

Root cause analysis by operators with the aid of a cognitive advisor in manufacturing

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II. Abstract

This thesis project examines the opportunities for manufacturing operators to use root cause analysis directly at the line with the support of a cognitive advisor. The project was part of the EU Horizon COALA project and uses a specific business case at a detergent company as a base for the research and the prototype development. The analysis of the business case showed that currently operators do not use methodological root cause analysis at the line.

The report describes the research, development and showcases a prototype of a textual cognitive advisor that has incorporated the “5 Why?” root cause analysis method. This prototype was developed making use of multiple sprints adding new functionalities over time. The prototype was built making use of the open source RASA framework, GraphQL and NEO4J to develop and demonstrate the technical feasibility of the project.

The final prototype is able to have a conversation with the operator, support the operator with the “5 Why?” from problem statement till root cause by implementing best practices, and save each connected step into a graph database.

Furthermore a validation of a voice-chat-enabled cognitive advisor based on the business case is researched by conducting a (lab based) scientific experiment with 20 participants. The results of the experiment showed that there are interesting opportunities for cognitive advisors for operators in manufacturing in terms of interaction time and data quality for quantitative analysis use, but more research is needed for this topic.

Keywords: Root cause analysis, Manufacturing, Operator, Cognitive Advisor, Conversational AI, 5 Why? Method

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Glossary & Abbreviations

List of terms and abbreviations that are used throughout the report.

Artificial Intelligence (AI) - Intelligence demonstrated by machines.

COALA - EU Horizon 2020 project: Cognitive Assisted agile manufacturing for Labor force supported by trustworthy Artificial Intelligence.

Cognitive Advisor - Conversational AI in either text or voice that can advise and support users in their day-to-day work.

Cyber-physical system (CPS) - Intelligent computer system controlling a mechanism.

Intelligent personal assistant IPA – Software agent that performs tasks or services for a user, in this thesis the term CA since that is the COALA standard

Human machine interaction (HMI) -Research field in design that focus on the interfacing between computers and humans.

Industry 4.0 - conceptualization of the 4th industrial revolution of the rapid change of technologies and industries due to interconnectivity and smart automation

Machine Learning (ML) - Field that is part of AI that creates methods for learning based on data

Natural-language understanding model (NLU) – Model that can interpret human language and perceive the intent (learned) of the user

Programme of Requirement (PoR) – Overview of the requirement and wishes of the prototype

Operator - Line operator in factories, employees that operate or control the machines

Quality and control (Q&C) – Department in manufacturing companies

RASA - Open source framework for a conversational AI

Root cause analysis (RCA) – Term for a collection of methods that is used to get to the root of a problem

1 Introduction

Currently operators are not using methodological root cause analysis at the line during the manufacturing process. This thesis project is looking at opportunities for supporting manufacturing operators by integrating root cause analysis in a cognitive advisor. This is done by developing a cognitive advisor prototype and a user study on the experience of such a cognitive advisor.

This first chapter explains the context of the project in the current state of the manufacturing world that is in a change towards new industry standards

The second chapter goes into the background of the project, going into the research questions, project approach and literature research on root cause analysis.

The third chapter contains information on the technologies used to create a technical feasible prototype.

The fourth chapter goes into the used business case for the project at Diversey, a detergent manufacturing company focussing on their current root cause analysis practices.

The fifth contains each prototype sprint, the final prototype and the prototype specifically designed for the user study.

The sixth chapter explains the user study and shows the results.

The seventh and final chapter ends with the discussion, conclusions and gives recommendations for further work and research.

1.1 Context

The work of the line operator is changing, with the change to a new industry standard, Industry 4.0.

The five major pillars of Industry 4.0 are digitization, optimization and customization of production, automation and adaptation, human machine interaction (HMI), value-

added services and businesses, and automatic data exchange and communication (Roblek et al., 2016, Posada et al., 2015). This correlates with the rise of Internet of Things and cloud computing. It indicates that industry 4.0 is an industrial process of value adding and knowledge management.

Improvements in manufacturing brings automation to mind which is often associated with the loss of jobs. According to Bessen (2016) this view fundamentally misunderstands what has been happening, but it does ask for adaptation or change from the workforce. With the arrival of industry 4.0 operators should not be replaced by machines and removed from the process but it should be accepted that the working landscape is changing and within that changing landscape new opportunities are imminent. Industry 4.0 enables new interactions between operators and machines. The increased use of assistance systems means that the qualitative changes brought about by Industry 4.0 will likely be positive for the workforce (Lorenz et al., 2021). The physical demanding jobs will move towards jobs asking for problem-solving and customization.

This technological change would not be possible without operators. There is a search for human-automation symbiosis, creating an operator 4.0 or smart operators, establishing principles of design of operator-friendly working conditions (Romero et al., 2016). In smart manufacturing systems, operators are a crucial link for optimal integration between real and virtual assets (Longo et al., 2017). Within this smart operator framework an intelligent personal assistant (IPA) equipped with an AI and vocal interaction capabilities fits the role of helping the operator interface with machines, computers and, other parts of the connected and integrated production system that are central in Industry 4.0 (Valentina et al., 2021).

An IPA that is able to perform tasks, such as data reporting and retrieval, or services, such

as problem solution recommendations can be of interest for operators. With the support of an IPA, operators in manufacturing might have the potential to integrate themselves more firmly in the Q&C (quality and control) process. Where the operator was seen as a liability in the process (Rooney & Vanden Heuvel, 2004), they can be an integral part in improving the manufacturing efficiency. In the manufacturing industry there is a constant search for improving both quality and productivity of the available machines (Kiran, 2013).

Untreated root causes are the most primary reason for, for example, an unwanted quality deviation in a final product or a decrease in overall equipment effectiveness (OEE) for a machine (Lokrantz et al., 2018). By supporting the operators with root cause analysis they could increase the efficiencies of machines.

This thesis project explores opportunities for facilitating line operators to aid in the root cause analysis process by supporting the operator with an IPA or so called cognitive assistant.

2 Background

2.1 Problem definition and high level objectives

Currently operators are not using methodological root cause analysis at the line during the manufacturing process. This causes many symptom treating solutions instead of solving the root problem. Many of the problems are solved based on the operator's experience and solutions often go undocumented.

The prototype should be able to:

- Communicate with operators.
- Support the operators with RCA method(s)
- Remember root causes
- Remember solutions
- Remember the steps taken during the RCA

This means that the operator should be able to communicate with the cognitive advisor to get to a root cause of a problem. For this process it is important that the cognitive advisor is able to retrieve existing data and communicate this to the operator. This should support the operator in solving the root of an issue. Next to that it should automatically log the steps and solutions for future purposes without the need for the operator to leave the line and manually enter this into a computer.

A more extensive project brief that was the kick-off of this project can be found in appendix 9.1.

2.2 Research Question

The objectives of the project ask for research as RCA with a cognitive for operators is currently not a well-researched area. Therefore multiple research questions are created to look for answers in these areas.

The main research question of this thesis is:

“Can a cognitive advisor support operators with root cause analysis”

To answer this question, the sub-questions below are divided into the categories user, performance and technical:

User (operators):

- 1) “How to communicate between the operator and the cognitive advisor about the root cause analysis?”
- 2) “Does root cause analysis with a cognitive advisor decrease the stress level of the operator?”

Performance:

- 1) “Does root cause analysis with a cognitive advisor increase the chance of coming closer to the root cause?”
- 2) “Does root cause analysis with a cognitive advisor decrease problem solving time?”

3) “Does root cause analysis with a cognitive advisor increase the quality of reporting data?”

3) “How to save and archive the root cause analysis and its steps in the system for later use?”

Technical:

- 1) “What are the current root cause analysis practices in the manufacturing Industry?”
- 2) “How to use existing root cause analysis tools in a cognitive advisor?”

2.3 Project approach

In Figure 1 you will find a roadmap of the project approach.

In Table 1 the major phases in the project are highlighted and explained.

Phase	Description
Literature and factory research	The first phase is focused on literature and factory research to the use of RCA and cognitive advisors in manufacturing but also to get to know the current practices on reporting and problem solving in general and specific to the case of Diversey
Prototype “framework”	The first start of the prototype based on a previous project and work done by the COALA team, including familiarization with conversational agents and the communicating of questions and answers between user and (smart) bot.
Data Collection and processing	The problem solving data gathered at and from Diversey needed to be processed and analysed. The data gives insight on the work of the operators and the problems they are running into.
Prototype “Knowledge”	Continues on “Framework” makes sure the data entering the prototype is saved into databases for later use and retrieval.
Prototype “RCA initiation”	First introduction of Root Cause Analyses in the prototype, simply asking the user why?
User study: Design	During this phase an experiment was designed to give answers to unanswered questions by the literature. Three design iterations were done that each were tested with multiple participants.
User study: Experiment	The user study experiment was conducted with 20 participant and resulted in insights for the final prototype and more importantly a scientific base for the use of a cognitive advisor for RCA.
Prototype “Finale”	Integration of the findings of the experiment into the prototype resulting in the final prototype of this project including RCA interaction. This final prototype is a showcase of one of the possibility of integrating RCA in a cognitive advisor.

Table 1 Project phase description

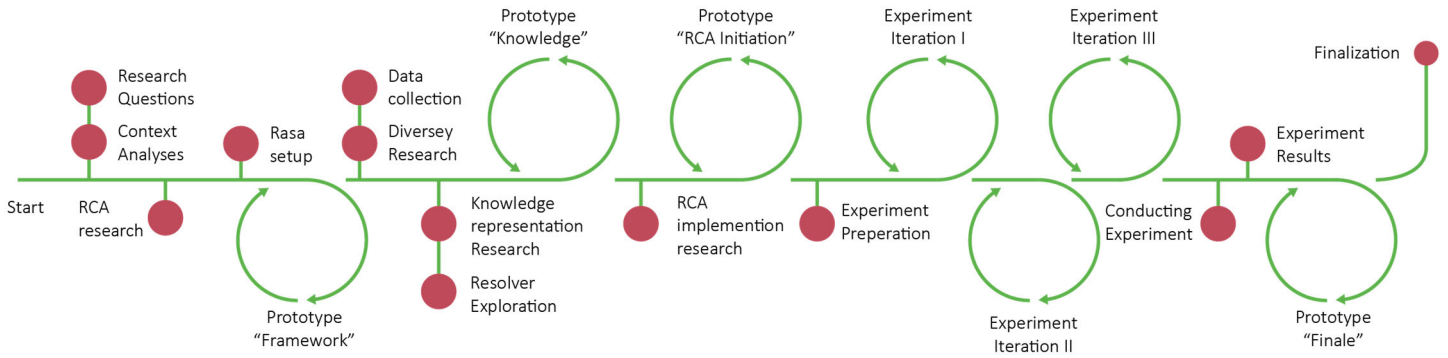


Figure 1 Design approach roadmap

2.4 Cognitive advisor

A cognitive advisor is a conversational AI that can assist users in their day to day tasks. It can support users for example in troubleshooting and provide information or in the case of this project by helping operators with root cause analysis methods.

2.4.1 Conversational AI

A conversational AI is the synthetic brainpower that makes machine capable of understanding, processing and responding to human language (*Boost.ai*, n.d.). Examples of well-known conversational AI's are Siri (Apple, 2022) and Google home (Google, n.d.). Other example are the chat bots that you can communicate with from your bank or other service provider.

In this project the same kind of framework is used to support operators with root cause analysis, more on this topic can be found in chapter 3 Technology.

2.5 Project collaboration: COALA

This thesis was written as part of an EU Horizon project named COALA (COALA, 2020). COALA (COgnitive Assisted agile manufacturing for a Labor force supported by trustworthy Artificial Intelligence) aims to develop a human-centred Digital Intelligent Assistant that provides a more proactive and pragmatic approach to support operative situations characterized by cognitive load, time pressure, and little or zero tolerance for quality issues. To read more about COALA see the project brief in the Appendix 9.1.

This means that some parts of this thesis were based on existing work or collaboration with other project members. In Table 2 you will find an overview of these elements explaining the foundation and collaborative elements of this thesis.

Foundation Elements	Parts	Description	Reference
COALA project (start)	Project goals	The goals of COALA are described in the COALA project proposal and can be found on the COALA website. RCA is a small part of the complete COALA project.	(COALA, 2020)
	Use cases	Three industry partners joined the project with different business scenarios of which this thesis focusses on detergent scenario 2	(COALA, 2020)

	General overview/ process	Visual abstract overview of how COALA should handle issue reporting of operators. In this overview this thesis focusses on RCA.	Appendix 9.2
	Industry and academic contacts	Multiple research, technology, industry, innovation and advisory partners in the COALA consortium	(COALA, 2020)
Conversational agent prototype	Rasa issue handling prototype	The Rasa development in this thesis uses the final result of the thesis of Boris Hadzisejdic as an example for the Rasa prototypes in this thesis	(Hadžisejdić, 2021)
	Rasa NLU library, entities and rules	The prototype in this thesis makes use of the gathered machine locations, Product components and product state that were collected during the thesis of Hadzisejdic	(Hadžisejdić, 2021)
Collaborative Elements	Parts	Description	Reference
Resolver development	GraphQL query development/integration	The resolver was developed together with a student from partner BiBa, rewritten and adapted to the detergent business scenario for this thesis	NA
Knowledge representation	Neo4J graph database structure	The knowledge representation structure was discussed and developed in collaboration with Santiago Ruiz-Arenas and Samuel Kernan Freire during multiple meetings. The results of this meeting have been rebuild and integrated as part of this thesis.	NA

Table 2 Foundation and Collaboration overview

2.6 Root cause analysis

Root cause analysis (RCA) is a collective term that is used to describe multiple approaches, tools and, techniques used to uncover (root) causes of a problem. RCA can be seen as part of total quality management (TQM). TQM describes a management approach to long-term success through customer satisfaction (Furterer, 2021).

This chapter explains what RCA is, its current practices and tools, how RCA is defined in this thesis project, and what the added benefit could be to integrating RCA with a cognitive advisor.

2.6.1 What is root cause analysis?

Root cause analysis (RCA) is a problem solving method that is used for identifying the underlying cause of an issue or incident, the root cause.

Root cause analysis is present in many different fields such as medicine, healthcare (Uberoi, 2007), IT operations (Dalal, 2013), accident analysis (Adekitan, 2017) but also in manufacturing where due to competition and technological advancements, a constant search for improving both quality and productivity of the available machines exists (Kiran, 2013).

According to literature RCA is used in a broad kind of events as RCA is a process designed for investigating and categorizing the root causes of events with safety, health, environmental, quality, reliability and production impacts (Rooney & Vanden Heuvel, 2004).

RCA is deemed important because, the root of the cause needs to be identified, if not, only the symptoms of the problems are addressed but the problem itself will still exist (Dogget, 2005). This is often visualized as a tree (Figure 2) where the leaves are the symptoms, the surface is the problem and the roots are the causes.

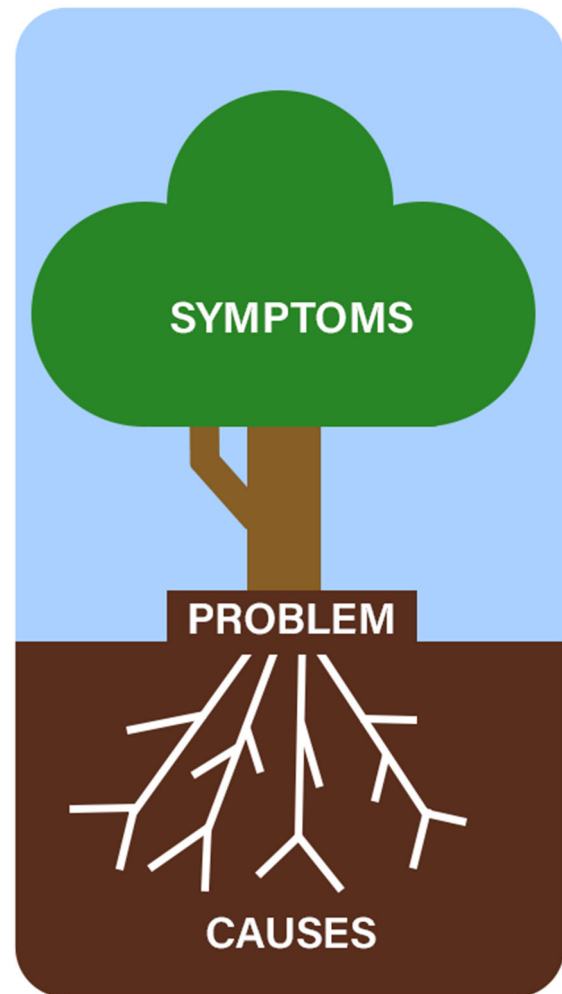


Figure 2 Symptom, problem, cause tree

There is a progression of actions and consequences that leads to a failure. RCA is a step-by-step method that helps to identify the causes or root causes creating these failures, the cause and effect trail from the starting problem back to the root cause (Mahto & Anjani, 2008) to help identify why an event happened and not only what and how it occurred.

In general RCA can be broken down in what, why and how. Asking the questions:

- 1) What happened? (reporting)
- 2) Why did it happen? (analysing)
- 3) How do we make sure it does not happen again (preventing)

This makes RCA a reactive process to predict preventively for problems to occur again, how predictive or reactive depends on the used tool or method.

Almost all RCA tools and methods use a similar outline of a four step process involving the following (Rooney & Vanden Heuvel, 2004; Kiran et al., 2013):

- 1) Data collection
- 2) Cause charting
- 3) Root cause identification
- 4) Recommendation

This breaks down to identifying the cause and recommend ways of preventing reoccurring, this seems very simple but investigating the real causes of a problem can take some effort,

meaning that identifying a problem's cause is paramount (Fagerhaug, 2006). RCA does not have a clear origin point on a timeline but is generally traced back to manufacturing in the 1950s and especially to the Toyota Production system where Taiichi Ohno started to look at problems to be opportunities to improve the production (Ohno, 1982).

2.6.2 Current practices and tools

These days many different RCA tools are being used in manufacturing, Table 3 shows an overview of commonly used RCA Tools. Most of these tools and methods are, on their own, not enough to get to the root cause but are generally used in combination to have an effective RCA.

Tool/method	Description
5 whys	Asking 5 times why; By asking at each stage of the problem why it occurred, the 5 why method tries to find the root cause (Mindtools, n.d.-a).
Fishbone / Ishikawa	The fishbone diagram or Ishikawa diagram helps to give an overview of the possible causes to a problem and the relation between them. All factors that could possibly be involved are written down in a fishbone structure (ASQ, n.d.).
Fault tree Analysis	The fault tree analysis is used to get to the root cause of a specific problem. It uses logic block diagrams that display states of the undesirable problem or failure. As the name implies it is a tree diagram that helps the user get to the root cause (Hessing, 2022).
Affinity Diagrams	The affinity diagram is an organizational RCA tool that helps sorting the data or ideas after e.g. a brainstorm into relevant categories (Dam & Siang, 2021).
Pareto Analysis	The pareto analysis is a method to compare many possible problems and estimate a set of most effective or beneficial actions (Mindtools, n.d.-b).
FMEA	The failure mode and effects analysis is a process or method used to review a system. For each component the possible problems or failures are written down and weighted to the resulting effects (Quality-One, 2020).
A3	A3 is a method for collaboration, learning and personal growth in employees. It is a tool that uses a plan, do, act and check model for using other RCA tools (Kanban Tool, 2021).
8D	The eight disciplines problem solving (8D) is a method that like A3 provides a template for RCA and systematic problem solving. (Quality-One, 2021)
TRIZ	TRIZ is a so called cause-effect chain analysis (CECA) tool. CECA is a way to create a diagram that follows the chain of events of the cause and effect. When drawn properly it show the relational chain between the problem and its causes. (Mindtools, n.d.-c)

Table 3 RCA Tool and method overview

These methods can be categorized in three clusters. One where the analysis is done before the issue has occurred, such as an FMEA where certain risks of failures are calculated beforehand. Another that is done after the issue has occurred, such as the 5 why analysis where the question of why something has happened is being answered. Finally there are tools that claim to be of added value to other RCA methods such as the Ishikawa diagram that gives an overview of relations between problems and causes.

2.6.3 Root Cause analysis defined

As root causes are the (underlying) reason for of a problem, it is important to first look at how problems will be defined and how they will be treated in this thesis.

A problem (statement) is:

- a question proposed for solution or discussion (Dictionary.com, n.d.)
- a situation, person, or thing that needs attention and needs to be dealt with or solved (Cambridge Dictionary, n.d.)

This means that:

- A problem is a state that is undesirable
- A problem has a solution to change the state to solved or more desirable

As there is some debate over the detailed definition of RCA, this thesis will use the following guidelines based on the definition of Rooney & Vanden Heuvel (2004).

(1) Root causes are specific underlying causes:

The more specific the cause the easier it is to come with specific recommendations

(2) Root causes are those that can be reasonably identified:

It should be cost beneficial. If it costs too much manpower to identify the root cause or if it goes beyond reason, there should be a reasonable end to the investigation

(3) Root causes are controllable to fix:

Exclude e.g. natural disasters and focus on what to improve, so the root cause cannot be an earthquake but it could be a building that was not able to withstand said earthquake.

(4) Root causes are those for which effective recommendations could be given:

This is to avoid general root causes such as operator failure, equipment not good enough or machine not performing well. As these are too vague to give recommendation for and probably means that the investigation has not gone specific enough to have found the root cause.

2.6.4 Root cause analysis levels

As mentioned before RCA is a broadly used method. Not only in different fields but also within organizational levels. If this is translated to the business case this means RCA can be used on a Business level, Factory level and operational level (Figure 3).

This does not mean that these levels exist apart from each other, all these levels cannot work without the other ones. Besides the root causes can intertwine, because a reoccurring problem in operation level can affect the business level. Figure 3 shows an example of the links between the problem statements on different levels.

This thesis focuses on the operational level, because this is the level operators are working in. This is done by looking into the operators and their interaction with the machines.

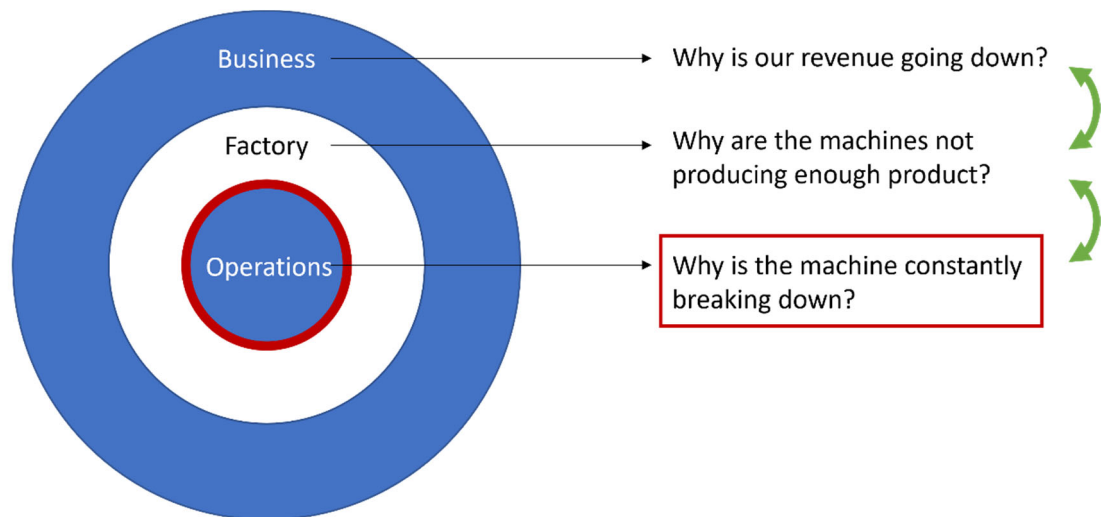


Figure 3 Different levels with a focus on operations

2.6.5 Root cause analysis and operators

In RCA a typical investigation can conclude that an operator error was the cause, which is an accurate description of what and how it happened, but it might not be the root cause. In the case of an operator making a wrong decision, often a recommendation such as retrain the operator on procedure and remind all the operators to be alert is the result. But you might also look to ask questions such as “was the procedure confusing?” or “Was the operator familiar with this particular task?”, recommendations might include revising the procedure or performing procedure validation. (Rooney & Vanden Heuvel, 2004)

2.6.6 Opportunities for operators and the cognitive advisor

There are multiple studies that show the benefits of RCA on long term time and cost efficiency in manufacturing by increasing operational efficiency and reduction in defects (Gangidi, 2019)(Hicks & Matthews, 2010). But where the management can look more towards business processes and human resources, operators can use RCA for investigating machining errors and collecting breakdown data. When looking at RCA in manufacturing you can dive deep into the machine. In research from Kiran et al. (2013) they exhaustively collected data on a machine with the goal to reduce breakdowns, resulting

in multiple recommendations for improving the machine. This data can already be collected straight from the operator. The cognitive advisor can be used as a data gathering assistant of the operator.

This can also hook into the introduction of machine learning in manufacturing, where machine learning is used more and more for (predictive) maintenance purposes and process improvement (Wuest et al., 2016). Current developments in RCA is the introduction of machine learning possibilities of building probabilistic graphical models of manufacturing processes to be able to analyse and predict the most probable root cause from a series of causes. (Lokrantz et al., 2018). A major challenge for the application of machine learning is the data quality (Jain et al., 2020). The cognitive advisor can help structuring the gathered data from the operator in an automated way.

Besides gathering data operators can also be more involved in RCA by directly conducting it when machine issues come up. The cognitive advisor could support the operators by assisting or guiding them with incorporated RCA methods and tools. At this moment there is little to no literature on operators conducting RCA.

2.6.7 RCA method to investigate: 5 Why method

This thesis project continues with a focus on the 5 why method. This is because of the following reasons:

- The 5 why method is heavily interaction focused, as it's questions answer based this creates opportunities for the interaction between operator and cognitive advisor.
- The business case makes use of the 5 why method (see chapter 4.2.2), making easier to connect to current practises.
- The 5 why is method is scalable, it can be used on a management level, but is also fit for operator level, as The 5 why method is most effective if used by people who have hands-on experience of the process or problem that is being investigated (MindTools, n.d.)

2.6.7.1 The 5 why method explained

The 5 why method is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem (Serrat, 2017)

The method follows a very simple line, if a problem occurs, you ask 5 times "why?" to come down to the root cause. The 5 is a rule of thumb it could be only 3 steps for simple problems or more steps for complex problems.

The 5 why method knows the following steps:

1. Assemble a team (if applicable)
2. Define the problem
3. Ask the first "why?"
4. Repeat step 3 until the root cause is found
5. Address the root cause
6. Implement countermeasures

An abstract example van be found in Figure 4 more detailed examples can be found in chapter 4.2.2.

Risks of the 5 why method are

- Tunnel vision to one root cause when there could be multiple root causes.
- Looping in questions and answers, causing a vicious circle.
- Needs the correct problem statement, otherwise the root cause will be harder to find.
- Going to deep, know when to stop to keep the root cause relevant for solutions.

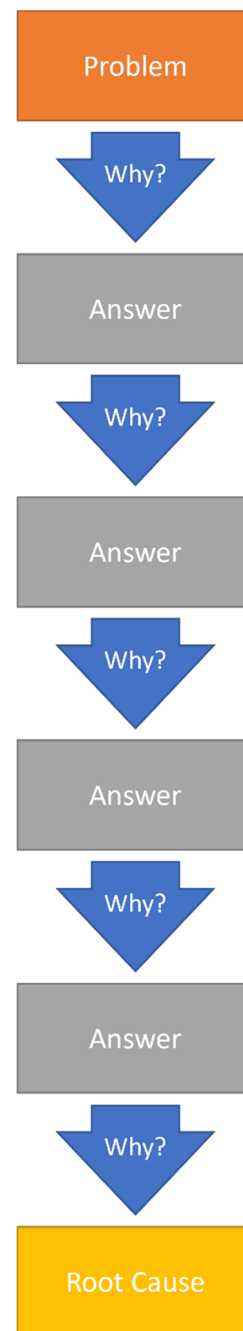


Figure 4 5 Why single lane steps

3 Technology

3.1 Introduction

This chapter explains the technical implementation of the prototype that has been build, looking at what tools and software the prototype uses and how this is implemented going into the versions and the specific application.

First Rasa, a conversational AI framework, is explained. In this part the connection with telegram via ngrok is explained as well.

Followed by introduction to and explanation of Neo4J, a graph database solution.

GraphQL is the communicator between Rasa and Neo4J, a so called resolver. This will be covered in the final piece of this chapter.

3.2 Conversational AI: Rasa

3.2.1 What is Rasa?

Rasa is an open source AI based framework for natural language understanding (NLU), dialogue management and integrations. With this you are able to create a text based assistants and chatbots (Rasa, 2021). Rasa is used as an interface in the environment of COALA for communication and decision making between the operator and the back-end knowledge representation.

Rasa provides a toolset that is used for developing a chatbot or conversational agent with integrated functions in the appendix you can find an overview of these functions. Rasa is open source software that is continuously being updated, for the versions Rasa Open Source, Rasa SDK and Rasa X used for this thesis

project of have been used can be found in Table 4

Rasa is an intent-action based framework, this means it will try to extract the meaning of the sentence of a user and link it to a specific actions. If a user says "Hello" Rasa can identify this as a greeting and can trigger an action to greet the user back (all defined in the back-end by the developer). Rasa makes use of a certain terminology to define how things work in their environment an overview can be found in appendix 9.8.1.

Within Rasa you can create a framework of intents, entities, slots, responses, forms and (custom)actions, which are placed in specific files, with these files you can train a so called natural-language understanding model (NLU) which is used to predict the intent of the user and which is followed by the action programmed in RASA.

RASA and the toolsets provided by Rasa are all programmed in python.

For an abstract overview of the workflow of Rasa see Figure 5.

Tool	Description	Version used (at time of writing)
Rasa Open Source	Supplies the human-to-computer interaction and is the main tool for creating the conversational agent	2.8.1
Rasa SDK	The software development kit provided by Rasa for running custom actions within your conversational agent	2.8.1
Rasa X	A tool for conversation-driven development (CDD), improving your assistant by listening to the users and providing insights	0.39.3

Table 4 Rasa tool description and versioning overview

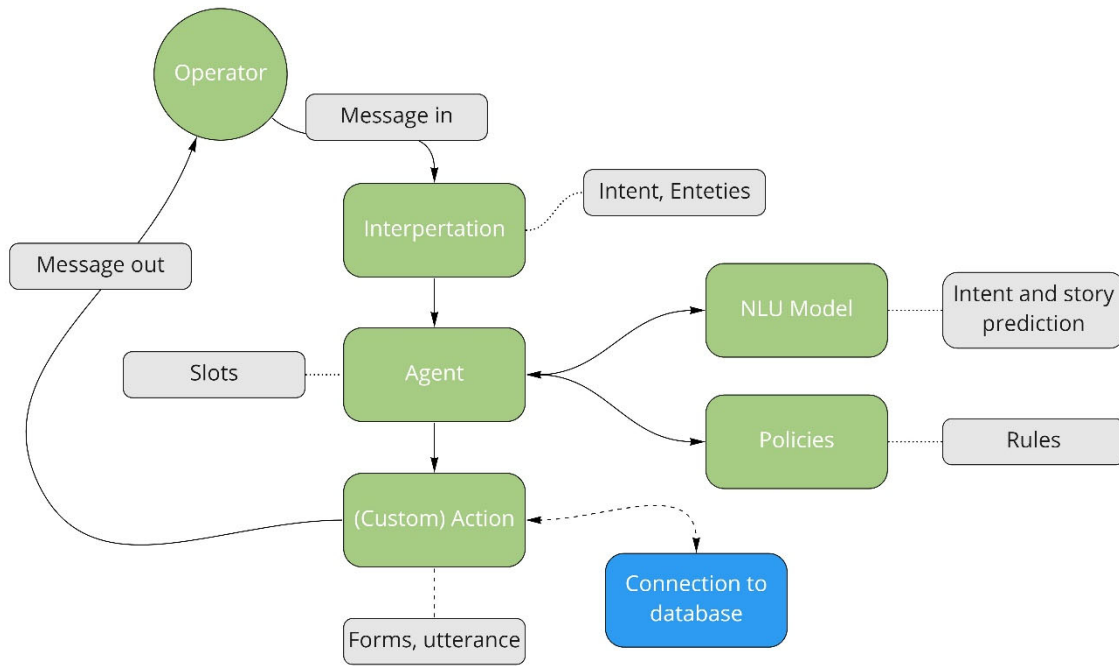


Figure 5 Abstract workflow of the Rasa framework

As the overview shows, the operator communicates with Rase, Rase interpreates this message with its learned (trained) intents and entities to an agent, which can save the interpreted message in slots and either run the NLU model or, if there is a policy, overrule this with predefined rules. This will result in an action that can utter a message or a custom action that can run a piece of code in the background.

