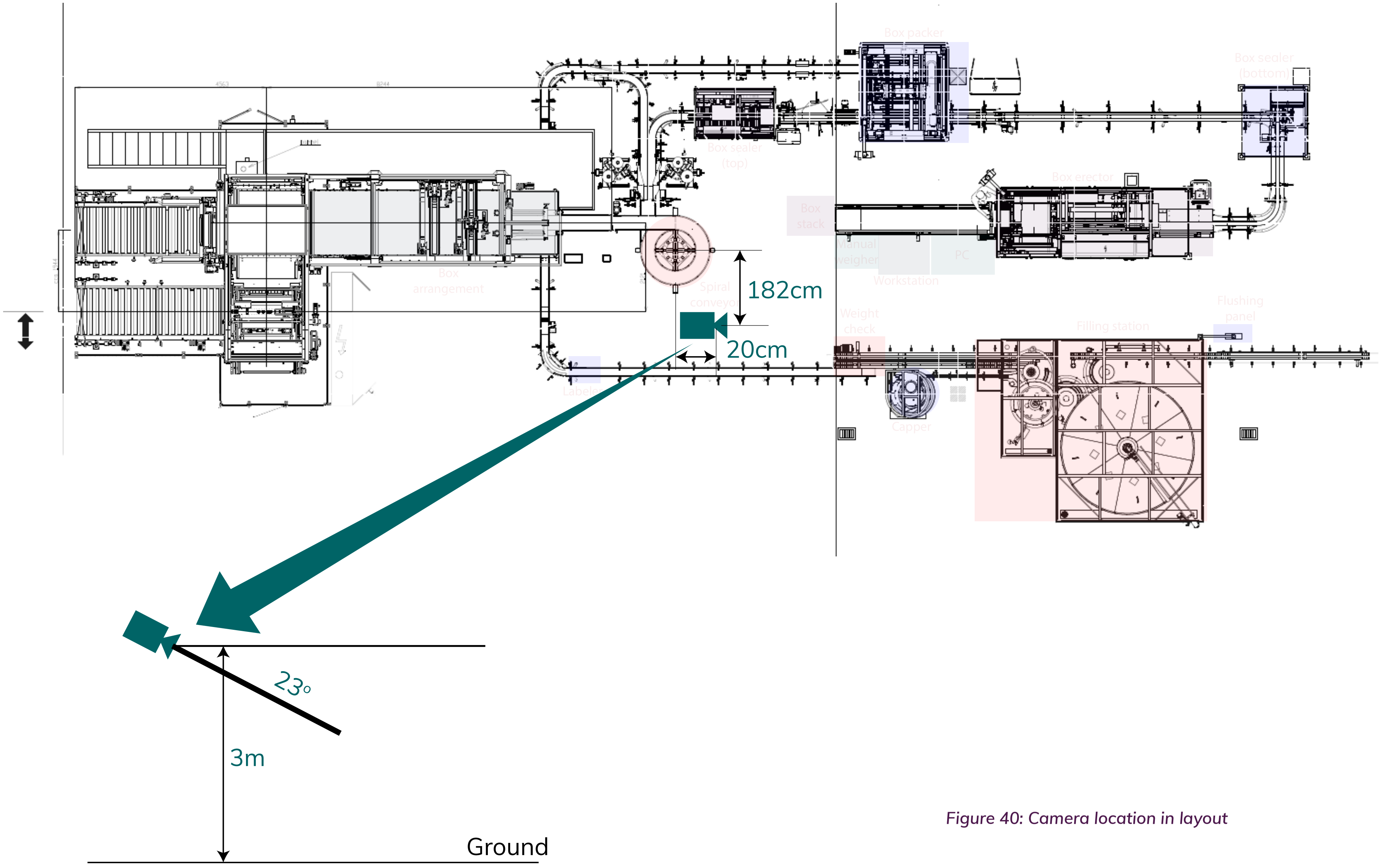


Figure 40: Camera location in layout

4.4 Post processing

First Iteration

First iteration of data processing was performed using Tableau, a data analytics software (https://www.tableau.com/). This is an interactive tool that is capable of creating visualizations effortlessly using its Graphical User Interface. Tableau has its own data processing software called Tableau Prep Builder which was used for the preliminary data processing. The deviations in Station detection and Date-time format were adjusted for consistent data series as shown in Figure 41. Angular adjustment of the X and Z values based on the camera orientation. The camera was oriented at a 23° angle to X-axis (based on Figure 40). This data were then visualized in Tableau for confirming the process.

Takeaways

- Time series data were difficult to handle directly as a string, so another column for Unix time was added to the following data collection code. Unix timestamp is the number of seconds elapsed from the epoch of Unix time starting in January 1st, 1970 00:00:00 UTC.
- ID was not captured consistently by

Timestamp	ID	Label		x-axis	y-axis	z-axis	istance from Camera	Velocity x-axis	Velocity y-axis	Velocity z-axis	Velocity	Activity	Skeleton data	
14:37:30	5	Person	2	602076530	-2.519127368	-10.48804664	.020601788782393	-0.4033227860	0.01524424366	0.83921456336	0.9312264	Filling station	.3178344	-1.8202828
14:37:30	5	Person	2	819663047	-2.522735118	-10.33095359	.856047700689421	-0.4031311273	0.01574319228	0.83930009603	0.9312288	Filling station	.2621157	-1.8142667
14:37:30	5	Person	2	660960674	-2.488184928	-9.733226776	.256486760858124	-0.3720326125	0.01487521082	1.35135531425	1.4017099	Filling station	.126786	-1.7820193
14:37:30	5	Person	1	984467029	-2.459978580	-9.422309875	941086823415203	-0.3485390841	0.01368350069	1.38183009624	1.4251740	Filling station	.999325	-1.7299861
14:37:30	5	Person	1	868310213	-2.286799669	-8.413055419	899534781365967	-0.3867346942	0.01636482216	1.74575543403	1.7881536	Filling station	.7617855	-1.6020623
14:37:30	5	Person	1	659002542	-2.357123374	-8.546419143	039674468256417	-0.5183502435	0.02038496173	1.57537674903	1.6585880	Filling station	.7127292	-1.6318432
14:37:31	5	Person	1	928908824	-2.352561950	-8.406179428	891809706086296	-0.5603070855	0.02186876349	1.42121064662	1.5278291	Filling station	.6385907	-1.6295841
14:37:31	5	Person	1	360702514	-2.407387256	-8.314330101	809104625311795	-0.6169726848	0.02269832976	1.69946336746	1.8081333	Filling station	.5865756	-1.639107
14:37:31	5	Person	1	759181976	-2.403742074	-8.010673522	510721733194591	-0.5302494168	0.01997684873	1.88485336303	1.9581204	Filling station	.543161	-1.6434896
14:37:31	5	Person	1	295660495	-2.441624641	-7.826196670	339691691870057	-0.5226805806	0.02022903971	2.05161476135	2.1172452	MOVING	.5044787	-1.6542289
14:37:31	5	Person	1	950773715	-2.477838993	-7.675971984	203382737326034	-0.4838251173	0.01813047192	2.05629825592	2.1125288	MOVING	.4751688	-1.6484613
14:37:31	5	Person	1	737205505	-2.481840133	-7.502159118	038269350533989	-0.3733478188	0.01531300880	1.87532591819	1.9121899	MOVING	.4634339	-1.6292914
14:37:31	5	Person	1	216840267	-2.482862234	-7.321739196	8608940465476795	-0.4041921496	0.01612842641	1.75100111961	1.7971189	PC	.4150594	-1.6384854
14:37:31	5	Person	1	900166749	-2.465025901	-7.282710075	813217333166992	-0.3569636642	0.00290934648	1.19681286811	1.2489165	PC	.380069	-1.6387923
14:37:32	5	Person	1	223559856	-2.405253410	-7.049813747	565298618945961	-0.3576522171	0.01744861528	0.95480144023	1.0197378	PC	.3107854	-1.6481766
14:37:32	5	Person	1	920911312	-2.465948343	-6.959241867	495428479238474	-0.3734192550	0.01625819876	1.33437788486	1.3857382	PC	.2772789	-1.6536089
14:37:32	5	Person	1	118148803	-2.449828147	-6.604963302	148125172891791	-0.4330820143	0.01351058296	1.70549881458	1.7596785	PC	.201413	-1.6505349
14:37:32	5	Person	1	615016460	-2.444565773	-6.434918403	980914177502055	-0.4126670956	0.01968934759	1.52879178524	1.5836306	PC	.154302	-1.6582001
14:37:32	5	Person	1	129093170	-2.435855627	-6.281711101	828752019724546	-0.3943414390	0.01606931351	1.34896111488	1.4055103	PC	.111039	-1.6627352
14:37:32	5	Person	1	599323511	-2.439100265	-6.100463867	6549474895728	-0.4058232605	0.01571640372	1.41131186485	1.4685845	PC	.0630094	-1.6570668

Date Time	ID	Timestamp	X calculated	Z- Calculated	X-Axis	Y-Axis	Z-Axis	Velocity	Activity
20-05-2021 14:37	5	14:37:30	0.560401879	-9.993993569	2.260207653	-2.519127369	-10.48804665	0.931226471	MOVING
20-05-2021 14:37	5	14:37:30	0.508187668	-9.851372297	2.181966305	-2.522735119	-10.3309536	0.931228868	MOVING
20-05-2021 14:37	5	14:37:30	0.489026173	-9.279740309	2.066096067	-2.488184929	-9.733226776	1.401709928	MOVING
20-05-2021 14:37	5	14:37:30	0.471775598	-8.983572437	1.998446703	-2.45997858	-9.422309875	1.425174076	MOVING
20-05-2021 14:37	5	14:37:30	0.423655433	-8.020923133	1.786831021	-2.286799669	-8.41305542	1.788153675	MOVING
20-05-2021 14:37	5	14:37:30	0.38174474	-8.155918092	1.765900254	-2.357123375	-8.546419144	1.658588081	MOVING
20-05-2021 14:37	5	14:37:31	0.332010636	-8.029101341	1.692890882	-2.352561951	-8.406179428	1.527829171	MOVING
20-05-2021 14:37	5	14:37:31	0.290549029	-7.94747774	1.636070251	-2.407387257	-8.314330101	1.808133359	MOVING
20-05-2021 14:37	5	14:37:31	0.279543302	-7.657282999	1.575918198	-2.403742075	-8.010673523	1.958120456	MOVING
20-05-2021 14:37	5	14:37:31	0.263173718	-7.482547158	1.52956605	-2.441624641	-7.826196671	2.117245223	MOVING
20-05-2021 14:37	5	14:37:31	0.253059081	-7.339735924	1.495077372	-2.477838993	-7.675971985	2.112528811	MOVING
20-05-2021 14:37	5	14:37:31	0.259666599	-7.171545651	1.473720551	-2.481840134	-7.502159119	1.912189944	MOVING
20-05-2021 14:37	5	14:37:31	0.237038901	-7.001720547	1.421684027	-2.482862234	-7.321739197	1.7971189	MOVING
20-05-2021 14:37	5	14:37:31	0.211994077	-6.96823512	1.390016675	-2.465025902	-7.282710075	1.248916556	MOVING
20-05-2021 14:37	5	14:37:32	0.182302224	-6.74909309	1.322355986	-2.40525341	-7.049813747	1.019737884	MOVING
20-05-2021 14:37	5	14:37:32	0.166853684	-6.664499801	1.292091131	-2.465948343	-6.959241867	1.38573829	MOVING
20-05-2021 14:37	5	14:37:32	0.144045804	-6.327535805	1.21181488	-2.449828148	-6.604963303	1.759678599	MOVING
20-05-2021 14:37	5	14:37:32	0.121466455	-6.167678655	1.161501646	-2.444565773	-6.434918404	1.583630678	MOVING
20-05-2021 14:37	5	14:37:32	0.097903495	-6.024169869	1.112909317	-2.435855627	-6.281711102	1.405510399	MOVING
20-05-2021 14:37	5	14:37:32	0.074479173	-5.85367785	1.059932351	-2.439100266	-6.100463867	1.468584592	MOVING

Figure 41: First iteration : Before data processing (top); After data processing (bottom); Red box shows the change happening in date time format, blue box corresponds to coordinate change and dark box shows the activity adjustment based on velocity

the Zed 2 camera. A person leaving the scene and reentering will be provided a new Random ID number. So, the captured data for about 5 hours resulted in Random ID running from 0 to beyond 500, even though there were only a maximum of 5 people in the scene.

- Due to ethical concerns, no comparison of physical attributes of the detected objects could be performed using the Zed 2 camera. So, a consistent method of ID detection was required. The desired solution was to provide ID starting 'A',

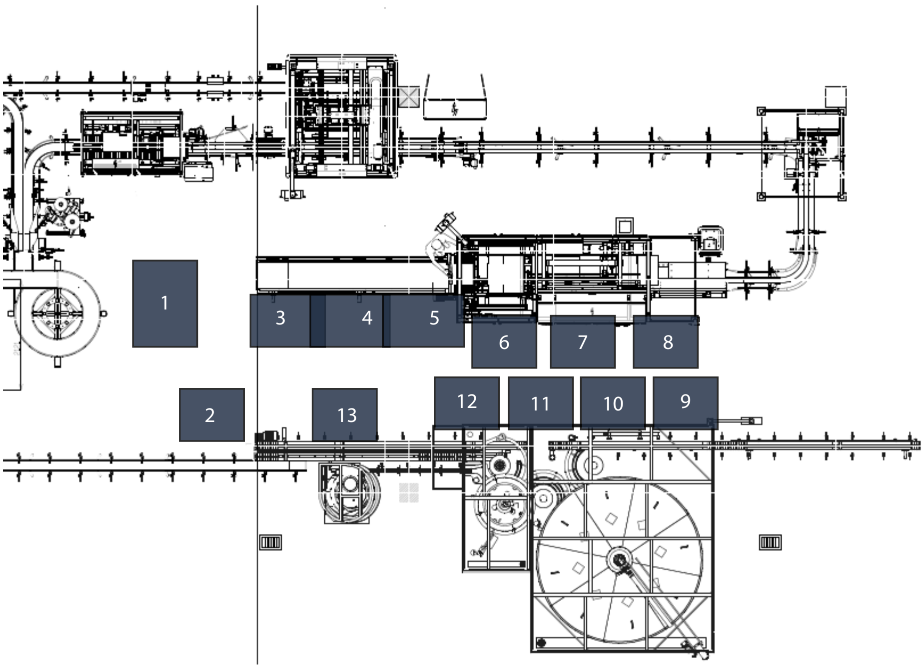
Second Iteration

As Tableau was not an open source software, it was preferred by Diversey to do both processing of data and developing the visualization interface using Python libraries. Pandas library in Python was one of the best options for handling dataframes. The csv or xlsx files with the data were passed onto a Pandas dataframe for processing. The tasks performed in this iteration were:

- Derive the station based on the identified location. A range of X and Z values representing an area around the respective station was cross checked with the object location to optimize the camera identified results (Figure 42).
- ID of the objects were updated to make it more consistent. The 'ID' (program defined letter A, B, C, ...) and 'Random ID' (camera defined number) were both compared to each other. Objects with the same Random ID were given the same ID letter. In case of an object detection is lost and then within a gap of 5 seconds detected again at a location within 1m distance shall be considered as the same ID.

Takeaways:

- ID letters exceeded beyond 10 letters and the inconsistency was not completely solved. There needs to be a code that resets the ID back to start from 'A' when there is no object detected with the same letter for a while.
- Station detection had overlap and so the detected station switched back and forth even with the person not moving.



1	Box loading
2	Weighing scale
3	Manual weigher
4	Workstation
5	PC
6	Box loading door 1
7	Box loading door 2
8	Box loading door 3
9	Filler door 1
10	Filler door 2
11	Filler door 3
12	Filler door 4
13	Capper

Figure 42: Designated area for each station

Third iteration

From the takeaways in previous iteration, necessary improvements were made to make the data better refined for the data visualization stage:

- The area corresponding to respective stations were made circular from previously used rectangular sections. This reduced the overlapping of objects In addition to that, the station location code was optimized to find the closest distance to each of the stations. This way fluctuation of stations for non-moving objects was avoided in the dataframe.
- Whenever there was a gap of more than 5 seconds for the same ID a null row was inserted to avoid scatter plot connecting between these points (Figure 43).
- The dataframe was reduced to one data per second from the 6-8Hz data collection frequency of the camera. The values for the same second and same ID were averaged during the reduction of the data. This improved the data processing speed and would be beneficial for real time data processing in the future work.

Takeaways:

- The data was buffered in advance for this iteration. But in order for the choice of the date-time for the user, the entire data loading structure into the program had to be changed as shown in Figure 44.

Fourth iteration

As the previous iteration made the working of the interface to the best possible way, it was necessary to change the data buffering algorithm to load as per user's wish. If all data was loaded in advance, the whole program would slow down to more than 5 minutes for each change. The new structure of dataflow is as shown on right in Figure 44.

To ease the load times, the filename corresponding to the given date and the hours ranging from start and end time and an additional one following hour was loaded as per user input.