3.2.2 Alternatives and decision making

The use of Rasa has been mainly a legacy choice as this has already been used by the COALA project for the issue reporting. Alternatives to Rasa are for example as Voiceflow, Diagflow (Google, n.d), Watson (IBM, n.d.) or Bot Framework (Microsoft, n.d.). Some of these alternatives have the advantage over RASA in offering a GUI for the conversational flow, but are closed source and/or costly. The main reason to stick with RASA is the fact that it is open source, which makes it adaptable and has many available resources and documentation.

3.2.3 Telegram and ngrok

To be able to communicate and test with the prototype Rasa gives the opportunity to use ngrok to share the local server on the cloud (ngrok, n.d.). For the prototype this is used together with a connection with Telegram. Telegram provides an API to create a shell for a chat bot (Telegram, n.d.), this makes the prototype able to communicate with the user via phone or tablet.

3.3 Knowledge representation: Neo4J

3.3.1 Neo4J; Knowledge Graphs

Knowledge representation of in the cognitive advisor environment is dedicated to represent the relevant information in a structured way, it should represent the information in such a way that is can be used to solve difficult tasks such as the root cause analysis and being able to supply this information to an operator in a natural way. This is memory of the environment where all data is stored, this should be done in a convenient way to be able to easily store the data that is extracted from the user via Rasa, retrieve the data that is needed to supply the user with the correct information and retrieve the data for analysing. In the cognitive advisor environment it might be necessary to have different forms of knowledge representation to be able to fully apply to the user's needs.

For the root cause analysis you need a knowledge representation that is techniques such as shortest path and centrality could be applied to. For this a more conventional way to store computer system data such as relational databases like SQL are not flexible enough. That is why for the root cause analysis the choice goes to a graph database, where you don't work with tables and strict rules, but with nodes and relations which are able to give you more flexibility.

The tool used for this in the cognitive advisor prototype is Neo4J AuraDB (Neo4J, n.d.), which is a cloud solution for a graph database. As mentioned a graph database works with nodes and relations (see Figure 6). The data structure has nodes as discrete objects which can be connected by relationships.

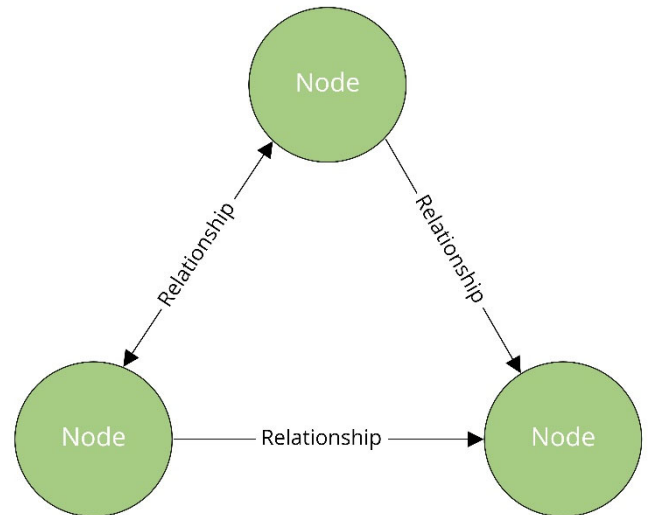


Figure 6 Nodes and relationships in Neo4J

Nodes

- Describe entities of a domain
- Can have zero or more labels to define what kind of node it is
- Can have zero or more properties to further describe them

Relationships

- Describes a connection between nodes
- Always has at least one direction
- Must have a type to classify what type of relationship they are
- Can have zero or more properties to further describe them

An example is given in Figure 7, here you see three nodes, where an issue node has a relationship with a cause node and with a location node. So this could provide information on the issue, the cause of the issue and the location of the issue, by just using two relationships.

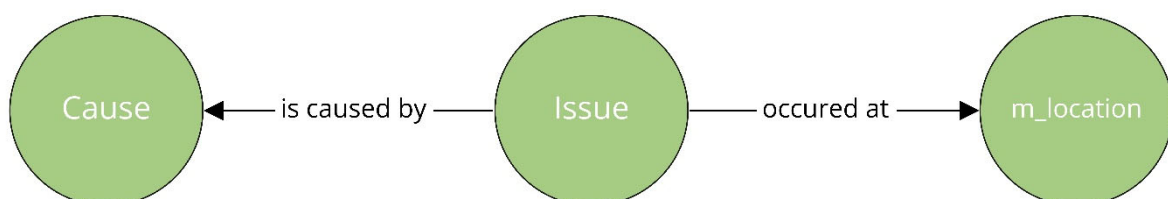


Figure 7 Diversey business case example of the relation between nodes

The knowledge graph can be populated by thousands of nodes, where each node can have multiple relationships with multiple other nodes. For this reason it is of importance to design the basic structure of the knowledge graph, how do you want to store the data and more importantly how do you want to retrieve it.

In appendix 9.7.2 an abstract version of a relational database and a graph database for the Diversey use case is shown. This design is used as a basis for the Neo4j graph database. This model can be seen as a 2D representation of a 3D model where underneath the 2D nodes and relations can be 1000s connected nodes with data.

3.3.2 Cypher

Neo4j works with the cypher language to pass queries to the database, cypher is just like SQL a way to provide and retrieve data to and from the database. It works with specific keywords that together form a query. For example Figure 8 shows a query where two nodes are created with a relationship. This query two m_component nodes with a relationship between them making the nozzle 21 node a sub component of the filler node.

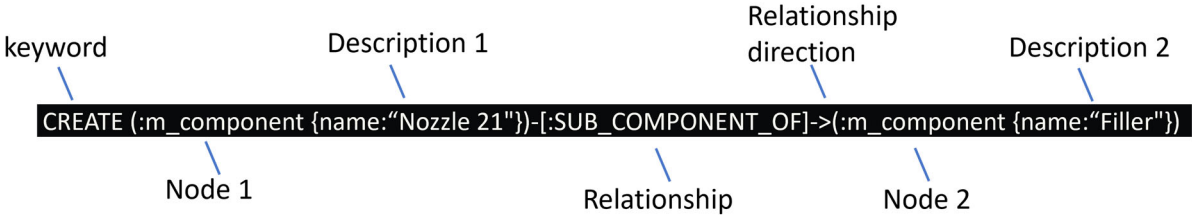


Figure 8 Neo4J Cypher Query

3.4 Resolver: GraphQL

A resolver is a function that translates data from software A to Software B, usually the frontend that communicates with a user to the backend that stores this data such as a database

3.4.1 What is GraphQL?

To exchange information between Rasa and Neo4j, the Cognitive Advisor makes use of GraphQL. With this query language the data is send and retrieved in JSON format. A GraphQL resolver is running on the server that connects to on the one hand the Rasa action server, and on the other hand Neo4j graph database for inputting and outputting data. The entire pipeline is depicted in Figure 9.

The operator interacts with Rasa and gives an input that triggers an action in the Rasa server, this action can contain a function that communicates via a GraphQL query with the database either storing data or retrieving data.

data you send to the database is in the correct format. This makes it more secure against malintent, but also against accidental programming errors that could damage or even erase the database.

GraphQL was already being used by another team in the COALA project so making use of this resolver was the easiest way for complete integration.

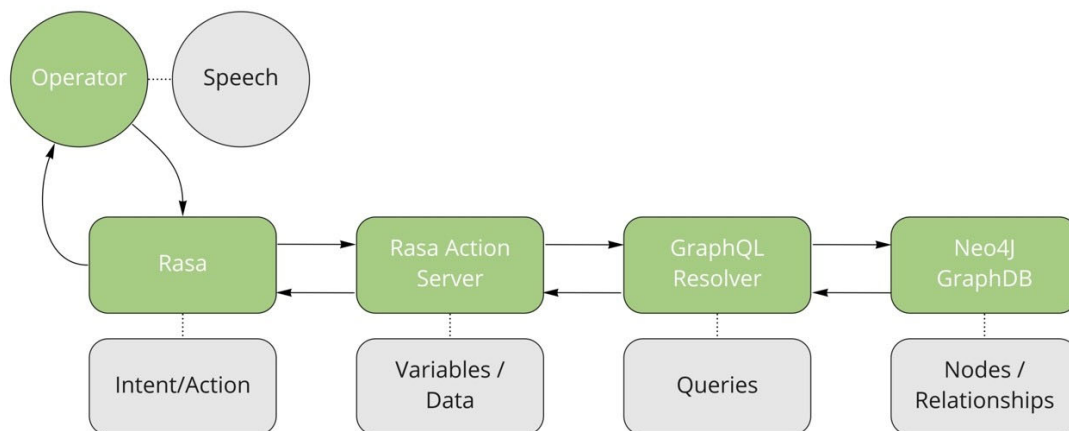


Figure 9 Entire pipeline from operator to database and back

The detailed workings and how to connect this to Rasa and Neo4J is described in appendix 9.7.3.

3.4.2 Alternatives and decision making

There are a few alternatives of doing it with a GraphQL resolver. Firstly you could communicate with the database directly from rasa via Python script, this has the advantage of being less work. Working via a resolver is however more robust, you make sure that the

4 Business case: Diversey

The business case used for this thesis project is provided by Diversey, Diversey joined the COALA project with two of their detergent factory teams, one in Enschede (NL) and one in Bagnolo (IT). For practical reasons the factory visits mostly took place in Enschede. Diversey provided resources to gather information about their operations, way of working, and, to some extent provided relevant data on problem solving and root cause analysis. This chapter explains the factory line that is used as

focus point and reports on the findings at Diversey.

4.1 5-10L Line

The business case focused on the 5-10L line (see Figure 10) this is one of the detergent filling lines at Diversey Enschede. This line can fill both 5 and 10 litre canisters with multiple different products. It goes through the whole process from unpacking the empty canister boxes to sealing the filled canister boxes. the global workflow can be found on the flowchart on the next page (Figure 11).

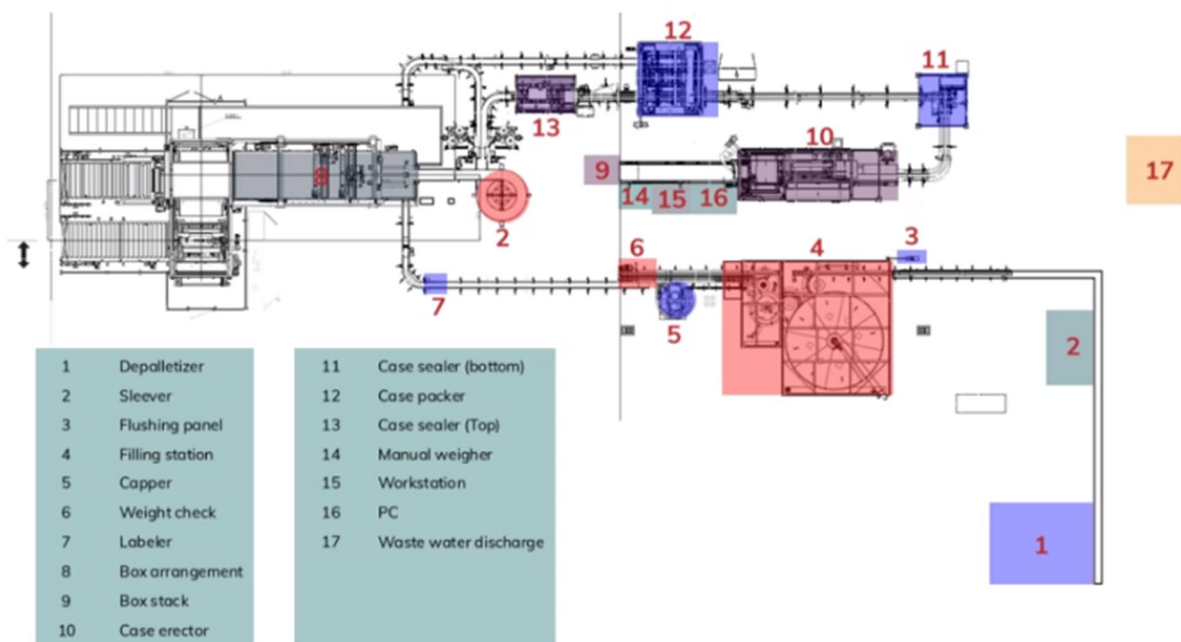


Figure 10 5-10L line Diversey Enschede, source: Diversey

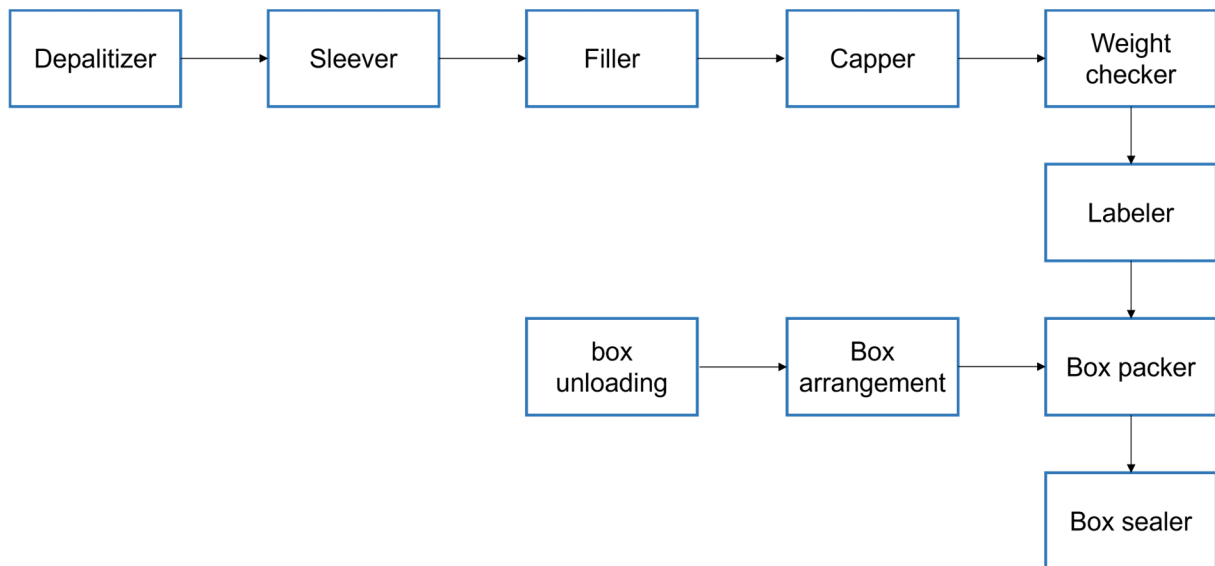


Figure 11 5-10L line high level workflow

4.2 Current practices

4.2.1 Issue reporting

Currently Diversey is not making use of a cognitive advisor. During the three factory visits at Diversey multiple I have spoken to employees from different departments, including the technical operators, technical services, quality and control, and management.

During the timeline of this Thesis at Diversey Enschede a lot of changes happened in terms of people who work there, they hired a new site manager and multiple new people on other management positions such as the line managers. With this the current practices are changing and new ways of working were and are being implemented.

For issue reporting and problem solving they currently don't have a set structure. During

interviews and observations I discovered that the operators do not have a detailed protocol they follow and work according to their own experience. Reporting issues and problem solving was done in the ODCE system, but since this system is not functioning on multiple occasions during the day, the majority of the operators do not use it.

During the timespan of this thesis Diversey Enschede was moving towards a new workflow management system. named manager plus (ManagerPlus, n.d.). This changes the structure on issue reporting and should make it easier for the operators as well as the technical services. For the new workflow see Figure 12. The issue reporting system ODCE was taken out of commission and AlisQI (AlisQI, n.d.) this software is used by Q&C and will be terminated with the coming of manager plus.

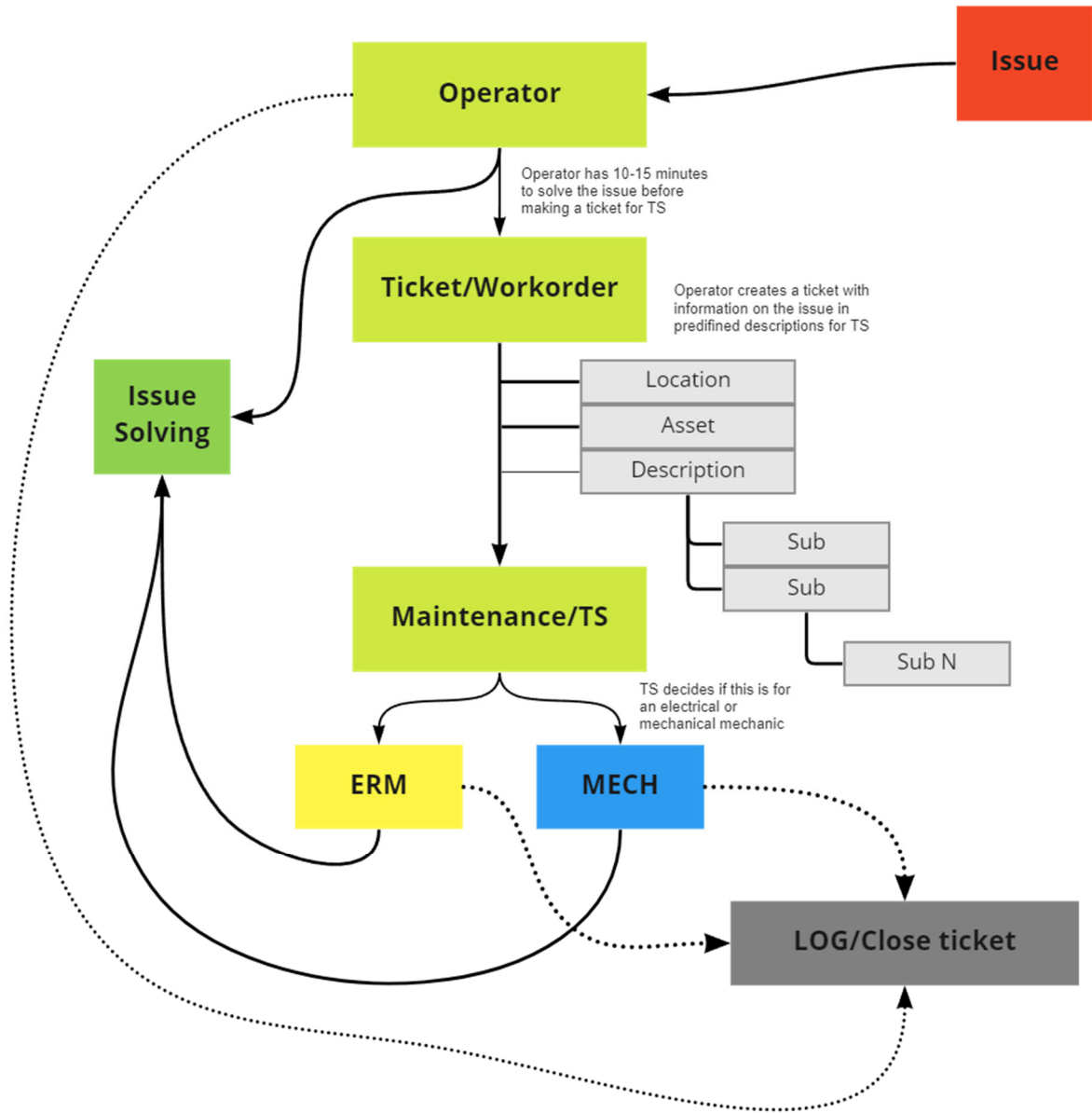


Figure 12 Issue reporting workflow with manager plus

4.2.2 Root cause analyses

At Diversey they make use of the 5 why method for RCA, it is being used in different ways. In Diversey Bagnolo they use the 5 why method to analyse major or long lasting issues. This is done by creating a multi-disciplinary team including employees from the supply chain, sales, R&D and finance next to the operators, technical services and quality control.

They use the following steps in their problem solving:

1. Initial perception of the problem
 - a. *Gather data*
2. Definition of the problem
 - a. *What should happen*
 - b. *Go and see*
 - c. *Split up problem in simple entities*
3. Identification of the point where the problem happened
 - a. *Go up throughout the process to determine the point where the problem happened*
4. Investigate cause
 - a. *Identify possible cause upstream*
 - b. *Confront with fact*

- c. *Use 5 why methods to narrow down on the root cause*
 - d. *Repeat the analysis until the root cause is found*
5. Counter-measure (temporary)
 - a. *Test the root cause*
 - b. *Define countermeasures*
6. Implementation, standardization and deployment (long lasting)
 - a. *Test the effect of each of the countermeasures, standardize those which work, deploy to similar problems*

In this problem solving continuum Diversey says that the 5 why method is the most important part of the problem solving process as it identifies the root cause of the problem, allowing them to identify preventive actions. They make a difference between restoring the flow (direct cause corrections) and solving the root cause of the problems to create preventive actions, the explanation of the 5 why method of Diversey can found in appendix 9.4

Table 5 shows an example of a RCA of a filler machine at the Diversey Enschede factory:

Step	Answer
Problem definition	CFILL 12 missed its target of 65% minimum efficiency
Why 1	Why was the target of 65% missed? (61%)
Answer 1	<i>Because the line was stopped for 56 minutes</i>
Why 2	Why was the line stopped for 56 minutes?
Answer 2	<i>Because of a hole in a bottle, this caused a leakage and the line had troubles containing the leakage</i>
Why 3	Why was there a problem to contain the leakage?
Answer 3	<i>Because there was no procedure to deal with this leakages and the containing kit was not available for the operators at that time.</i>
Root cause	Lack of containing kits close to operators
Counter measures	<ol style="list-style-type: none"> 1) Put containing kits available to brigade cabinet, close to operators 2) Train operators how to use the kit 3) Train operators to request assistance from brigade in case of leakage

Table 5 A 5 Why example at Diversey Enschede

As stated before, the previous 5 why method is implemented for larger problems. In Enschede the 5 why method is not used directly at the line by operators, where they mostly solve problems with the experience they have. In contrary to the factory in Bagnolo, here the operators are able to report using the 5 why method by filling out a paper form (Figure 13). The form has two sides and asks on the front the operator to state, next to some general data, the problem, the root cause and the countermeasures. On the back printed is a template for the 5 why method, which can be filled out manually. This is done by operators as well as quality and control, and technical services.

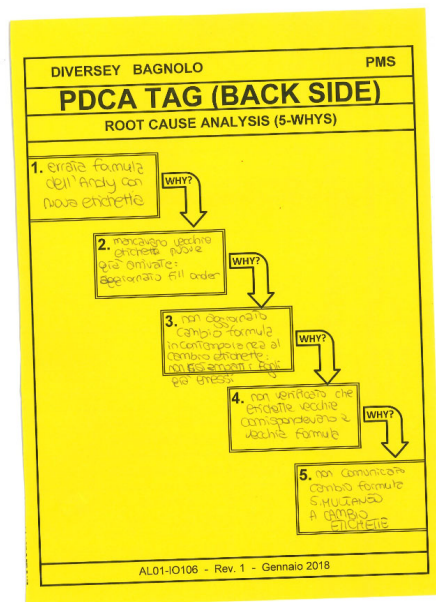


Figure 13 Yellow tag backside: Bagnolo 5 why method template

On these so called yellow tags (See appendix 9.3 (translated from Italian)), you can see the various outputs of the operators and other staff. Some of the papers are quite extensive others short with less information. You can also see that some of the operator struggle to use the method as the “Why?” questions are looping. For example YT10008 about a can that hit a nozzle;

- 1.) “The centering device was not fixed”
- 2.) “It was not fixed”
- 3.) “It was put in place but not fixed”
- 4.) “because it was not fixed”

As you can see this RCA is looping around the fact that the centring device of the nozzle was not fixed, never asking the question why this device was not fixed.

In conclusion you can say that RCA at Diversey is done in various ways and it differs per factory. In Bagnolo operators are asked to (at some occasions) do an RCA on the line while in Enschede they are added to a multidisciplinary team after a problem has occurred and often already been solved. Trying to answer the question “How could this have happened in the first place?”. Table 6 gives an overview of what kind of RCA they conduct and what possible improvements are. Currently neither of the locations use RCA directly at the line so this is an opportunity to research.

RCA method	Bagnolo	Enschede	Possible added value of a cognitive advisor
5 why in team	Yes	Yes, but after the problem has been solved	Adding value by giving data inputs to the team
5 why as operator	Yes, with the yellow tags	No, most problems are solved with experience	Adding value by start RCA at the operator and give guidance

Table 6 Possible added value for Diversey

5 Prototypes

In this chapter three different prototype sprints are explained to show the road of how the final prototype was created.

If you are interested in the technological background and the reasoning behind the used technologies of the prototypes please see chapter 3 Technology.

It starts off with the foundation of the prototype and the programme of requirements.

The first prototype “*Framework*” is used more as an exploring exercise than a prototype. Mainly to get to know how to use the conversation agent software Rasa and integrate previous done work. It can hold a very basic conversation and report an issue specific to the Diversey 5-10L line.

Prototype “*Knowledge*” continues on “*Framework*” and integrates a Neo4J Graph database to be able to save entries. It can save parts the conversation and the reporting via a connection between Rasa and Neo4J, so this can be retrieved for later use or analysis.

Prototype “*RCA Initiation*” introduces root cause analysis in the prototype being able to use basic why questions and give probably solutions to a few specific problems. This prototype was the input for specification of the user study (chapter 6) how to help operators with RCA.

Chapter 5.6 shows the final prototype with the input from the conducted study, the prototype

phases in this chapter show the specific steps on how I got to that point.

Please note that the prototype is built in Dutch as it was created based on the Diversey Enschede factory and operators.

5.1 Foundation

This graduation project makes us of the work of another COALA member (Hadžisejdić, 2021). This project focused on the issue description within the same business case.

In his project Boris used the 5-10L line at Diversey as a basis to gather multiple issue descriptions and integrated these into the Rasa chatbot. His end result prototype is a base for the prototype of this graduation project. In the prototype an operator is able to describe an issue and with a conversation with the cognitive advisor an issue description is created and logged into a spreadsheet on google drive. In this log the following information is stored:

- Machine location
- Product Component
- Product Component State
- Date
- Time

With this you are able to produce an issue description list which would look like shown in Table 7 .

This tells you where on the line the issue is, which product component has an issue, what is the state of that component, which describes the issue and at what day and time the issue occurred.

m_location	p_comp	P_comp_state	date	time
Dopperdraaijer	Dop	Vast	14/09/2021	9:33:31
Vuller	Product	Schuiemen	14/09/2021	12:39:16

Table 7 Issue description list

5.2 Programme Of Requirements

This chapter contains the list of requirements (Table 18). The list is based on earlier work done in COALA, literature research (Chapter 2.5), research at Diversey (Chapter 4) and the design iterations (Appendix 9.5), the technological limitations and opportunities (Chapter 3) and the findings of the user study (Chapter 6).

The programme of requirements is to guide the process of the prototype development in this PoR you can find the required points and the wishes of the final prototype. The list is ordered by operator, technological, business & COALA. The number shows the number per category the R indicates it is a requirement the W indicates it is a wish.

Type	Number	Requirement/Wish
Operator	O.R.1	Prototype can understand the operator
	O.R.2	Prototype can converse in a natural way
	O.R.3	Prototype can communicate text based (via chat bot)
	O.W.1	Prototype can communicate via text-to-speech/speech-to-text
Technological RASA	TR.R.1	RASA can communicate with the operator
	TR.R.2	RASA is able ask and to understand the context of the operator <i>e.g. location, machine and parts</i>
	TR.R.3	RASA RCA: Start the 5 why method and formulate a why question from the problem statement
	TR.R.4	RASA RCA: Rephrase the answer into a new question
	TR.R.5	RASA is able to save the text input
	TR.R.6	RASA RCA is able to stop a running a 5 Why method once it has started
	TR.W.1	RASA is able to handle chitchat
	TR.W.2	RASA RCA: Recognize loops in 5 why questioning
	TR.W.3	RASA is able to answer Frequently asked questions
Technological GraphQL	TG.R.1	Resolver can retrieve data form RASA
	TG.R.2	Resolver can send data to NEO4J
	TG.W.1	Resolver can retrieve data from NEO4J
	TG.W.2	Resolver can send data to RASA
	TG.W.3	Resolver can send data to SQL database
	TG.W.4	Resolver can retrieve data from SQL database
Business	B.W.1	Data is retrievable for analyses
	B.W.2	Data can be send to a dashboard for insights technical services
	B.W.3	Data can be send to a dashboard for insights quality and control
COALA	C.W.1	The prototype can be integrated into the COALA environment

Table 8 Programme of Requirements

5.3 Prototype Framework

5.3.1 Goal

The goal of prototype framework is to get a basic version of Rasa running, explore how Rasa works and integrate a previous prototype that was used for issue reporting so that this prototype already has the foundation that was built. This includes some contextual awareness of the business scenario at Diversey and can have chitchat with the user in Dutch. As already stated, the technologies behind the functionalities can be found in chapter 3.

5.3.2 Added functionalities

In this prototype the foundation functionalities are rebuild, so they can run locally on my pc.

Added functionalities to the foundation are:

- New local phrases to explore how Rasa works.
- Ask for the time to explore Rasa custom actions.
- Proxy server to be able to communicate outside of my pc via ngrok.
- Integration with Telegram bot to be able to communicate in a chatbot manner without the use of (as of now unsupported) Rasa X module.

5.3.3 Show case

In Figure 14 you can see the chat with the cognitive advisor based on the foundation explained in the previous chapter. In the next figure you can see a chat where the functionality of asking the time is shown ending the conversation with the local phrase “Goad Goan” (Low Saxon saying meaning “goodbye”) which is recognized and understood by the prototype.

5.3.4 Test to PoR

The very basics are now functional in the prototype. This means that O.R.1, O.R.2, O.R.3, TR.R.1 and TR.R.2 of the PoR are operational.



Figure 14 Interaction with COALA based on the foundation



Figure 15 Asking for the time and using a local phrase

5.4 Prototype Knowledge

5.4.1 Goal

The goal of prototype knowledge is to be able to save (parts) of the conversation between the operator and the cognitive advisor in a Neo4J graph database. This should be done making use of the resolver created with GraphQL. As already mentioned, the breakdown behind technologies and the reasoning behind the functionalities can be found in chapter 3.

5.4.2 Added functionalities

- Connection to a local Neo4J database.
- A GraphQL resolver to communicate between the client and the database.
- Ability to translate Rasa input to Neo4J data

5.4.3 Show case

In Figure 16 can see a visualization of a Neo4J database that is populated with multiple nodes and some relations. In Figure 17 you can see the chat with the cognitive advisor where the user asks for the time and the corresponding node in the Neo4J database.

Here Rasa connect to the database via the resolver depending of the intent of the user and the corresponding action that is trigger by that intent. This can be used as a basis for saving the “5 Why” method steps in the following prototypes.

5.4.4 Test to PoR

The cognitive advisor is now able to save the input from the operator and communicate this to a database via a resolver. Adding T.TR.5, T.GR.1 and T.GR.2 to the operational functionalities.

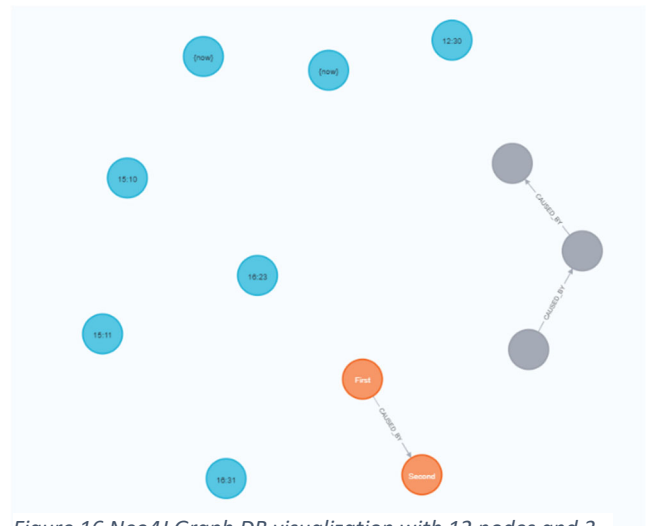


Figure 16 Neo4J Graph DB visualization with 12 nodes and 3 relations

The top part of the image shows a Neo4J interface. The command bar contains the query: `neo4j$ MATCH (n) RETURN n LIMIT 100`. The main area displays a circular graph visualization with a central red node labeled '16:49'. A sidebar on the right shows 'Node properties' for the selected node: `<id> 4`, `timestam 16:49`, and `p`. The bottom part of the image shows a chat interface with a blue background. The chat history includes: a user message 'Hi! Hier COALA, waar kan ik je mee helpen?' at 16:49; a system message 'Hi 16:49' with a checkmark; a user message 'Hoe laat is het?' at 16:49; a system message '16:49 16:49' with a checkmark; and a user message 'Dankjewel!' at 16:49 with a checkmark. The input field at the bottom says 'Write a message...'.

Figure 17 Neo4J time node (above) as a result of the chat (below)

5.5 Prototype RCA Initiation

5.5.1 Goal

In prototype “RCA Initiation” the goal is to incorporate the 5 why method into the framework and communicate this with the operator.

5.5.2 Added functionalities

- Added recommendations from work instructions
- Added “Why” question

5.5.3 Show case

In Figure 18 you can see the chat with the cognitive advisor where an operator mentions an issue and the cognitive advisor asks what the cause of this issue is. When the operator answers with a question that the cognitive advisor recognized, it states an option for a solution

5.5.4 Test to PoR an next steps

During the development of this prototype, there was a lack of knowledge on how to incorporate the 5 Why method. In this prototype the cognitive advisor gives answers based on work instructions and is unable to do anything with a issues that are unknown.



Figure 18 RCA initiation conversation

There was no literature or information on how to conduct the 5 Why method with operators. For further development I deemed it necessary to do research on the interaction between the cognitive advisor and the operator focussed on the root cause analysis. This initiated the user study which can be found in chapter 6.

5.6 Final prototype

This chapter shows the final prototype that is the result of this thesis project, it has incorporated all functionalities of the previous prototypes and the way of conducting RCA by using the 5 Why method as tested in the user study. (see also the showcase video attached to this report)

This prototype incorporates the functionalities of the previous prototypes and the findings from the user study in chapter 6.

For the code behind the prototype see appendix 9.8.

5.6.1 Goal

The goal of this prototype is showcase or demo a cognitive advisor that can support operators with RCA. This can be used to let people know of the opportunities that exist by introducing a cognitive advisor on the manufacturing workplace. Besides it can be a building stone for the next step in this area.

5.6.2 Functionalities and testing to PoR

The key functionalities are:

- Starting the 5 why method by request of the operator
- Rephrasing the initial problem statement into a “Why?” question.
- Ask for the root cause statement
- Saving the problem statement, steps and root cause in a database while keeping the link.

Other functionalities:

- Sentence analysis for easily rephrasing questions while keeping close to the operators answers
- Detection of looping

5.7 Showcase

In Figure 20 you can see a chat history of the interaction between a user (operator) and the cognitive advisor, each functionality is indicated, and is explained below.

In box 1 the operator initiates the “5 Why” method by telling the cognitive advisor “I want to start the 5 why method”. This triggers the cognitive advisor and the advisors ask for the starting problem statement.

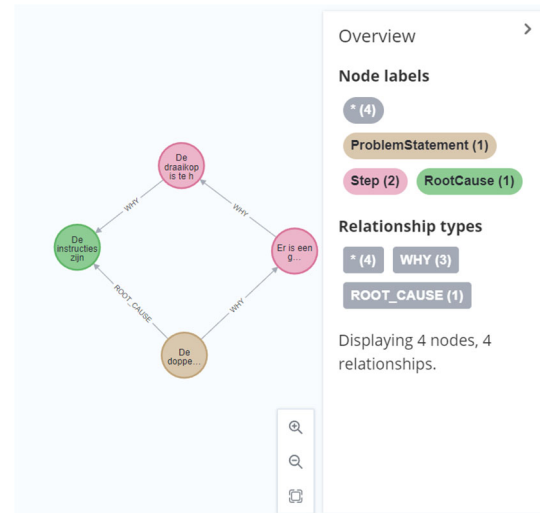


Figure 19 database results of conversation

In box 2 the operator gives the starting problem statement and the cognitive advisor rephrases this sentences asking the operator why there is a problem.

The prototype does this by analysing the sentence checking it for known machine parts and machine states.

In box 3 the operator keeps answering the questions from the cognitive advisor supporting each other to find a root cause

In box 4 the cognitive advisor notices that the operator is looping; giving the same or similar question as mentioned before. The cognitive advisor explains to the operator what it detected and repeats the previous question.

In box 5 the operator mentions that they have found the root cause of the problem, the cognitive advisor asks for confirmation and repeats the given root cause.

In box 6 the cognitive advisor mentions that the 5 why method is completed and informs the operator that the results are send.

In Figure 19 you see the results of this conversation in the graph database. The database differentiates between; initial problem statement, in between steps and the root cause. With a “Why” relation between each node and a root cause relation between the problem and the found root cause.

5.7.1 Test to PoR

In Table 9 you can see the programme of requirements with the indication if it was added as a functionality.

Type	Number	Requirement/Wish	Final Prototype
Operator	O.R.1	Prototype can understand the operator	Yes
	O.R.2	Prototype can converse in a natural way	Yes
	O.R.3	Prototype can communicate text based (via chat bot)	Yes
	O.W.1	Prototype can communicate via text-to-speech/speech-to-text	No
Technological RASA	TR.R.1	RASA can communicate with the operator	Yes
	TR.R.2	RASA is able ask and to understand the context of the operator <i>e.g. location, machine and parts</i>	Yes
	TR.R.3	RASA RCA: Start the 5 why method and formulate a why question from the problem statement	Yes
	TR.R.4	RASA RCA: Rephrase the answer into a new question	Yes
	TR.R.5	RASA is able to save the text input	Yes
	TR.R.6	RASA RCA is able to stop a running a 5 Why method once it has started	Yes
	TR.W.1	RASA is able to handle chitchat	Yes
	TR.W.2	RASA RCA: Recognize loops in 5 why questioning	Yes
	TR.W.3	RASA is able to answer Frequently asked questions	No
Technological GraphQL	TG.R.1	Resolver can retrieve data form RASA	Yes
	TG.R.2	Resolver can send data to NEO4J	Yes
	TG.W.1	Resolver can retrieve data from NEO4J	Yes
	TG.W.2	Resolver can send data to RASA	Yes
	TG.W.3	Resolver can send data to SQL database	No
	TG.W.4	Resolver can retrieve data from SQL database	No
Business	B.W.1	Data is retrievable for analyses	Yes
	B.W.2	Data can be send to a dashboard for insights technical services	No
	B.W.3	Data can be send to a dashboard for insights quality and control	No
COALA	C.W.1	The prototype can be integrated into the COALA environment	No

Table 9 PoR with checked requirements to the prototype

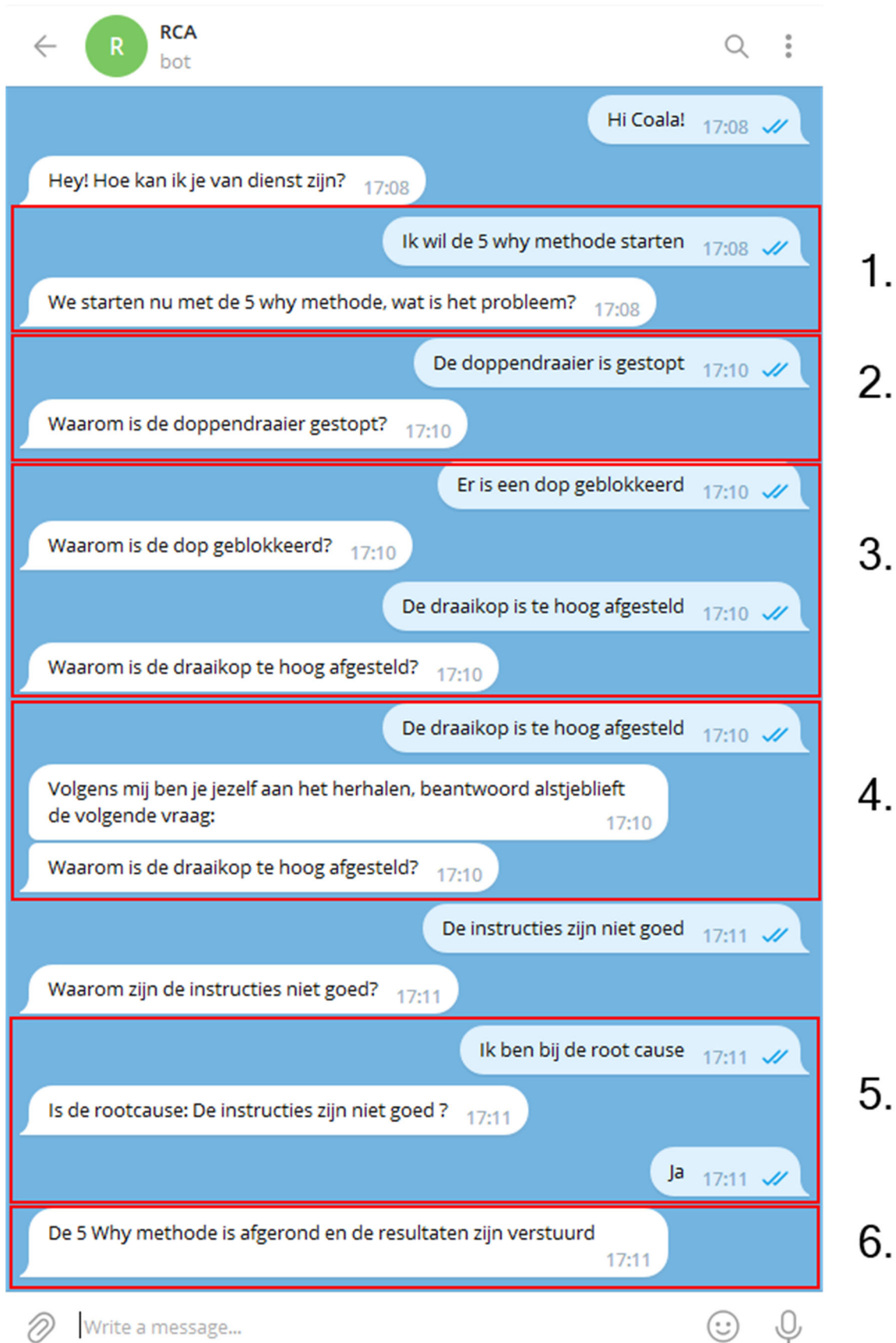


Figure 20 Screenshot of prototype in Telegram showing (1) initiating "5 Why?" method (2) Rephrasing the problem statement (3) Rephrasing each step (4) Asking for clarification if it detects looping (5) Stating the root cause and ask for confirmation (6) Letting know that the steps are saved and send.

5.8 User Study prototype

This chapter explains the design of the user study in the next chapter and prototype used in the experiment. The experiment has the goal of finding out the differences between RCA conducted on paper (current practice) and RCA conducted with the support of a cognitive advisor in form of a voice chat. The experiment asks the participants to act as operators in a green house and fix lights (of a prototype) that went out of order during the previous shift.

The participants will be divided in to two groups. One group (A) will not make use of a cognitive advisor and report via a paper 5 why template (changing to paper instead of a computer form was decided in iteration IV), the other group (B) will make use of a cognitive advisor. The paper template and cognitive advisor are used to conduct the 5 why RCA method.

As I found it to be quite difficult to design an experiment with that has a proper root cause analysis, I chose to, instead of running only one

pilot, to design the experiment in multiple iteration to improve the setup before conducting the actual research.

An extensive report about the iterations and changes throughout the process can be found in appendix 9.5.

5.8.1 Design Methodology

For designing this experiment two design methodologies are combined. One is focused on user interaction with (typically) a physical prototype; Interaction Prototype & Evaluation (IPE) (Boeijen et al., 2014). The other methodology is called Rapid Iterative Testing and Evaluation (RITE) (Medlock et al., 2002). With the combination of these two methods, via quick iterations, improvements can be made to the experiment as well as the final prototype. How this Rapid Iterative Testing Interaction Prototyping and Evaluation (RITPE) can be seen in Figure 21, for a more extensive explanation see appendix 9.5.1.

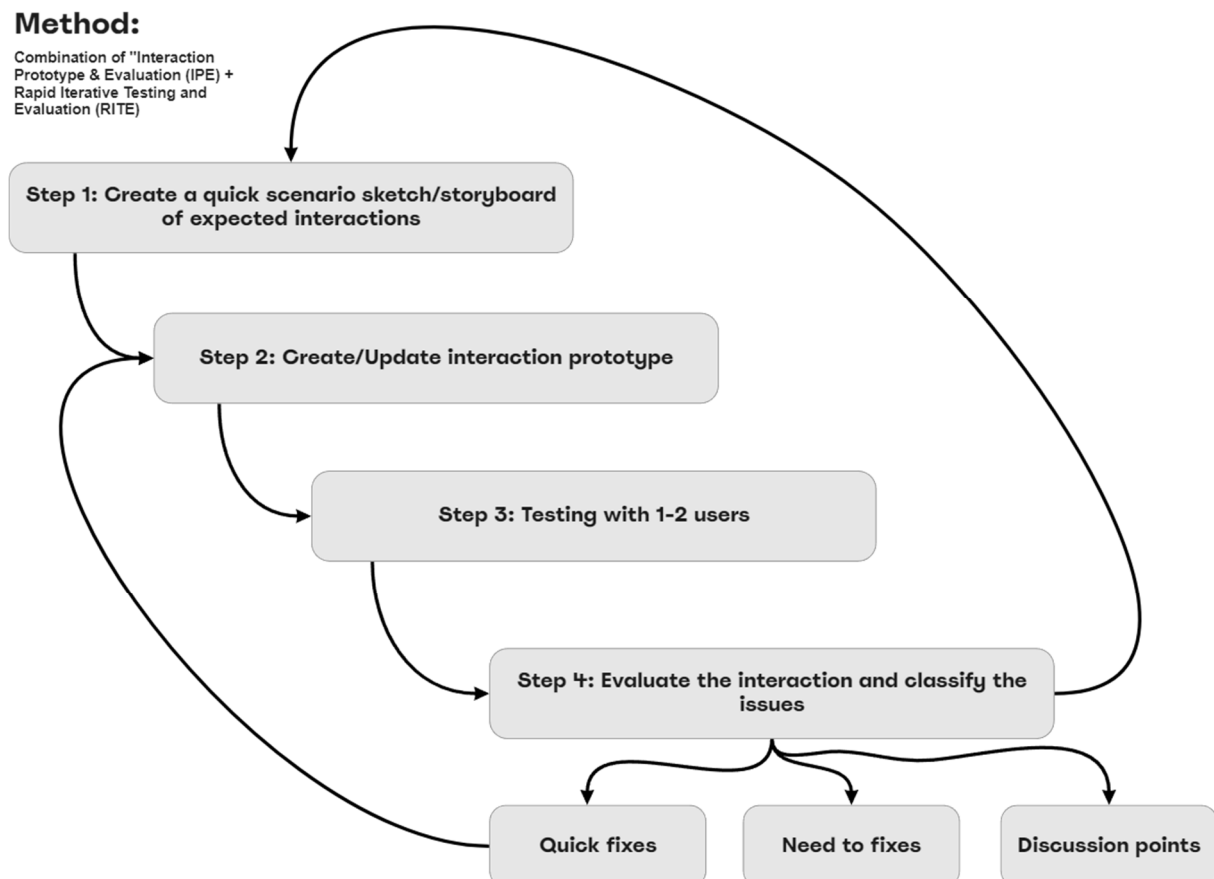


Figure 21 Design Iteration Method RITPE step by step overview

5.8.2 Prototype

The high level requirements of this prototype is to be a “Puzzle” that:

- Is not too complicated to solve for students/employees of a technical university.
- Has enough steps (at least 3) to do a proper RCA.
- Has a link to the works of an operator.

This resulted over multiple iteration into the design that can be found in Figure 22. The components and starting state of the components can be found in Table 10. Multiple ideas were considered, in the end the electrical prototype was picked because this is closer to the operators work than a digital prototype, easier to reassemble compared to a mechanical prototype, and has many potential participants. The steps and decisions taken during the design can be found in appendix 9.5.1

The task for the participants is to set the LED lights to a certain voltage, but currently the LEDs are not working.

With the components and the start state the participants are able to do a root cause analysis with the starting problem of broken/non-emitting LEDs. The predetermined root cause is a too high voltage battery but a participant might set their root cause as the broken fuse or a too highly set potentiometer.

This can give different outcomes, which can be compared between the two test groups.

The build user prototype can be found in Figure 23.

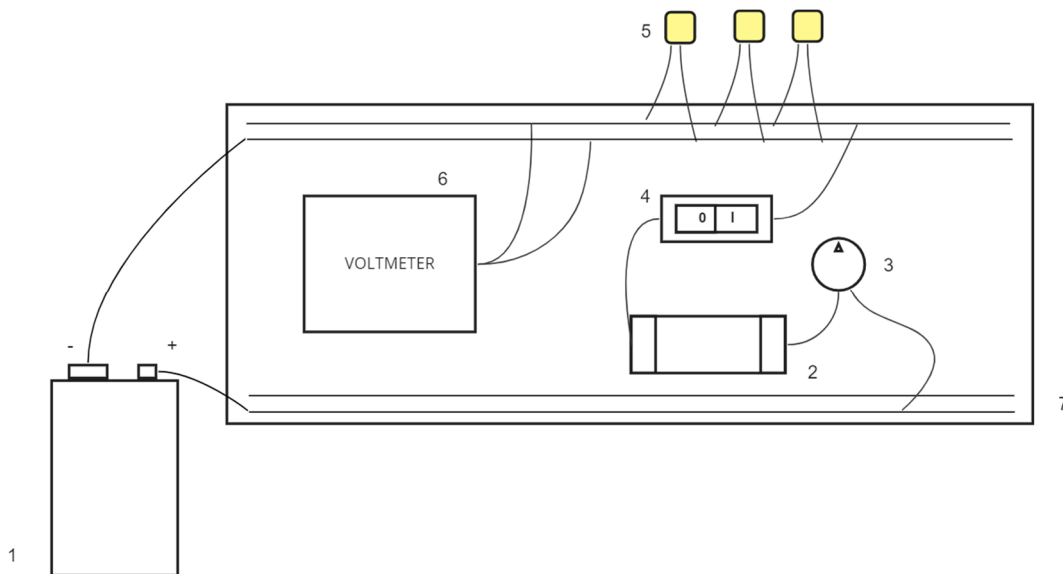


Figure 22 User study prototype design

Number	Component	Start State
1	Battery	Too high voltage
2	Fuse	Broken
3	Turning knob	Full power
4	Switch	Turned on
5	3 High-powered LEDs	Not emitting
6	Standalone voltmeter	Displaying the voltage level over the LEDs
7	Breadboard	-

Table 10 User study prototype component and start state overview

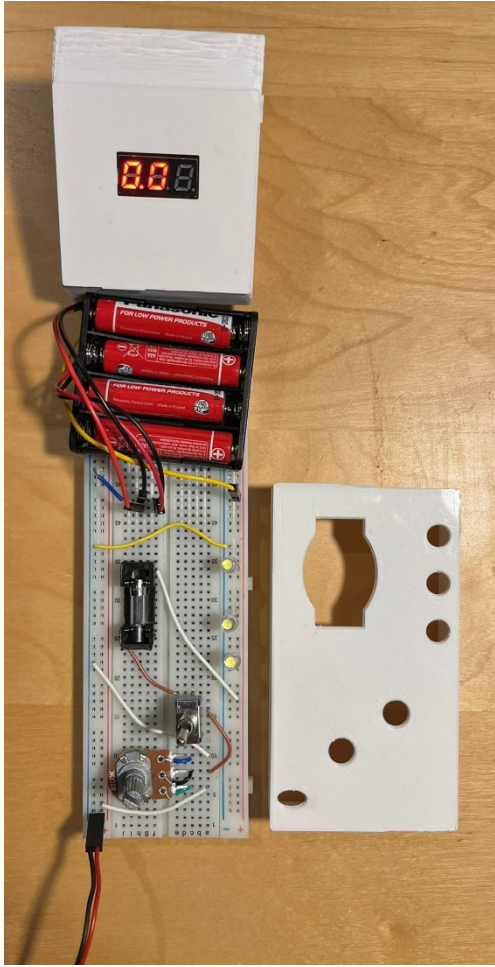


Figure 23 User study prototype with on the left side an open case and on the right side a closed case

6 User Study

6.1 Introduction

At the Diversey business case the reporting of problems and problem solving is done at the end of the process via a computer or handwritten form.

Operators on the line are not consciously trying to find the root cause of a problem; they want to solve the existing problem that is occurring at that moment. So they are not concerned with finding the underlying root of the problem and want to get the line up to running as fast as possible.

Currently there is little to no information on the benefits of using a cognitive advisor for reporting and problem-solving or finding root causes at the line in factories, although studies do show that there is potential in increased cognitive capabilities of systems and the improvements for operators (Chacón et al., 2020).

This experiment is focused on assisting operators with root cause analysis tools in the problem solving process. To validate whether it is in the participants' interest to be accompanied by a cognitive advisor. This advisor can help solve issues with root cause analysis and broadening the scientific base on this topic. One of the current industry standards for root cause analysis is using the 5 Why method within a team when running into hard-to-solve problems.

In this experiment the basis of the 5 Why method will be used directly with operators (participants). The participants consists of two groups, where one group will be conducting the experiment with a cognitive advisor and the other group without. During and after the performed task performance and user experience variables (NASA TLX & UEQ) are measured and collected to see if there is a difference between the two groups.

Due to the uncertain availability of the operators of Diversey and the costs of

conducting the experiment with the actual machines, I decided to create a prototype and give the participants a problem to solve with basic electronic components. The participants of the study were all technical students with an expected minimal knowledge on electronics, which approximates to the prior knowledge of operators on the machines.

6.2 Relevant research questions

This experiment is developed to give answers or insights on the following research questions of this thesis:

Performance

- 1) "Does root cause analysis with a cognitive advisor increase the chance of coming closer to the root cause?"
- 2) "Does root cause analysis with a cognitive advisor increase the quality of data?"
- 3) "Does root cause analysis with a cognitive advisor decrease problem solving time?"

Operator

- 1) "In what way does root cause analysis with a cognitive advisor influences the user experience of the operator?"

6.3 Hypotheses

Hypothesis 1 (Primary): Participants with the help of the cognitive advisor will more often come closer to the root cause than the participants without. (RQ P.1)

I expect that participants with the help of the cognitive advisor come closer to the root cause than participants without, as the cognitive advisor is triggering the thought process of using the 5 Why RCA method

Hypothesis 2 (Secondary): Participants with the help of the cognitive advisor will higher quality data during RCA than participants without (RQ P.2)

I expect that higher quality data is given by participants with the cognitive advisor than those without because the cognitive advisor helps the participant by repeating the previous

step in a why question. The definition of quality data is explained.

Hypothesis 3 (Secondary): Participants with the help of the cognitive advisor will conduct the experiment assignment (problem solving & fixing + RCA) faster than the participants without. (RQ P.3)

It is expected that participants with the help of the cognitive advisor will be faster than those without since they are able to conduct the 5 Why method verbally instead of written RCA

Hypothesis 4 (Secondary): Participants with the help of the cognitive advisor will feel more comfortable and less stressful during the performance of the experiment assignment (problem solving & fixing + RCA) than the participants without. (RQ O.1)

It is expected that the participants group aided by the cognitive advisor will feel more comfortable and less stressful than those without as they are supported in during the RCA and don't have to do the thinking process on their own.

6.4 Research Method

6.4.1 Context and setting of the study

This is an A/B testing participant experience experiment where two variants will be run to compare the different responses of the participants. As stated the use of on-premises testing and experimenting at Diversey was not a realistic option, therefore I have chosen to conduct the experiment by using a prototype at the Industrial Design Engineering faculty of the TU Delft, the participants are students or employees of the university with at least a basic understanding of prototyping electronics. The experiment is conducted in a closed room at the faculty, to minimize external stimuli.

During the experiment the participants got a presentation including a script with an explanation of the tasks and the setting (Appendix 9.6.6 & 9.6.7). The prototype is a simulated lighting system for greenhouses where the lights should be set to a strength and

not exceed a maximum. This can be done in multiple ways.

The experiment knows the following roles:

Participant: Simulator of the operator, does not have prior knowledge of the experiment.

Supervisor: Either the observer in Group A or the "replier" in Group B.

6.4.2 Study Design

During the experiment the participants were asked to perform tasks with a prototype and report their findings and procedure at the end of their tasks. Group (A) will conduct the RCA on paper with a 5 Why template and have no ability to communicate with the cognitive advisor. Group (B) conducted the RCA via the cognitive advisor which is able to support the participant with the 5 Why method.

6.4.3 Apparatus & System

6.4.3.1 Physical Prototype

The physical prototype (Figure 25) is created on an electronic breadboard, the schematic can be found in Figure 24. On the breadboard 3 high powered LEDs, a fuse holder with a fuse, a switch, and a potentiometer are mounted and wired accordingly. The plus/minus are connected to batteries in a battery case. The voltage over the system is measured by a volt meter that is connected to the system but powered separately. The prototype is protected by a 3D printed case which is partly removable for the issue solving assignment (Figure 25). A full list of the components can be found in Appendix 9.6.5.

There is no difference in the physical prototype or the interaction with the physical prototype for group A and B.

Participants of both group A and group B are given the following assignment:

- LEDs should be emitting light
- The LEDs should have brightness a value between 2.85 – 3.10
- The LEDs value should not go over 3.15
- Your shift takes 15 minutes

- Report your RCA via (A: 5 Why template, B: Cognitive advisor)
 Next to the assignment, all participants are given the following information as input from the prior (fictive) shift :

- The LEDs are not working
- Nothing is wrong with the wiring
- The Brightness meter is working properly

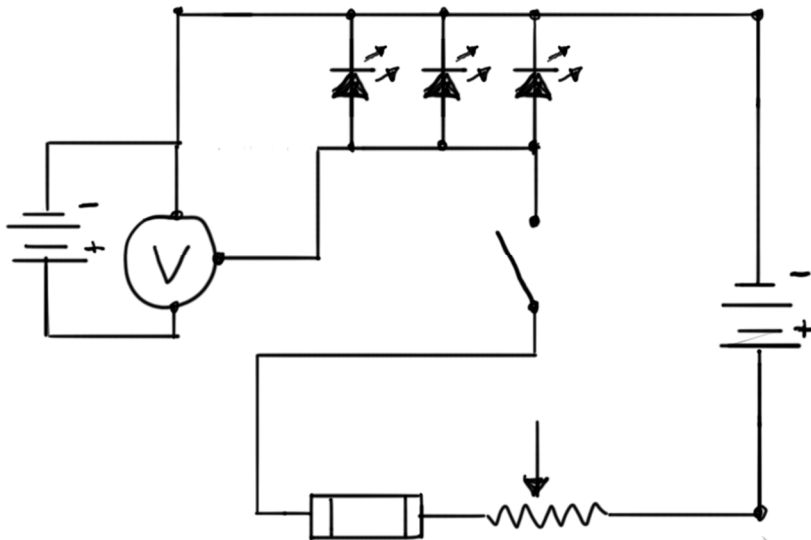


Figure 24 Physical prototype electronics schematics

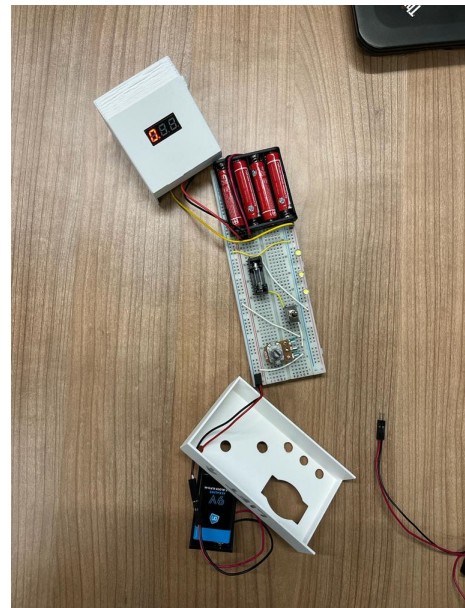


Figure 25 Left the prototype (in fixed state) with close case, right the prototype (in broken state) with open case

6.4.3.2 RCA Interaction prototypes

The way of conducting the RCA is different per test group:

Group A

Group A makes use of a paper 5 Why method template (See Figure 26 and appendix 9.6.3). This form is based on the yellow tags that are used at the Diversey factory in Bagnolo. The written form is being used during the experiment because no other way (such as computer forms) of using the 5 Why method directly without operators was found. Therefore this is the closest to a real world scenario. The participant is asked to do the given assignment and report their 5 Why steps via the form after solving the problem.

Group B

Group B interacts with a cognitive advisor that I developed by making use of the Wizard of Oz methodology (Laskowski, 2014). The participants speak to a computer that is connected to another computer in different room via Microsoft teams. The supervisor can hear the participants and gives an answer to their questions according to a flowchart in voiceflow (Voiceflow, n.d.) the complete overview can be found in Appendix 9.6.9. The premeditated answer to the questions are downloaded from Amazon Polly (Amazon Polly, n.d.) text to speech cloud service making use of the Neural, English, US female Joanna voice. All the utterances are placed into a soundboard made in PowerPoint (Figure 27) to be clickable by the supervisor. For the full soundboard overview see Appendix 9.6.8. The participants do not know they are not talking to a robot/computer.

On completion of the tasks the user can trigger the cognitive advisor and together they will execute the 5 Why method. The instructions of how this works is given on paper (see appendix 9.6.4) to the participants as well as the explanation in the presentation before the assignment. The steps are as follows:

The form consists of the following sections from top to bottom:

- Problem statement:** A large empty rectangular box.
- Step 1:** A box labeled '1.' with a 'WHY?' arrow pointing down to the next box.
- Step 2:** A box labeled '2.' with a 'WHY?' arrow pointing down to the next box.
- Step 3:** A box labeled '3.' with a 'WHY?' arrow pointing down to the next box.
- Step 4:** A box labeled '4.' with a 'WHY?' arrow pointing down to the next box.
- Step 5:** A box labeled '5.' with no arrow below it.
- Root Cause:** A rectangular box.
- Comments:** A rectangular box.
- Empty box:** A final empty rectangular box at the bottom.

Figure 26 Paper 5 Why template

1. Starting:

Participants can trigger the 5 Why method by saying:

“Hey COALA! I am ready to report”

Or

“Hey COALA! I am ready to start the 5 Why method”

2. The cognitive advisor starts the 5 Why method and asks the participant for the problem statement

3. The cognitive advisor and the participant go through the 5 Why method together, each time the participants answers a why question, the advisor rephrases the answer into a new why question

4. At any given time the participant is able to state the root cause by saying “I am ready to state the root cause”

5. After the root cause is stated by the participant, the cognitive advisor will asks for any other comments or remarks until the participant does not have another comment.

I. If a participant wants to stop the 5 Why method they can ask “Stop reporting” or “Stop the 5 Why method”, after confirmation the sequence will stop

II. If a participant wants to restart the 5 Why method they can ask “Restart reporting” or

“Restart the why 5 method”, after confirmation the sequence will restart

The participant instruction can be found in Appendix 9.6.4.

During the experiment a second screen will be shared with audio via Microsoft team, the screen has a COALA background and an audio level adjustable spectrum to indicate to the user that the cognitive advisor is talking and listening.

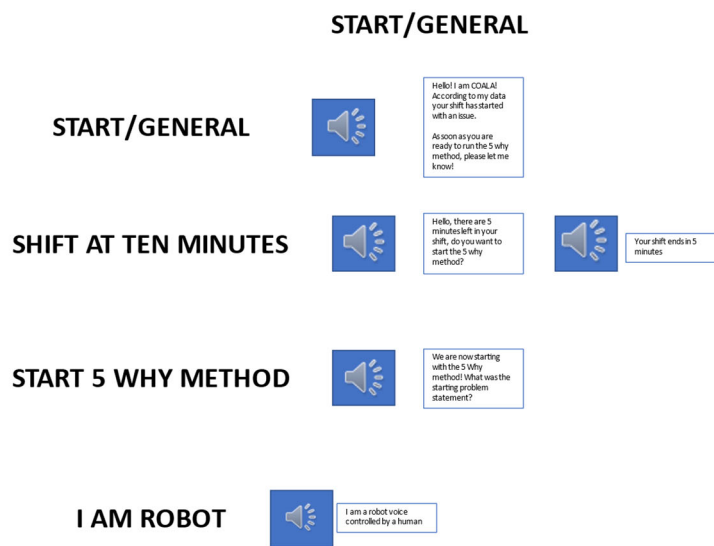


Figure 27 Slide 1 of 2 of the PowerPoint soundboard

6.4.3.3 Installation of the experiment room

Group A

The group A participant is seated in a room with the physical prototype and the 5 Why method paper template. Their actions are filmed and audio recorded for analytic purposes. The supervisor in a different room] to avoid intervening with the participants. For the overview of the room see Figure 28.