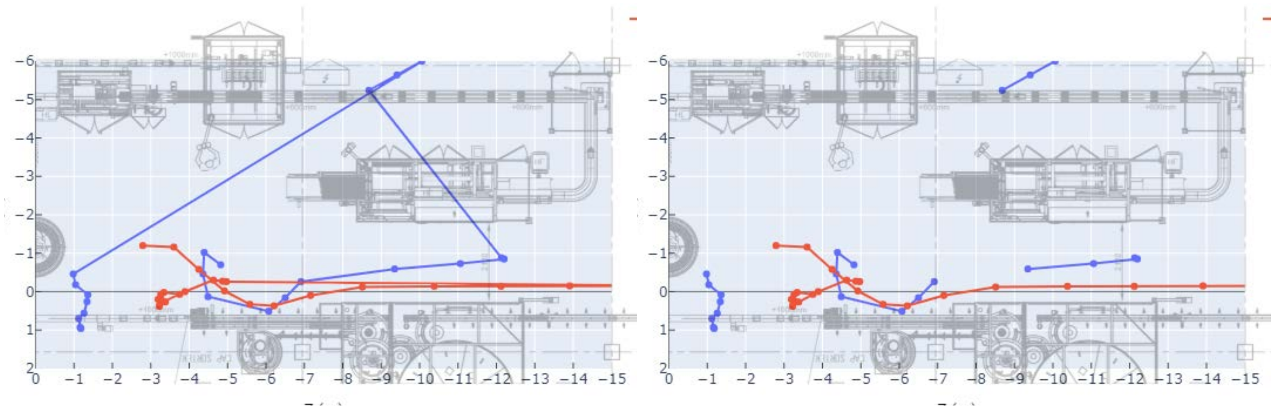


Figure 43: Visualization of operator location from 15:15 to 15:17 on 16th June 2021; Left: Visualization before and Right: After applying Null rows for gap in data;

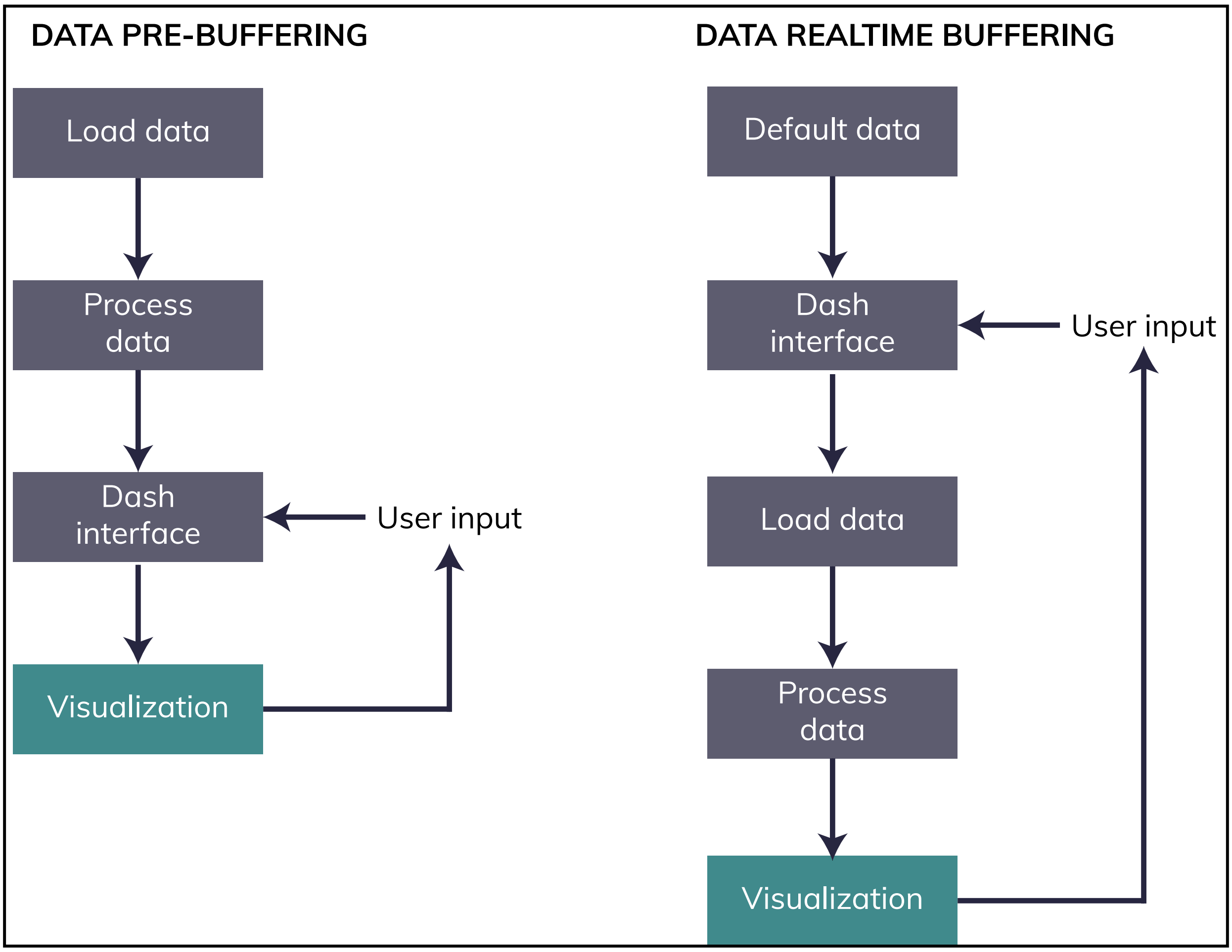


Figure 44: Data pre-buffering vs Realtime buffering

5 IDEATION

5.1 Introduction

This section deals with the exploration of different visualizations possible with the data collected and what questions need to be answered by them. First, the collected data were checked back to the outcome of the brainstorm session with Diversey (Figure 10). The questions that need to be answered were crosschecked with the user's needs. Once this was done, the second step was to explore the different ways of meaningfully representing these data.

5.2 What needs to be solved?

The following questions were formulated with insights, from the user interview and brainstorm session with Diversey (Section 2.2), that were most important for Diversey and their process improvement team (Figure 45). The solutions to be represented to the end user (process improvement team and Diversey) included:

- activity information of operators
- station activity
- concentration of operators' location,
- time spent on specific locations,
- frequently visited stations
- whether it was during machine running or stoppage and
- average changeover time for specific SKU.

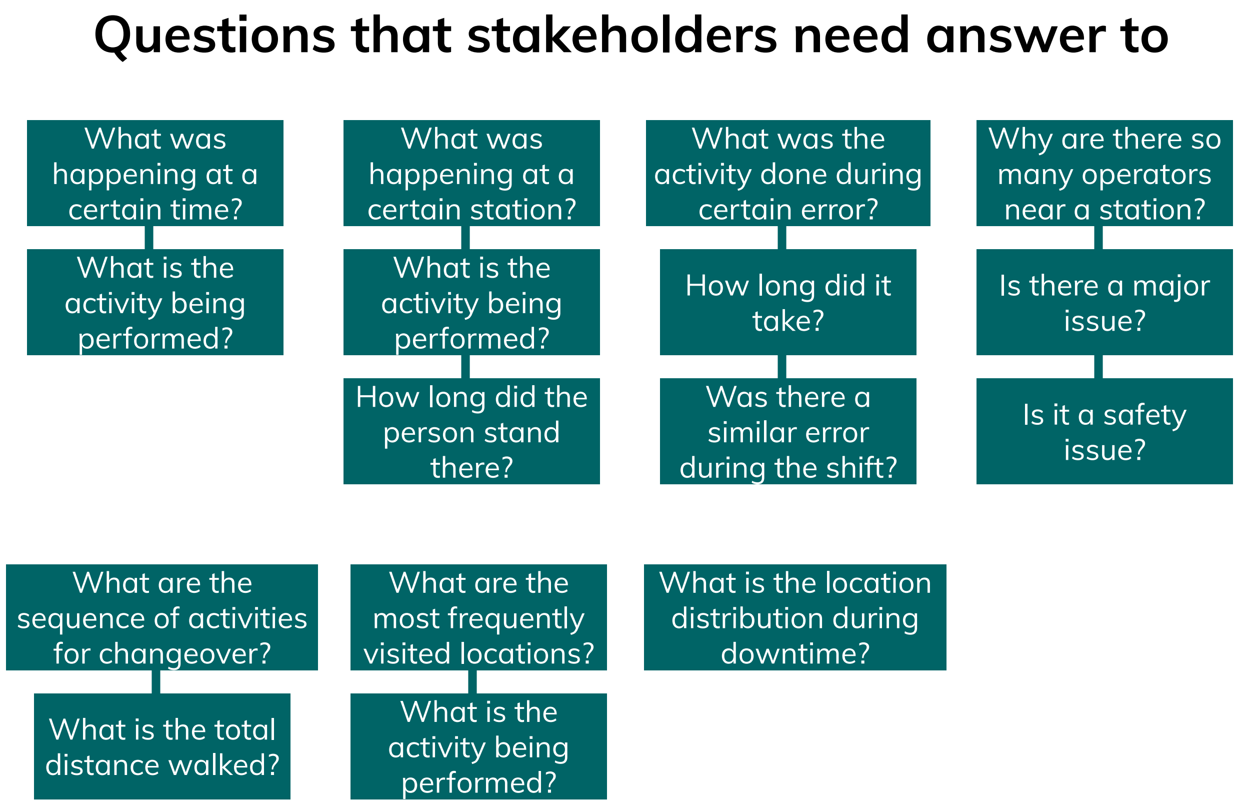


Figure 45: Questions for generating ideas

5.3 Possible directions

The questions in Section 5.2 can be answered using the charts specified in Figure 47.

As the location data of the operators with respect to time or events such as line stoppages, Spaghetti chart was found adequate. The details of the activity being performed can be visualized using an activity map or a skeleton animation. The distribution of the location can be read using Heat map, bubble charts or Pareto charts.

An event marking is necessary to mark the time of interest for the user. These events markings could be safety issues, multiple people at same place, long stoppages, etc.

5.4 Ideas

Various ideas were generated to provide meaningful visualizations that tackle the questions given in Section 5.2. Seven of the ideas that were created are presented here.

Spaghetti diagram (Figure 46) was most important to show the movement path and the total distance traveled by the operator. Also, it was able to show where the concentration of movement was in a particular timeset. Spaghetti chart is being used currently by Diversey for the SMED analysis. So, it is more familiar for the user to visualize the process improvement potential at the site. What was desired by the user was a more interactive Spaghetti chart unlike the traditional pen and paper chart which gets unreadable after a few overlapping lines. They expected a chart which was interactive to show only a specific period of data when an event was triggered at site.

The advantage of an interactive Spaghetti chart is that it enables the user to understand the sequence of activities during changeover or it is even possible to compare side by side the sequence of movement between two changeovers. This could help in COALA project's vision of identifying best practices in the production line.

Heat map (Figure 48) provides insights about

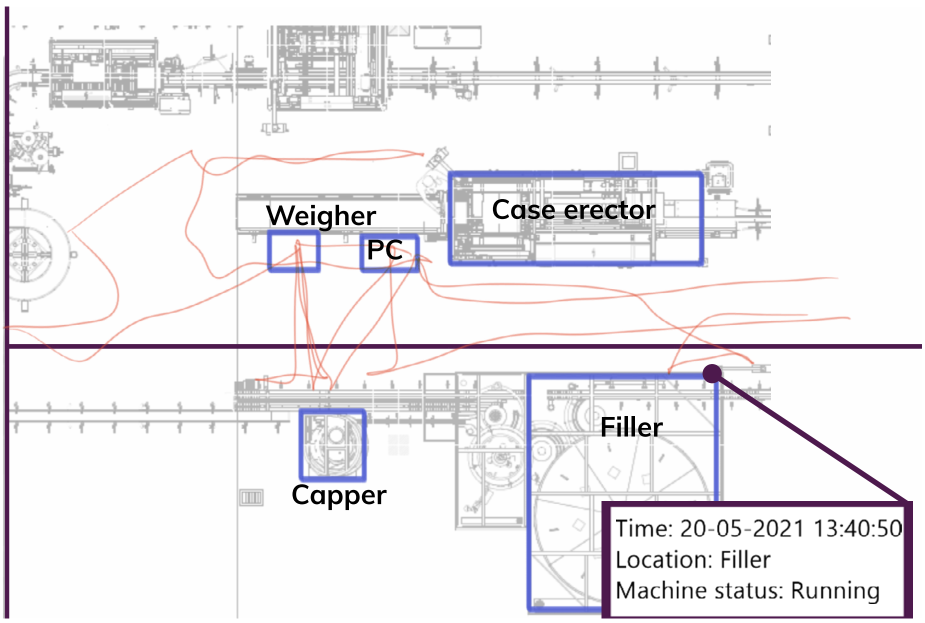


Figure 46: Visualization 1 - Spaghetti chart

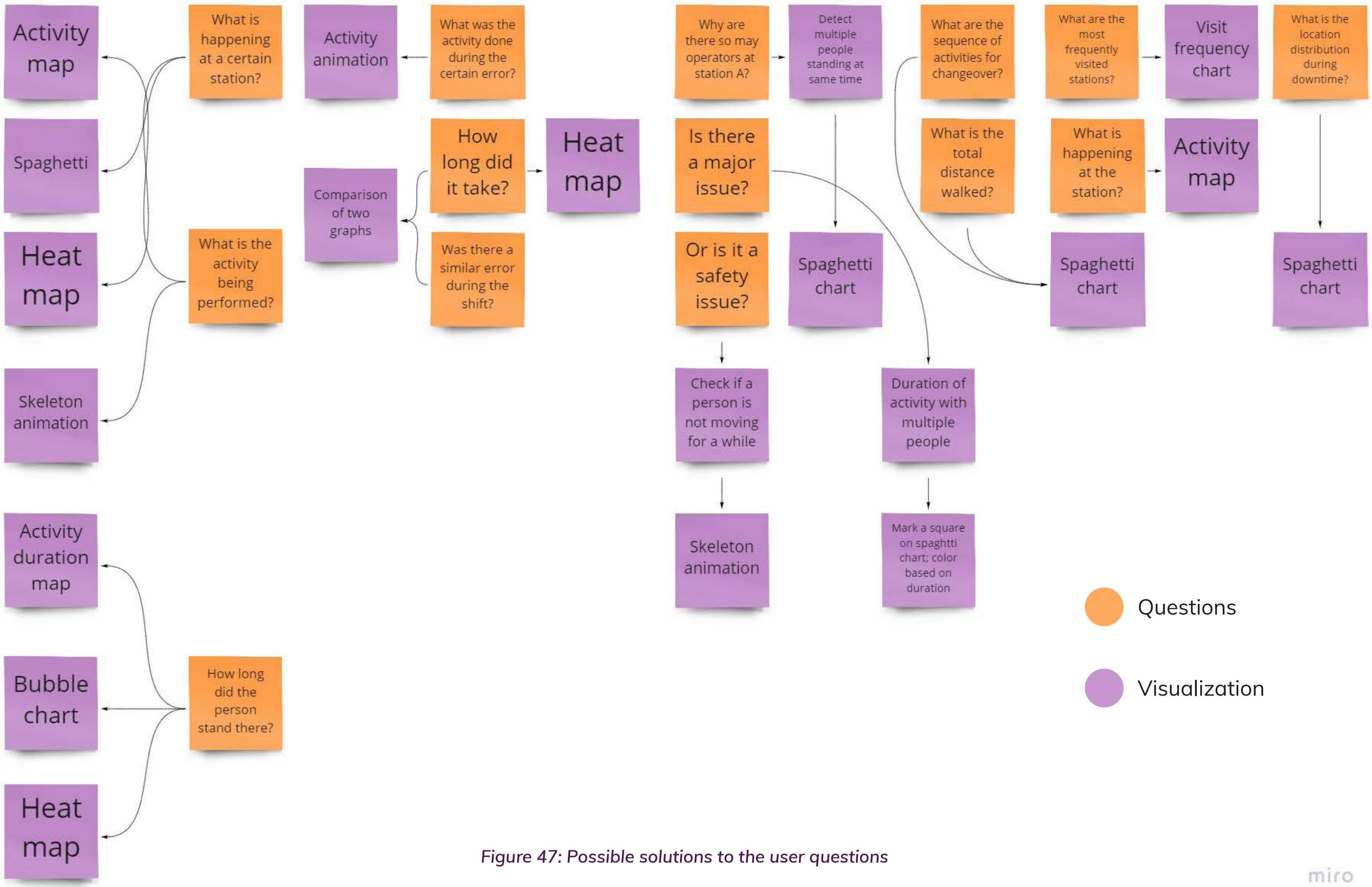


Figure 47: Possible solutions to the user questions

the concentration of time spent by operators. It can also be used to notify the frequency of visits to a particular station.

Time spent map (Figure 49) was used to show the operator time present at a station. Each of the circles indicate the number of visits and the size of the circle represents the time spent. Longer the time spent, the bigger the circle. This could also provide insights on the time spent during a particular stoppage. This map could potentially be combined with an activity skeleton map which can give an idea of what the operator was doing during that cluster of time.

Pareto chart (Figure 50) shows the time spent at specific stations. This is useful to visualize the top three visited locations in a week for issue analysis. Multiple weeks of data can be compared to see any patterns of station visits. Another variant of this could be with number of visits instead of time spent. All the clusters of visits more than 5 seconds at a specific station would be counted and their frequency are plotted on a similar

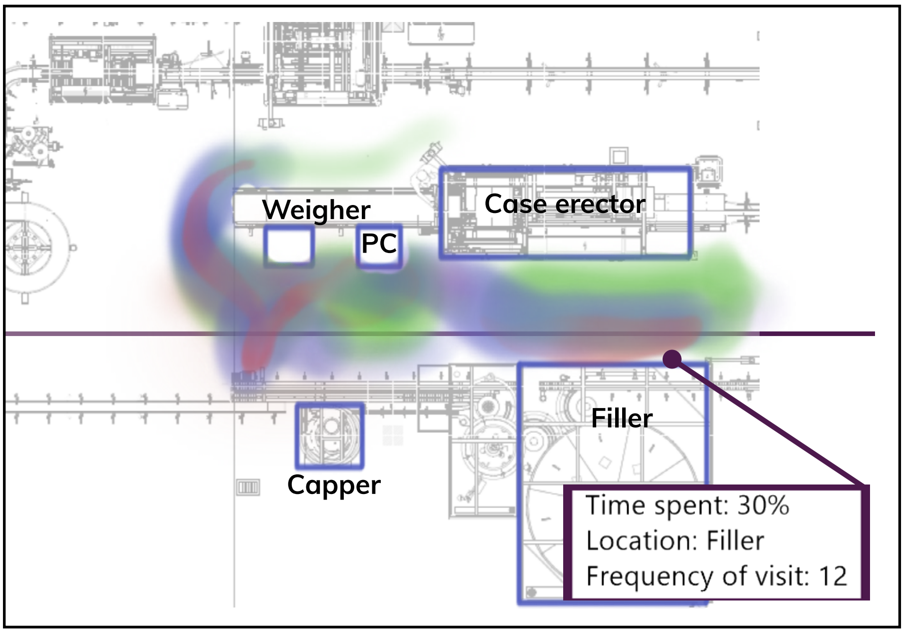


Figure 48: Visualization 2 - Heat concentration of operator position

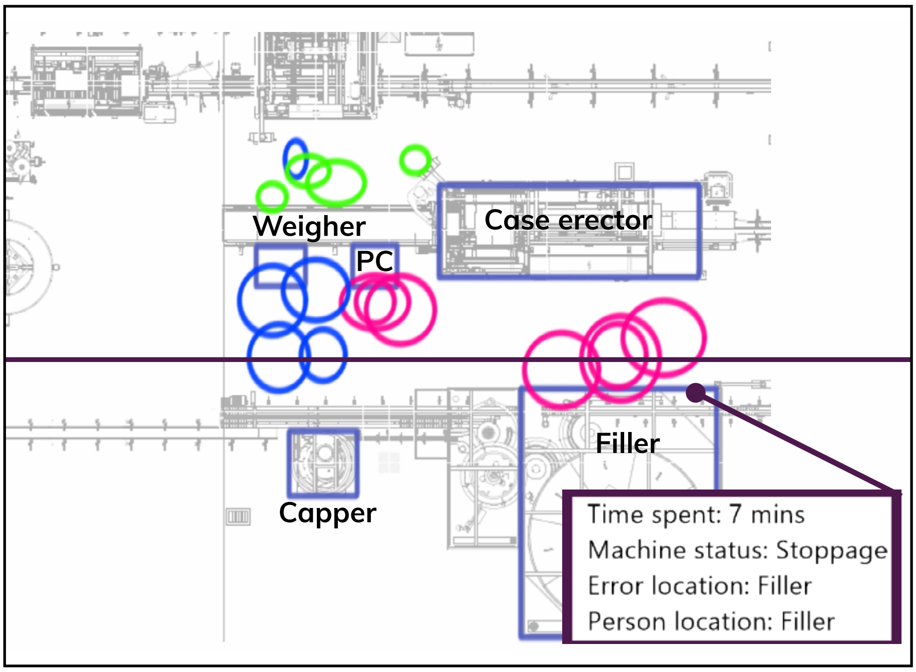


Figure 49: Visualization 3 - Time spent map of operator position

Pareto chart.

A possible alternative for Pareto chart is a **bubble chart** which shows the time spent at stations based on the size of the bubble as shown in Figure 51. The X-axis corresponds to the timeline and Y-axis is the number of people present in that visit. Each of the visit is shown with a different bubble. The user can visually derive the most visited and longest time spent stations.

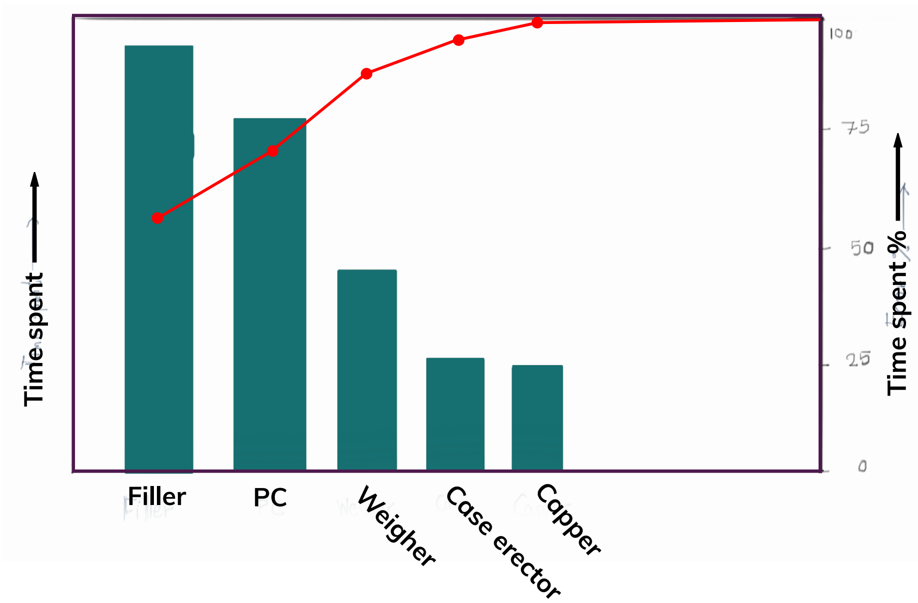


Figure 50: Visualization 4 (a)- Pareto chart of time spent / station visits

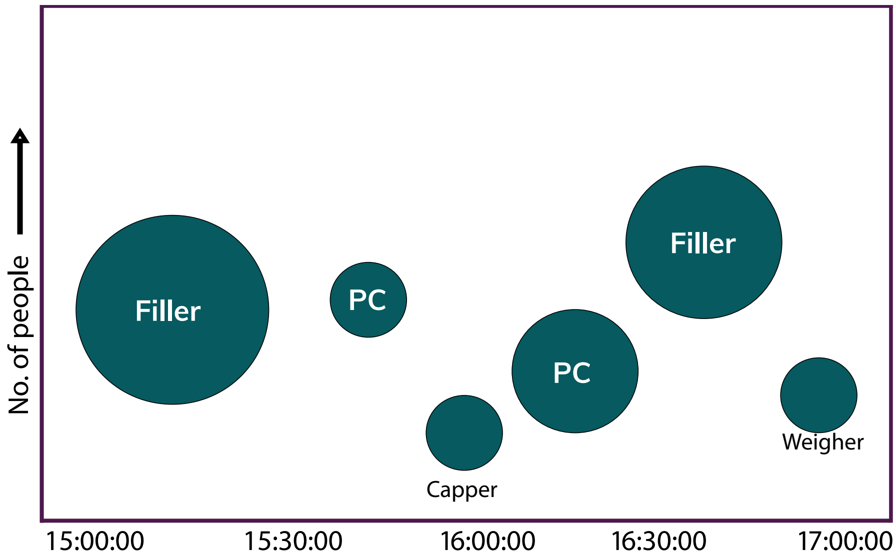


Figure 51: Visualization 4 (b) Bubble chart of time spent / station visits

Changeover time comparison chart (Figure 52) focused on comparing the percentage of time spent in stoppages and changeover. If they could compare the run of the same SKUs, it is identifiable what went wrong in the worse one or what was done right in the better one. This chart could be assisted with the sequence of activities data which can give more understanding of changeover. As OEE (Overall Equipment Efficiency) is an important calculation for Diversey, this graph helps in visualizing the ratio of Run time to Planned Production time. This is also helpful in comparing OEE between shifts.

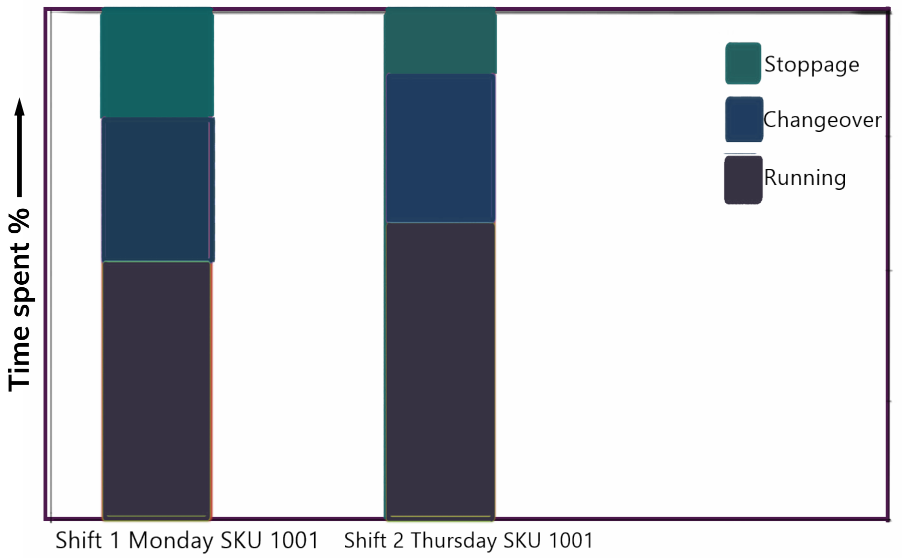


Figure 52: Visualization 5 - Changeover time comparison

Activity map (Figure 53) provides data about the activity performed at a particular station. The activity analysis has to be done through the captured skeleton data animation. This skeleton data can be template matched with skeleton data of known activities at site. The best matching activity is classified as matched based on the findings from Laptev & Lindeberg (2003). This graph facilitates visualizing what the activities being performed by the operators during a certain changeover period were. In case the heat map shows more density of operator visits at a certain station, this graph can be beneficial in visualizing the type of activity performed at that station.

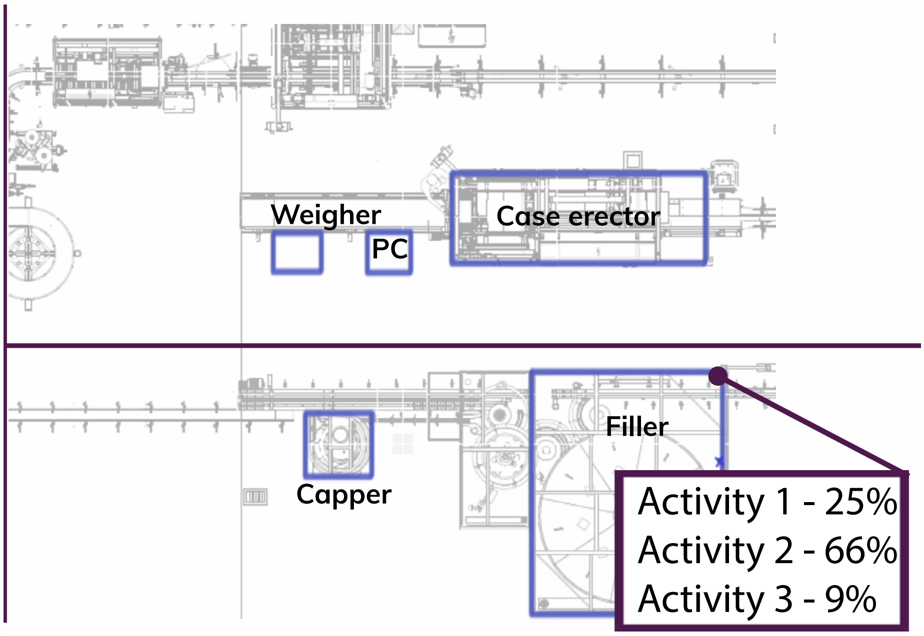


Figure 53: Visualization 6 - Activity map

5.5 *Ideas for interaction*

Interactions with the graphs are essential for providing the users the convenience to filter data as per their requirements. Therefore, several ideas were tested out by trial and error to find which suits the interface expected by the user. A few of the ideas that came up in this section were arranged on a morphological chart to mix and match the intuitiveness of the interface (Figure 54).

First, the parameters that need to be adjustable were decided. From the interactions with Diversey, it was identified that the time and date are the foremost importance in visualizing the data. As there were multiple graphs to be presented, interactions for choosing graphs and filtering the graph data were also looked into.

With different interactions listed, the first and second preference (Figure 54) of interaction setup were tested out.

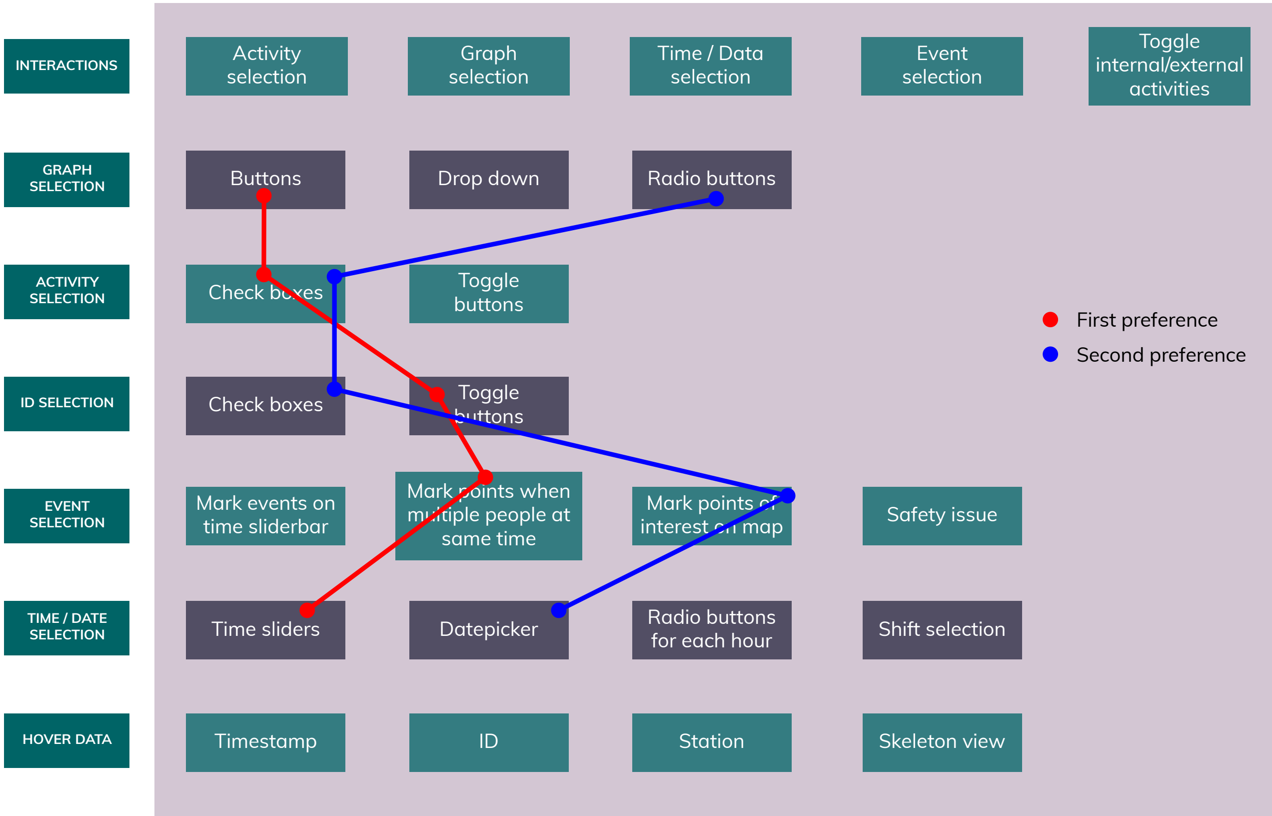


Figure 54: Morphological chart of interaction ideas

5.6 Takeaways

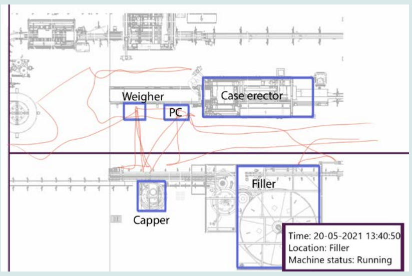
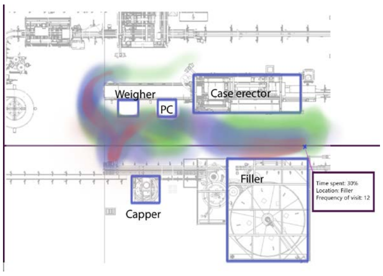
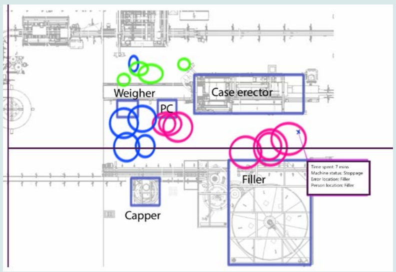
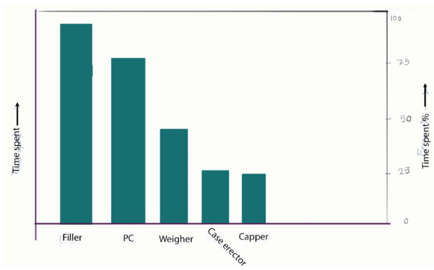
This section presented the different ways of possible meaningful visualizations of collected data (Figure 45). The Spaghetti chart and heat map are most traditionally used in lean manufacturing industries for process improvement. Alternatives and other visual representations were explored for the collected data. Most important findings from this ideation process are:

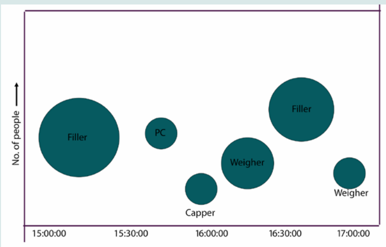
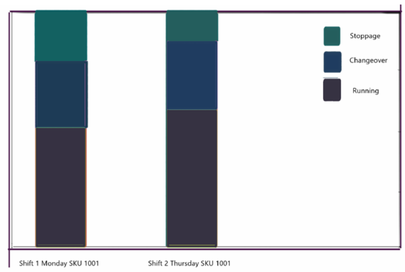
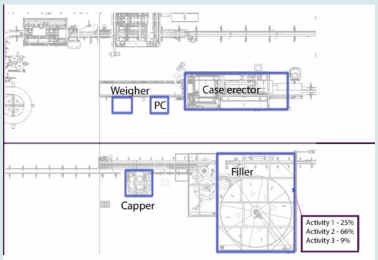
- Spaghetti charts are important in visualizing the parameters during changeovers such as sequence of activities, multiple people involved in activities and emergency of an event based on operator velocity change. So, Spaghetti charts were found to be information rich graph beneficial for user, lean manufacturing methods and best practice
- Another important parameter that users would like to see from this data is the time spent at locations. Visualization 2, 3 and 4 are dealing with the time spent by operators at different stations. The convenience and intuitiveness of these graphs need to be tested in the next section.
- Visualization 5 - Changeover time comparison chart facilitates to easily visualize the Availability calculation for OEE improvement. This chart can help in checking the changeover efficiency of the line.