Group B

The group B participant is seated in a room with the physical prototype and a laptop/tablet that is actively connected to the computer of the supervisor. Their actions are filmed and audio recorded for analytic purposes. The supervisor is in a different room to communicate with the participants according to the voiceflow flowchart making use of pre-recorded audio files setup in a PowerPoint, but will not intervene with the participants. The screen of the supervisor is recorded to be able to see the interaction. For the overview of the room see Figure 29.

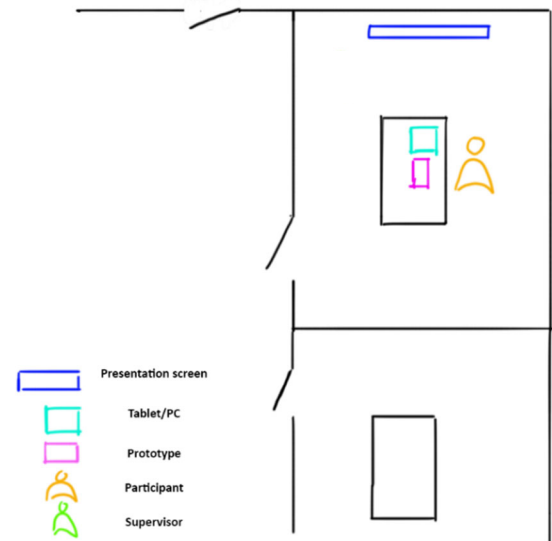


Figure 28 Group A room setup

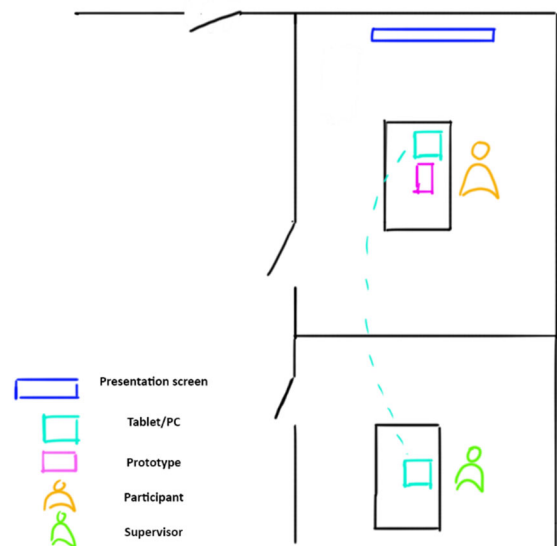


Figure 29 Group B room setup

6.4.4 Measures

The data that is collected is the same for each group. The data variables that are collected give insight in

- the background of the participant (age, gender, prior experience).
- the stress level and workload of the participant during the experiment (NASA TLX).
- the user experience of the participants (UEQ short)
- the performance of the participants (Time, .

The independent variable is the way of conducting the RCA; Group A: paper template, group B: Voice chat.

All variables can be seen in the table below (Table 11).

Questionnaire A is given directly after the completion of the assignment, questionnaire B will follow after A.

Variable description	Variable		Means of measurement	Related to hypothesis number
Group A/B	Group A = paper template RCA Group B = Voice chat supported RCA		Depending on time participant is participating (different day = different group)	-
Age	In years		Questionnaire B	-
Gender	Male Female Non-binary Do not want to Specify		Questionnaire B	-
Electronics experience	No - Professional Experience	Rated 1-10	Questionnaire B	-
Technical Problem solving experience	No – Professional Experience	Rated 1-10	Questionnaire B	-
NASA TLX	Mental demand	Rated 1-10	Questionnaire A (Directly after assignment)	4
	Physical demand			
	Temporal demand			
	Performance			
	Effort			
	Frustration level			
UEQ Short	Obstructive – supportive	Rated 1-7	Questionnaire A (Directly after assignment)	4
	Complicated – easy			
	Inefficient – efficient			
	Clear – confusing			
	Boring – exiting			

	Not interesting – interesting			
	Conventional – inventive			
	Usual – leading edge			
Total Time	From start of assignment till stating the root cause	Minutes. Seconds	Measured on stopwatch (during assignment) and/or Checked with video footage (after assignment)	3
Interaction Time	The time the participant is interacting with the 5 Why method (template or cognitive advisor)			
Problem Solving Time	The time the participant is solving the problem of the prototype			
Root cause description correctness	1 = Participant did not give a root cause	Rated 1-3	Observed (during assignment) and/or based on video footage (after assignment)	1
	2 = Participant indicated incorrect root cause (e.g broken fuse)			
	3 = Participant indicated correct root cause (Wrong battery pack (attached))			
Quality of data	1 = poor quality 2 = medium quality 3 = good quality	Rated 1-3	Based on the 5 Why steps and the quality check	2

Table 11 Variable overview

Data Quality check

To evaluate the quality and quantity of data that is mentioned or written down during the 5 Why method, the following awarding method

(based on earlier work by Kernan Freire (n.d.) is used.

In Table 12 an overview of the awarding system is shown:

Data type	Description	Award
Components	Identifying components such as “fuse”, “LED” ,or “potentiometer” (synonyms are also valid)	+1 point
Component state	Identifying the state of the component such as “broken”, “wrongly adjusted” or “misplaced” (synonyms are also valid)	+1 point
Combined	Combining the component and component state such as “broken fuse” if relevant	+1 point

Looping	If the “combined” data type has already been mentioned before and no other data of added value is mentioned	-1 point
----------------	---	----------

Table 12 Data quality scoring overview

With this awarding system each step in the 5 Why method can be analysed on the added value to the 5 Why report. This is of relevance to be able to analyse the data later. Or this could be helpful for the handover of the issue to the technical services or another

Component and component states are of importance to be able to use the data reported, it gives information of what happened and what the steps are during the RCA. A combination has more information than only a singular component or component state. The award system gives minus points for looping in the RCA as this is circular reasoning and gives no new information on the problem or root cause, only double information of what already has been mentioned. An example of the awarding system is shown in Table 13.

Step number	Description	Award
1*	The LED is broken	+3 points (component + state + combination)
2	The fuse is the problem	+1 point (component)
3	Potentiometer wrongly adjusted	+3 points (component + state + combination)
4**	Potentiometer set too high	-1 points (Looping)
		Total: 6 points

Table 13 Data quality scoring example

**If the problem statement was used as a first step, it also counts towards the score and the first step will not be count as looping if repeated, but will be ignored.*
***If the root cause statement is used as a final step, it also counts towards the score.*

The score will be divided over the total steps that are taken by the participant (including problem statement and root cause if used as first or final step). Otherwise scores that have

fewer steps because of the participant not knowing the next step are disproportionately charged. The scores will be ranked 1-3 as follows:

1 = bottom 33.3%

2 = middle 33.3%

3 = top 33.3%

6.4.5 Participants

The participants for the study were recruited on the TU Delft campus, the recruitment was done in the following ways:

- Mouth-to-mouth: actively asking people to join.
- QR-code scanning on signs around the experiment setup linking to a sign-up page.
- Spreading invitation via WhatsApp-groups with students with a link to a sign-up page

The minimal requirement of signup was having used a breadboard before.

The participants were able to sign in to a free timeslot of their own choosing between 9:00-18:00 or 19:30 – 21:30.

During the first minute of the introduction lecture and before recording started, all participants were asked to read and sign a consent form (see appendix 9.6.1 & 9.6.2). The participant is asked to comply with the variables to be gathered (via video) and analysed and explained what happens with this data. At this moment the participant has the possibility to opt-out of the experiment without any data gathered or recorded.

6.4.6 Step by step

Every participant is received in the same room, after the consent form is signed they get a presentation with information about the experiment and the tasks that are to be performed. (See appendix 9.6.6 & 9.6.7). This presentation gives the participant the following explanation:

- Introduction
- Roadmap of the experiment
- Scenario of the experiment
- Explanation of the 5 Why method
- Explanation of the RCA reporting
 - o Group A: Paper template
 - o Group B: Voice chat
- Overview of the prototype/items
- Goals of their assignment
- Report of the previous shift
- The last PowerPoint slide with the report from the previous shift and the participants assignment will stay on the screen during the experiment.

Both group A and B start the experiment with the same “broken” prototype, the fuse is burned because A too highly powered battery pack is connected (Figure 30). The participants task is to problem solve the issue. The goal is to **fix** the LEDs and set them to a number between 2.85 & 3.10 volts, the LEDs should not be exceed a voltage of 3.15. This means that

the participants can solve the problem in two ways, one way in which the LED is burning correctly but it can exceed the power limit (non-optimal solution) and one way where it cannot exceed the limit (optimal solution).

To give the participants a time pressure their shift takes 15 minutes. Within this time they should:

- Solve the problem
- Identify the root cause
- Report via 5 Why
- State the root cause

The participant gets the following tools, components and spare parts to use (Table 14):

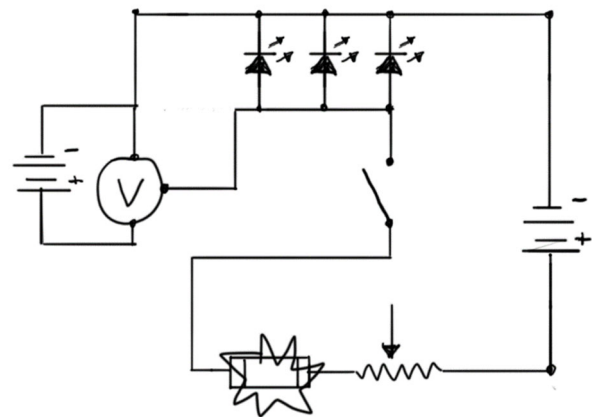


Figure 30 Prototype schematic with broken fuse indicated

Group	Component/Tool
Spare parts	High Powered LED
	Wires
	Fuses
	Potentiometer
	Switch
	Fuse holder
Battery packs	1.5 Volt
	3 Volt
	4.5 Volt
	6 Volt
	9 Volt
Diagnostics	Multimeter
	Component List
	Paper template or Voice assistant

Table 14 Tools and component overview

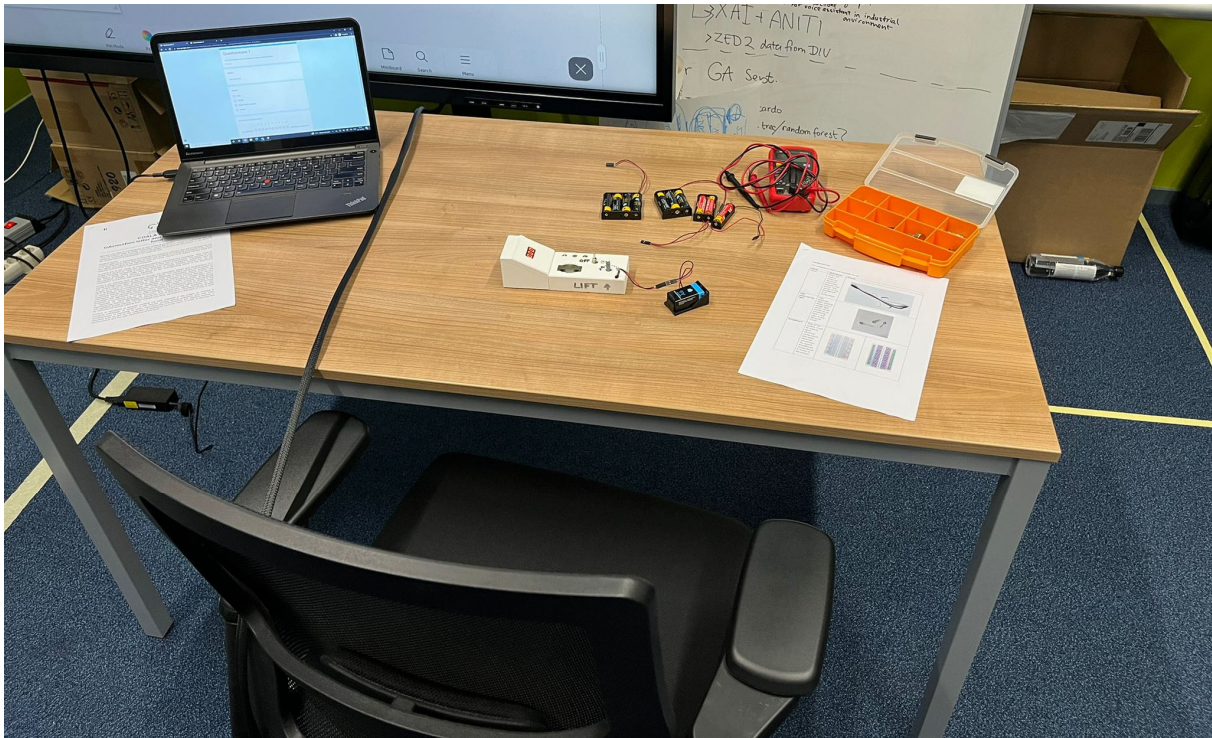


Figure 31 From left to right, consent form, laptop for forms/voicechat, "broken" prototype, Battery packs, Multimeter, Spare components & component List.

The experiment takes a maximum of 25 minutes per participant depending on the solving speed of the participant and excluding preparation and setting up. The experiment table preparation of group B can be seen in Figure 31. Per group A and B the step by step

sequence can be found in Table 15 & Table 16 respectively. For both groups the maximum amount of time of 15 minutes used for RCA and reporting has been taken into account, without assuming group A or B is faster in problem solving.

Group A		
Step No	Description	Time indication in minutes (Cumulative)
1	Invite participant in room	0:00
2	Participant reads & signs consent form (A)	1:30
3	Give the participant explanation via PowerPoint (A)	4:00
4	Start video recording	4:30
5	Start tasks (and timer)	5:00
6	Reminder that participants shift is almost over and should start reporting	15:00
7	Participant reports their RCA via the 5 Why template	19:00
8	Participant will write down their found root cause	20:00
9	Participant fills out questionnaire A: NASA TLX UEX Short Open feedback	22:00

10	Questionnaire A asks for: Name (not used in dataset) Age Gender Electronics experience	22:30
11	Thank participant for participation	23:00

Table 15 Timetable overview Group A

Group B		
Step No	Description	Time indication in minutes (Cumulative)
1	Invite participant in room	0:00
2	Participant reads & signs consent form (B)	1:30
3	Give the participant explanation via PowerPoint (B)	4:00
4	Start video recording	4:30
5	Supervisor moves to other room	4:40
6	Supervisor starts timer and gives voice chat indication that the shift has started and if the participant can hear the voice chat	5:30
7	Reminder that participants shift is almost over and should start reporting	15:30
8	Participant reports their RCA via the voice chat	19:30
9	Participant will state their found root cause	20:30
10	Participant fills out questionnaire 2: NASA TLX UEX Short Open feedback	22:30
11	Questionnaire A asks for: Name (not used in dataset) Age Gender Electronics experience	23:00
12	Thank participant for participation	23:30

Table 16 Timetable overview Group B

6.4.7 Analysis method

For analysing the data gathered during the experiments SPSS statistics is used.

To know which kind of statistical test should be used the variables are tested on normal distribution per group.

To determine if the data was normally distributed per variable making use of the Sharipo-Wilk test (Shapiro & Wilk, 1965). The Sharipo-Wilk test was chosen because the sample group is $n < 50$. Since the groups were relatively small it's quite likely that not all variables will have a normal distribution. If one of the groups does not have a normal

distribution, both group variables will be treated as not a normal distribution.

After the distribution is determined the data is tested for significant differences between groups by using:

- Mann-Whitney U test if the data is **not** normally distributed
- Independent-Samples T test if the data **is** normal distributed

A 95 percentile mark is used for significance so, with value $p < 0.05$ a significant difference is deemed between group A and group B.

To analyse if the different groups had any influence on the fact that the root cause was found, the Chi Square independence test is used.

6.5 Results

6.5.1 Participants

A total of 25 participants joined in the experiment (Figure 32), all participants were (recent graduated) students from Delft University of Technology or The Hague University of applied sciences, to ensure a minimal level of basic electronics and technical knowledge. Besides that a minimal requirement was that the participant at least once made use of a breadboard.

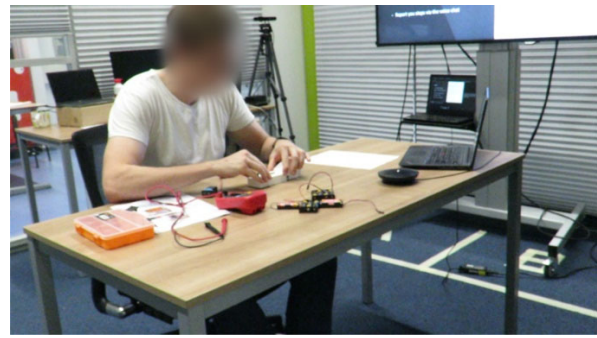


Figure 32 Group A participant right and Group B participant left

From the data analyses 5 of the 25 participants were deemed insufficient to use for the statistical analysis due to:

- Not understanding the assignment (e.g. not able to problem solve anything)
- Circumventing the assignment (e.g. hooking up the battery packs straight to the LEDs)
- Starting with a different 0 state (e.g. unintended broken part that was missed during the setup)

This resulted in the following participant groups:

Group A: 10 participants (n = 10)

Group B: 10 participants (n =10)

6.5.2 Normal distribution

In appendix 9.6.10 the results of the Shapiro-Wilk Test can be found, the numbers that are significant are bold. In the last column the appropriate test is indicated. If the p value is smaller than 0.05 the null hypothesis can be rejected and distribution can be assumed as not normal.

From all the variables 9 had normal distributed data and are tested with the independent-t test and 11 have non-normal distributed data and are tested with a Mann-Whitney U test.

6.5.3 Experience Level

In Figure 33 the results of the experience with electronics and technical problems solving are shown.

The participants Electronics experience scores of Group A ($Mdn = 6.5, n = 10$) were higher than group B ($Mdn = 5.0, n = 10$). However a Mann-Whitney U test indicated that this is a **non-significant difference** [$U = 45.5, z = -.680, p = 0.496$].

Technical Problem Solving Experience

The participant technical problems solving experience are close, but group A ($M = 6.6, SD = 2.12, n = 10$) is slightly lower than group B ($M = 6.8, SD = 2.251, n = 10$). An Independent Samples T test indicates that there is **non-significant difference** [$t(18) = -.205, p = .840$].

Electronics Experience

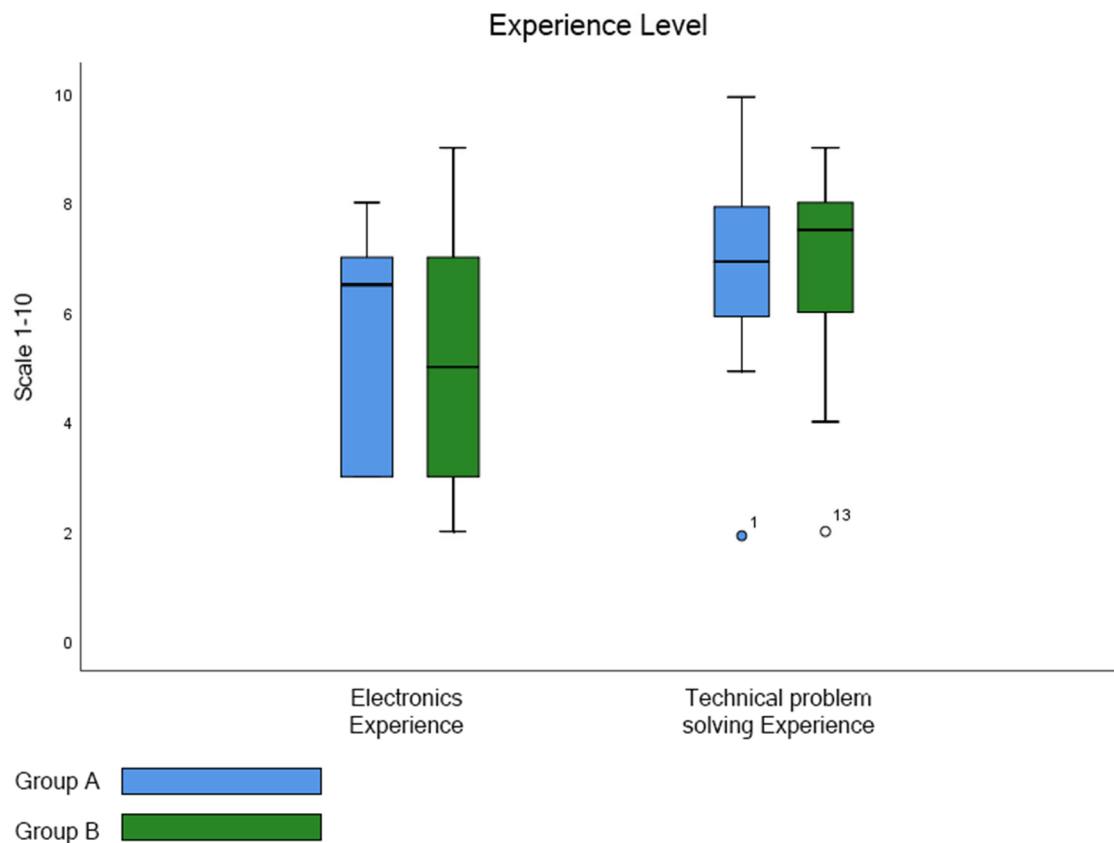


Figure 33 Experience of study's participants: On the y-axis the scale from 1-10, on the x-axis the type of experience, no significant differences found

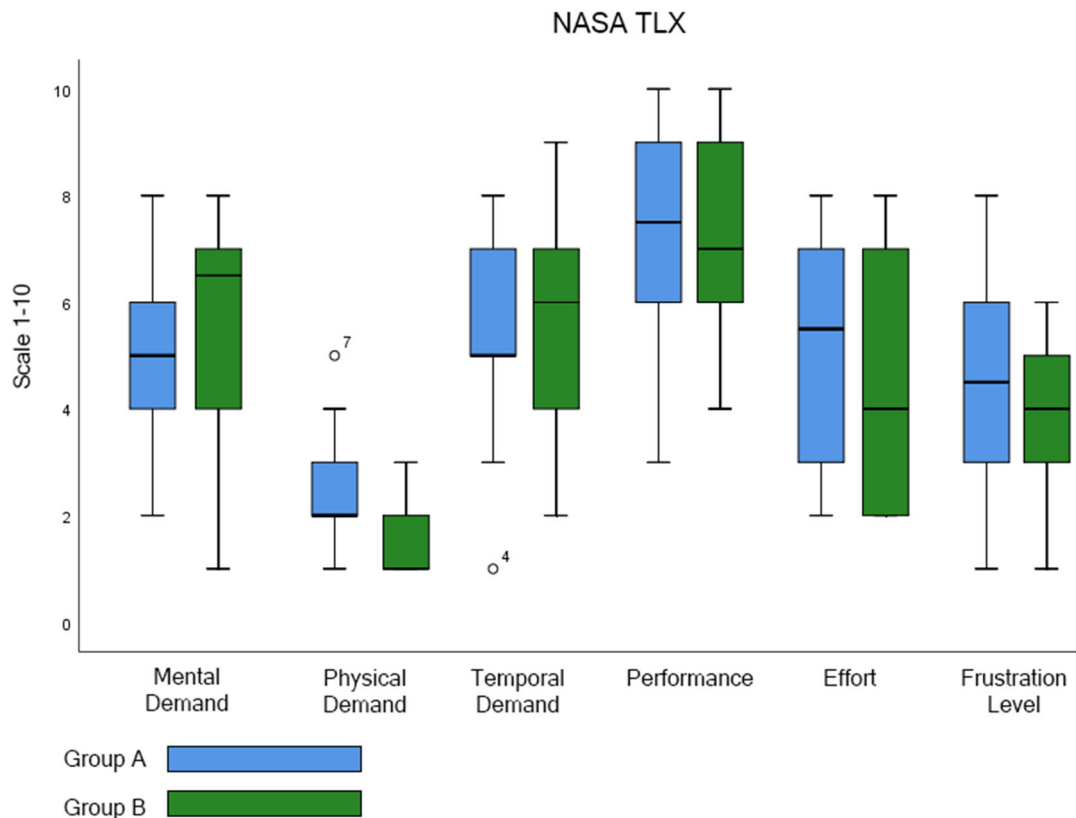


Figure 34 NASA TLX results of the study: On the y-axis the scale from 1-10, on the x-axis the variables, no significant differences found

6.5.4 NASA TLX

In Figure 34 the results of the NASA TLX questionnaire are shown.

Mental Demand

Both participant groups experienced a medium mental demand during the assignment but Group A ($M = 5.1$, $SD = 1.729$, $n = 10$) experienced a lower mental demand than group B ($M = 5.6$, $SD = 2.221$, $n = 10$). An Independent Samples T test indicates that there is **non-significant difference** [$t(18) = -.562$, $p = .581$.]

Physical Demand

Both participant groups experienced a low physical demand during the assignment but Group A ($Mdn = 2.0$, $n = 10$) experienced a higher physical demand than group B ($Mdn = 1.0$, $n = 10$). However a Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 34.5$, $z = -1.532$, $p = .126$].

Temporal Demand

Both participant groups experienced a medium temporal demand during the assignment but Group A ($M = 5.3$, $SD = 2.111$, $n = 10$) experienced a lower temporal demand than group B ($M = 5.5$, $SD = 2.273$, $n = 10$). An Independent Samples T test indicates that there is **non-significant difference** [$t(18) = -.204$, $p = .841$].

Performance

Both participant groups gave themselves a medium-high performance rank, group A ($M = 7.2$, $SD = 2.098$, $n = 10$) slightly higher than group B ($M = 7.1$, $SD = 1.912$, $n = 10$). An Independent Samples T test indicates that there is **non-significant difference** [$t(18) = .111$, $p = 0.913$].

Effort

Both participant groups ranked the assignment with medium effort, group A ($M = 5.1$, $SD = 2.173$, $n = 10$) slightly higher than group B ($M = 4.6$, $SD = 2.271$, $n = 10$). An Independent

Samples T test indicates that there is **non-significant difference** [$t(18) = .520, p = .610$].

Frustration Level

Both participant groups ranked the assignment with a medium frustration level, group A ($M = 4.5, SD = 2.025, n = 10$) slightly higher than group B ($M = 3.8, SD = 2.271, n = 10$). An Independent Samples T test indicates that there is **non-significant difference** [$t(18) = .857, p = .403$].

6.5.5 UEQ Short

In Figure 35 the first part of the results of UEQ short questionnaire are shown, the second part can be found in Figure 36.

Obstructive-Supportive

The paper template (A) as well as the cognitive advisor (B) were perceived as supportive, but the participants in group A ($Mdn = 5.5, n = 10$) found the paper template to be more supportive than group B ($Mdn = 5.0, n = 10$) the voice assistant. However a Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 49.0, z = -.439, p = .661$].

Complicated-Easy

Both groups found the support method easy to understand, but the participants in group A ($Mdn = 6.0, n = 10$) found the paper template to be less easy than group B ($Mdn = 7.0, n = 10$) the voice assistant. However a Mann-Whitney U test indicated that there is a **non-significant**

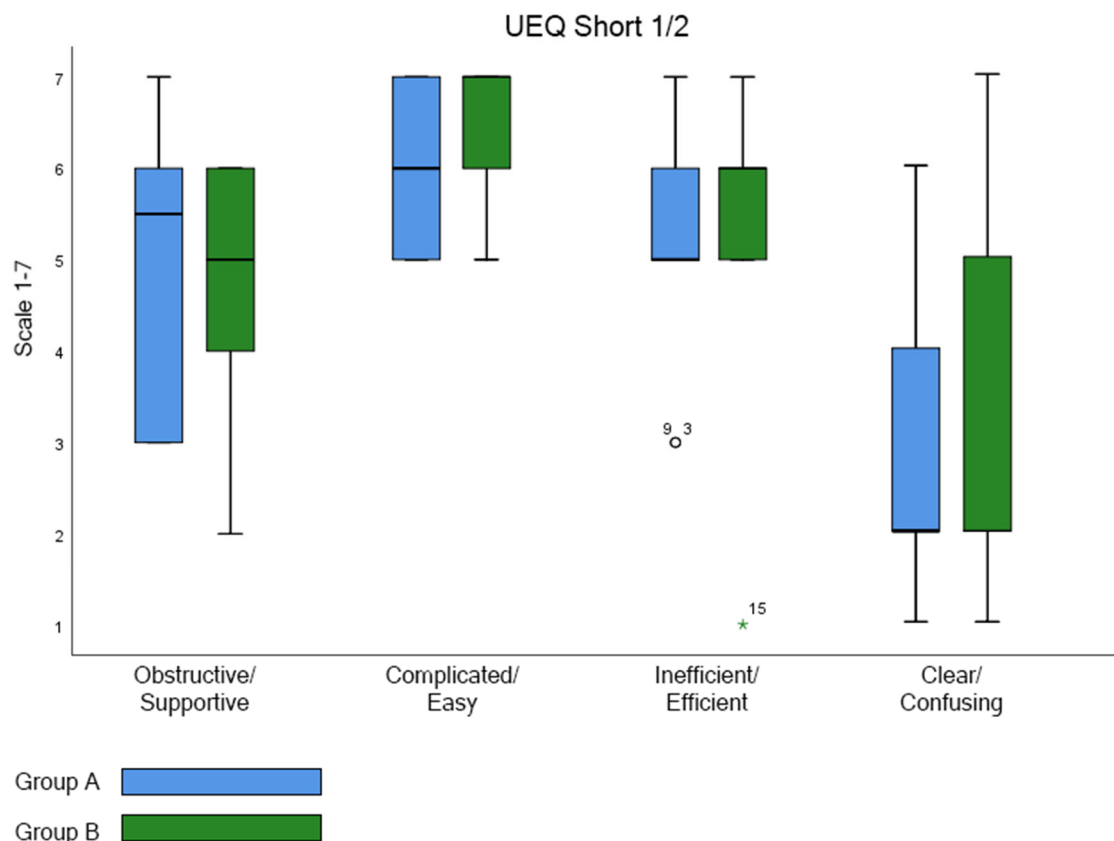


Figure 35 UEQ short results 1/2: On the y-axis the scale from 1-7, on the x-axis the variables, no significant differences found

difference [$U = 47.0, z = -.606, p = .544$].

Inefficient-Efficient

Both groups found the support method efficient, but the participants in group A ($Mdn = 5.0, n = 10$) found the paper template to be less efficient than group B ($Mdn = 6.0, n = 10$) the voice assistant. However a Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 41.5, z = -.999, p = .318$].

Clear-Confusing

Both groups found the support method equally clear, the participants in group A ($Mdn = 2.0, n = 10$) found the paper template to be as clear as group B ($Mdn = 2.0, n = 10$) the voice assistant. Evidently Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 45.5, z = -.724, p = .469$].

Boring-Exciting

Group A ($Mdn = 3.0, n = 10$) found the paper template to be more boring and group B (Mdn

$= 4.0, n = 10$) found the voice assistant to be more exciting. A Mann-Whitney U test indicated that there is a **significant difference** [$U = 26.0, z = -2.121, p = .034$].

Not Interesting-Interesting

Both groups found the support method interesting, but the participants in Group A ($Mdn = 5.0, n = 10$) found the paper template to be less interesting than group B ($Mdn = 5.5, n = 10$) the voice assistant. However a Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 42.0, z = -.943, p = .345$].

Conventional-Inventive

Both groups found the support method inventive, but the participants in group A ($M = 4.6, SD = 1.265, n = 10$) perceived it as less inventive than group B ($M = 5.5, SD = 1.269, n = 10$). However an Independent Samples T test indicates that there is **non-significant difference** [$t(18) = -1.588, p = .130$].