6 CONCEPTUALIZATION

6.1 Comparison of ideas

Table 7: Comparison of visualizations

Ideas	Pros	Cons
 Visualization 1: Spaghetti chart	• Visualizing sequence of activities • OEE improvement • Total distance walked during changeovers	• Needs to filter time or else it gets crowded with lines
 Visualization 2: Heat map	• Identify location concentration of operators • Identify issue locations in a shift	• No duration data of each visit. • No data of time of visit
 Visualization 3: Time spent map	• Visualize data of the duration of each visit • Frequency of visit is observable easily based on number of circles • Identify issue locations based on time spent. • Changeover time spent maps can be compared for best practices.	• In large datasets, the circles could get mixed up and would not be intuitive to read
 Visualization 4(a): Pareto chart of time spent	• Identify top three issue locations • This would be really helpful in the process improvement team's daily task of previous day performance • This can have a variant of time spent or frequency of visits.	• Does not show what time the person was at that station.

Ideas	Pros	Cons
 Visualization 4 (b): Bubble chart of time spent	• Same advantages as Idea 4(a)	• Does not show what time the person was at that station. • Multiple similar sized bubbles will not be intuitive.
 Visualization 5: Comparison of changeover performance	• OEE improvement • Changeover performance comparison between shifts	• Can raise ethical concerns if the personnel evaluates operator performance based on shifts
 Visualization 6: Activity map	• Can be insightful combined with Idea 3. • Time spent map with activity map, provides good vision of what the operator was doing at the station.	• Need detailed template matching study of activities to properly identify the activities.

Takeaways:

After discussions with the users Spaghetti chart, heat map and Pareto chart were chosen to proceed with in project. An alternative proposed to heat map was the Visualization 3 of Time spent map. The users did not find this more desirable than the proposed Visualization 2 - Heat map. Also, the scope of the project did not cover the activity template matching and so the Idea 6 was also not taken forward.

6.2 Visualization tools

To conceptualize the aforementioned ideas, initial plotting was done in Tableau. Tableau is an interactive business analytics and data visualization software. Tableau was used for only validating the data visualizations as mentioned in Section 4.4. The tabulated data columns were easily dragged into axes and necessary filters were applied to check the required interactivity of the final interface (Figure 55).

Diversey (user) requested a new interface designed in Python. Within Python's numerous libraries related to data visualizations, Plotly appeared easier to code and interactive for creating meaningful visualizations (Iacomi, 2020). In addition to that, Plotly had its own dashboard library called Dash which works in Python creating web based applications. Dash is an open source software and works directly from the browser (Dash overview, n.d.). In this project, Dash HTML components were utilized for the design of the interface.

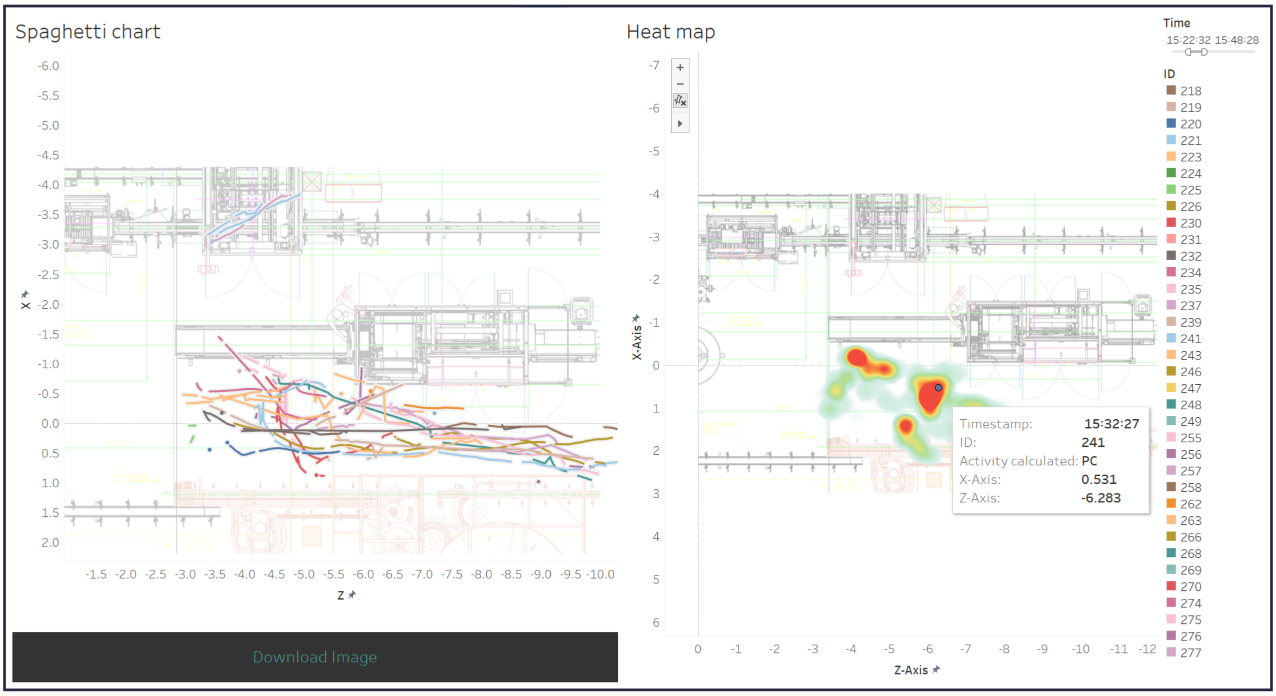


Figure 55: Dashboard in Tableau

6.3 Version 1 - Minimum viable product

The first version of the interface was about creating the minimum feasible product with just working conditions to plot the interactive Spaghetti chart (Figure 56(a)) and the Spaghetti chart animated (Figure 56(b)). The graphs were generated using Plotly's plotly express library functions for scatter charts. The animation frames were created based on the Timestamp from the data series and the color filter based on the ID of the object.

Core functions related to Dash were applied in the version wherein there was a radio button selection for the type of graph, Each of the graphs were provided hover data consisting of the location data, ID, Station and Velocity.

Takeaways

- The Spaghetti chart was visualized with all data at once and it did not provide any additional benefits to the pen and paper method (Figure 56). A data filtering method is necessary to make it more

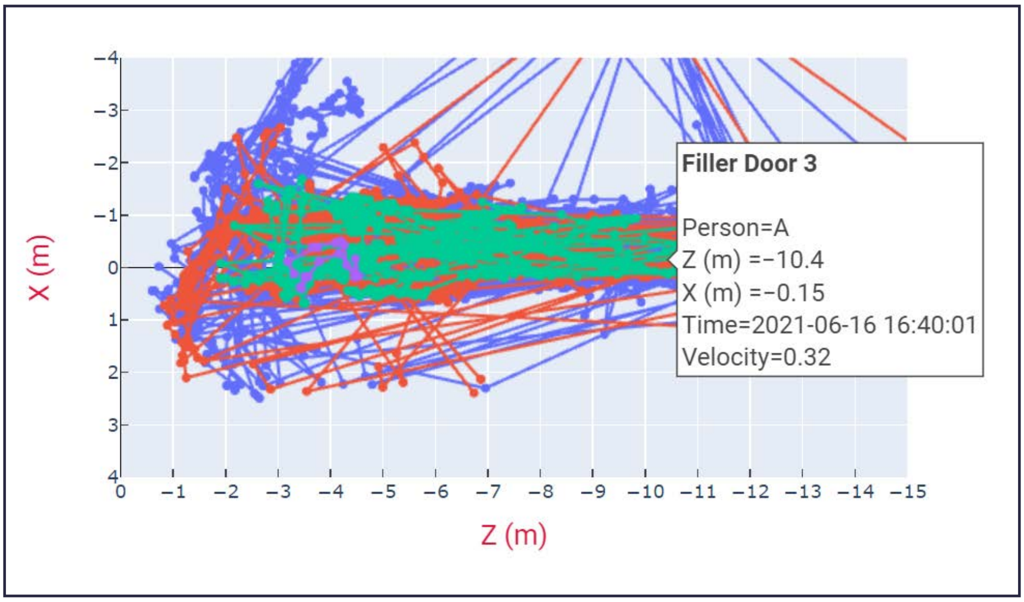


Figure 56(a): Version 1 - Spaghetti chart (unfiltered data from 16.00 to 17.00 on 16th June 2021)

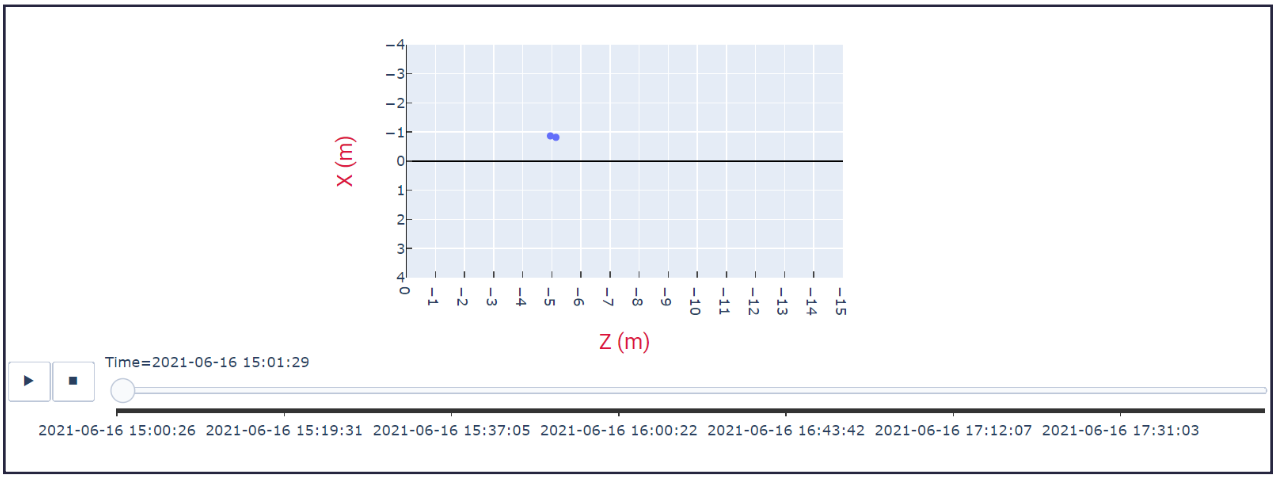


Figure 56 (b): Version 1 - Spaghetti chart animated (unfiltered data from 15.00 to 18.00 on 16th June 2021)

intuitive.

- The chart had noisy lines due to objects going out of the camera view and new objects reentering elsewhere on screen (Figure 57). In such a situation, the scatter plot connected all the lines, which seemed to look like the person got "teleported" to a farther distance in the same second. In the next step, the data which had a gap of a few seconds or was farther from the initial point needed to be disconnected using "Null'' rows in the data series.
- Spaghetti chart animated did not leave a trailing line and so it was not easy to visualize the path traced by objects.

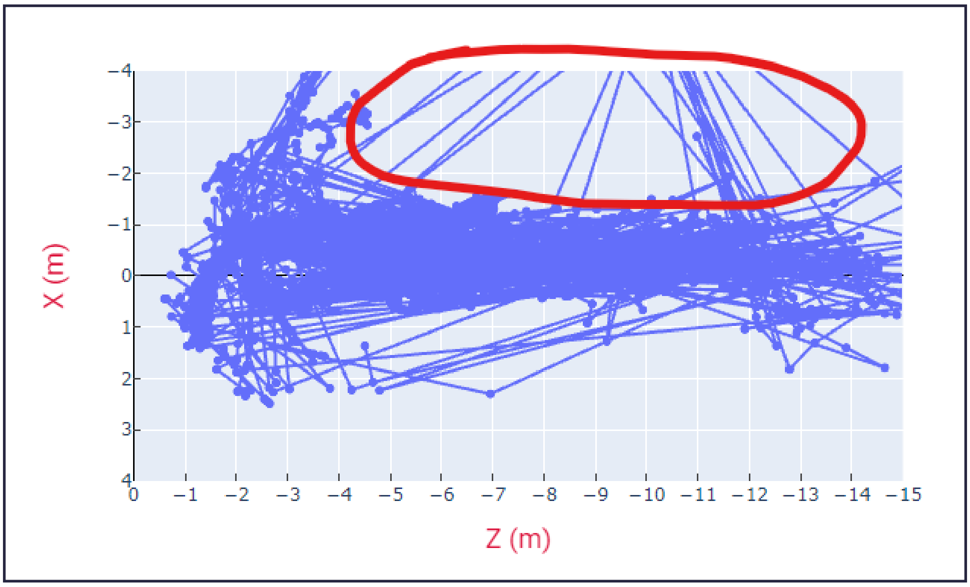


Figure 57: Noisy lines in version 1

6.4 Version 2 - Dashboard with multiple plots

In this version, new graphs were explored that could benefit the process improvement. The earlier Spaghetti animated chart was updated using plotly graph objects library. In this library, multiple plots were possible by adding line graph to show trailing lines and scatter plot to show the current location (Figure 59). The animations were applied using each timestamp being passed on as a frame for the animation.

Other plots were heat maps (Figure 60) and density contour maps to show the time location distribution of the operators.

Takeaways

Interactive elements are yet to be done in this version. Without that, the graphs does not seem to be intuitive for the user.

The charts would make more sense if there was the production line layout superimposed in the background.

Heat maps (Figure 60) were difficult to read and zero count was given a purple color which was not desired. In later versions, new libraries for plotting heat maps need to be explored for creating meaningful way of showing location concentration.

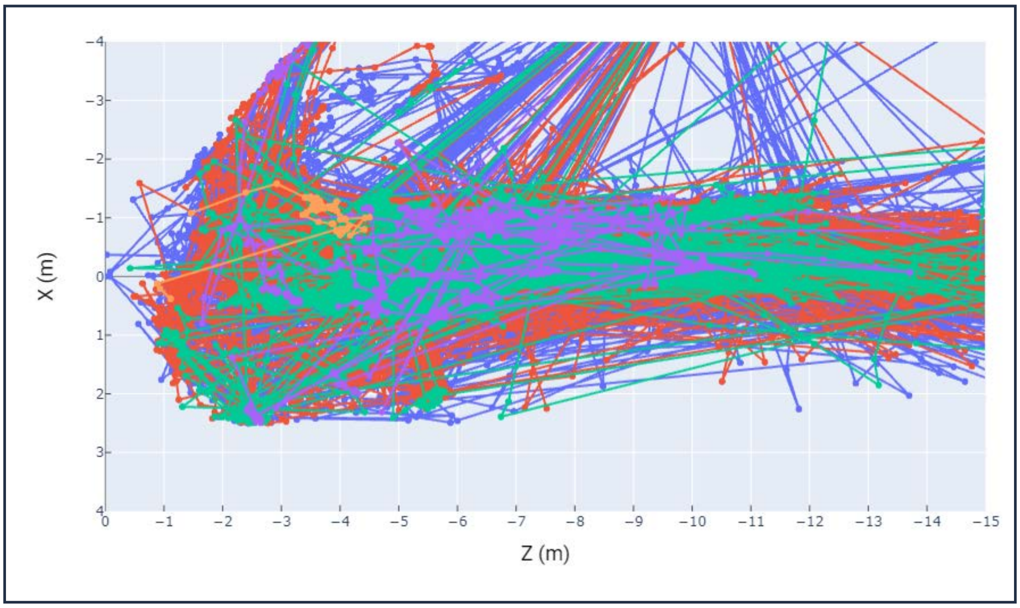


Figure 58: Version 2 - Spaghetti chart (unfiltered data from 15.00 to 17.00 on 16th June 2021)

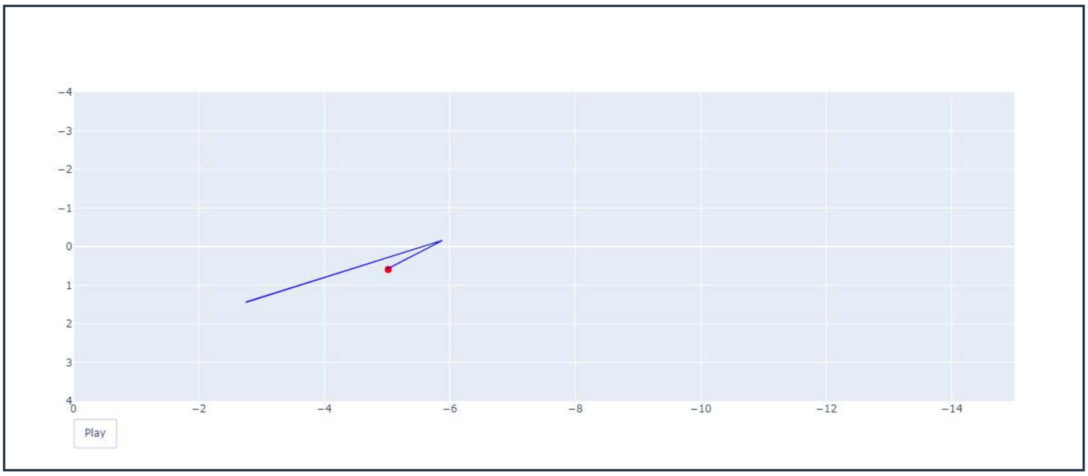


Figure 59: Version 2 - Spaghetti chart (animated) with trailing lines

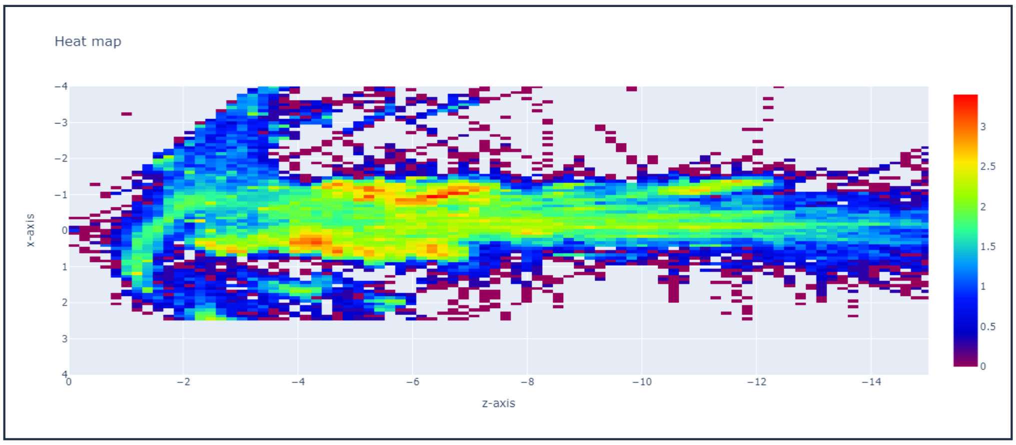


Figure 60: Version 2 - Heat map

6.5 Version 3 - Interactive dashboard

This version implemented all the interaction features which were expected for the final implementation (Figure 61). These include:

- Radio buttons for the graph selection - four graphs with Spaghetti chart and Pareto chart fully working, Spaghetti chart animated and Heat map - partially solved.
- Activity selection checkbox for filtering the location data based on the particular checkbox.
- Date picker for choosing the start and end date of the visualized data.
- Time range sliders for filtering the time from the above picked date.