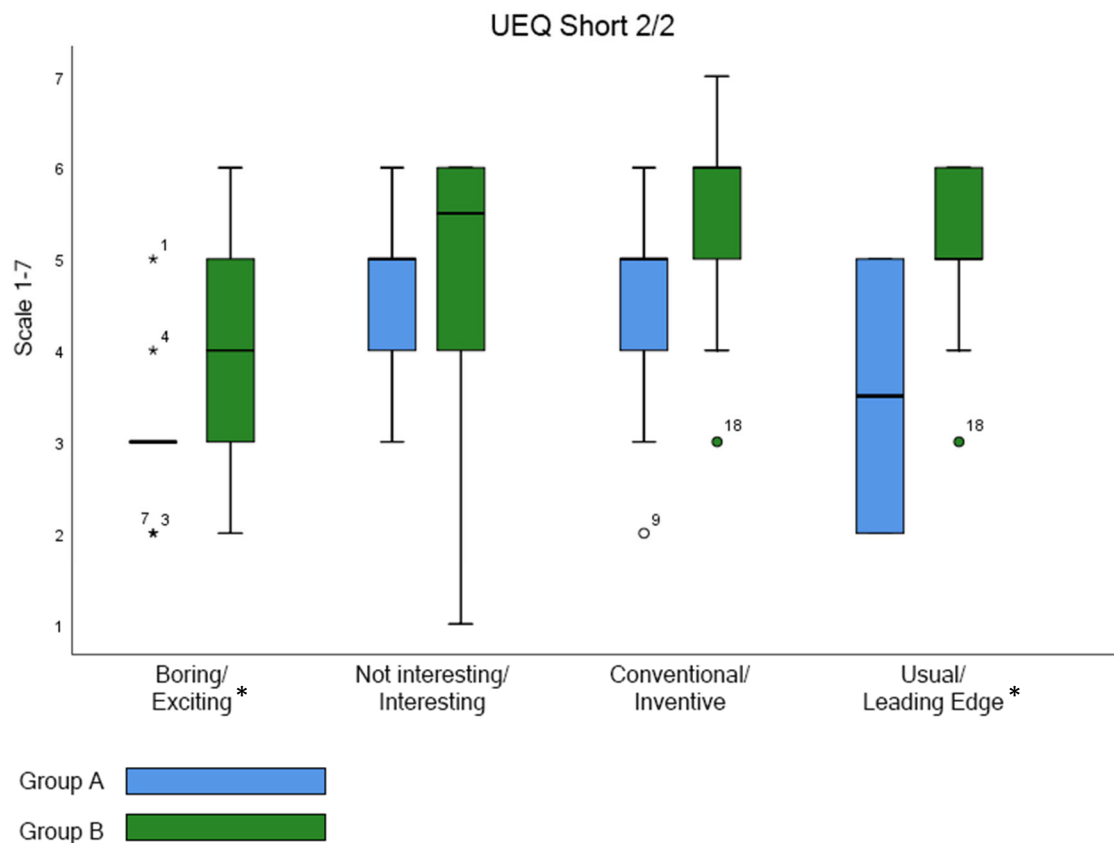


Figure 36 UEQ short results 2/2: On the y-axis the scale from 1-7, on the x-axis the variables, significant differences: Boring/exiting, Usual/Leading Edge

Usual-Leading edge

Group A ($Mdn = 3.5, n = 10$) found the paper template to be not very usual but also not very leading edge, group B ($Mdn = 6.0, n = 10$) found the voice assistant to be more leading edge. A Mann-Whitney U test indicated that there is a **significant difference** [$U = 15.5, z = -2.858, p = .004$].

6.5.6 Root Cause

In Figure 37 results of the root cause correctness and data quality can be found.

Root Cause Description Correctness

Both groups have the same median scores for the root cause description correctness, the participants in Group A ($Mdn = 3.0, n = 10$) had the same findings as group B ($Mdn = 3.0, n = 10$). A Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 51.0, z = -.330, p = .741$].

Root Cause found per group

A Chi-Square Test of independence is performed to assess the relationship between how many times participant found the root cause and their participant group. There is a non-significant difference between the two variables [$X^2(1, 20) = 0.000, p = 1.000$]. Both groups got exactly the same results.

Data Quality

Group A ($Mdn = 1.5, n = 10$) has a lower data score than group B ($Mdn = 3.0, n = 10$). A Mann-Whitney-U test indicated that there is a **significant difference** [$U = 19.5, z = -2.445, p = .014$].

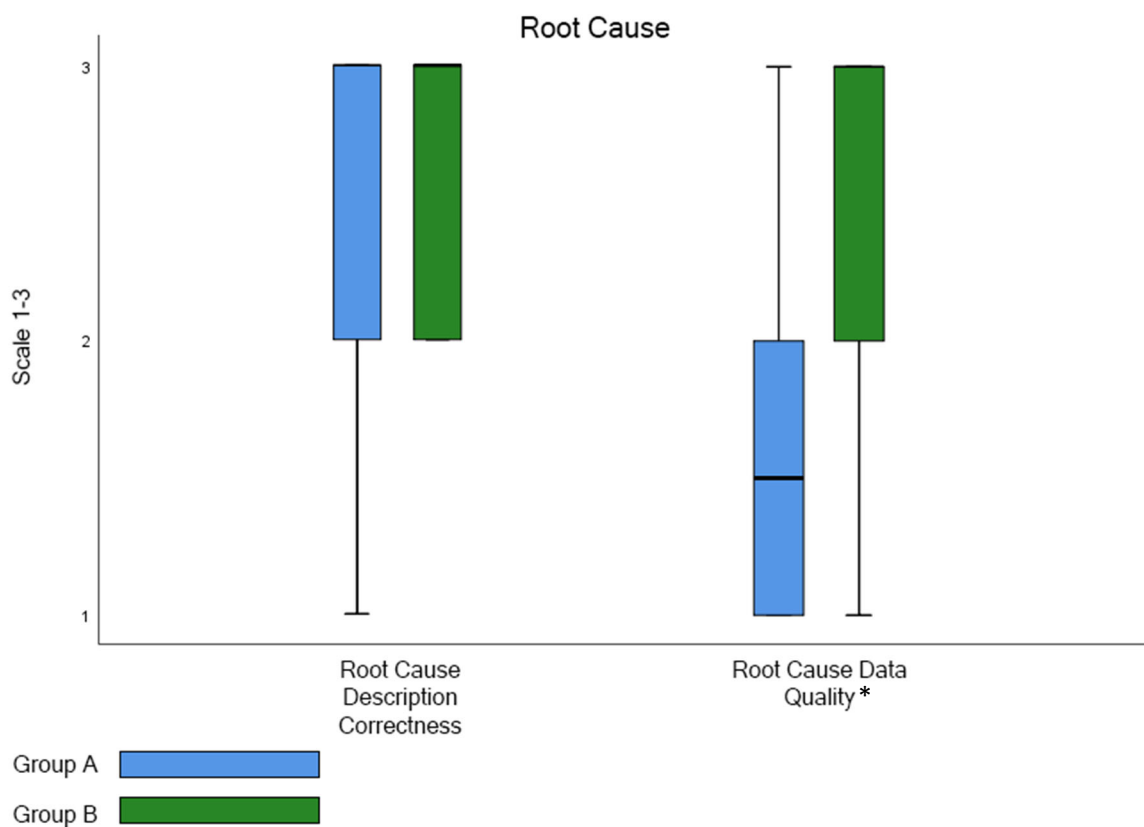


Figure 37 Root Cause analysis results, on the y-axis the scale from 1-3, on the x-axis the variables, significant differences found in Root Cause Data Quality

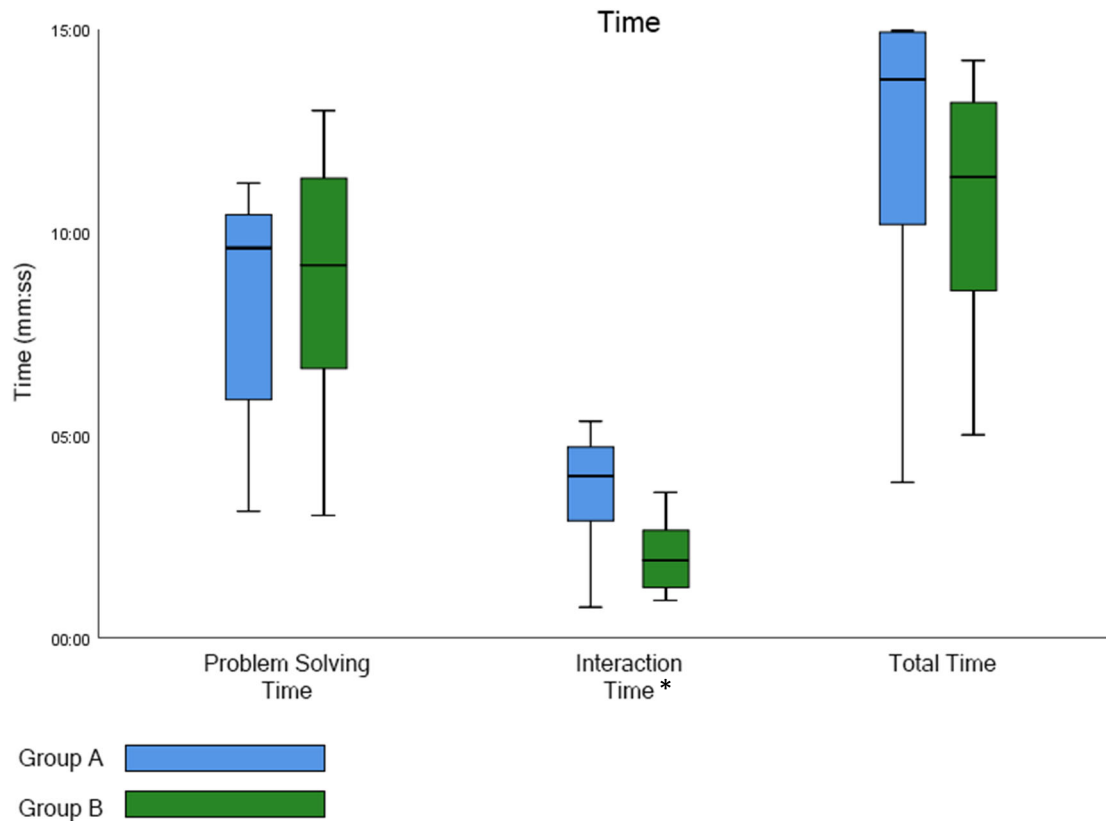


Figure 38 Time result, on the y-axis the time in mm:ss, on the x-axis the variables, significant differences found in Interaction Time

6.5.7 Time

In Figure 38 the time results of the assignment are shown.

Problem Solving Time

Group A (M = 08:24 (mm:ss), SD = 02:43 (mm:ss), n = 10) has nearly the same mean problem solving time as group B (M = 08:37 (mm:ss), SD = 03:24 (mm:ss), n = 10). An independent T test confirmed an indication that there is a **non-significant difference** [$t(18) = -.151, p = 0.881$].

Interaction Time

Group A (M = 03:37 (mm:ss), SD = 01:22 (mm:ss), n = 10) has a higher interaction time than group B (M = 02:03 (mm:ss), SD = 00:52 (mm:ss), n = 10). An independent T test indicated that there is a **significant difference** [$t(18) = .3078, p = .006$].

Total Time

Group A (Mdn = 13:48 (mm:ss), n = 10) has a higher total time than group B (Mdn = 11:24 (mm:ss), n = 10), However a Mann-Whitney U test indicated that there is a **non-significant difference** [$U = 40.0 z = -1.056, p = .291$].

6.6 Key Findings

6.6.1 Hypothesis 1 (Rejected)

Hypothesis 1 (Primary): Participants with the help of the cognitive advisor will more often come closer to the root cause than the participants without. (RQ P.1)

I expected that participants with the help of the cognitive advisor would find the root cause more often, but the test results indicate there is no significant difference between the paper template and the cognitive advisor, therefore **this hypothesis remains unproven**.

6.6.2 Hypothesis 2 (Supported)

Hypothesis 2 (Secondary): Participants with the help of the cognitive advisor will give more

quality data during RCA than participants without.

I expected that the quality of the data given as input with the cognitive advisor would be higher than those with the paper template. The test result indicate that indeed there is a significant difference in favour for the cognitive advisor, therefore ***this hypothesis is supported.***

6.6.3 Hypothesis 3 (Rejected)

Hypothesis 3 (Secondary): Participants with the help of the cognitive advisor will conduct the experiment assignment (problem solving & fixing + RCA) faster than the participants without.

I expected that participants with the cognitive advisor would conduct the assignment faster, but the test results indicate that there is no significant difference between the total time of the participants in the different group, therefore ***this hypothesis remains unproven.***

However the test results do indicate that the interaction time is shorter for those making use of the cognitive advisor.

6.6.4 Hypothesis 3 (Rejected)

Hypothesis 4 (Secondary): Participants with the help of the cognitive advisor will feel more comfortable and less stressful during the performance of the experiment assignment (problem solving & fixing + RCA) than the participants without.

I expected that the participants with the cognitive advisor would feel more comfortable during the assignment, but both the NASA TLX as the UEQ short results indicate that there is no significant difference in comfort level of the participant. The only difference that can be supported is that the participant found the cognitive more exiting and more leading edge than the paper template. This means that ***this hypothesis remains unproven.***

7 Discussion, Recommendations & Conclusions

7.1 Discussion

7.1.1 Main findings user study

Finding root cause

Unfortunately no difference was proven between the ability to find the root cause with or without the aid of the cognitive advisor.

This result could be explained by several factors: (1) Participants are asked to first do the problem solving and then start with the 5 Why method, making the problem solving a separate task, which is also indicated by the fact there is no significant difference between the 2 groups in problem solving time. (2) The problem that the participants faced was not complex enough to be able to create a notable difference as more than 70% of the participants were able to find the correct root cause. This was not expected since only (2) The participants first got a mini lecture in the 5 Why method already “triggering” their mind into thinking in “whys”.

Data quality

The results indicate that the quality of data is higher if the cognitive advisor is used.

This could be explained by the following factors: (1) Because the cognitive advisor rephrases the previous answer into a new question, the participant is pushed towards a “better” answer. (2) The paper template gives a lot of freedom and many rephrasing possibilities that it becomes confusing to the participant. (3) Because running the 5 Why method with the cognitive advisor is faster, participants are inclined to give more details.

Stress level & workload

The results indicate that there are no differences between the comfort and workload

level of using the paper template and the cognitive advisor.

Possible explanations could be: (1) The assignment was not extensive enough for the participants to have a noticeable difference. (2) Talking with a cognitive advisor to run the 5 Why method is new to the participants and takes some time to feel comfortable with. (3) the participants simply are not more comfortable or less comfortable by using paper or a cognitive advisor.

What can be noted is that the results were quite positive as both the paper and cognitive advisor were easy and clear to use in a supportive way. All of the participants were able to interact with the cognitive advisor and had a positive experience in doing so.

Time factors

The problem solving time did not differ largely between the two groups. The amount of interaction time the participants needed for conducting the 5 Why method with the cognitive advisor was significantly less than those with the paper template, but this did not have enough impact to significantly influence the total assignment time.

This result could be explained by the following factors: (1) There was no difference between the problem solving time as participant were asked to first complete the assignment and then do the 5 Why reporting. (2) Talking is more efficient than writing. (3) The experience with (electronics/technical) problem solving has a larger impact than the usage of the 5 Why method.

Results side note

In the results you can see that group B is often closer to the preferred result than group A, but without a significant indication, this could very

well be different if more participant would be added to the study, as for the current results the minimum of 20 participants was used.

7.2 Limitations

The first and foremost risk: this thesis was (partly) executed during the COVID-19 pandemic. This has influenced many aspects of the project. The ability to work properly together with the TU Delft team, being able to visit the Diversey factories and conducting on-site research and interviews, the closing of the TU Delft faculties and the forced working from home.

As this graduation project is a small part of the larger COALA project. There are some dependencies that cannot be influenced, for example other partners need to deliver works such as the voice-to-text part of the project. The data that is necessary to improve and test the concepts of this thesis was to be provided by the business partners but did not always exists or is of questionable quality and quantity.

The operators from Diversey are on a tight work schedule and had limited time to answer questions and especially participate in research. Besides that the use of actual machines at location for research was not possible, which is the reason for conducting local experiments.

7.2.1 User Study limitations

This study includes many factors and had a very broad-based scope, this comes with some Limitations. Below the limitations are explained per category, in cursive the measures taken to minimize the impact of the limitation

Not the real environment

Ideally the study would have been done with the operators at the actual factory in a realistic environment to be able to get close to actual experience.

Participants from a specific demographic were asked to join to minimize the differences

between the prior experience of the participants.

Not a real cognitive advisor

The cognitive advisor was controlled by a human and not a computer, to simulate a good working product, if this would be a computer the interaction might have been different.

To be able to come as close as possible to a computer-human interaction the participants did not know they were not interacting with a computer, the answers given to them were in a robot voice.

Exterior influences of participants

Participants condition, such as stress, tiredness, distraction level, private matters, hunger, illness, etc. at the start or during the experiment can all be of influence.

Participants were able to pick their own timeslot to participate, giving them to opportunity to pick a spot that fits the best in their planning.

Environmental factors such as noise, light, smell or temperature could all have been of influence.

The lower the impact of this factor, the study was conducted in a closed environment with minimal external influences.

Participant instructions

Before the assignment quite an extensive explanation with a mini lecture on the 5 Why method was given to the participant. It can be different per participant how well they understood the assignment. Also the way of learning of the may have been an influence on the conducting of the assignment and the results of the experiment.

The introduction was kept as concise as possible, instruction that were necessary to remember were also printed out and available to the participants.

Cognitive advisor

The intent of the utterances were processed by a human and not a machine, this influences the responses, as a human brain processes the intents in a different way than a preprogrammed piece of software.

Only predetermined answers were picked from a soundboard following a flowchart, if it did not fit any of the replies a standard question for elaboration followed.

7.3 Conclusions

7.3.1 Conclusions: User Study

This study aimed to **show a significant improvement of finding the root cause** with the 5 Why method **using a cognitive advisor** instead of a paper template, unfortunately this was **not proven by the results**.

It does however show that the time **conducting the 5 Why method** is significantly **more efficient with the cognitive advisor** with an improvement in the data quality over the paper template.

The comfort and workload factors that were measured could **not give a significant outcome** to either one group or the other. But the result in overall were positive, so the **participants did enjoy** or were at least not annoyed by the **interaction** with the cognitive advisor.

This study has shown that a cognitive advisor can give an advantage for operators, but cannot be conclusive yet as to what extent. This subject needs to be researched more and this study gives a base for further explorations.

7.3.2 Conclusions research questions

The goal of this thesis project is to support manufacturing operators by conducting root cause analyses with the aid of a cognitive advisor. To reach this goal I set out to answer the following question

“Can a cognitive advisor support operators with root cause analysis”

Below I answer the research sub-questions per cluster.

User (operators):

“How to communicate between the operator and the cognitive advisor about the root cause analysis?”

“Does root cause analysis with a cognitive advisor decrease the stress level of the operator?”

There are multiple technical options to communicate between the cognitive advisor and the operator, for the prototype accompanying this thesis the conversational agent rasa was used. The real question is how the communicative interaction between should be done. In the user study iterations this was one of the main challenges. It should be clear to the operators when they want to start the communication and how they want to start the communication, if the conversation has started, the flow goes quite naturally. In the prototype this was solved by adding a “trigger”.

From the user study I have to conclude that from the current design there is not a difference in comfort based on stress levels and user experience by using the cognitive advisor as opposed to the current way of work. Of course this is hard to translate to the real life situation as comfort can be short term and long term. On the long term benefits for user experience and the decrease of stress levels more research is needed.

Performance:

“Does root cause analysis with a cognitive advisor increase the chance of coming closer to the root cause?”

As stated in the user study, I could not prove a significant difference of a higher chance of finding or coming closer to the root cause.

“Does root cause analysis with a cognitive advisor decrease problem solving time?”

The problem solving time itself was not improved, but the interaction time with the cognitive advisor compared to the paper template is significantly faster.

“Does root cause analysis with a cognitive advisor increase the quality of reporting data?”

The quality of data is significantly higher by making use of the cognitive advisor, this should be of increased value for data analysing.

Technical:

“What are the current root cause analysis practices?”

Many tools and methods of root cause analysis are on the market, there is little to no literature on the success factor of the specific tools. For this thesis the 5 Why method was picked because it was being used at the business case and it is a conversational heavy RCA method.

“How to use existing root cause analysis tools in a cognitive advisor?”

The 5 Why tool is incorporated in the conversation of the cognitive advisor, by rephrasing the problem statement to a question the operator is supported in conducting the method, but as stated above, it is not proven that this is an improvement over the current standards.

“How to save and archive the root cause analysis and its steps in the system for later use?”

The cognitive advisor is connected to a graph database, this database works with nodes and relations that are able to save the history of the RCA steps and can be used for later use.

To answer the main research question:

“Can a cognitive advisor support operators with root cause analysis”

I answer with a cautious yes. As stated before, this area is in need of more research on which this thesis and prototype can contribute to. The

operator is supported by a faster interaction time and can provide increase quality data.

7.4 Future work & Recommendations

7.4.1 user study

The experiment itself has opportunities for further research by using this experiment as a base:

- Conducting the experiment with more participant for more input
- Focusing the experiment to specific cases:
 - o it can be adapted to focus on doing the 5 Why method during the problem solving vs after.
 - o Different ways of conducting the 5 Why method e.g. rephrase vs open questions
 - o Incorporating different RCA techniques
- Translating this experiment into a study that can be conducted on the work floor with actual operators.
- Use the variables of this study and measure them over a longer period of time during normal working hours while giving operators different tools to conduct the 5 Why method.
- Use this experiment with different variables such as measuring the difference between a loud and quiet environment

Next to using the experiment as a base for further research it peaks the interest for research in related areas:

- How can the data from the root cause analysis be effectively analysed?
- How can the data together with the cognitive advisor be used to give recommendations to the operators?
- How to make use of current in use machine systems such as PCL data?
- How can a cognitive advisor help operators in other ways than with

reporting issues and conducting root cause analysis?

- How can the context of the operators be of use to come to a more efficient root cause analysis?

7.4.2 General

7.4.2.1 Research

As stated throughout the report, the specific area of root cause analysis with operators has not much research available, to further explore opportunities I would suggest but not limit to the following topics.

- Cognitive advisor use on the line by operators
- RCA & Operator interaction
- Beneficial RCA for manufacturing
- RCA and machine learning in manufacturing

- Problem solving capturing by operators

7.4.2.2 Prototype

The current prototype can be a base for future added functionalities and additions or interfaces

Added functionalities:

- Recommendation of solutions based on previous RCA
- Report straight to technical services
- Incorporate different types of root cause analysis
- Include ML to analyse data
- Update conversational AI vocabulary based on the input of operators

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9 Appendix

9.1 Project Brief

Personal Project Brief - IDE Master Graduation



Root cause analysis implementation in COALA (cognitive voice assistant) project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 08 - 11 - 2021

15 - 04 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,..), technology, ...).

The project will take place in the context of the COALA initiative. COALA (COgnitive Assisted agile manufacturing for a LAbor force supported by trustworthy Artificial Intelligence) aims to develop a human-centred Digital Intelligent Assistant that provides a more proactive and pragmatic approach to support operative situations characterized by cognitive load, time pressure, and little or zero tolerance for quality issues.

The COALA consortium (<https://www.coala-h2020.eu/>) exists out of 14 partners representing research institutes (among which the TU Delft), technology providers and industrial partners from 5 EU member states. The COALA project has a timeline of 3 years and is divided over different work packages assigned to different stakeholders.

The objectives of COALA are:

- Reduce the number of quality incidents in manufacturing
- Overcome barriers regarding the use of a voice-enabled digital assistant in manufacturing (Acceptance)
- Reduce the time needed for on-the-job training of workers in manufacturing
- Improve competencies of manufacturing workers in managing AI opportunities

COALA is aiming to change the current practices of issue handling for operators. An abstract overview of the issue handling can be found in Figure 2.

For my graduation the focus will be on root cause analysis in COALA at Diversey, a worldwide hygiene and cleaning company. In the COALA project two sites of Diversey are participating one in Enschede (Netherlands) and one in Bagnolo (Italy), I will be focusing mainly on Enschede, more specifically their 5/10L detergent line (Figure 1), where I have access to their current data, the operators and other staff involved in issue solving, such as the technical services and Q&C.

This comes with some limitations and risks as currently it is unclear how much time the staff will have to answer questions and how much data is available and usable for the project. This may cause the planning to alter as data gathering will be a larger piece of the thesis.

Next to that a challenge will be to convince the operators to use such a device, and if they are open to answer question they feel like could intervene with how they do their job.

Due to the fact that multiple parties are working on the same project this also comes with some dependencies, as BiBa is working on the voice to text of COALA I am unsure if I can implement this in my project, which will in that case not go past the text input phase in terms of interaction. This in combination with the fact that the technology is quite immature will make prototyping and testing more challenging.

space available for images / figures on next page

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30

Page 3 of 7

Initials & Name J. Schunselaar Student number 4287290

Title of Project Root cause analysis implementation in COALA (cognitive voice assistant)

introduction (continued): space for images



image / figure 1: S/10L Canister line at Diversy Enschede (picture taken by Sarath Surendranadha Panicker)

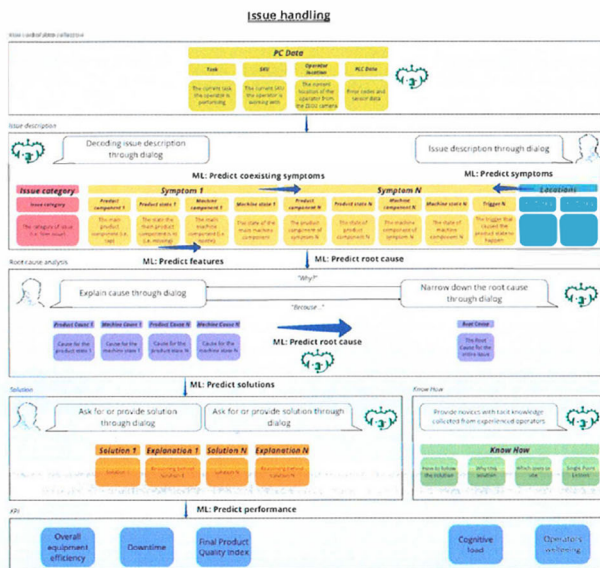


image / figure 2: Issue handling (source: TUD COALA team)

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

At this moment COALA is only able to report an issue to a database, in this project I will create a prototype implementing the next step which is the (predictive) root cause. How can COALA give, after the issue description, get the most probable root cause of the issue to the operator or mechanic (maintenance).

This means that the operator should be able to communicate with COALA to pin the root cause down and COALA should be able to learn from the existing data and the communication with the operator. This should give the operator more information on how to solve the issues and automatically log the solutions for future purposes without the necessity for the operator to leave line and manually enter this into a computer, ultimately making the process more efficient.

The project will exist out of a research part on why the root cause is important to COALA and the current practices on root cause analysis at Diversey. Looking into what kind of tools they are currently using, if this is sufficient for the implementation of COALA and how can we integrate this into the system.

Next to the research a prototype will be developed and tested for the context of Diversey Enschede. This prototype should receive an issue description via voice (depending on the results of others) and interact with the operator to return the most probable root cause to this description. The prototype will be developed in Python and making use of Rasa X a open source tool for conversation-driven development.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

How to analyze the root cause of an assembly line issue with existing information and through dialog with an operator making use of COALA and implement the root cause in the COALA environment.

The assignment will exist out of multiple deliverables.

(Literature) Research on

- Why root cause analysis is important for COALA
- How to implement root cause analysis in COALA looking at current practices and existing tools

Prototype/Demo and documentation for the interaction between operator/mechanic and COALA

- Making use of what is available at that moment (aiming for working voice commands)
- Implementation of root cause analysis in the COALA environment

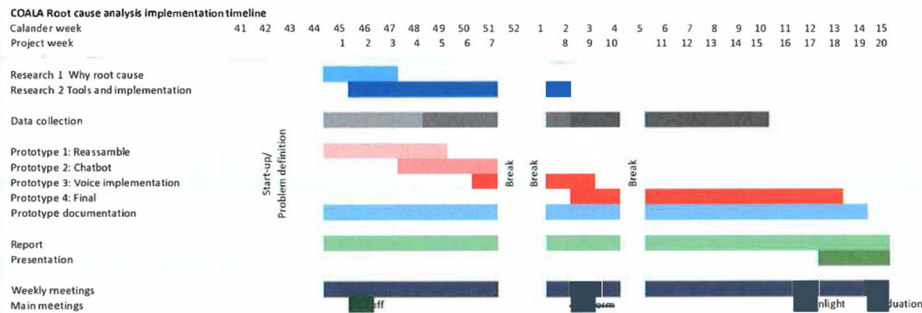
The aim is to test the prototype with operators from Diversey Enschede, if this is not possible due to availability this will be simulated.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 8 - 11 - 2021

15 - 4 - 2022 end date



This is the main overview of the project.

The first part will focus on the research on root cause analysis and data collection of machines, issues and solutions at Diversey Enschede (and to a less degree Bagnolo) and the breakdown of this data to make it usable.

In the meanwhile I will be starting with the prototypes, the aim is to test each prototype at Diversey Enschede.

The first prototype will be built upon the work of a previous graduation student, his prototype will be used as a base of mine, but first needs to be reconstructed/reassembled for proper use.

The second prototype will be the first one with the root cause implemented.

The third will be with the voice to text implementation (provided that BiBa can deliver this in time).

The final prototype will be building upon the root cause implementing the found data and connecting the data to come to a more predictive root cause model.

In the meanwhile (bi-)weekly meetings will be held with the COALA team, Diversey and the Chair and Mentor

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, Stick to no more than five ambitions.

This project fits my interest and acquired skills/competences from elective courses next to the standard IDE courses nicely. The project is largely software based which comes together in the software minor and electives I followed during my bachelor and my master.

That being said this is the first time I work on such a large scale project, so I am eager to learn from so many people and seeing how I can contribute to the COALA voice assistant.