The relevant graphs were provided with the background layout for easy understanding of the positions. Also, the interface was updated to show two graphs in a side by side style for comparison of graphs of different time periods.

In addition to that, heat maps (Figure 63) were improved from earlier Heat map (Figure 60) using plotly density Heat map plots.

Pareto charts were able to clearly depict the time spent at different stations during the chosen period of time (Figure 64). This was useful in identifying the issue locations during a stoppage or changeover.

Takeaways

- Heat map had a purple mask for zero value and also the heat map area decreased based on the location covered by operators (Figure 65).
- Spaghetti chart and Pareto chart is fully defined and ready to be evaluated by the user. Necessary extra information, such as visit frequency and timestamp, ID, activity in Spaghetti chart, were provided on hovering over the corresponding data.

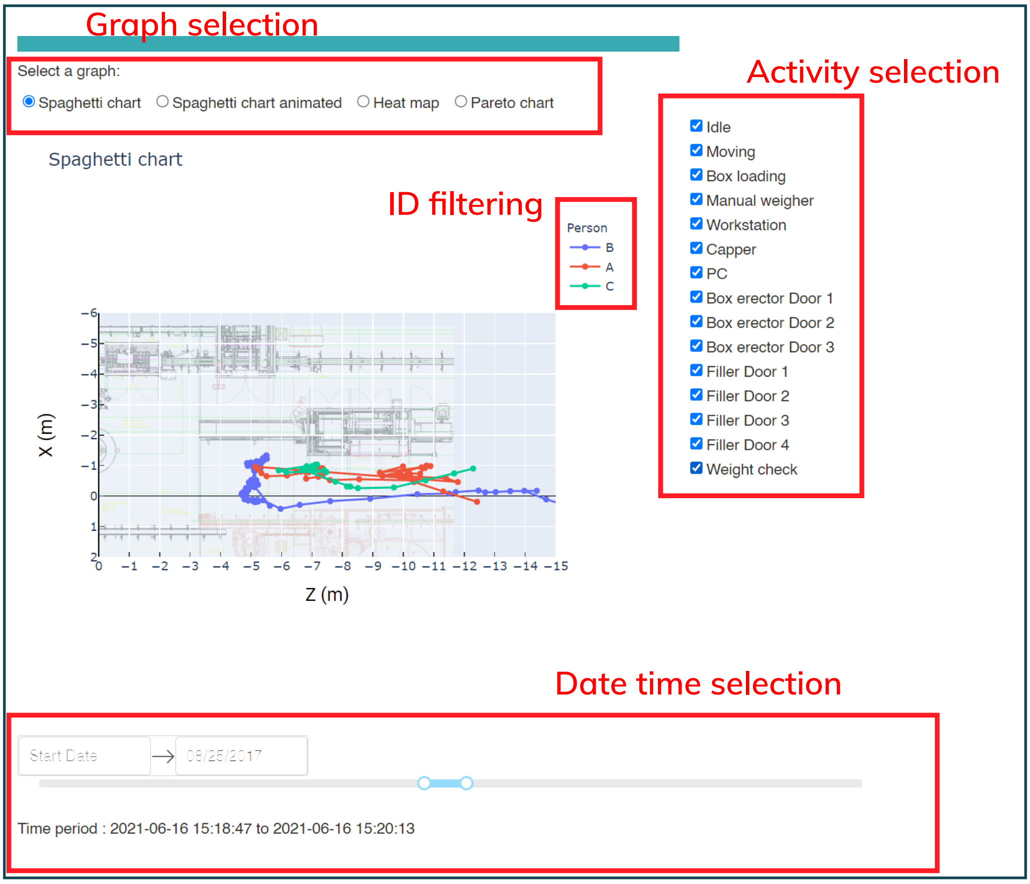


Figure 61: Interactive elements of dashboard

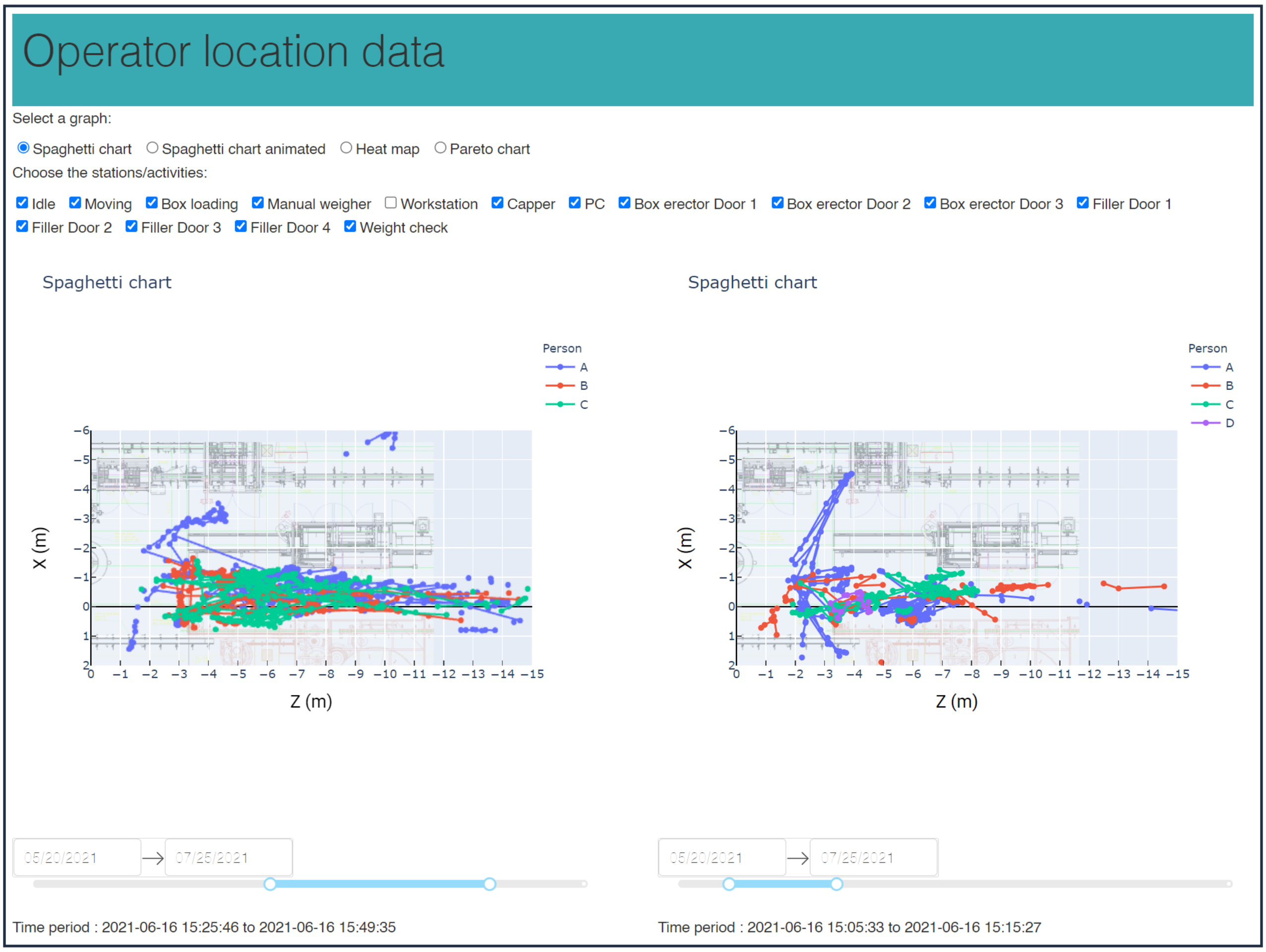


Figure 62: Version 3 - Spaghetti chart

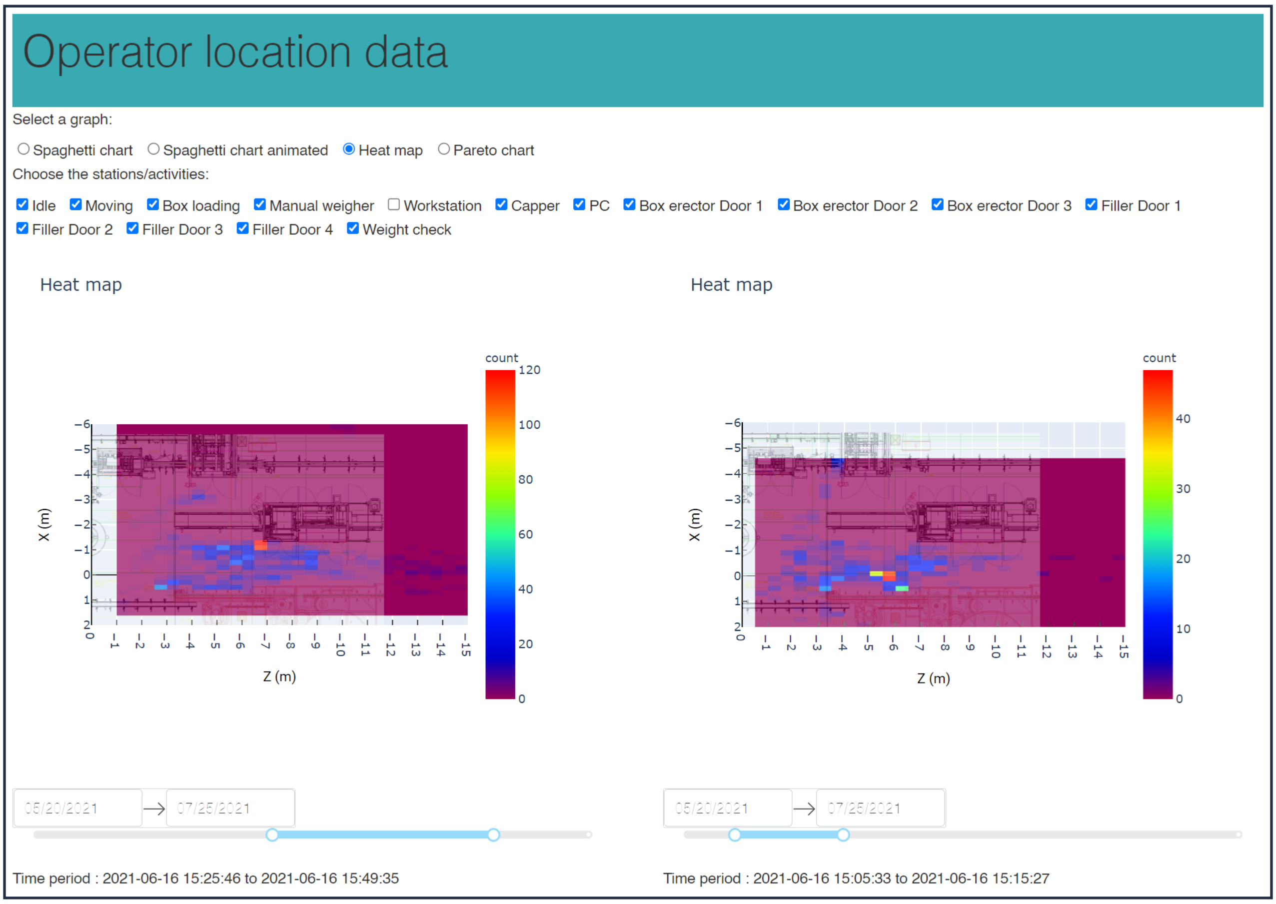


Figure 63: Version 3 - Heat map

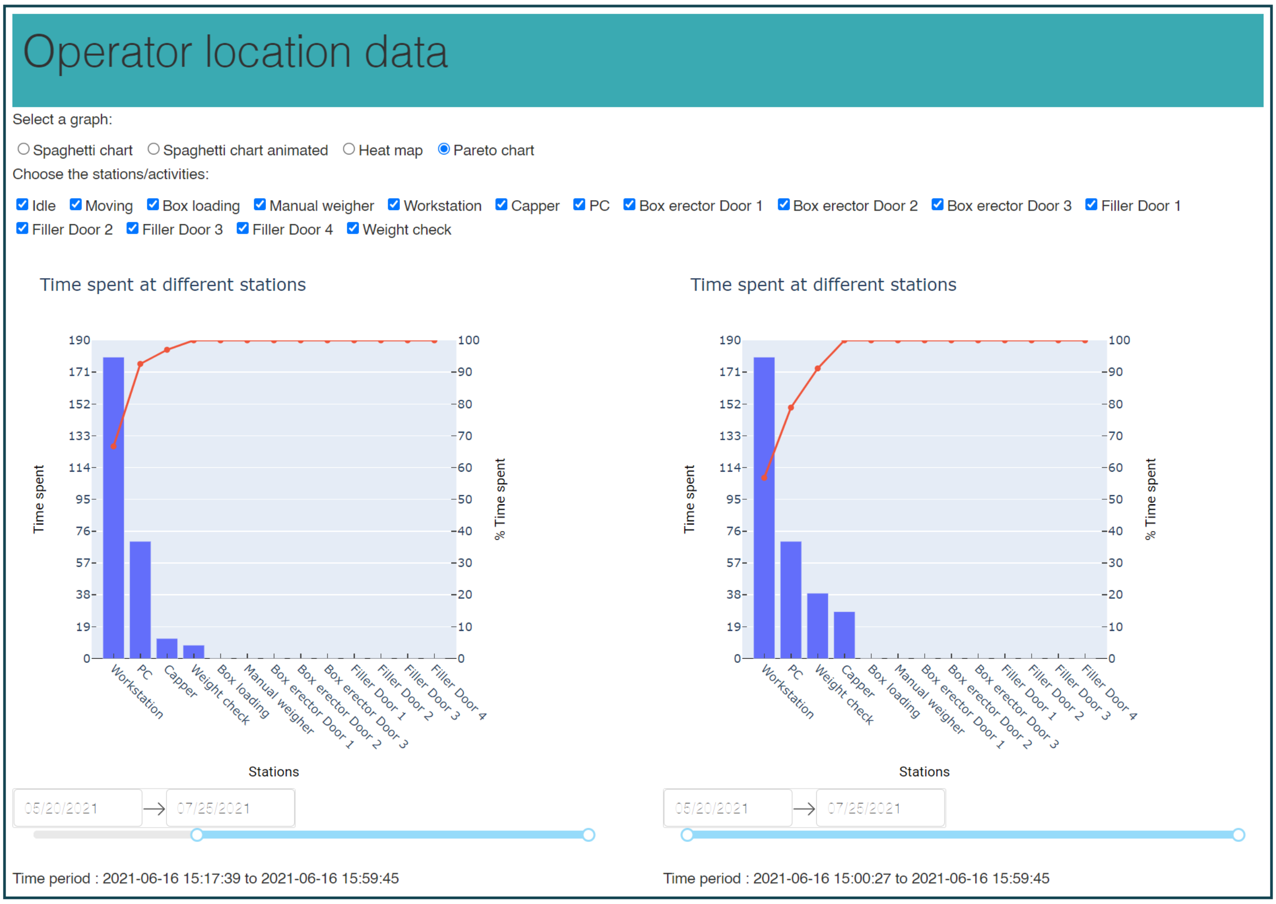


Figure 64: Version 3 - Pareto chart

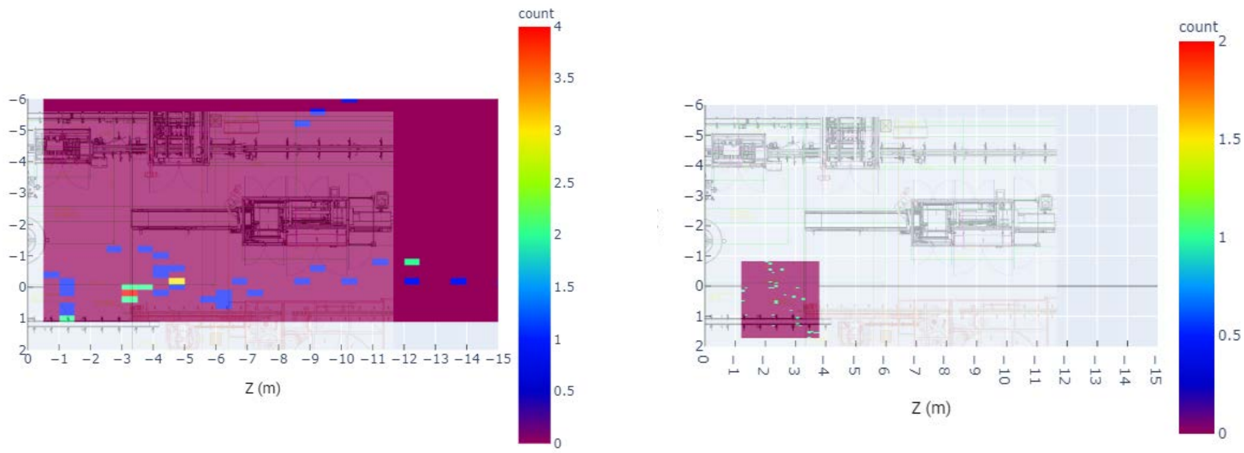


Figure 65: Area reduction in Heat maps when data is concentrated in one specific location

7 EVALUATION

7.1 Test session plan
7.2 Desirability for users
7.3 Feasibility to deploy at Diversey
7.4 Viability of the project
7.5 Takeaways

7.1 Test session plan

Goals

The session was conducted to test the working of the interface and its effectiveness for the user. This evaluation aims to evaluate the following:

- Desirability of the visualizations
- Feasibility of using this interface for process improvement
- Interactivity and intuitiveness of the interface
- Relevance of information being provided

Users

The expected users for this evaluation were the process improvement department and the technical department of Diversey. For this evaluation, four participants were involved from the Diversey process improvement team and the management.