During this project I have the following five ambitions in no particular order:

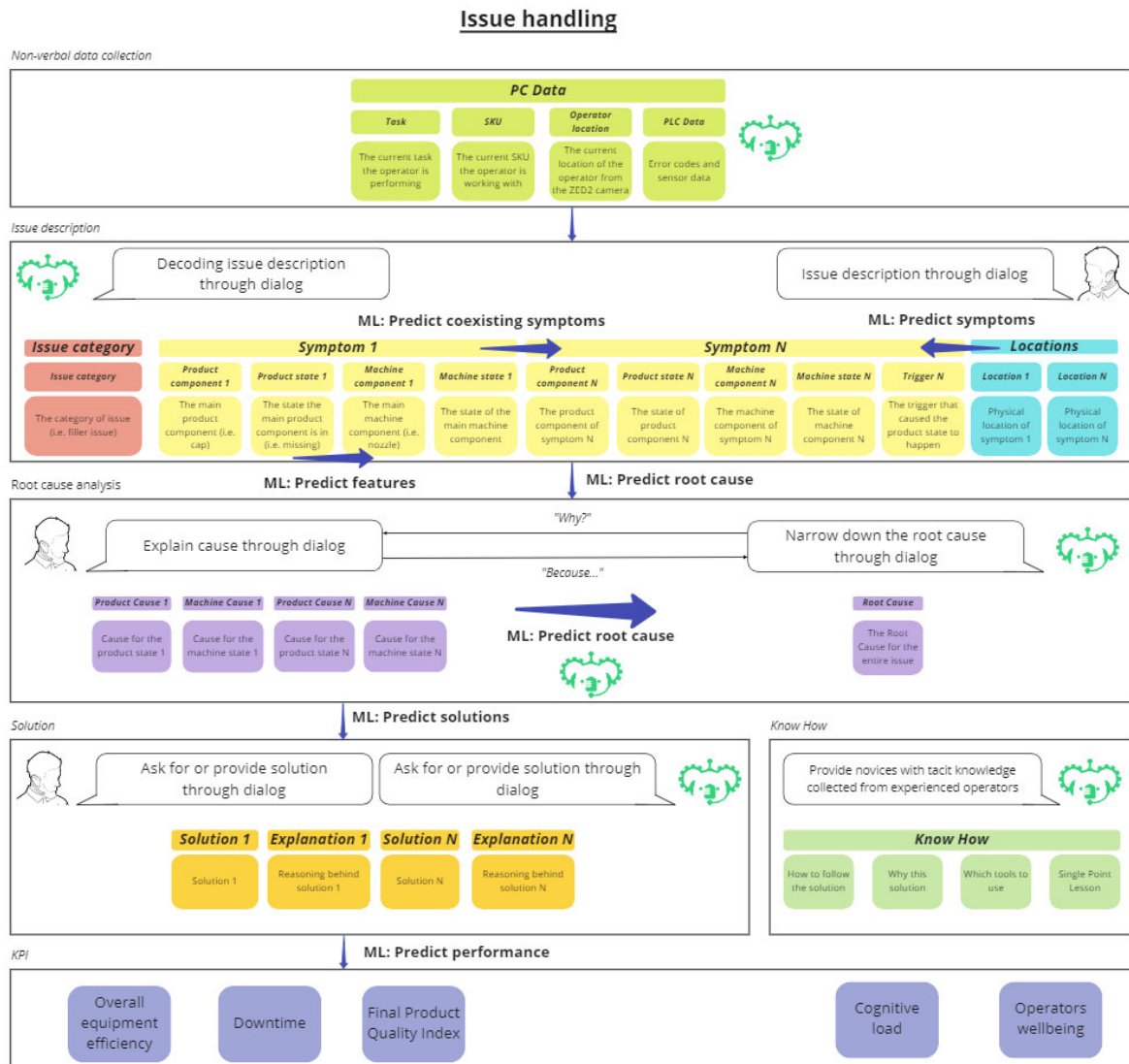
- Participate in working on innovate large scale project
- Developing a working prototype, useful to the COALA consortium
- Bringing together my design and software skills
- Doing research on (mainly) unexplored terrain
- Helping with creating a more safe and efficient working environment in factories

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

9.2 Abstract Overview COALA issue handling

Source: COALA TU Delft team

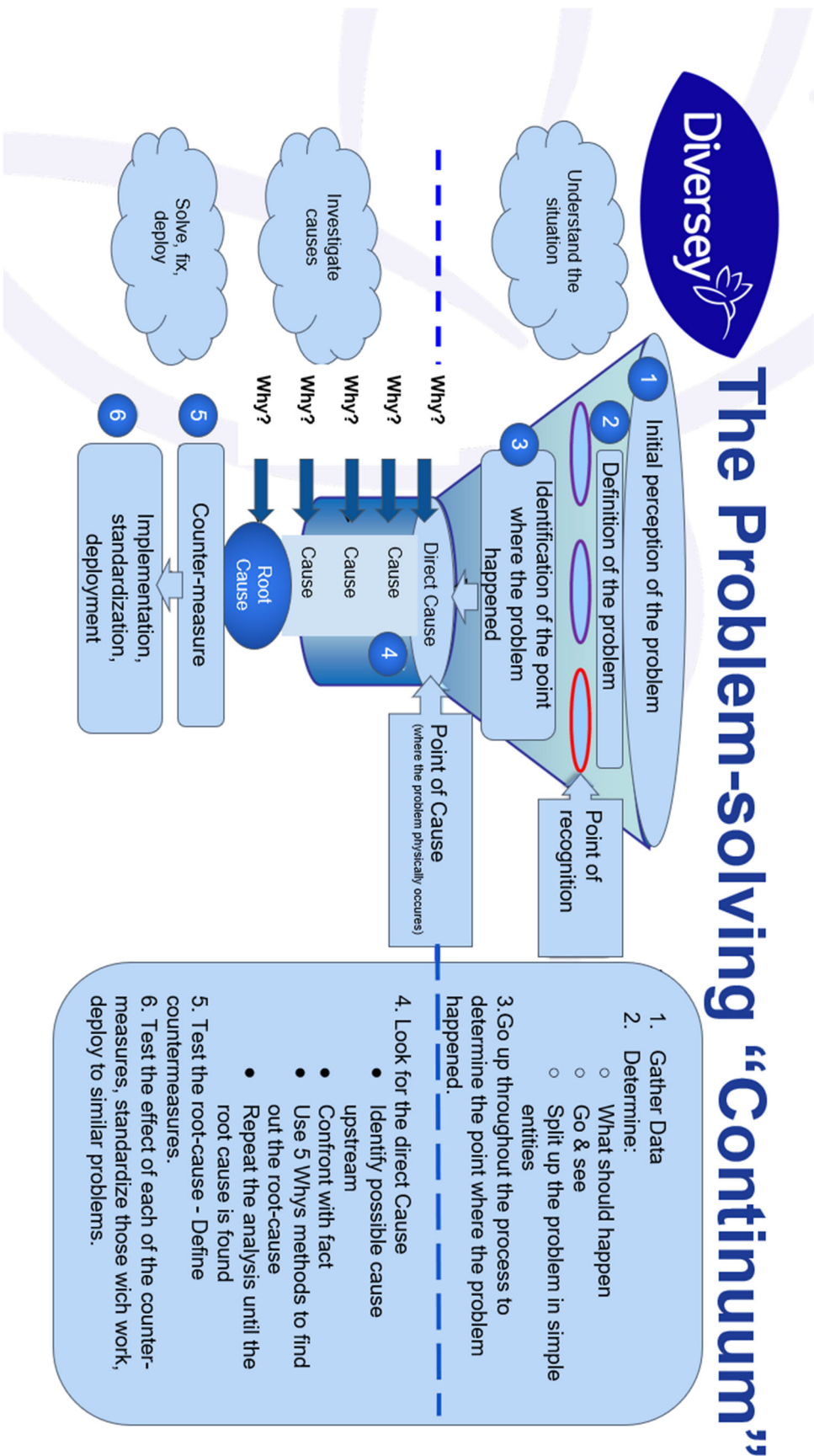


9.3 Data collection

Data collection is confidential information and can be found in the not public appendices

9.4 RCA: 5 Whys at Diversey

In the slide below the Diversey use of the 5 why technology



9.5 User study Design iterations

9.5.1 Design Methodology

For designing this experiment two design methodologies are combined. One is focused on user interaction with (typically) a physical prototype; Interaction Prototype & Evaluation (IPE) (Boeijen et al., 2014). The other methodology is called Rapid Iterative Testing and Evaluation (RITE) (Medlock et al., 2002). With the combination of these two methods, via quick iterations, improvements can be made to the experiment as well as the final prototype. How this Rapid Iterative Testing Interaction Prototyping and Evaluation (RITPE) works is explained below.

In Figure 21 you can see an overview of the steps of the method. Below is a detailed description of the steps:

Step 1

In step one you create a quick scenario sketch or storyboard that explains your expected interaction of the participant with the prototype(s). Everything from a quickly

scribbled down text base scenario or a more worked out visual storyboard. This step is to beforehand think about what will happen and during the iterations explaining what kind of effect the changes should have on the expected result. During this step you should also be considered what you are going to focus on, what is still uncertain and what knobs do you want to tweak.

Step 2

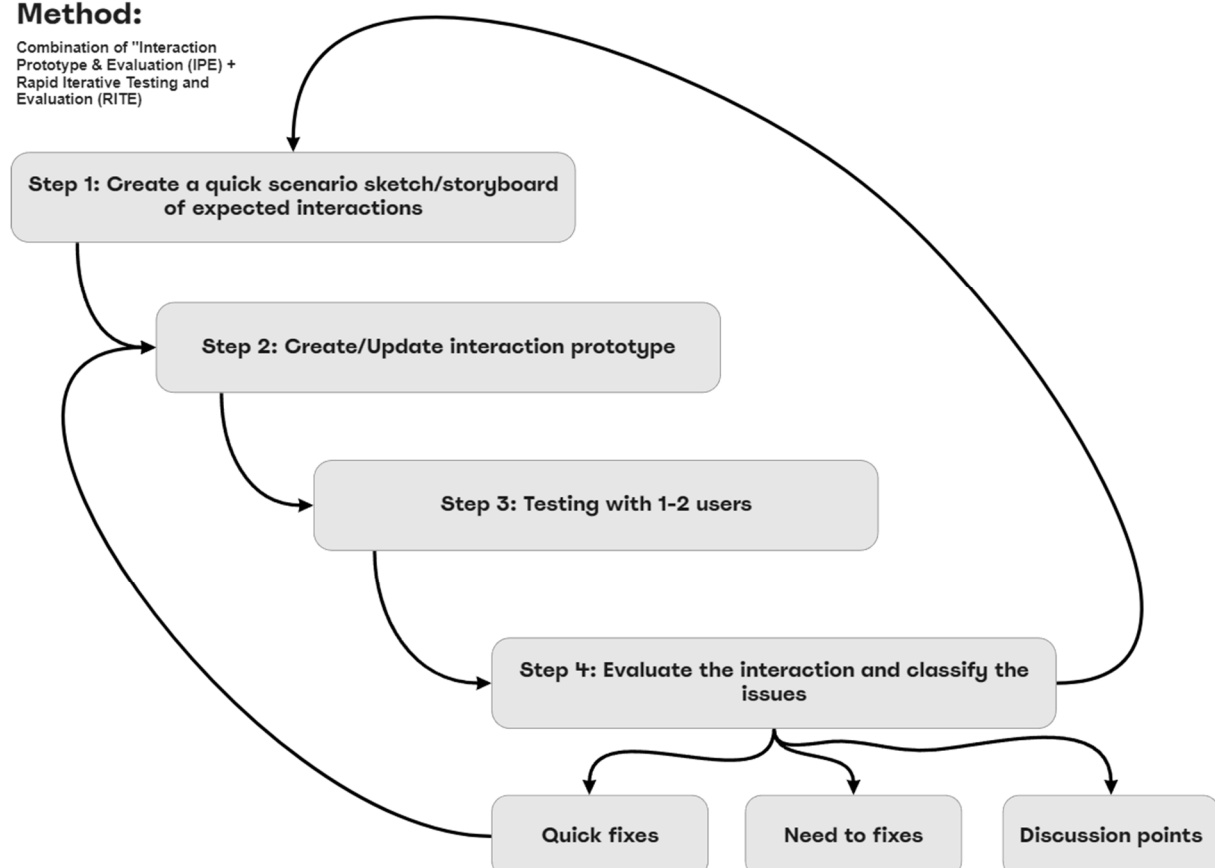
In step two you create or update the prototype, in the context of this project this means the digital as well as the physical prototype. For the first iteration you build, or if you already have a prototype, you adapt the prototype to interaction you intent. In the following iterations you update the prototypes with the new insights from the user interaction.

Step 3

In step three you do tests with users to see if your predicted interaction is correct and get insights from the users on how to improve the prototypes. The focus should be on the users behaviour and not necessarily on the feedback

Method:

Combination of "Interaction Prototype & Evaluation (IPE) + Rapid Iterative Testing and Evaluation (RITE)



they give. For capturing the interaction, the use of video camera is recommended. In this case as this is also used as a pilot for an experiment, it is also used to tweak the experiment and check if anything about the experiment setup can be improved.

Step 4

In step four you evaluate the interaction of the users by watching the footage and process the notes. The evaluation results in a list of issues and findings that can be classified in three clusters.

Quick fixes

Quick fixes can be fixed before the next iteration to improve the interaction. A quick fix can be for example fixing mistakes in the supplied explanation, update the assignment, swap a component or create a new 3d printed part.

Need to fixes

The need to fixes are not something you can do quickly but will be necessary to fix before, in this case, conducting the actual experiment. A need to fix can be for example a part that is not functioning as expected and needs to be replaced by a better option, but this takes time for delivery.

Discussion points

Figure 39 Design Iteration Method RITPE step overview

These points are used to discuss in the thesis report for evaluation as they might need some more research. There are issues that can't be or aren't realistic to be solved before conducting the experiment but should be addressed in the paper and discussed on how this influences the outcomes.

9.5.2 Iteration 0: Prototype base

9.5.2.1 Goal

For creating the physical prototype the goal was to:

- Create a “puzzle” prototype
- It should be not be too complicated to solve for students/employees of a technical university
- It should have enough steps to do a proper RCA
- It should have a link to the works of an operator

9.5.2.2 First design

The first design is a result of multiple options that I looked into:

- A physical mechanical prototype
- A physical electronics prototype
- A computer simulation.

I chose for the electrical prototype as the best options because it is more in line with

realistic operator work than a computer simulation, has more opportunities for finding participants at the university, and is not too difficult to (re-)set up in the same state after the experiment is conducted and the participants used it for problem solving and root cause analysis.

The first design for the prototype was an electronic breadboard with multiple actuators that could all have a fault (Table 17). Each component has a state and could be broken or wrongly placed. An overview of the components and the start state is found in Table 17.

The problem with this prototype is that there are a lot of singular faults to solve. Multiple problems have to be fixed but they do not have a linked meaning. This would lean more towards a reporting exercise than RCA.

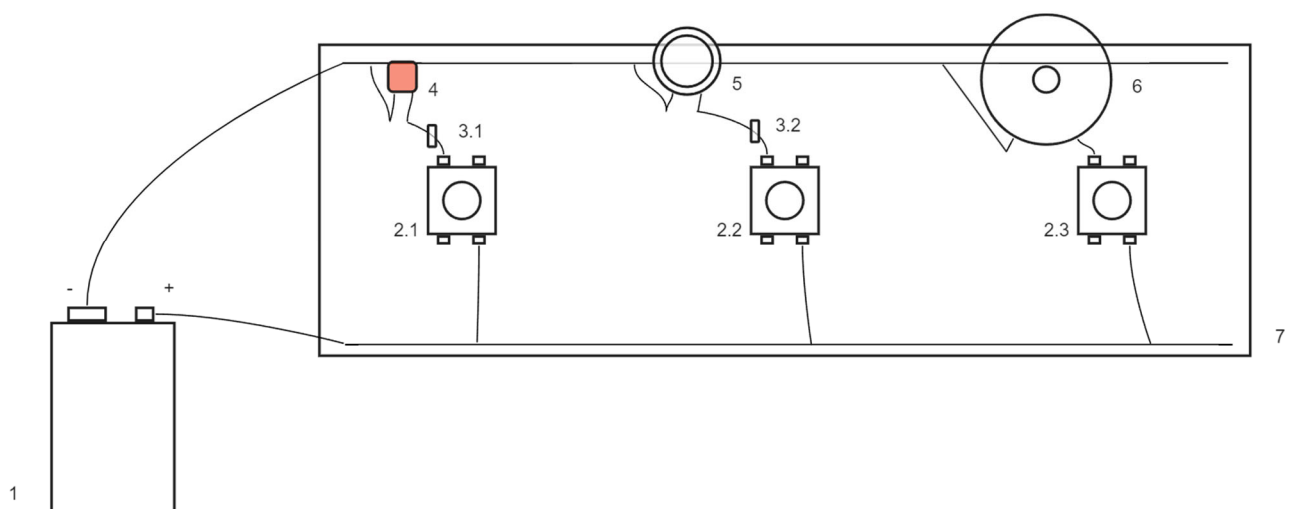


Figure 40 First design electronics design

Number	Component	Start State
1	Battery	Empty
2	Push button	2.2 Broken
3	Resistor	-
4	LED	Incorrect colour (green)
5	Piëzo element	-
6	Buzzer	Broken
7	Breadboard	Wiring from + to button 2.1 misplaced

Table 17 Component overview and starting state

9.5.2.3 Second Design

For the second design the improvement is a simpler breadboard layout, less components, but components that can be linked and collaborate with each other to make something functional. By setting it up this way a non-functional component A can be caused by an error or fault in component C or D.

In Figure 41 the sketch of the second design of the prototype can be seen, together with the components and state in the table below Table 18.

In this design you can create more linked variables:

- The LED can be broken.

- The LED can be turned to a high or low brightness by adjusting the turning knob.
- The multimeter can measure the voltage or current level, which can be put on a given threshold.
- The fuse can break because of high current level.
- The battery pack can be swapped to change the maximum current level.

This gives at least three steps using the 5 why RCA method, but should still not be too difficult to solve.

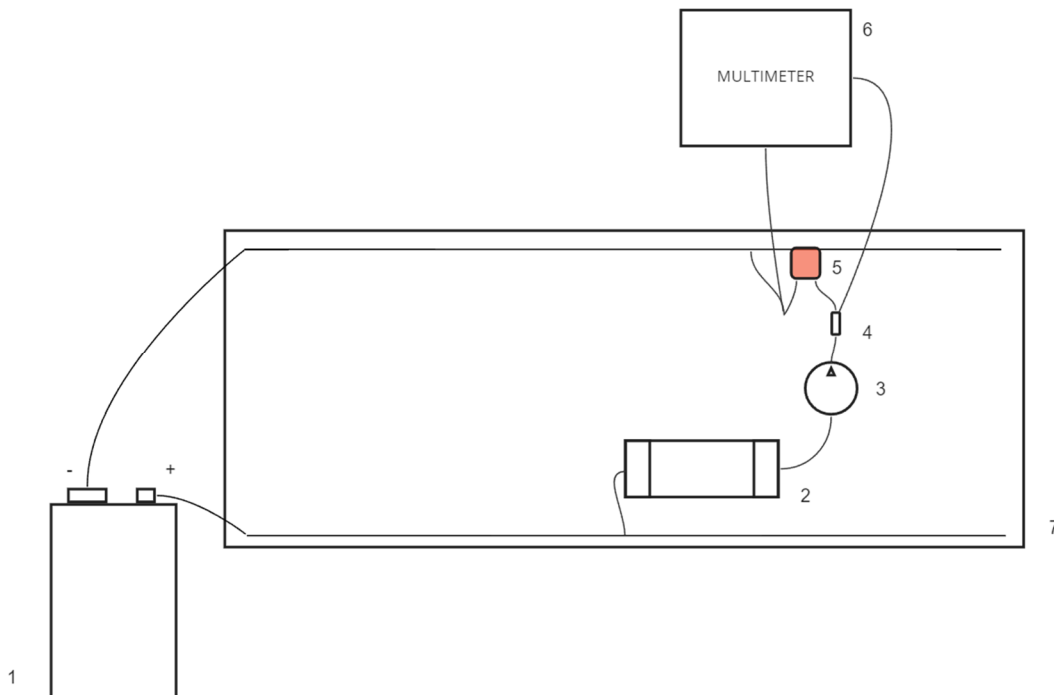


Figure 41 Second electronics design

Number	Component	Start State
1	Battery	Too high voltage
2	Fuse	Broken
3	Turning knob	-
4	Resistor	-
5	LED	Not emitting
6	Multimeter	For checking the Amps through the LED
7	Breadboard	-

Table 18 Component overview and starting state second design

9.5.2.4 Creating the prototype

The first two designs resulted in the final design that can be seen in figure (See Figure 42). Because measuring with a multimeter can be difficult, I chose to incorporate a standalone voltmeter in the design. This makes sure that people don't need to know how to work with a multimeter to be able to participate in the experiment.

The resistor is swapped out with a switch to give one more option to the participant to interact with, furthermore I chose to use three high-powered LEDs so that there is a larger difference in voltage over the circuit and this is also visible to the eye.

The 5 Why path you can create is similar to the previous design but can be more refined. In Table 19 you can find an overview of the components.

The built breadboard can be found in Figure (Figure 43, left) on the next page .

The voltmeter is fixed in a 3D printed case, so participant will not be able to tinker with it. The first idea was to leave the breadboard open, but as this might overwhelm participants without much electronics experience, a case was 3D printed for this part of the breadboard as well (Figure 43, right).

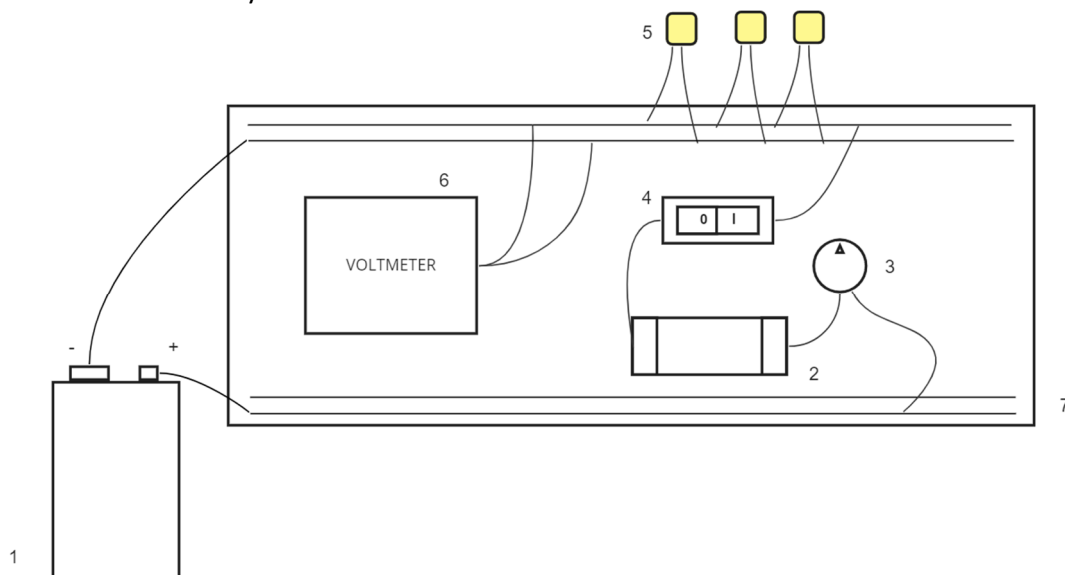


Figure 42 Final electronic design

Number	Component	Start State
1	Battery	Too high voltage
2	Fuse	Broken
3	Turning knob	Full power
4	Switch	Turned on
5	3 High-powered LEDs	Not emitting
6	Standalone voltmeter	Displaying the voltage level over the LEDs
7	Breadboard	-

Table 19 Component overview

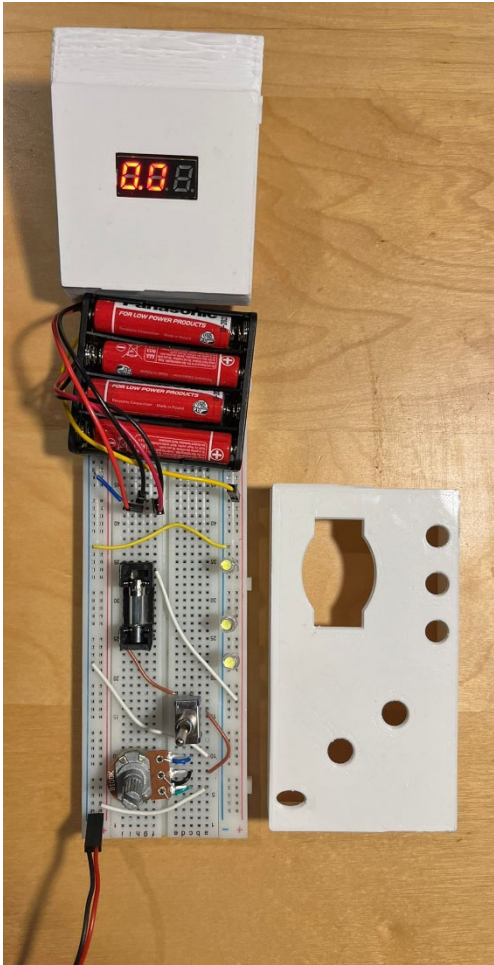


Figure 43 Final physical prototype, left with case removed, right with case on

9.5.3 Iteration I: First pilot

9.5.3.1 Purpose

The purpose of the first iteration is to test if the experiment is actually working as intended, if the participants understand all parts of the assignment, and if they are able to solve (part of) the problem and are able to understand and use the 5 why reporting method. To focus on this, I chose to only look at the A group of participants as this is less complicated to set up

and observe as opposed to the B group. One participant was tested with group B, but due to technical difficulties, not much information for the iteration was received.

9.5.3.2 Scenario sketch

In Figure 44 you can find the scenarios of the first iteration of group A

Group A Computer form

User with no experience with wiring or electronics, does not know what to do to problem solve and tackle this problem at the get go

Expected interaction

- Does not read the instructions on components
- Opens up the prototype
- Checks the wiring
- Fills out the form at the end

Expected emotions/behaviour

- Is engaged
- Knows what to do
- Solves the task (although does not get to the best solution)

Context

- The user gets the instructions from a powerpoint presentation of the context of the prototypes and the tasks that are needed to solve
- User does not get any help via the (voice) - chatbot

Key activities and tasks

- Get instructions from moderator
- Set the LED to certain strength
- Makes use of the 5 why model
- Report steps via a computer form

Figure 44 Scenario sketch group A iteration I

Focus points

To be able to have points to improve the below points are focused on during this iteration, as stated the main purpose is to see if participants can complete the assignment. The main focus points are stated below:

Assignment

- Does the participant understand the assignment?
- Does the participant engage and execute the assignment?
- Is the assignment too easy/too complicated
- How long does the assignment take

Root Cause Analysis

- Is the participant able to get to and state a root cause?
- Is the participant able to perform the 5 why method?

Physical Prototype

- Is the participant able to interact with the prototype as intended?

Computer form

- Is the form clear to the participant? (A)
- Is the form used as intended? (A)

Questionnaires

- Is the participant experiencing any emotions and workload?
- Does the participant understand the questionnaire?

9.5.3.3 Pilot test I

The first iteration to improve the experiment was conducted with three participants. Two participant tested the A group experiment and one tested the B group experiment.

The findings during the experiment are stated per participant

The first participant

Group: A

Experience with electronics: 10/10

The participant was very interested in figuring out not only what was wrong but the whole physical prototype.

During problems solving he ran into some problems with the multimeter and checking out different fuses and setups. In the end he solved the problem by replacing the fuse, but it did take a lot of time.

He did not replace or swap any of the battery packs. As a root cause he stated "Improper design of the installation" as there was no indication what was increasing or decreasing the power so a previous operator had accidentally turned it completely on and not off.



Figure 45 First pilot participant during the assignment

The second participant

Group: A

Experience with electronics: 6/10

Was engaged in getting the prototype to work, although a bit hesitant remove the case similar to the first participant a lot of options were checked which took a lot of time.

The participant was able to get the lights to work and stated as root cause "Dead fuse". This participant also did not think of the option to swap the batteries.

The third participant

Group: B

Experience with electronics: 5/10

Tried getting the prototype to work, but was more interested in the workings of the cognitive advisor. Asking questions that were not easily answered by the predetermined answers.

Unfortunately during the execution of the experiment the participants laptop started a Windows update, disconnecting the voice chat and abruptly ending the experiment.

9.5.3.4 Evaluation

In Table 20 you will find the findings clustered by quick fixes, need to fixes and discussion points.

Assignment

The participants were able to solve the problem and report the root cause.

A few things can be improved, the one standing out the most is the fact that there was no time pressure. All the participants took their time to play around with the prototype and figuring out every detail, even after they got the light to work.

Root Cause Analysis

The participants understood the 5 why method well enough to perform it and did not have any questions on the explanation.

Because none of the participants was able to find the actual root cause it should be monitored. If no participant is able to find the root cause, there is no purpose to the experiment. But for this moment in time now I did not see a reason to change the base of the experiment.

Physical Prototype

It would be less confusing if the case gave an indication of the workings of the switch and knob (on/off, softer/brighter)

It took the participants some time to realize that the case could be removed from the breadboard.

Questionnaires

Participants were able to fill out the questionnaires with no problems or questions, but did note some errors in the form and in the spelling.

Other findings

All participant’s answers gave insight into the interactions the cognitive advisor can expect and gave the ability to update the voice flow chart.

Quick Fixes	Need to fixes	Discussion Points
Give a time indication/pressure, currently the participants take too long (25+ minutes) and interact out of interest and not to solve the issue	The case needs to be redesigned as the switch is not completely lined out	Up until now no participant have been able to find the “Real root cause, this should happen in the future, maybe more emphasis on the batteries?
Turn off automatic updates on all laptops for no interference	Check if multimeter is working properly	Start with a filled out Why question to steer everyone in the right direction?
Change the goal from 2.90 to between 2.85 and 3.15 as the potentiometer is quite sensitive		
Give the switch an on/off indication		
Give the potentiometer a higher/lower indication		
Not clear that the case can be taken off, add indication for the participant		
Change the introduction powerpoint to the new situation		
NASA TLX form does not have labels, should be added for next iteration		
UEQ form too much options → change from 10 to 7		
Add conducting the 5 why method to the assignment goals		
Spelling errors in the basic data form should be corrected		

Table 20 Overview of improvements for the experiment iteration I

9.5.4 Iteration II: Cognitive advisor

9.5.4.1 Purpose

The purpose and main focus of the second iteration is to test if the group B experiment is working properly and the wizard of oz interaction is passing as computer assistant. On top of that it is used to see if the changes after the first iteration are an improvement or not. The most important improvement being the added time pressure.

9.5.4.2 Improvements & Scenario Sketch

In the scenario sketch (Figure 47) you will find the new expected interaction.

For this iteration the following improvements have been made to the experiment and prototypes.

Assignment

- Added time pressure by stating that the operator has more issues to solve and should be as fast as possible while still delivering quality.
- Changed the meter goal to 2.85-3.10 as this does not influence the root cause but is easier to reach with adjusting the potentiometer.



Figure 46 Case improvement

Physical prototype

- Printed a new case with better fittings to the components
- Adapted the case to give an indication for on/off and dimmer/brighter (See Figure 46), this was done with a sharpie and not on the design itself to give the participant the feeling they can think with the case and its contents
- Indicated on the case that the

Group B Voicechat

Expected changes to improvement

Participants will

- do their assignment faster
- open up the case faster
- be less confused by the buttons on knob

Expected interaction

- Does not read the instructions on components
- Opens up the prototype
- Checks the wiring
- Does not ask FAQ to the bot

Expected emotions/behaviour

- Is engaged
- Knows what to do
- Solves the task (gets to the best solution)

Context

- The user gets the instructions from a powerpoint presentation of the context of the prototypes and the tasks that is needed to solve

Key activities and tasks

- Get instructions from moderator
- Set the LED to certain strength
- Makes use of the 5 why model
- Report via voice chat

Figure 47 Scenario sketch Iteration II group B

- Added conducting the 5 why method to the assignment goals

participant can open it up (See Figure 46)

Digital Prototype

- Added steps taken by the group A user to the flowchart
- Added more FAQ

In Figure 49 a flowchart shows the interaction sequence of the utterance of the user up until the received feedback.

Questionnaires

- The NASA TLX questionnaire was after the UEQ short, changed to the other way around

An empty screen is shared from the supervisor's computer with shared audio. On the participant side only an empty screen and the chat is visible.

Updated labels and removed errors

The following focus points are addressed

9.5.4.2.1 Focus Points

The main focus point of this iteration is the voice chat interaction. This is the second time the wizard of oz setup is tested with participants. The current setup on the supervisor's computer screen is shown in

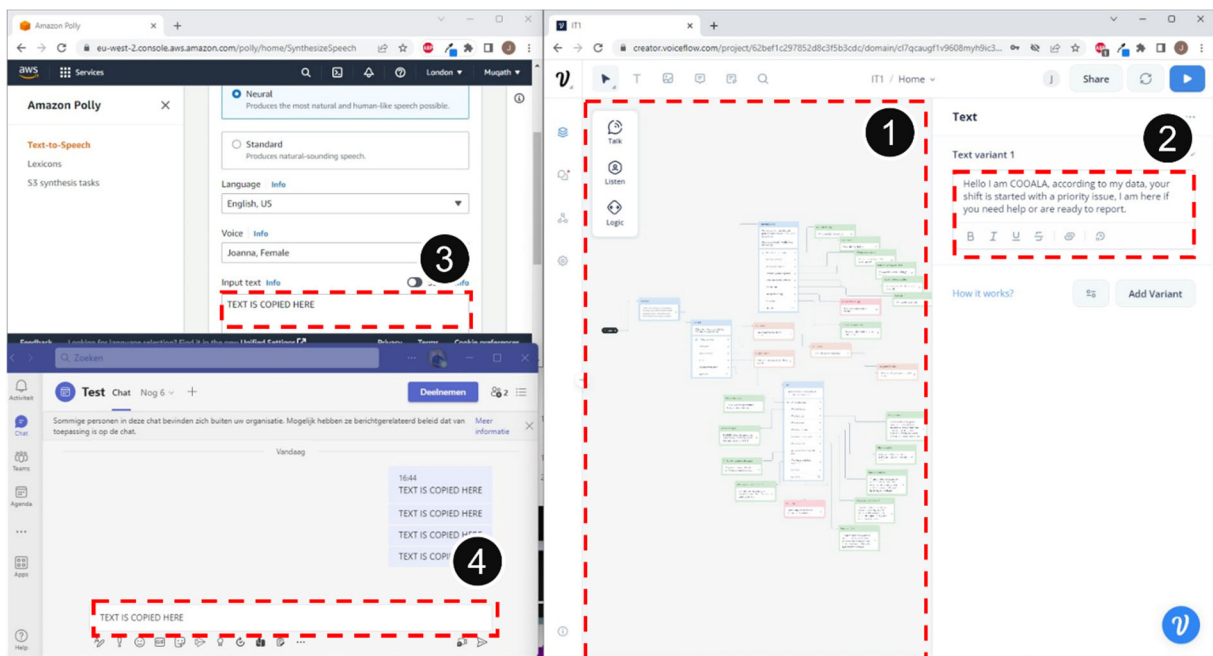


Figure 48 Screen capture of wizard of oz screen setup supervisor

Figure 48.

If a message is received from the participant, these steps are followed:

1. Link message to corresponding voice chart message
2. Copy message from voiceflow
3. Paste message in Amazon Polly and click on "Listen" button
4. Paste message in chat and press sent

during this iteration.

Assignment

- Does the time pressure improve the assignment setup

Root Cause Analysis

- Are participants able to get to the “real” root cause, e.g. not only change the broken fuse.
- Are participants able to do the 5 why method with the voice chat?

Physical Prototype

- Does the improvement to the case make it more clear to the participant

Digital Prototype

- Is the predefined flow sufficient? (B)
- What needs to be changed for better interaction? (B)
- Can the participant hear/follow the feedback (B)
- Does the participant understand the feedback? (B)



Figure 50 Pilot participant interacting with cognitive advisor

The first participant (Figure 50)

Group: B

Experience with electronics: 6/10

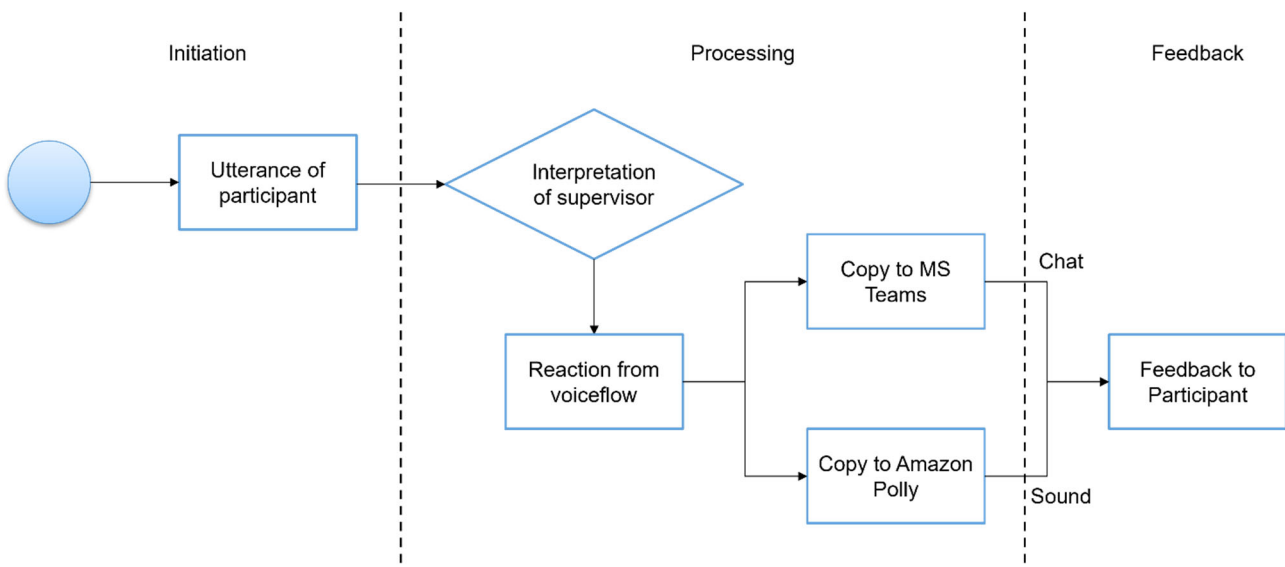


Figure 49 Flowchart overview of interaction sequence

9.5.4.3 Pilot test II

The second iteration to improve the experiment was conducted with 2 participants. Both participants were aided by the cognitive advisor (Group B)

The participant got to the root cause during the assignment without help from the cognitive advisor.

While conducting the 5 why method the communication went messy, there was no indication from the cognitive advisor that the participant was being heard, so in the processing time the participant already started new questions or steps.

The second participant

Group: B

Experience with electronics: 4/10

The participant was hesitant to interact with the physical prototype and did not really know what to do to change anything.

When the reporting started, the communication was messy because the participant did not wait for the answer to be processed.

The participant was still able find the correct root cause without solving the problem by going through the 5 why steps with the cognitive advisor.

9.5.4.4 Evaluation

The second iteration focussed on the B group, the interaction was not streamlined, it wasn't clear to the participants when they could talk to the cognitive advisor and how long it took for the cognitive advisor to answer. In table Table 21 you will find an overview of the improvements for the next iteration.

Assignment

The time pressure improved the focus of the participants, but it was still unclear and over 15 minutes, it should be a set time.

Root Cause Analysis

Both participants were able to get to the root cause which takes away the uncertainty from the first iteration that the assignment might be too difficult.

Conducting the 5 why method with the voice chat was not smooth mostly due to the fact that the interaction was not clear.

Digital Prototype

Some of the answers were not in the voiceflow chart and should be added. The FAQ has not been used yet, if that stays the case, it might be removed as it has no added value.

It is not clear that the cognitive advisor takes a while before the participants gets the answer. This should be better explained during the instructions.

Both participants had no trouble in hearing and understanding the cognitive advisor. Besides the fact that there was some talking over each other due to the confusion.

Quick Fixes	Need to fixes	Discussion Points
Slots to be added to Voiceflow: -Ending of assignment -Ask to be more specific -Unable to hear participant -Cable → more general -Other comments -No power -No voltage -No current	Case improvement	Up until now no participant have been able to find the “Real root cause, this should happen in the future, maybe more emphasis on the batteries? Root cause was found 2/2 times during this iteration
Synonyms for words: LED – Lights Broken – not working – burned Power supply – Battery pack – Power source Potmeter – potentiometer – knob	Better setup for supervisors computer → More screens	Start with a filled out Why question to steer everyone in the right direction? Voicechat is now stating the starting issue
Set assignment time to 15 minutes max		Frequently asked questions have not been used, is this still necessary?
Add explanation to PowerPoint on how to interact with the cognitive advisor		Checking the cabling still takes a lot of time during the problem solving, even though by design there are no cabling issues.
Check on clarity and speed of some responses: Add more punctuation Change COALA to COOALA		None of the participants noticed that they also received the chat, could remove this.
		Supervisor: the processing flow takes a too long and is prone to errors. This has to be practiced to do it faster or another solution has to be found.

Table 21 Overview of fixes iteration II

9.5.5 Iteration III: Last Pilot

9.5.5.1 Purpose

The purpose of the third and final design iteration of the experiment is testing if all the changes are an improvement and the experiment is ready to be conducted. The iteration takes both group A and B into account.

9.5.5.2 Improvements & Scenario Sketch

In the scenario sketch you can find the new expected interaction.

For this iteration the following improvements have been made to the experiment and prototypes.

Major change

- Between iteration II & III, I made the decision to go from the digital 5 why form (Group A) to a paper 5 why template. I made this decision because no prior occurrence of using a computer form for conducting the 5 why method is known, so to compare it to a real situation the Diversey Bagnalo 5 why paper templates were used as an example.

Assignment

- Added a clear timespan of 15 minutes, in this "Shift" the participants should complete the whole assignment.
- Added instructions of a fictional operator from the previous shift, explaining that the meter and wiring has been checked, so the participant should not waste time on that.
- Stated that the participant should do the 5 Why reporting after the problem solving because this is more similar to the current situation.
- Decided to not prefill the problem statement to keep the situation more similar to the current situation, but give this information by providing the participant with previous shift information.

Physical prototype

- Resoldered some of the fittings of components that were not a good fit to the breadboard.

Digital Prototype

- Added multiple 5 Why step answers to the voiceflow chart.
- Removed the prefilled problem statements that stated that the LED was broken and opted to ask the user for the problem statement.
- Changed the setup for the supervisor's pc to give more space for the tasks that need to be executed during the processing.
- Added a sound level changer to give an indication that the cognitive advisor is listening.
- Decided to keep in the chat function..

Questionnaires

- Moved the general question questionnaire to after the assignment and after the assignment related questions to not intervene with what participants think the experiment is about.

9.5.5.3 Focus points

This is the final pilot before the experiment is conducted, the main focus is a proper running experiment, which is almost achieved but the interaction between participant and the cognitive advisor needs to be better.

Major change

- Is the 5 why paper template is understood?

Assignment

- Is 15 minutes enough time for the participants to finish the assignment (can still be tweaked to 16 or 17).

Root Cause Analysis

- Complexity check: is it not too complicated?

Physical Prototype

- Check for wear after use, to see if some components need maintenance in between participants.

Digital Prototype

- Is the updated predefined flow sufficient to answer the participants?
- Is the process of communicating with the cognitive advisor clear?
- Is the FAQ used?
- Do participants read the chat?

9.5.5.4 Pilot test III

The final iteration to improve the experiment was conducted with 3 participants. Two participants were aided by the cognitive advisor (Group B) and one was using the paper template (Figure 51).

The first participant

Group: A

Experience with electronics: 3/10

The first participant was the try-out of the paper template. The participant had no trouble understanding the assignment, but (in hindsight probably due to lack of electronics experience) did make a lot of use of the component list.

Within the time limit the participant was able to find their root cause (Dead fuse) and fill out the paper template with no issues.

Besides the fact that it took some time for the participant to remove the case I noticed nothing out of the ordinary or in need of change concerning the experiment.



Figure 51 Participant making use of the paper 5 Why template

The Second participant

Group: B

Experience with electronics: 6/10

This participant took quite some time before starting the 5 why method with the cognitive advisor, to the point where the 15 minutes were almost finished.

Unfortunately due to a dying camera battery, only a part of the experiment was recorded, so it's unclear why the participant took such a long time.

The conversation with the cognitive advisor went quite smoothly, besides the fact that the answers on the supervisor side did not contain anything on the brightness of the LED. The given root cause was a dead fuse in combination with a badly adjusted potmeter.

After the experiment the participant noted that he did not know he had to start the conversation with the cognitive assistant.

The Third participant

Group: B

Experience with electronics: 5/10

The participant quickly came to a conclusion and after 4 minutes they asked the cognitive advisor to conduct the 5 why method.

Even though all of the utterances of the participant should have been answered. This did not go very well because of bad copy and pasting in the processing of the responses. The conversation between the participant and the cognitive advisor was very messy.

The final root cause stated by the participant was a badly functioning potentiometer.

9.5.5.5 Evaluation

Assignment

The 15 minute time limit seems like a good fit, all participants were able to complete the assignment within the given time.

Root Cause Analysis

None of the participants got to the root cause even though one did change the battery pack. Apparently it did not occur to them that this could be part of the cause. The assignment seems to have a good balance between complex and easy.

Paper template

The paper template was clear and did not cause any confusion.

Digital Prototype

The cognitive advisor prototype still has some issues, mainly that it was not clear to the participant how to initiate the communication.

The way of processing the comments is prone to errors that can mess up an entire experiment, some changes should be made here.

Still some additions to the overview can be added, but that makes sense as in real practise the cognitive advisor should be able to learn as well.

9.5.5.6 Final changes

Digital prototype

The chat is removed because the participants were not aware of it.

Because of too many errors in the current supervisor setup I chose to change it to a PowerPoint sound board (See Appendix 9.6.8). All sound bites are downloaded from the Amazon Polly tool and loaded into a PowerPoint with the text next to it. This makes the processing a lot easier because there are fewer steps.

To initiate the 5 why method a trigger is added to the cognitive advisor that is explained in the mini lecture and given to the participant as a handout

Quick Fixes	Need to fixes	Discussion Points
Slots to be added to Voiceflow: - Brightness	None of the participants noticed that they also received the chat, could remove this. Remove to make the cognitive advisor more consistent in speed, besides the fact no participant made use of it.	Checking the cabling still takes a lot of time during the problem solving, even though by design there are no cabling issues. Mentioning it in the explanation works well

	<p>Frequently asked questions have not been used, is this still necessary?</p> <p>Still not used, the availability might confuse participants and give them another advantage over group A, so should be removed.</p>	
	<p>Supervisor: the processing flow takes a too long and is prone to errors. This has to be practiced to do it faster or another solution has to be found.</p> <p>Change to PowerPoint sound board</p>	
	<p>Create trigger to start the 5 why method with the cognitive advisor.</p>	

Table 22 Iteration III findings overview

9.6 User study

9.6.1 Consent form Group A



COALA Project Information letter and Informed Consent form

Would you like to participate in the COALA project?

This information letter provides information about the COALA project to individuals who are asked to contribute and provide input to the project. It will give you information on the goals of the project and what participation will mean for you.

Project Goal

COALA features a consortium of industrial and academic partners who will investigate the use of AI techniques to inform and train workers and students on industrial processing lines, about the nature and status of the machines they are using. The aim is to reduce training costs and improve productivity in industrial processes.

Humans are at the center of knowledge-intensive manufacturing processes. They must be skilled and flexible to meet the requirements of their work environment. The training of new workers in these processes is time-consuming and costly for companies. Industries, such as the Italian textile sector suffer from the shortage of skilled workers caused, e.g., by the demographic change. A second challenge for the manufacturing sector is the continuous competition to produce high-quality products.

COALA will address both challenges through the innovative design and development of a Digital Intelligent Assistant for the manufacturing sector. The COALA solution will be based on the privacy-focused open assistant Mycroft. It integrates prescriptive quality analytics, AI system to support on-the-job training of new workers, and a novel explanation engine—the WHY engine. Critical components for the adoption of the solution are a new didactic concept to reach workers about opportunities, challenges, and risks in human-AI collaboration, and a concurrent change management process. Three use cases—textile (Piacenza), white goods (Whirlpool), liquid packaging (Diversey)—will evaluate the results in common manufacturing processes with significant economic relevance. COALA will contribute with its results to the European AI community, e.g., via the AI4EU platform, and it will involve Digital Innovation Hubs to replicate its demonstrators for Europe's first trustworthy digital assistant for the manufacturing industry. We expect to reduce the cost of failures in manufacturing by 30-60% with assisted worker training. For the change-over time, we expect a reduction of 15% to 30% by reducing the worker training time.

COALA is committed to ethically curating the data collected in the project on workers in industrial processes. In addition, it will actively pursue ethical questions and their legal consequences of exploiting AI within manufacturing environments and decision-making in sensitive areas as well as the collection of feedbacks from the users in order to improve the performances and the user experience of the tools.

Who is responsible for the project?

The coordinator of the COALA project with the overall responsibility for its implementation is BIBA "BREMER INSTITUT FUER PRODUKTION UND LOGISTIK GMBH," based in Germany. TU Delft is the partner in the consortium with the responsibility of carrying out the local user studies that investigate the Cognitive Advisor, a critical component of the COALA project in the IDE premises, at Delft, the Netherlands. TU Delft is part of a consortium of 14 partners, funded by the European Union's Horizon 2020 research and innovation programme under grant agreement No 957296.

Why are you asked to participate?

To support the design and validation of the COALA Cognitive Advisor and to ensure the results from the COALA project are useful and adoptable, data and information about the target operating and training processes need to be collected, analyzed, and understood. The project will test the proposed concept in 3 use cases provided by Whirlpool, Piacenza and Diversy, and collect feedback from users through user studies, deployments, interviews, workshops, and questionnaires.

The participants are expected to interact with the Cognitive Advisor to get help with solving problems and receive support in planning operation processes. At the same time, the Cognitive Advisor will accompany the learning process of the individual participant by suggesting custom learning strategies based on the participant's existing knowledge.

Accordingly, the adoption of the Cognitive Advisor in manufacturing will depend on operators' and managers' understanding of the benefits, limitations, and risks of AI systems. Building trust in AI systems relies on a change in the management process that begins early and involves many stakeholders. Thus, it is crucial to involve both operators and managers in the process of building and validating the COALA solution.

You receive this invitation because you are identified as a potential participant who can help us realize the COALA project objectives.

Participation is voluntary

It is voluntary to participate in the project and you can at any time withdraw your consent without giving any reason. If you withdraw all your personal data (if any), interview transcripts and recordings will be irreversibly anonymised. In case anonymisation is not possible the information will be deleted. There will be no negative consequences for you to withdraw your consent.

Your privacy is important to us – how we store and handle the information you provide

The data you provide will only be used for the purpose described in the previous sections. All data will be treated confidentially and in line with the General Data Protection Regulation (GDPR).

- Only the responsible researchers at IDE, TU Delft who will have direct contact with you will have access to your information.

- All data will be subject to anonymisation by design approach: the databases containing user personal data will be held by subjects different from the ones holding the data recorded by COALA system about the use of the platform.
- Only anonymised data will be included in publicly available reports and articles.

What does it mean for you to participate in the project?

In this case study you will be asked to perform certain task and interact with a prototype and test setup, the goals and context of the tasks will be explained to you with an introduction presentation if you want to get the introduction before signing this form please ask the onsite researcher.

Data about the participants' activities that are relevant to the COALA project will be collected through the following means--- please indicate if you agree by marking the corresponding boxes:	yes	no
A camera records your activity for later reference and analysis	<input type="checkbox"/>	<input type="checkbox"/>
We will capture video/audio/pictures during the study to understand how you complete the tasks	<input type="checkbox"/>	<input type="checkbox"/>
You will be asked to complete surveys/questionnaires in either online forms	<input type="checkbox"/>	<input type="checkbox"/>
Your performance scores and completion times will be collected during the process of the tasks	<input type="checkbox"/>	<input type="checkbox"/>
Your physiological data such as brain activity (EEG) and heart rate variability (HRV) will be collected to estimate your objective cognitive workload and your physiological stress, respectively, during the process of the tasks	<input type="checkbox"/>	<input type="checkbox"/>
You understand that personal information collected about you and that can identify you, such as your name and age, will not be shared beyond the study IDE, TU Delft team.	<input type="checkbox"/>	<input type="checkbox"/>
You agree that the data, pictures, and notes that you provide as part of the study can be analyzed, reported, shown, or quoted in research outputs (e.g., publications), as long as you remain non-identifiable.	<input type="checkbox"/>	<input type="checkbox"/>

What happens to your information when the project ends?

The project started on October, 1st, 2020 and is planned to end on September 30, 2023. **Following the end of the project, your data will be stored on TU Delft servers for a maximum of 12 months before being deleted, including video, audio, and imagery data.** This is to allow time for the project to close and delete all data according to required procedures, and to enable final project publications after the end of the project.

Your rights

If you can be identified in the data material, you have the right to:

- ask for incorrect, inaccurate or incomplete data to be corrected;
- request that data be erased when it's no longer needed or if processing it is unlawful;
- receive your data in a machine-readable format (data portability); and,
- file a complaint to your National Data Protection Authority (DPA).

Our rights to handle information provided by you

We handle the information you provide in this project based on your informed consent.

On behalf of HREC Committee, Members and Team at TU Delft who has assessed that the processing of data in this project is in accordance with the governing privacy policy.

Will I receive any financial compensation for my participation?

We will not compensate you financially for the time you spend in this user study.

I think the project sounds interesting. How can I find out more about its activities and results?

You can find more information on our website at: <https://www.coala-h2020.eu/>. If you want to contact us directly for more detailed information or any other reason, please contact the researchers responsible.

You have read and understood the study information, or it has been read to you. You have been able to ask questions about the study and your questions have been answered to your satisfaction. You agree to participate in this study.

Signatures

_____ Name of participant	_____ Signature	_____ Date
Jeroen Schunselaar Responsible Researcher 1	_____ Signature	_____ Date

Contact details for further information:

- Jeroen Schunselaar (j.schunselaar@student.tudelft.nl)
- Samuel Kernan Freire (S.KernanFreire@tudelft.nl)
- Dr. Evangelos Niforatos (e.niforatos@tudelft.nl)



COALA Project

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COALA will address both challenges through the innovative design and development of a Digital Intelligent Assistant for the manufacturing sector. The COALA solution will be based on the privacy-focused open assistant Mycroft. It integrates prescriptive quality analytics, AI system to support on-the-job training of new workers, and a novel explanation engine—the WHY engine. Critical components for the adoption of the solution are a new didactic concept to reach workers about opportunities, challenges, and risks in human-AI collaboration, and a concurrent change management process. Three use cases—textile (Piacenza), white goods (Whirlpool), liquid packaging (Diversey)—will evaluate the results in common manufacturing processes with significant economic relevance. COALA will contribute with its results to the European AI community, e.g., via the AI4EU platform, and it will involve Digital Innovation Hubs to replicate its demonstrators for Europe's first trustworthy digital assistant for the manufacturing industry. We expect to reduce the cost of failures in manufacturing by 30-60% with assisted worker training. For the change-over time, we expect a reduction of 15% to 30% by reducing the worker training time.

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Why are you asked to participate?

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The participants are expected to interact with the Cognitive Advisor to get help with solving problems and receive support in planning operation processes. At the same time, the Cognitive Advisor will accompany the learning process of the individual participant by suggesting custom learning strategies based on the participant’s existing knowledge.

Accordingly, the adoption of the Cognitive Advisor in manufacturing will depend on operators’ and managers’ understanding of the benefits, limitations, and risks of AI systems. Building trust in AI systems relies on a change in the management process that begins early and involves many stakeholders. Thus, it is crucial to involve both operators and managers in the process of building and validating the COALA solution.

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Participation is voluntary

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- Only anonymised data will be included in publicly available reports and articles.

What does it mean for you to participate in the project?

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Data about the participants' activities that are relevant to the COALA project will be collected through the following means--- please indicate if you agree by marking the corresponding boxes:	yes	no
A camera records your activity for later reference and analysis	<input type="checkbox"/>	<input type="checkbox"/>
We will collect your utterances and chat transcripts during the conversation with the Cognitive Advisor (chatbot).	<input type="checkbox"/>	<input type="checkbox"/>
We will capture video/audio/pictures during the study to understand how you interact with the Cognitive Advisor.	<input type="checkbox"/>	<input type="checkbox"/>
You will be asked to complete surveys/questionnaires in online forms	<input type="checkbox"/>	<input type="checkbox"/>
Your performance scores and completion times will be collected during the process of the tasks	<input type="checkbox"/>	<input type="checkbox"/>
Your physiological data such as brain activity (EEG) and heart rate variability (HRV) will be collected to estimate your objective cognitive workload and your physiological stress, respectively, during the process of the tasks	<input type="checkbox"/>	<input type="checkbox"/>
You understand that personal information collected about you and that can identify you, such as your name and age, will not be shared beyond the study IDE, TU Delft team.	<input type="checkbox"/>	<input type="checkbox"/>
You agree that the data, pictures, and notes that you provide as part of the study can be analyzed, reported, shown, or quoted in research outputs (e.g., publications), as long as you remain non-identifiable.	<input type="checkbox"/>	<input type="checkbox"/>

What happens to your information when the project ends?

The project started on October, 1st, 2020 and is planned to end on September 30, 2023. **Following the end of the project, your data will be stored on TU Delft servers for a maximum of 12 months before being deleted, including video, audio, and imagery data.** This is to allow time for the project to close and delete all data according to required procedures, and to enable final project publications after the end of the project.

Your rights

If you can be identified in the data material, you have the right to:

- ask for incorrect, inaccurate or incomplete data to be corrected;
- request that data be erased when it's no longer needed or if processing it is unlawful;
- receive your data in a machine-readable format (data portability); and,
- file a complaint to your National Data Protection Authority (DPA).

Our rights to handle information provided by you

We handle the information you provide in this project based on your informed consent. On behalf of HREC Committee, Members and Team at TU Delft who has assessed that the processing of data in this project is in accordance with the governing privacy policy.

Will I receive any financial compensation for my participation?

We will not compensate you financially for the time you spend in this user study.

I think the project sounds interesting. How can I find out more about its activities and results?

You can find more information on our website at: <https://www.coala-h2020.eu/>. If you want to contact us directly for more detailed information or any other reason, please contact the researchers responsible.

You have read and understood the study information, or it has been read to you. You have been able to ask questions about the study and your questions have been answered to your satisfaction. You agree to participate in this study.

Signatures

_____	_____	_____
Name of participant	Signature	Date

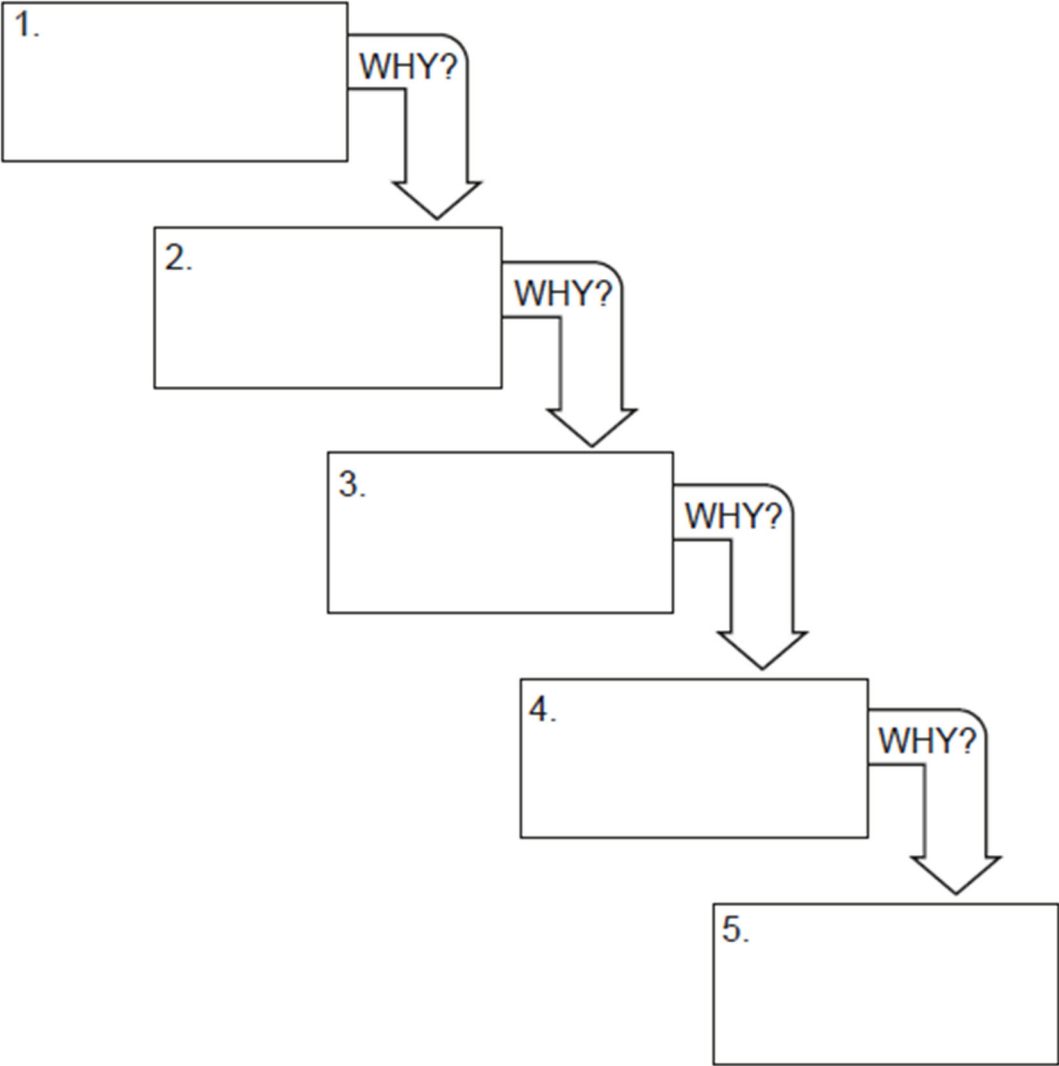
<u>Jeroen Schunselaar</u>	_____	_____
Responsible Researcher 1	Signature	Date

Contact details for further information:

- Jeroen Schunselaar (j.schunselaar@student.tudelft.nl)
- Samuel Kernan Freire (S.KernanFreire@tudelft.nl)
- Dr. Evangelos Niforatos (e.niforatos@tudelft.nl)

9.6.3 5 Why paper template

Problem statement



Root Cause

Comments

STARTING

You can trigger the 5 why method by saying:

“Hey COALA! I am ready to report”

Or

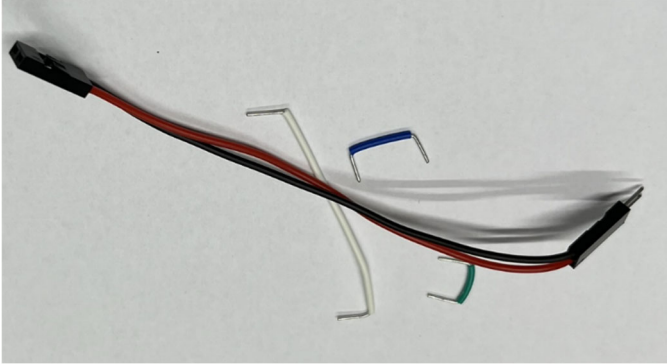

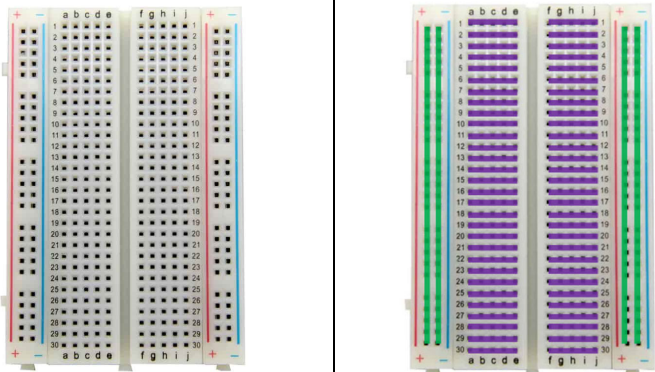
“Hey COALA! I am ready to start the 5 why method”

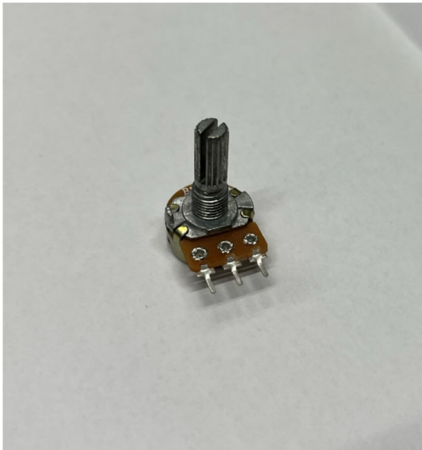


5 WHY METHOD WITH COALA

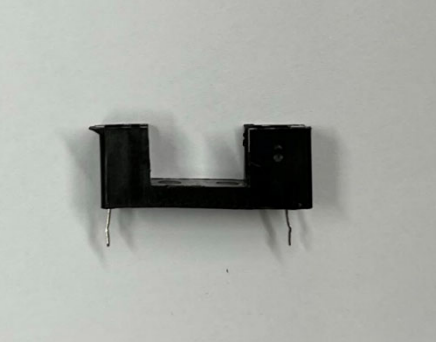

1. COALA starts the 5 why method and asks you for the problem statement
2. Do the 5 why steps together with COALA
 - a) Say if you are ready to state your root cause
3. COALA will ask you to state your root cause
4. COALA will ask you for any other comments or remarks
 - a) Every step can take a few seconds to process so wait for the reply
 - b) If you want to stop reporting ask for a stop
 - c) If you want to change something you can ask for a restart

Component List

The components below are available for use

Name	Description	Picture
Wires	Wires are used to create an electrical connection between two points. This can be on the breadboard or to components.	
High powered LED Light	High powered Light emitting diode (LED) a simple light which can be turned on by connecting both + and - sides to the electrical circuit	
Breadboard	Base of the system, it can be used to place electrical components and make electrical connection, the typical breadboard wiring layout is shown in the picture.	