Test setup

For the evaluation process, the interactive prototyping method (Van Boeijen, 2014, p.131) was used for evaluating the usability of the designed interface. Concept version 3 (Section 6.5) was used for the users to test the interface. The evaluation was performed online through online screen sharing with mouse access control for the user to get access to the interface.

The dashboard for data visualization had data pre-buffered from 16th June 15.00 to 18.00 on the same day. The dashboard was capable of showing four types of graphs: Spaghetti chart, Spaghetti chart (animated), Heat map and Pareto chart of time spent at stations.

The dashboard is interactive with provision for choosing the date of data, time range sliders, selection of activity to visualize. Also, a side by side graph mode was provided for data comparison of two different time periods.

Methods

Here, the participants were asked to act out interaction of the interface based on predefined scenarios. These scenarios were normal site events such as changeover, stoppages or normal production working scenarios. The participants were

During the usage of the interface, the participants were asked to speak out loud what they are looking for and whether they find the data easily and whether the interface is intuitive.

Process

First, the participants were briefly explained about the basic working of the interface and what they are expected to do for the experiment. After the explanation, the participants were provided mouse control to work on their own for defined scenarios. The scenarios were as follows:

Scenario 1: Stoppage of production line at 15:30 - 15:35

Scenario 2: Changeover process at 15:50 - 16:00

Scenario 3: Normal operation from 15:00 - 16:00

Scenario 4: Compare changeover at 15:20-15.30 and 15:50-16.00

Scenario 5: Participant defined scenario (if any)

During the scenario acting, the participant spoke out loud what they were doing and what they expected in the interface. The feedback from the participants was noted down for implementation in the final design. A qualitative and quantitative evaluation was performed after this. Quantitative assessment was done using a Google Form which asked the participant to rate each of the graphs and the dashboard on the attributes of interactivity, appearance, intuitiveness, usefulness of graph and usefulness of hover data (Figure 66).

For the qualitative assessment, the participants were asked the following questions:

- How was the overall experience of the dashboard?
- Do you foresee the feasibility of using the dashboard for process improvement?
- Name three positives about the dashboard
- Name three negatives about the dashboard
- Do you have any suggestions for improvement?

Results

The interface was found to satisfy the expectations of the users. The quantitative assessment results were positive about dashboard and charts except for Spaghetti chart animated (Figure 67). The interactivity of the Spaghetti chart animated was found lacking as the data being presented was not easily readable. The full version of the quantitative assessment can be found in Appendix J. From the observation of the

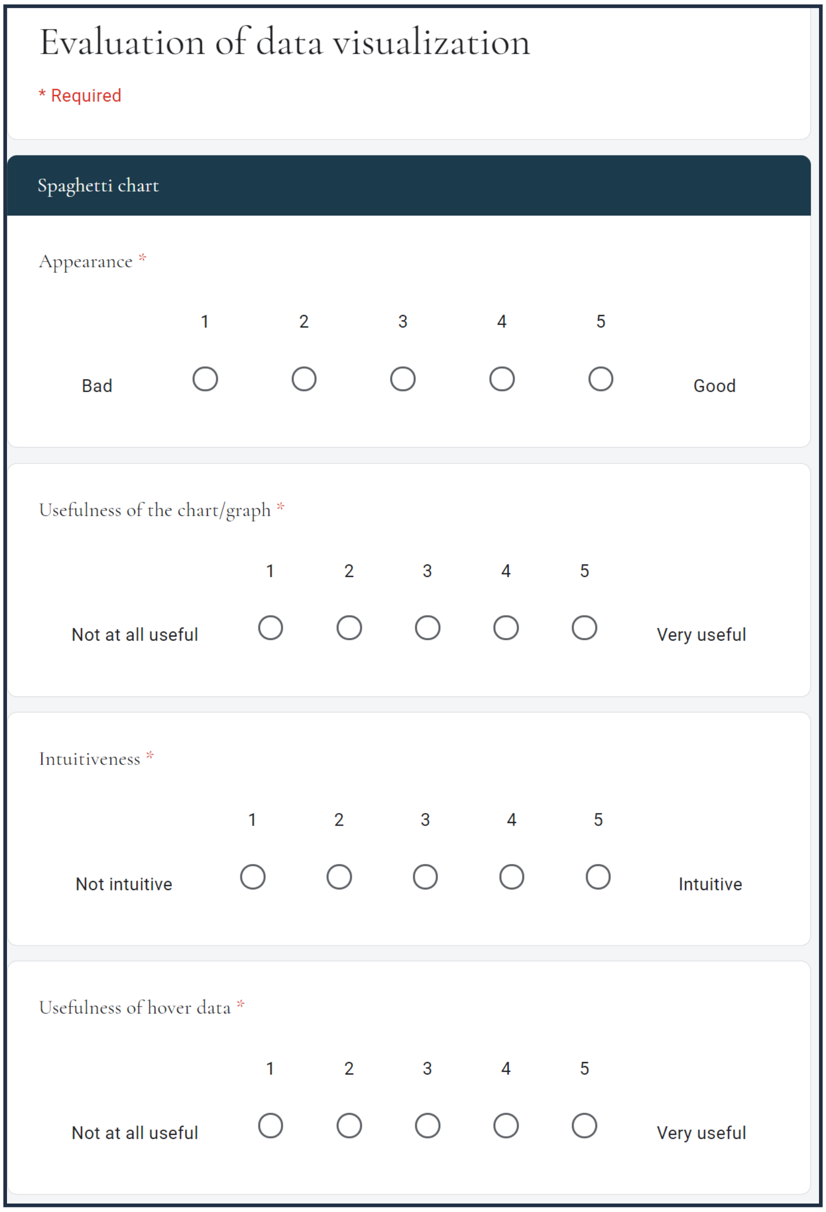


Figure 66: Screenshot of quantitative assessment of the interface provided to participants

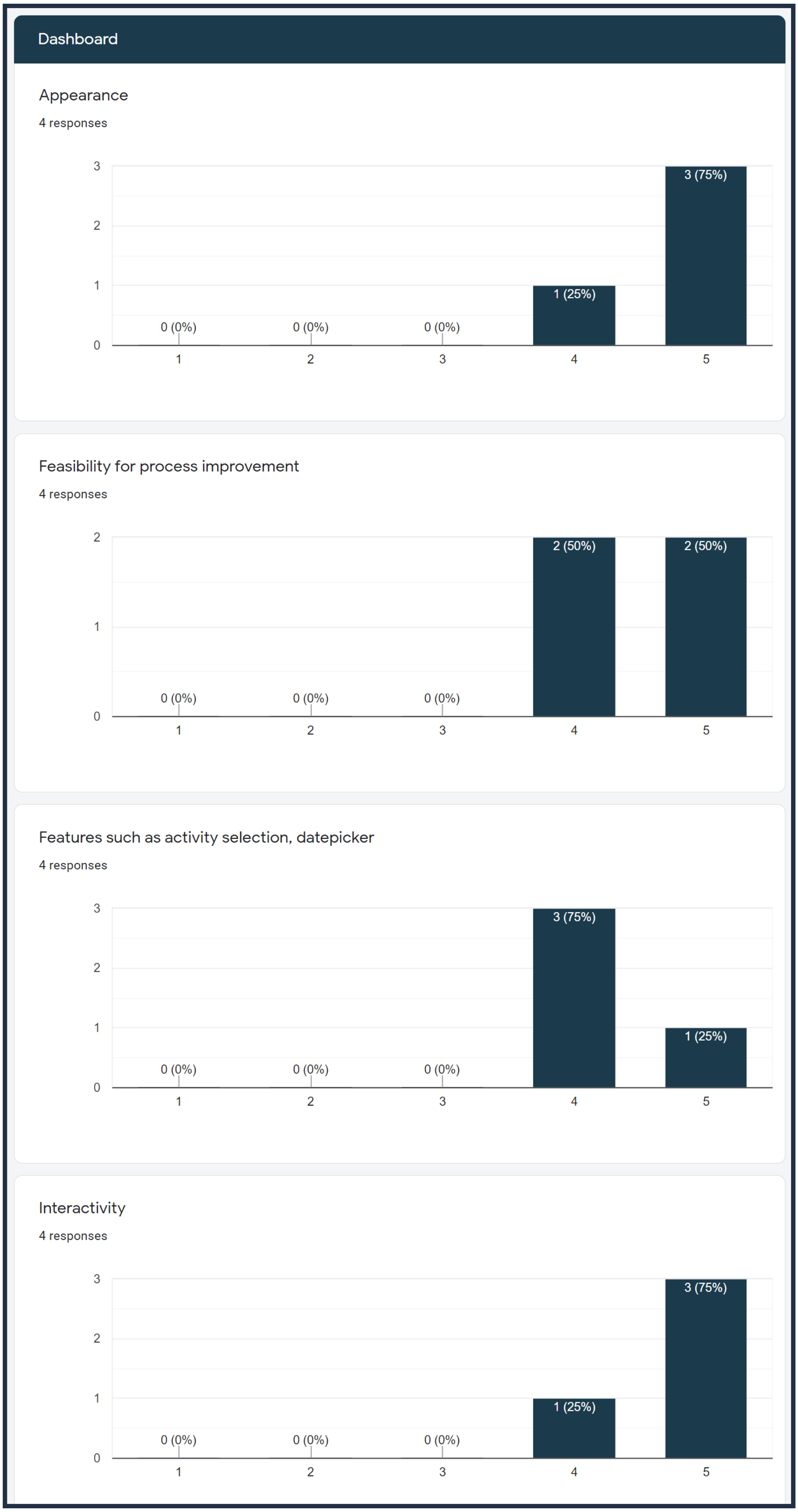


Figure 67: Results of quantitative assessment of the dashboard

participants interacting with the interface, it was clear that the interactive elements provided in the interface was not user-friendly. Once they got the hand of it, the usage was smooth. Selection of date and time was still difficult to set at the correct range specified in the scenarios.

Heat map and Pareto chart were found to be most useful for the participants. Spaghetti chart animated was not found intuitive to use and needed some changes in its appearance such as the play/ pause button for animating, slider bar for seeing the current time being visualized to make it better fit the dashboard. Hover data on Pareto chart needed additional data such as the individual visit time and timestamp of visit to the particular station. The participants wanted to know the details of each of the visits and their duration of each visit.

Some of the improvements (Figure 69) mentioned by the participants were :

- Type-in box for time filter
- Demarcate the station areas in the background layout (Figure 68)
- Option to toggle all stations simultaneously
- Hover data on Pareto chart to show when the operator visited the station
- The second graph on the right of Figure 69 needs to be only shown when there is a need for comparison

The participant from the process department agreed that the Spaghetti chart and Heat map were vital for the process improvement. The required data were found in the

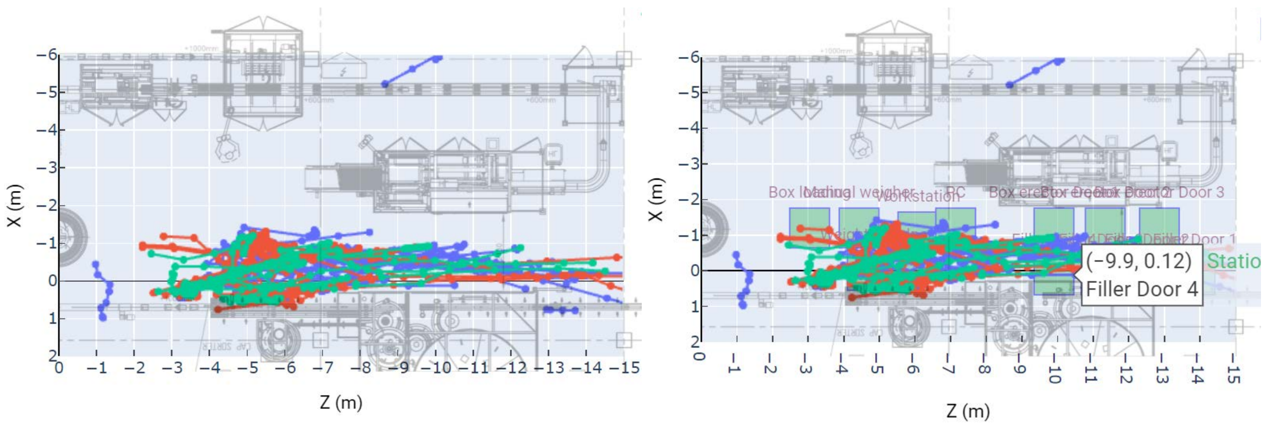


Figure 68: Station marking in the layout implemented after evaluation (right); left shows Spaghetti chart during evaluation session

"Useful tool to support lean manufacturing improvement."

"Pareto is more important for us during the Lean SMED event. The frequency and time duration are the most important information when we compare the same SKU change overs."

"Good quick view of the operator data."

"Previously when we need SMED event, we needed 5 or 6 people. Now it can be done without any person."

dashboard and the interface was found to be intuitive. The visualizations would help the process improvement team to get instant access to the performance of the production line. This is perceived to be more efficient and accurate than approaching the operators to get the data verbally. The Spaghetti chart was viewed to be chaotic when many overlapping data are shown. So the Spaghetti chart animated needs to be improved to get the best visualization of the operator movement.

The participants from Diversey management found the Pareto chart and the heat map most relevant for identifying operator information and identifying issue hotspots. The feature for side by side comparison was found desirable to compare the same SKU from different shifts performance. Although the Pareto chart was important, the data shown in the dashboard were difficult to identify each visit duration. Also, the side by side view of the graphs was non-intuitive and distracting when comparison was not required. So, one of the participants suggested to show the second graph only when clicking “Compare” button.

One suggestion for future improvement was connecting the data from ODCE into this graph such that the user can easily pinpoint the data to the time of events. This needs further work on the interface that is beyond this project’s scope by connecting the existing databases used by Diversey.

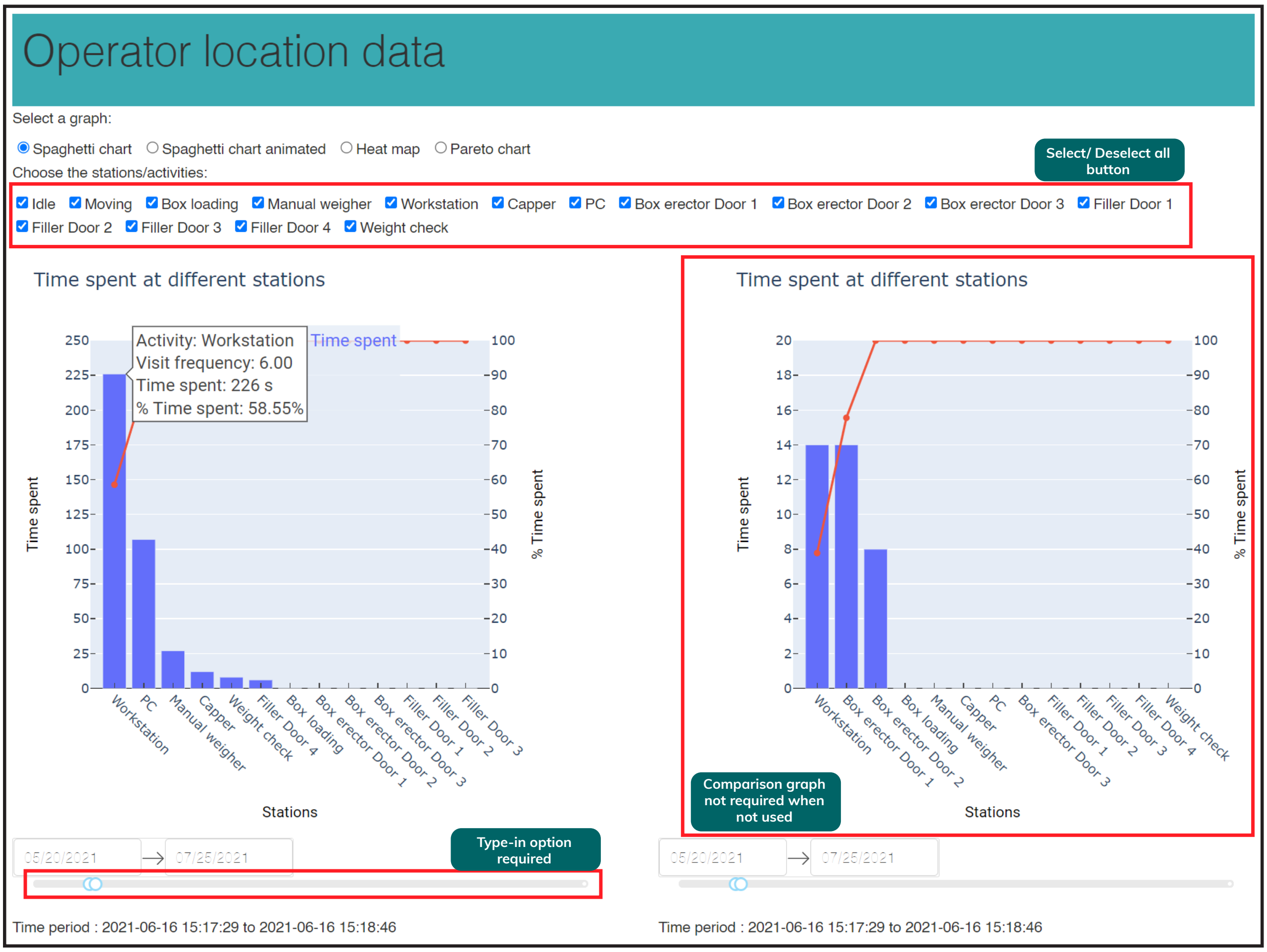


Figure 69: Improvements mentioned in evaluation session

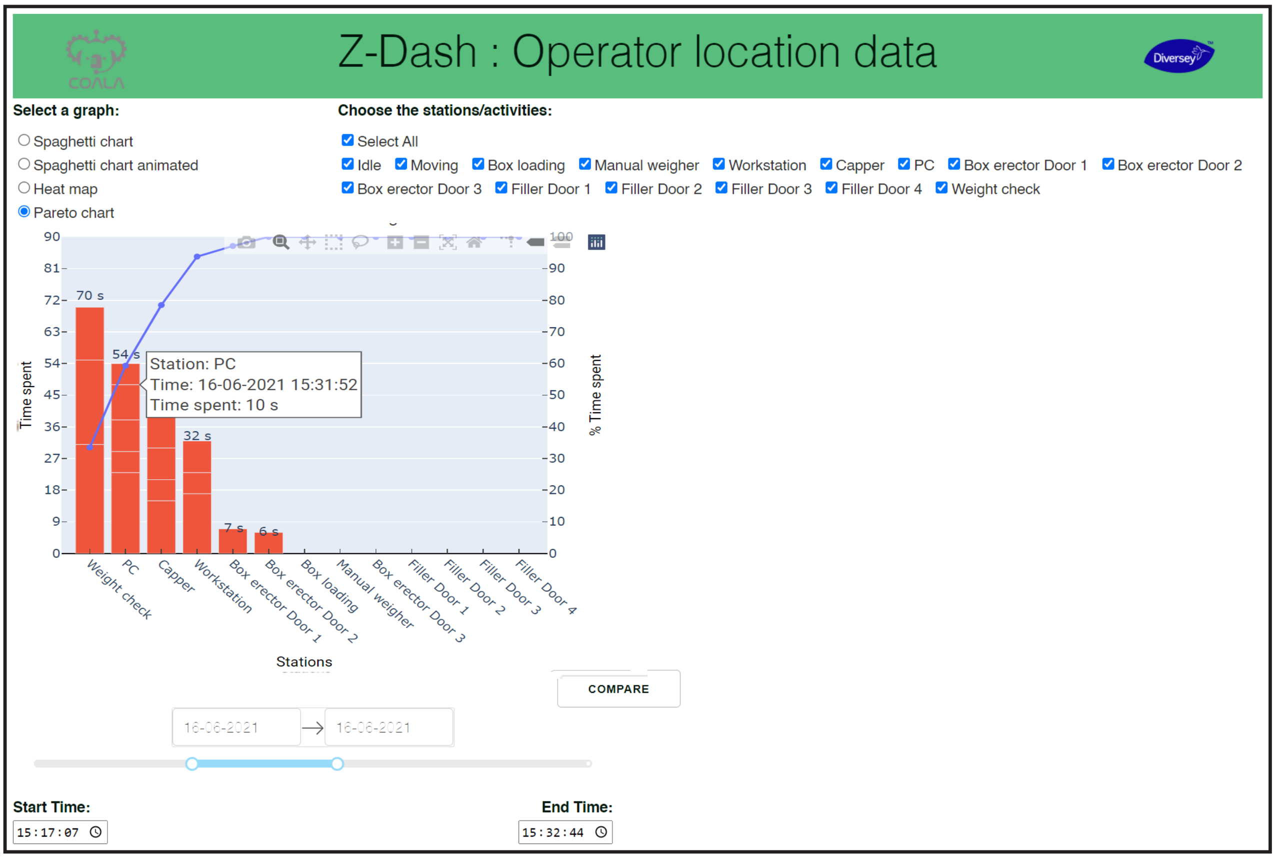


Figure 70: Dashboard after improvements implemented

7.2 Desirability for the users

After the evaluation session, the desirability of Z-Dash was found as follows:

- The dashboard provides an automatic temporal location data collection method of the operators in 5L/10L production line. It could be useful for graphically visualizing normal working as usual, issue tracking, issue handling and changeover over a specified period of time.
- The dashboard provides instant access to location data through a single medium and could in future connect data from ODCE. This could make it more convenient to get the desired data representations quickly.
- If an event time is known through ClickView or ODCE, it could be traced back on graph when an event occurred, what activities were done.
- One of the pain points mentioned in persona (Figure 23) was that the process department personnel had to approach operators in order to get the information about previous day performance. With the location data, potentially with ODCE data visualized in meaningful and intuitive representations, it is made easier.
- In case the Spaghetti chart shows multiple people at the same time, then this could be shown as an event on the map and could be inferred as the quality or technical department was involved in the issue. This could provide an estimate of safety/quality issues happening at site.
- The lean production methods such as SMED process can be more efficient with the data from Spaghetti chart and Pareto chart. Currently, the SMED is performed using 5 or 6 people - wherein they each have tasks such as drawing Spaghetti, recording time, recording video. With the dashboard containing Spaghetti chart, location and time data recording are automated.

7.3 Feasibility to deploy at Diversey

The dashboard would pave the way for digitization and automation into the Diversey's existing methods such as production performance analysis, lean activities such as SMED and changeover comparison. The operator tracking technology has been tested to be feasible for implementation at Diversey Enschede (Section 4.3).

The final version of the dashboard from this project has been presented as a base for future improvements with activity tracking. Integrating ODCE data will help in classifying activities as internal or external ones. Activity tracking technology of Zed 2 camera was also proven feasible in the pilot test (Refer Section 2.6). The collected activity data (or skeleton data) can be used to identify the activities using template matching method described in Laptev, I., & Lindeberg, T. (2003).

7.4 Viability of the project

The results of this project could provide valuable improvements in Diversey's processes. It could help reduce the changeover time by implementing the best practices. The total estimated production improvement is around an extra 60 hours meaning around 252 tonnes extra yearly.

The technology has been proven feasible in the feasibility study and has been partially operational in the Enschede site for around 3 months. The readiness and desirability of the data visualization interface has also been proven with working concept.

For the technology to be viable longer into the future, the interface needs to be integrated with other data sources and features as shown in the roadmap (Refer Figure 78).

With this, the future business of Diversey could transform into more digital as compared to currently used traditional activities including SMED and OEE calculation. With the potential digitalization of Diversey business, the benefits such as eliminating unplanned stoppages, continuous learning and dispensing recommendations to operators for best operational efficiency could have a positive impact on Diversey's growth.

7.5 Takeaways

This results of this project has met various expectations of the user. The evaluation has shown that the users are satisfied with the outcome with certain additions and interactions mentioned in Section 7.1 to make the dashboard more intuitive. The connection with ODCE could provide more information about events in the dashboard. This way the user does not need to switch between different media to get the data. So, a provision for connecting ODCE was required for the users.

In the initial plan of the project, it was decided to provide the operators with the collected data to involve them in this process. But the evaluation with the process improvement team showed that the outcome is more relevant to the process improvement team, technical department and management of Diversey than to the operators.

8 IMPLEMENTATION

8.1 Design proposal

The final outcome of this project is a data visualization interface which processes data in realtime based on the data recorded by the Zed 2 camera. The purpose of this interface is to facilitate the process improvement at the 5L / 10L production line of Diversey at Enschede factory. This interface can help the management to visualize what are the issues or bottlenecks in the production line.

Chosen visualizations

- Spaghetti chart (Figure 71)

Spaghetti chart showed the temporal location data of the operators. It helped Diversey observe the most visited locations and the sequence of activities. When the time data is filtered to an event, it helps the users see where the operators were working. This is helpful if, for example, there is a stoppage and can infer where the issue was during that stoppage. Similarly, during changeovers the sequence of activities can be seen using the animated version of the Spaghetti chart. Spaghetti charts are important for automation of processes such as SMED and issue hotspot mapping.

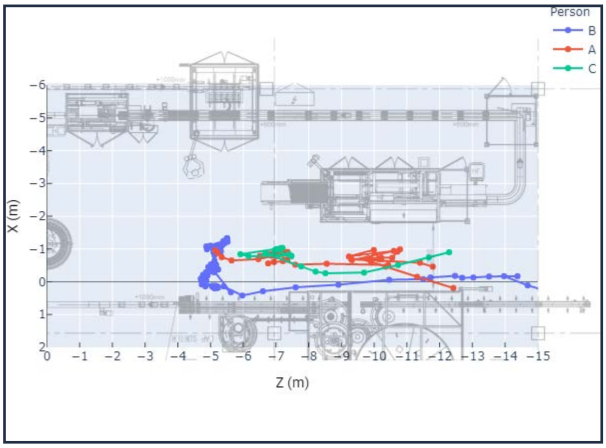


Figure 71: Typical Spaghetti chart (data shown from 15.17 to 15.19 on 16th June 2021)

- Heat map (Figure 72)

Heat map shows the location hotspots of the operators. During changeovers, this helps the users identify where the operators spent most time. This could possibly help Diversey infer where the issue was and how long it took at each station. This combined with Pareto charts can give full idea of the operator locations during a certain event.

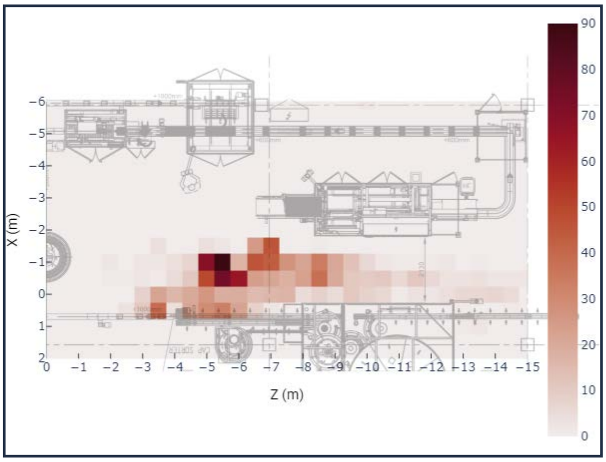


Figure 72: Typical Heat map (data shown from 15.17-15.19 on 16th June 2021)

- Pareto chart (Figure 73)

Pareto chart was found to be the most important out of these visualized representations by both the management and process improvement team of Diversey. This chart visualizes data arranged in descending order of time spent by operators at corresponding stations. In the scenario of a changeover or stoppage, this depicts what the most time spent locations and the most frequently visited locations were. The most time spent location may indicate an issue hotspot and necessary steps can be taken to rectify issues.

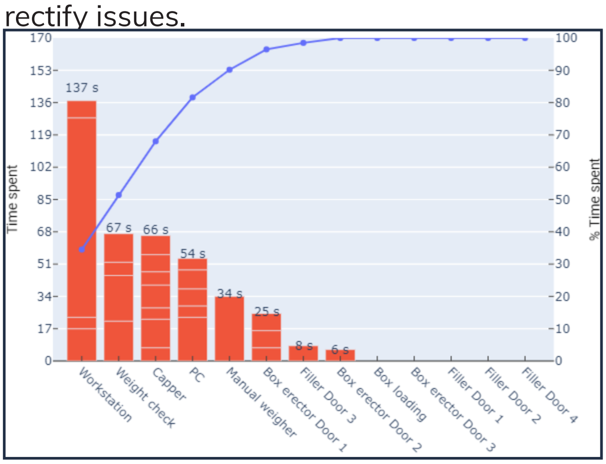


Figure 73: Typical Pareto chart (data shown from 15.00-15.30 on 16th June 2021)

8.2 Final design

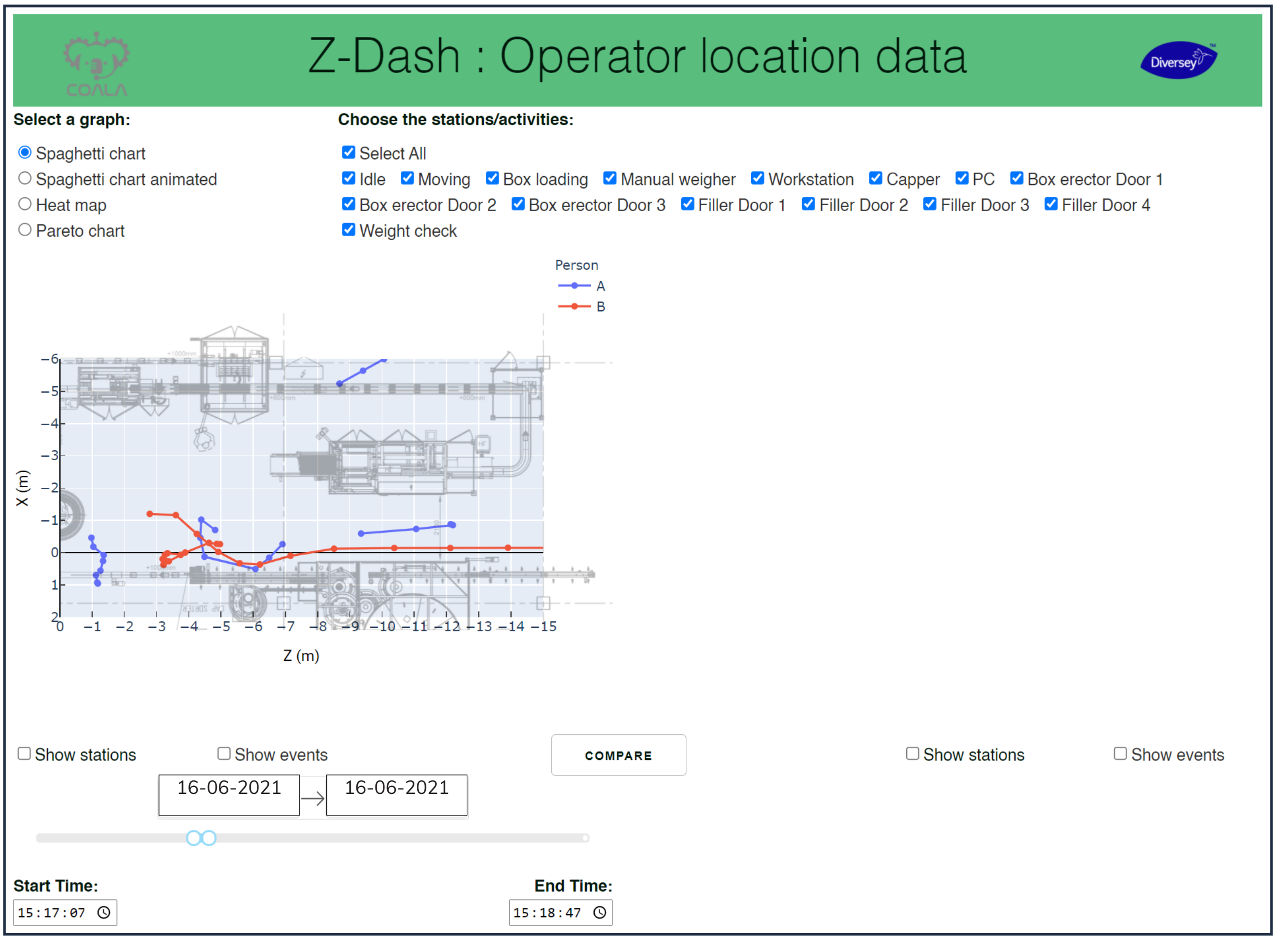


Figure 74: Final Design

The final Z-dash design consists of the three graphs mentioned in Section 8.2 accompanied by user interaction elements that make it easy to filter the relevant data for visualizing. The suggestions from the users during the evaluation session have been implemented and the final design looks as shown in Figure 74.

User interaction

- Graph selection: Radio buttons were used for switching between the graphs.
- Activity selection: Check boxes for each activity and also a select/deselect all button.
- ID selection: Toggle button for each ID.
- Show station: A checkbox to toggle view/ hide the station area in the background layout.
- Show events: A checkbox to toggle the view of events where there are multiple operators at the same place for more than 5 seconds.
- Compare button: Button provided to view/ hide the right side graph for comparison of data from two different time periods. This is beneficial for identifying patterns in changeover activities and time per activity.
- Date-Time selection: Type-in box for start date and end date. Type-in box for start and end time. Range slider for minor updation of the time within the hour range selected in the type-in box.

8.3 Benefits for Diversey

Z-Dash is developed for Diversey for process improvement and identifying the operator movement in the production line. The benefits for Diversey are:

- Taking a step forward in introducing Industry 4.0 technology in Diversey's chemical environment.
- Optimizing production line by reducing changeover time which in turn improves the OEE. (Currently, changeover takes around 40% of the total production time and sometimes can last more than 2 hours. Optimizing the changeover process can create significant cost reduction.)
- Finding the best practices and standardizing them into production line activities. (Currently, production line efficiency is highly dependent on the operator experience on dealing with the events happening on the production line. Standardizing these best practices from highly experienced operators could reduce the gap between novice and experienced operators.)
- Sequence of activities performed during changeover or certain stoppages can be analyzed for better issue handling. (Currently, the quick fixes performed by experienced operators go undocumented. Such incidents can be easily detected when machine status and location data are integrated.)
- Assisting lean activities such as SMED.
- Step by step analysis of the workflow.

8.4 Benefits for COALA project

Apart from the benefits for Diversey, the dashboard provides the following benefits for COALA project and the TU Delft researchers:

- Capture and contextualize the location data of events or changeovers.
- Compare performance between changeovers or between stoppages.
- Capture location data for COALA cognitive assistant and also easy reporting of location data for errors/ stoppages.
- Assisting COALA cognitive assistant with operator issue handling behaviour. (When activity template matching is applied, COALA cognitive assistant can be taught to understand if the operator is stuck with an issue then take over the assistance based on that.)
- Applying Augmented Manufacturing Analytics (AMA) at Diversey. (COALA Objective 1 (Appendix K) aims to apply AMA by connecting the data sources such as ODCE from the site.)

9 CONCLUSION & FUTURE WORK

The project has accomplished the design vision and has met 10 out of 12 design requirements mentioned in Section 3.3. The design requirements that were not realized in this project P.2 and O.2 are put forward for future work due to time constraints with integrating ODCE data with the dashboard and activity template matching study respectively. The entire project covered the steps from establishing a tracking system in the production line to an intuitive dashboard with the data visualizations.

Section 9.1 addresses the design challenges stated in the Section 1.3. Section 9.2 defines the challenges faced in various stages of the project. The challenges due to ethical concerns needed special emphasis which is explained in Section 9.3. Later, Section 9.4 addresses the future work possible and roadmap to make this project viable.

9.1 Contributions

Object tracking method using Zed 2

The project started with the requirement of establishing an operator tracking method using the Zed 2 camera system. First, the project explored the relevant data that needs to be collected with the object tracking camera as mentioned in RQ1. The data collected were related to the temporal location data and skeleton data of the operators.

One of the hurdles with operator location tracking was to decide the ethical way of capturing this data. The ethical and privacy concerns of the operators as well as the concerns of other stakeholders were explored next (RQ2). According to COALA Objective 3 (Appendix K), it aims to establish an AI system in the industry which could get the trust from the employees. To earn their trust, the ethical concerns of the camera tracking was paramount for the project. The tracking was established on site with the consent of the operators (Appendix L) after sharing with them the complete details of what data would be recorded. The Zed 2 camera was programmed to capture only details in a spreadsheet format and operators were tracked with a random ID with no physical features connected to them.

Data preprocessing and preparation of Drive for automated data storage

The data collection procedure was refined to collect only the data of the detected humanoid object. The collected data included the timestamp, XYZ coordinates of the object, 18 point skeleton, ID, velocity and station proximity. For the automatic data upload to Google Drive, the json file was loaded in the local folder from which the files would be uploaded. The user authentication to Drive was signed in advance and the required Python libraries - pydrive.auth and pydrive.drive were loaded in the Python code.

Automated data collection and data storage in drive

Two indefinitely running Python codes were used - one for automatic data collection and one for automatic data upload from local drive to cloud for remote data processing

Postprocessing of data

The postprocessing of data was performed using Pandas library in Python for handling dataframe. In this step, the collected data was refined by removing noisy data and applying a new algorithm for keeping ID consistently on objects as long as they are in the view of the camera. Apart from that, the calculations required for the visualizations (e.g. station visit frequency and time spent) were done at this stage.

Data visualizations

The collected data were represented into meaningful forms (RQ4) using data visualizations such as Spaghetti chart, Heat map and Pareto chart. These visualizations provide the insights required by the stakeholders (RQ3). Spaghetti chart showed the temporal location data of operators, the heat map showed the concentration of location visits by operators and the Pareto chart showed the time spent by operators at each of the stations.

Dashboard with interactive elements

To make the created graphs more interactive, the graphs were combined into a dashboard made by Python library Dash. The dashboard was provided with interactive elements to switch between graphs, toggle the station/ activity, filtering the time, and most importantly, visualizing the graphs side by side for comparison.

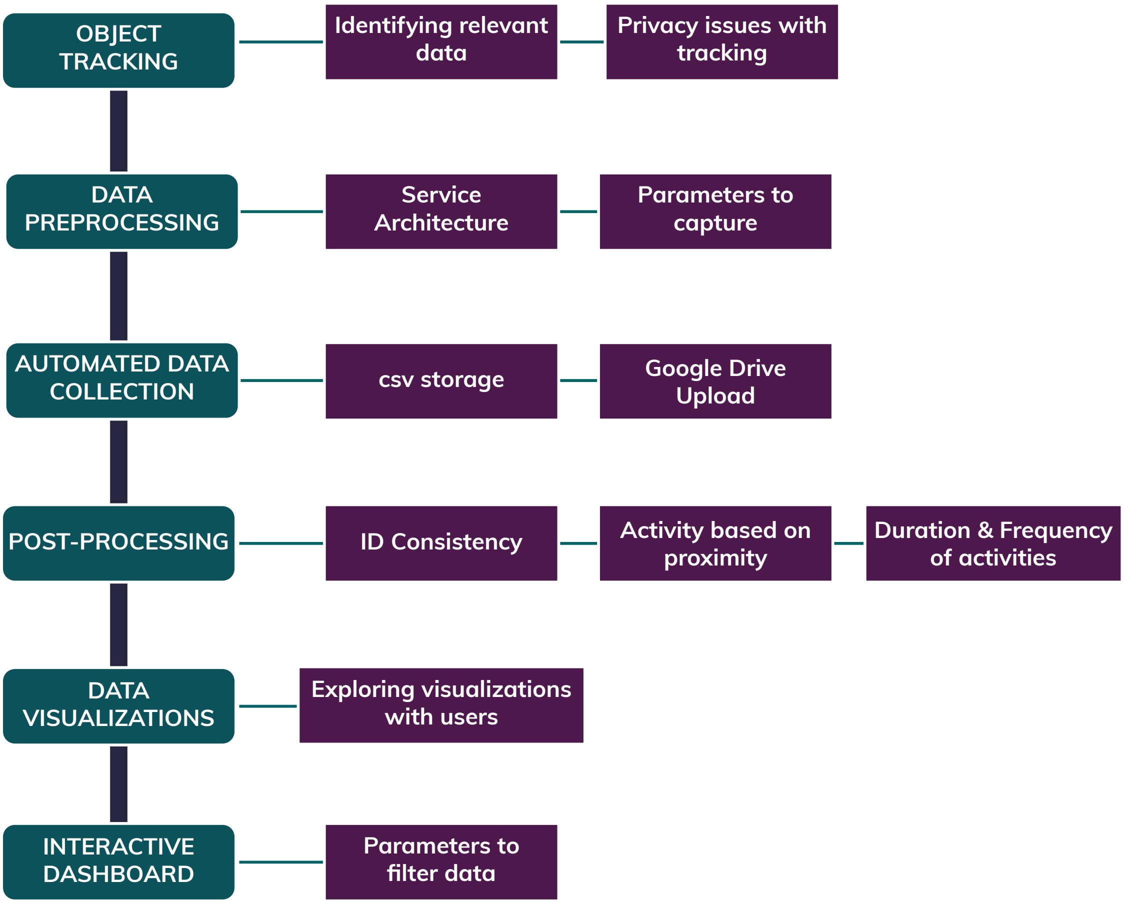


Figure 75: Contributions of the project

9.2 *Challenges in the project*

The project faced many ups and downs during its timeline. Some of the challenges faced were:

- Deploying an ethical way of tracking the operator position was the first hurdle faced in the implementation of Zed 2 system. From the start of the project, the operators were given the complete details of the project. Also, understanding their concerns and giving due attention to their privacy, the operators were on-board with the project implementation.
- Fixing a location for camera setup. The camera was initially planned to be set near the spiral conveyor (Figure 19) but due to obstruction with USB cable, the position had to be changed to the position shown in Figure 38. The angle

of the camera was also set pointing horizontally. The camera angle was later changed using a clamp as shown in Figure 76.

Figure 76: Clamp for holding camera at an angle

- The data collection software in the initial phase of the project had a single Python code that created new xlsx spreadsheet files every hour and uploaded the same file to the cloud as soon as the file was written. This caused considerable data loss of 3-6 seconds, data not being uploaded due to internet connection issues and memory leakage due to the Python GoogleAuth libraries. The issue was resolved by creating separate Python codes - one for data collection and another for file upload. The internet connectivity issue was resolved by running the second Python code to upload all the files in the local folder every hour. In that way, any file that was not uploaded due to connection issues would be uploaded in the following hours.
- Allowing remote access to the PC handling the Zed 2 camera. The initial PC used for the data collection was an Nvidia Jetson Xavier but due to its ARM 64-bit architecture, it was difficult to install most of the remote desktop client softwares. At the later stage, this was solved using a different PC of HP Omen 25L Desktop with Nvidia RTX3070 running Windows 10.
- The new PC installed at site had technical difficulties even with the right hardware. The USB extension cable used initially did not work as a USB 3.0 due to attenuation of signals beyond 5m length. USB 3.0 is required for Zed 2 camera connection or else the images recorded are of lower VGA quality. An active extension cable had to be used for proper operation of USB 3.0.
- Even with the right hardware, the software version had conflicts with the CUDA drivers and Zed camera SDK. Several trials were done with combination of CUDA drivers and Zed SDK of older versions. The issue was eventually solved with CUDA toolkit v11.1.0 (Sept 2020) and Zed SDK for Windows10 v3.5.0.
- Spaghetti chart animated was created using each time series row data passed on as animation frames. But due to the Dash library not being able to handle frames inside the Dashboard, the Spaghetti chart animated does not work as intended inside the dashboard interface. This was resolved by running the graph in a separate independent window but without any interaction elements which Dash offered.

9.3 *Tackling the ethical concerns*

Ethical concerns were one of the most important driving factors for the project. According to COALA Objective 3, it aims to adopt a Human-AI collaboration to overcome barriers and skepticism regarding the Digital Assistant. In these steps before establishing a COALA cognitive assistant at Diversey, it was necessary to set ethical design rooted in the project.

Using VSD, all the (direct and indirect) stakeholder values were integrated into the design. There were requests from the side of Diversey and management to use the camera to see the video of what had happened at a specific time. When the operators were interviewed at Enschede factory, they were wary of anyone from the Diversey getting to see them through the camera. In order to satisfy the objective of this project as well of COALA project, the decision had to be made to perform anonymous tracking with no operator identifiable by any physical traits and also no recording in visual format. This decision came at a considerable drawback of not being able to keep the object ID consistent but was necessary for COALA to keep its trust in the operators.

Earlier endeavours to use a camera to identify the issues at the wrapping machine did not succeed in Enschede. In this project, a closer approach with the stakeholders and especially operators were used to get them to understand the project and how it benefits them. To disseminate the project objectives, a project poster (Refer Figure 77) outlining the data being collected and what it will be used for was placed in various places in the production line. The operators were provided the opportunity to contact the project owner regarding any issues or concerns with the project.

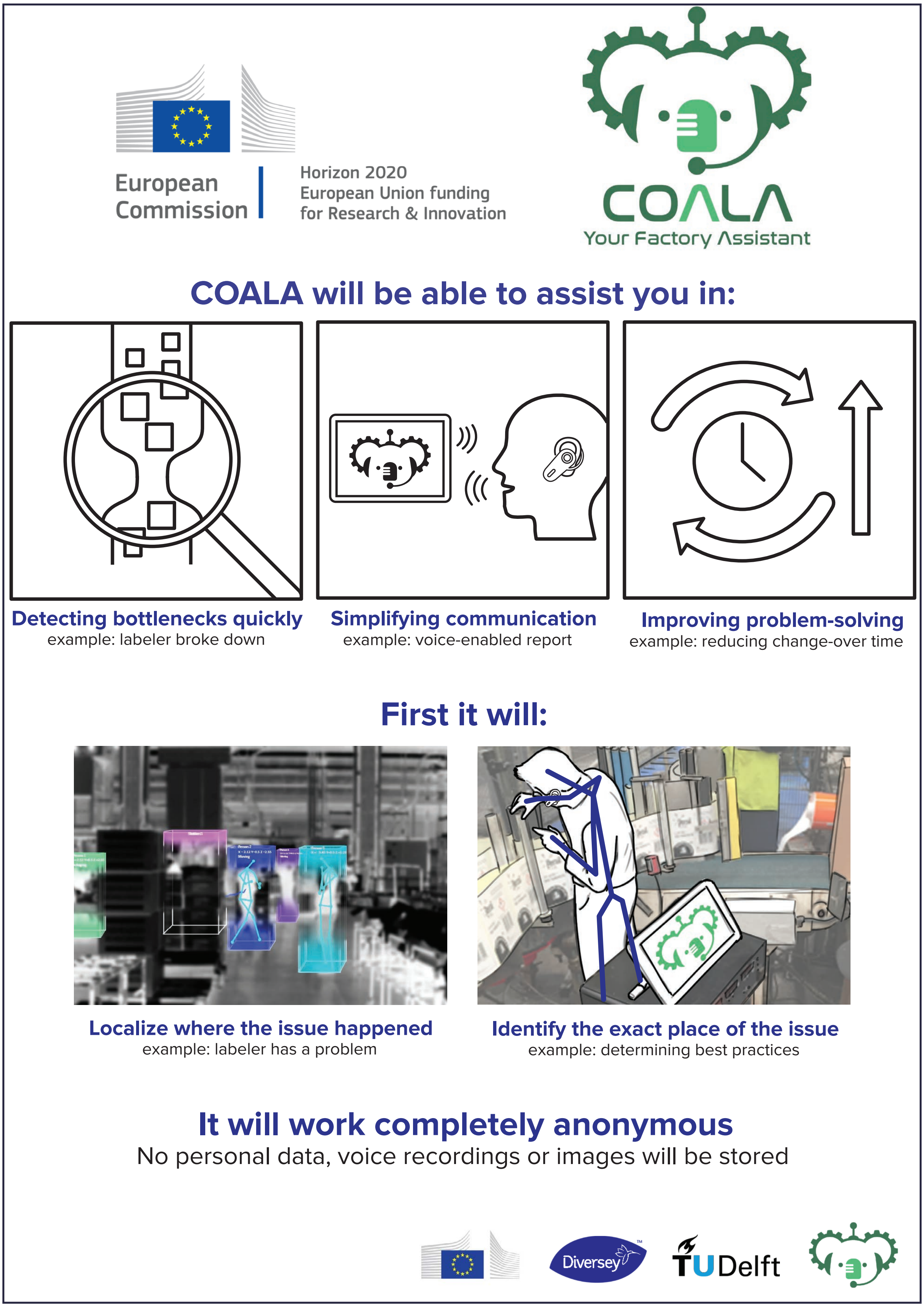


Figure 77: Project poster displayed at Enschede site

9.4 Future work

Z-Dash is still in its nascent stage at the end of this project. There is still scope for additional features that could help it meet more objectives of the COALA project. The roadmap towards the Z-Dash with COALA digital assistant is illustrated in Figure 78.

The future work should include:

- Additional graphs can be provided such as velocity map or activity map (Refer Figure 53).
- To achieve the activity map, activity analysis needs to be implemented in the post-processing. This could be performed in similar manner as Activity Template matching method mentioned in Laptev, I., & Lindeberg, T. (2003).
- Multiple Zed 2 cameras need to be implemented to cover the total 5L/10L line in Enschede. The coordinate systems of all cameras need to be aligned correctly to get the complete data. Besides that, the activity analysis might be more accurate with data obtained from cameras at multiple angles.
- Integrate ODCE data into the interface for easily pinpointing towards data of important events and visualizing them.
- If these data will be provided in the future with digital assistant device, the interface needs to be updated for touchscreen interactions.

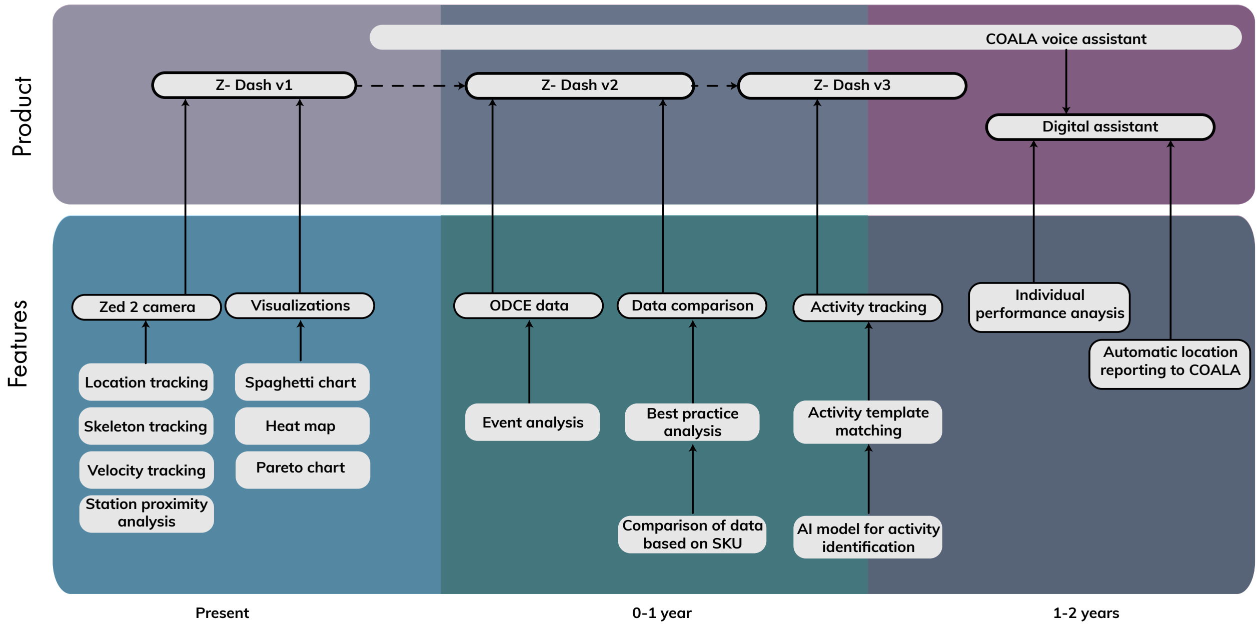


Figure 78: Roadmap for future work

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