<p>Potentiometer (knob)</p>	<p>The potentiometer is a variable resistor that can regulate the resistance, this means you can control the output of the system by turning it up or down.</p>	
<p>Switch</p>	<p>A simple on off switch that you can flip to break or connect the circuit.</p>	
<p>Fuse</p>	<p>A threshold for the system, the fuse will allow only up to a certain amount of electrical current through the circuit. If the fuse is exposed to too much electrical current for too long it will break the circuit, which stops the system to work until the fuse is replaced.</p>	

Fuseholder	Holder for the fuse that makes it easy to replace the fuse if necessary.	
Battery pack	The battery pack is the power source of the system on the battery pack you can see the voltage. You can use multiple battery packs	

Welcome

Thank you for participating



Roadmap

- Sign consent form
- Explanation
- Start video recording
- Do the assignment
- Fill out questionnaire



Scenario

- You work in a greenhouse as an operator to maintain the lighting installation.

- At the start of your shift, some of the lights are off and your job is to investigate what went wrong, find the root cause, solve the issue and report the investigation via an online form.

- You are going to solve and report the issue by using the 5 why method.



5 Why method

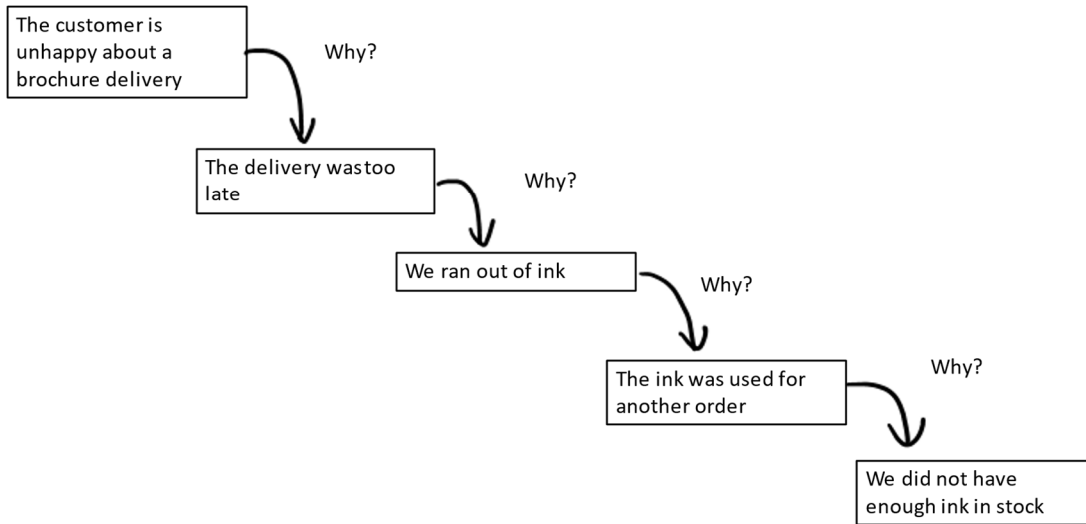
The 5 why method is simple tool to get to the root of a problem.

After you defined the problem at hand, you simply ask the question: "why is this problem existing"

You continue asking yourself why until the root of the problem is found.

WHY?
↳ BECAUSE
↳ WHY?
↳ ...

Example for a Printing company



Reporting

You have a paper sheet with a 5 why template where you can describe your steps and formulate the root cause.

Problem statement

1.

WHY?

2.

WHY?

3.

WHY?

4.

WHY?

5.

Root Cause

Comments

On the table you see

- A prototype of the lighting installation
- A component/tools list
- Spare components
- Multimeter for diagnostics
- 5 Why Template



Goals

- 3 LEDs should be emitting light
- The LEDs should have a value between 2.85 – 3.10
- The LEDs value should not go over 3.15
- Your shift takes 15 minutes
- Report your steps via computer form



Goals

- 3 LEDs should be emitting light
- The LEDs should have a value between 2.85 – 3.10
- The LEDs should not go over 3.15
- Your shift takes 15 minutes
- Report your steps via computer form

Report Previous shift

- LEDs are not working
- LED Brightness meter is working properly
- Nothing seems to be wrong with the wiring

Welcome

Thank you for participating



Roadmap

- Sign consent form
- Explanation
- Start video recording
- Do the assignment
- Fill out questionnaire



Scenario

- You work in a greenhouse as an operator to maintain the lighting installation.

- At the start of your shift, some of the lights are off and your job is to investigate what went wrong, find the root cause, solve the issue and report the investigation via a voice assistant.

- You are going to solve and report the issue by using the 5 why method.



5 Why method

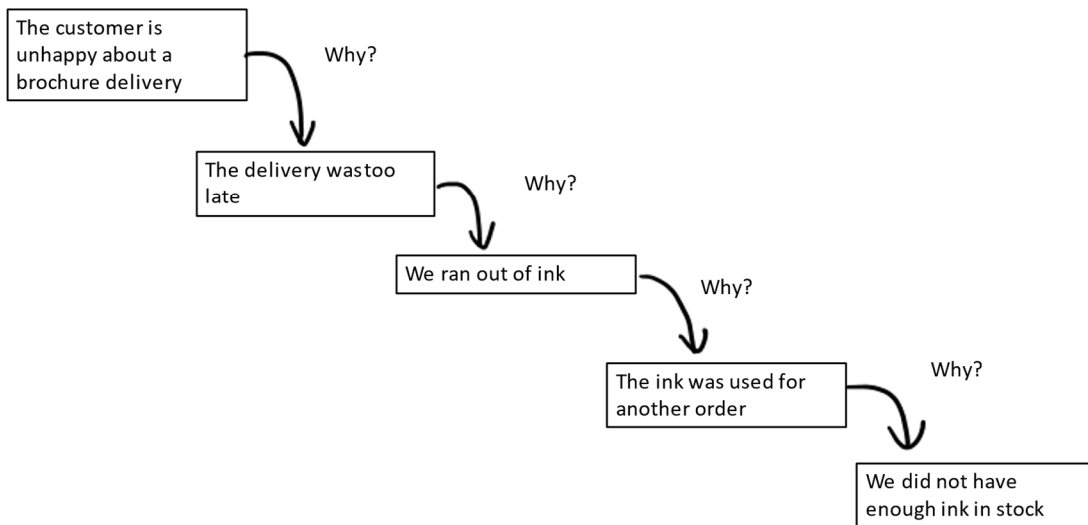
The 5 why method is simple tool to get to the root of a problem.

After you defined the problem at hand, you simply ask the question: "why is this problem existing".

You continue asking yourself why until the root of the problem is found.

WHY?
↳ BECAUSE
↳ WHY?
↳ ...

Example for a Printing company



Reporting

You have a laptop with that is setup with a voice assistant, during the experiment you can ask questions (FAQ)

After the you solved the issue, you can use the voice assistant to report your 5 why steps and the root cause



Reporting: 5 Why method with COALA

You have a laptop that is setup with a voice assistant

After the you solved the issue, you can use the voice assistant to do the 5 why method and report and the root cause, you can always go back and restart

Reporting: 5 Why method with COALA

You have a laptop that is setup with a voice assistant

After the you solved the issue, you can use the voice assistant to do the 5 why method and report and the root cause, you can always go back and restart

STARTING

You can trigger the 5 why method by saying:

"Hey COALA! I am ready to report"

Or

"Hey COALA! I am ready to start the 5 why method"

5 WHY METHOD WITH COALA

1. COALA starts the 5 why method and asks you for the problem statement
2. Do the 5 why steps together with COALA
 - a) Say if you are ready to state your root cause
3. COALA will ask you to state your root cause
4. COALA will ask you for any other comments or remarks
 - a) Every step can take a few seconds to process so wait for the reply
 - b) If you want to stop reporting for a stop
 - c) If you want to change something you can ask for a restart

On the table you see

- A prototype of the lighting installation
- A component/tools list
- Spare components
- Multimeter for diagnostics
- Laptop with active voice chat



Goals

- 3 LEDs should be emitting light
- The LEDs should have a value between 2.85 – 3.10
- The LEDs value should not go over 3.15
- Your shift takes 15 minutes
- Report your steps via the voice chat

Goals

- 3 LEDs should be emitting light
- The LEDs should have a value between 2.85 – 3.10
- The LEDs value should not go over 3.15
- Your shift takes 15 minutes
- Report your steps via the voice chat

Report Previous shift

- LEDs are not working
- LED Brightness meter is working properly
- Nothing seems to be wrong with the wiring

START/GENERAL

START/GENERAL



Hello! I am COALA!
According to my data
your shift has started
with an issue.
As soon as you are
ready to run the 5 why
method, please let me
know!

SHIFT AT TEN MINUTES



Hello, there are 5
minutes left in your
shift, do you want to
start the 5 why
method?



Your shift ends in 5
minutes

START 5 WHY METHOD



We are now starting
with the 5 Why
method! What was the
starting problem
statement?

I AM ROBOT



I am a robot voice
controlled by a human


LED

 Why are the LEDs not working?

 Why are the LEDs not working?

BRIGHTNESS

 Why is the brightness too high?

 Why is the brightness too Low?

LIGHT

 Why are the lights turned off?

FUSE

 Why is the fuse broken?


 Why is the fuse burned?

UNABLE TO HEAR

 Sorry, I could not hear you, could you please repeat?

 Could you please be more specific?


POTMETER

 Why is the potentiometer wrongly adjusted?

KNOB


 Why is the turning knob wrongly adjusted?

BATTERYPACK


 Why is the wrong battery pack attached?

COMPONENT

 Sorry, I do not know this component.


 Do you want to restart the 5 why method?

POWERSUPPLY


 Why is the wrong power supply attached?


POWER

 Why is the power too high?


 Why is the power too low?


VOLTAGE

 Why is the voltage too high?

 Why is the voltage too low?

CURRENT

 Why is the current too high?

 Why is the current too low?


FROM WHICH STEP?

 From which step?

SWITCHED OFF

 Why is the switch off?

STOP

 Why is their no current?

 Are you sure you want to stop reporting?

 Reporting is aborted

NO

 No

YES

 Yes

USER ERROR

 Is your found root cause a user or protocol error?


CABLING

 Why is the cabling wrong?

SWITCH BROKEN

 Why is the switch broken?

STEP/ROOTCAUSE

 Is there another step? Or did you reach the root cause?


ROOTCAUSE

 Please state your found root cause

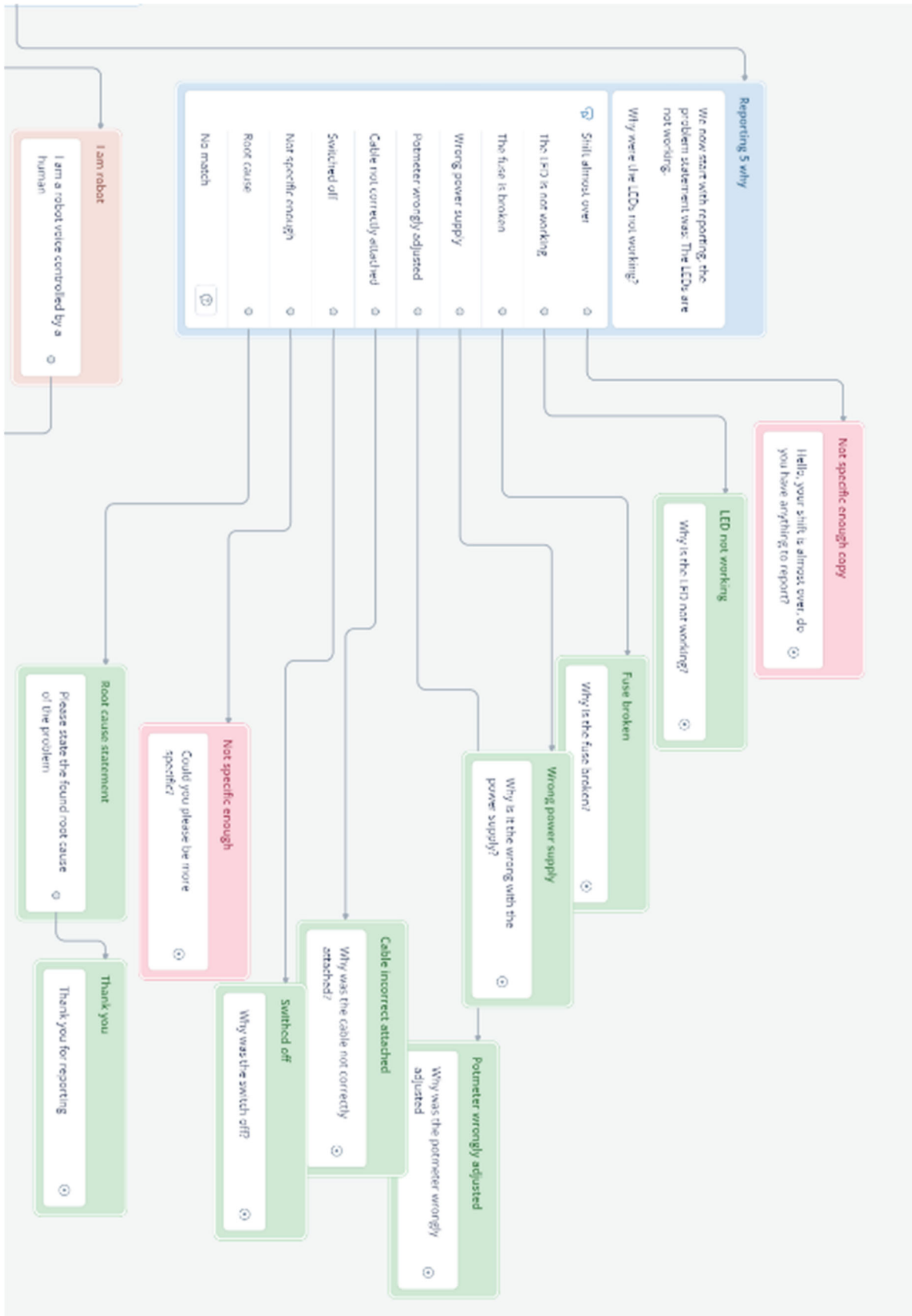
OTHER COMMENTS

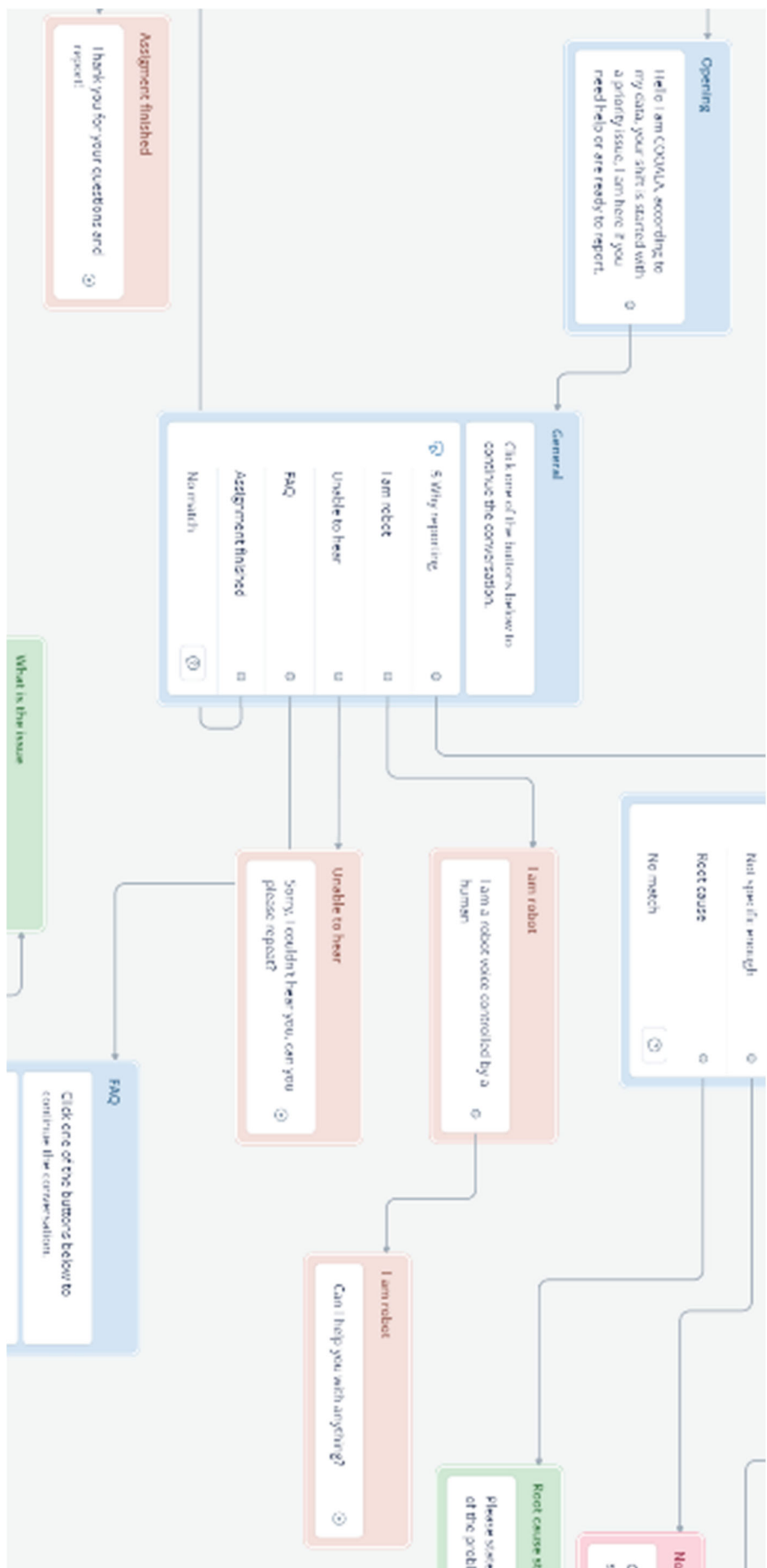
 Do you have any other remarks or comments?

THANK YOU

 Thank you for your report! The supervisor is coming your way.

9.6.9 Flowchart





9.6.10 Shapiro-Wilk Test: Normal distribution

Variable	Group	Shapiro-Wilk Test			Test type
		Statistic	df	Sig.	
Electronic Experience	Group A	0.814	10	0.021	Mann-Whitney U
	Group B	0.937	10	0.522	
Technical Problem Solving Experience	Group A	0.930	10	0.443	Independent-Samples T
	Group B	0.857	10	0.071	
Mental Demand	Group A	0.968	10	0.874	Independent-Samples T
	Group B	0.848	10	0.056	
Physical Demand	Group A	0.849	10	0.056	Mann-Whitney U
	Group B	0.717	10	0.001	
Temporal Demand	Group A	0.900	10	0.217	Independent-Samples T
	Group B	0.922	10	0.378	
Performance	Group A	0.951	10	0.684	Independent-Samples T
	Group B	0.969	10	0.883	
Effort	Group A	0.944	10	0.596	Independent-Samples T
	Group B	0.884	10	0.145	
Frustration Level	Group A	0.984	10	0.983	Independent-Samples T
	Group B	0.945	10	0.609	
Obstructive/Supportive	Group A	0.835	10	0.039	Mann-Whitney U
	Group B	0.871	10	0.102	
Complicated/Easy	Group A	0.805	10	0.017	Mann-Whitney U
	Group B	0.731	10	0.002	
Inefficient/Efficient	Group A	0.879	10	0.127	Mann-Whitney U
	Group B	0.702	10	0.001	
Clear/Confusing	Group A	0.778	10	0.008	Mann-Whitney U
	Group B	0.777	10	0.008	
Boring/Exciting	Group A	0.820	10	0.026	Mann-Whitney U
	Group B	0.953	10	0.703	
Not interesting/Interesting	Group A	0.892	10	0.177	Mann-Whitney U
	Group B	0.800	10	0.015	
Conventional/Inventive	Group A	0.849	10	0.056	Independent-Samples T
	Group B	0.903	10	0.238	
Usual/Leading edge	Group A	0.806	10	0.017	Mann-Whitney U
	Group B	0.829	10	0.033	
Root Cause Description Correctness	Group A	0.731	10	0.002	Mann-Whitney U
	Group B	0.640	10	0.000	
Data Quality	Group A	0.781	10	0.008	Mann-Whitney U
	Group B	0.731	10	0.002	
Problem Solving Time	Group A	0.876	10	0.119	Independent-Samples T
	Group B	0.909	10	0.277	
Interaction Time	Group A	0.933	10	0.483	Independent-Samples T
	Group B	0.953	10	0.708	
Total Assignment Time	Group A	0.842	10	0.046	Mann-Whitney U
	Group B	0.899	10	0.213	

9.6.11 Dataset

See added excel file in repository

9.7 Technology

9.7.1 Rasa glossary

Action#	A single step that a bot takes in a conversation (e.g. calling an API or sending a response back to the user).
Action Server#	The server that runs custom action code, separate from Rasa Open Source. Rasa maintains the Rasa SDK in Python for implementing custom actions, although it's also possible to write custom actions in other languages.
Annotation#	Adding labels to messages and conversations so that they can be used to train a model.
Business Logic#	Conditions that need to be fulfilled due to business requirements. For example: requiring a first and last name, an address, and a password before an account can be created. In a Rasa assistant, business logic is implemented using rule-based actions like forms.
Chitchat#	A conversation pattern where the user says something that isn't directly related to their goal. This can include things like greetings, asking how you are etc. Read about handling Chitchat and FAQs to learn how to implement this with Rasa Open Source.
CMS#	A way to store bot responses externally instead of including them directly in the domain. Content Management Systems decouple response text from training data. For more information, see NLG Servers.
Conversation-Driven Development (CDD)#	The process of using user messages and conversation data to influence the design of an assistant and train the model, combined with engineering best practices. There are 6 steps that make up CDD: Share, Review, Annotate, Fix, Track, and Test.
Conversation Tests#	Modified story format that includes the full text of the user message in addition to the intent label. Test conversations are saved to a test set file (conversation_tests.md), which is used to evaluate the model's predictions across an entire conversation.
Component #	An element in the an assistant's NLU pipeline in the Model Configuration. Incoming messages are processed by a sequence of components called a pipeline. A component can perform tasks ranging from entity extraction to intent classification to pre-processing.
Conditional Response Variation#	Response variation that can only be used when the current dialogue state satisfies some constraints as defined in the domain or responses files. If there's a match between the constraints and the dialogue state, Rasa can use this variation.
Custom Action#	An action written by a bot developer that can run arbitrary code, mainly to interact with external systems and APIs.
Default Action#	A built-in action that comes with predefined functionality.
DIET#	Dual Intent and Entity Transformer. The default NLU architecture used by Rasa Open Source, which performs both intent classification and entity extraction.
Domain#	Defines the inputs and outputs of an assistant. It includes a list of all the intents, entities, slots, actions, and forms that the assistant knows about.

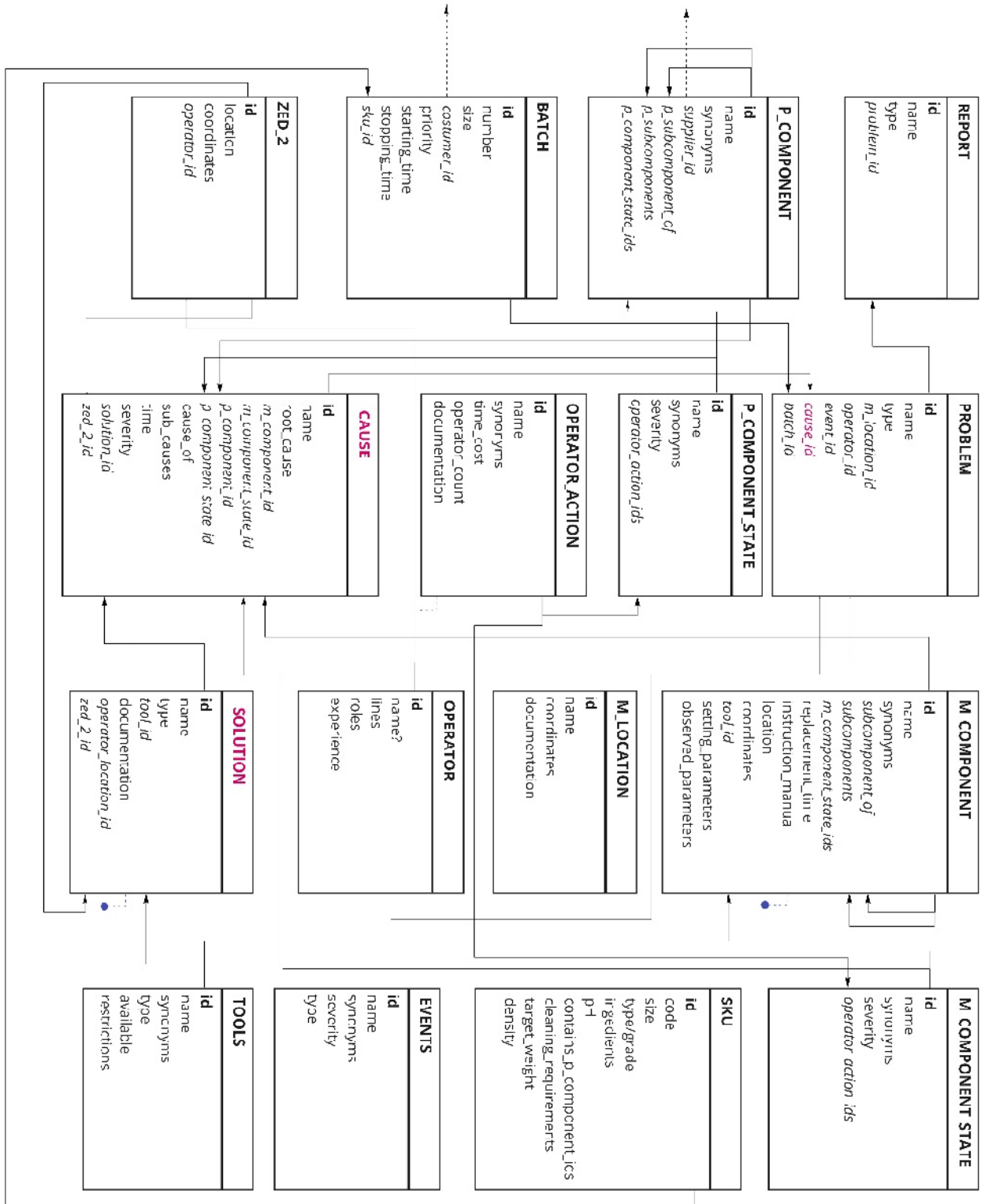
Entity#	Keywords that can be extracted from a user message. For example: a telephone number, a person's name, a location, the name of a product
Event#	Something that happens in a conversation. For instance, a UserUttered event represents a user entering a message, and an ActionExecuted event represents the assistant executing an action. All conversations in Rasa are represented as a sequence of events.
FAQs#	Frequently asked questions (FAQs) are common questions that your users ask. In the context of building an assistant, this typically means the user sends a message and the assistant send a response without needing to consider the context of the conversation. Read about handling Chitchat and FAQs to learn how to implement this with Rasa Open Source.
Form#	A type of custom action that asks the user for multiple pieces of information. For example, if you need a city, a cuisine, and a price range to recommend a restaurant, you can create a restaurant form to collect the information. You can describe business logic inside a form, like offering the customer a different set of menu options if they mention a food allergy.
Intent#	In a given user message, the thing that a user is trying to convey or accomplish (e.g., greeting, specifying a location).
Interactive Learning#	In Rasa X or the Rasa CLI, a training mode where the developer corrects and validates the assistant's predictions at every step of the conversation. The conversation can be saved to the story format and added to the assistant's training data.
Knowledge Base / Knowledge Graph#	A queryable database that represents complex relationships and hierarchies between objects. Knowledge Base Actions allow Rasa Open Source to fetch information from a knowledge base and use it in responses.
Level 3 Assistant#	An assistant that can handle conversations more complex than simple back-and-forth exchanges. Level 3 assistants are capable of using the context of previous conversation turns to choose the appropriate next action.
Messaging Channels#	Connectors that integrate Rasa Open Source with external messaging platforms, where end-users can send and receive messages. Rasa Open Source includes built-in messaging channels like Slack, Facebook Messenger, and web chat, as well as the ability to create custom connectors.
Minimum Viable Assistant#	A basic assistant that can handle the most important happy path stories.
NLG#	Natural Language Generation (NLG) is the process of generating natural language messages to send to a user. Rasa uses a simple template-based approach for NLG. Data-driven approaches (such as neural NLG) can be implemented by creating a custom NLG component.
NLU#	Natural Language Understanding (NLU) deals with parsing and understanding human language into a structured format.
NLU Inbox#	The area within Rasa X where new user messages are collected for review and annotation. Only messages not already represented in the training data will appear in the NLU Inbox.

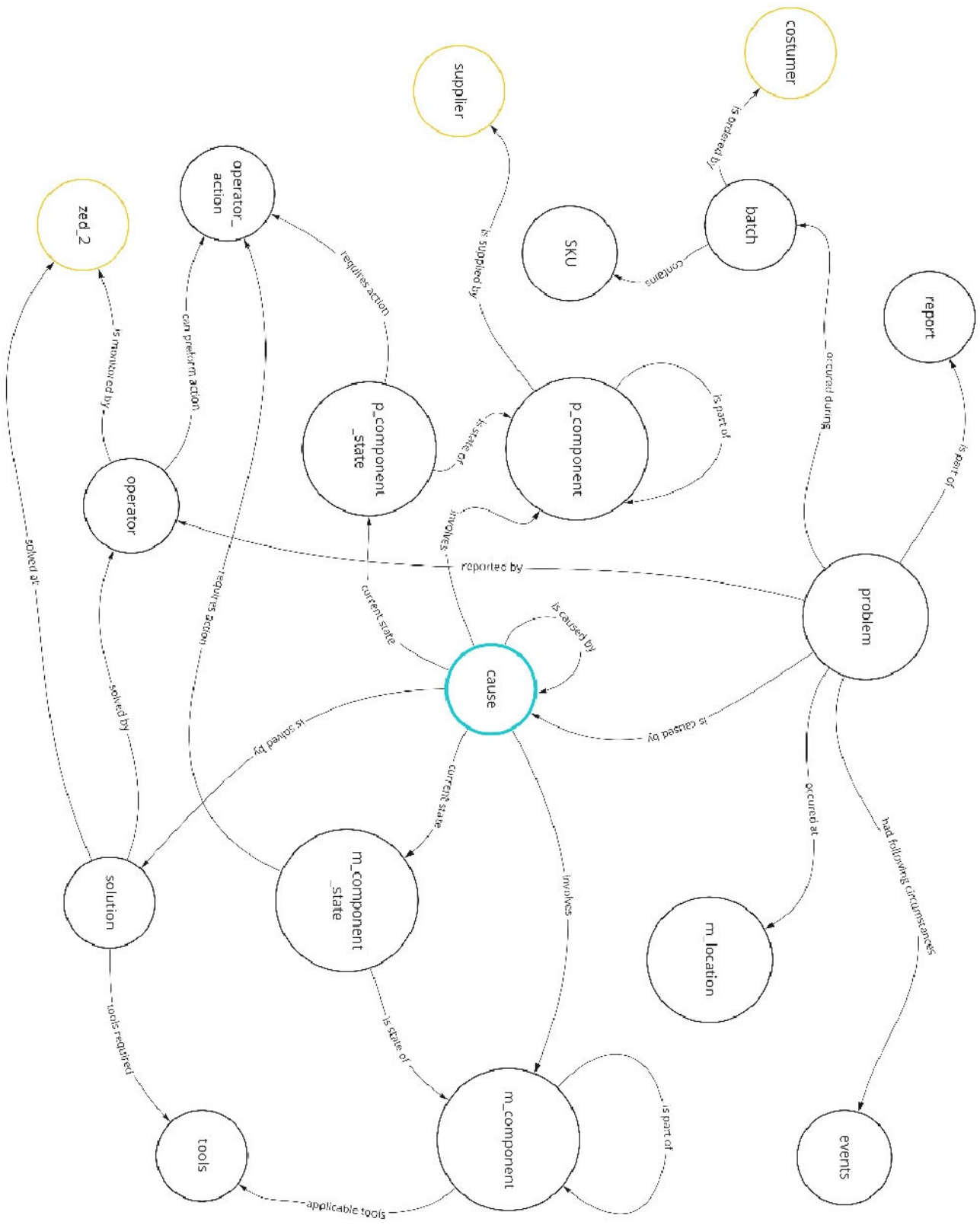
Pipeline#	The list of NLU components (see NLU Component) that defines a Rasa assistant's NLU system. A user message is processed by each component one by one, before returning the final structured output.
Policy#	Rasa Open Source components that predict the dialogue system's next action. Policies make decisions about how the conversation flow should proceed. A typical configuration includes multiple policies, and the policy with the highest confidence decides the next action to be taken in the conversation.
Rasa NLU#	Rasa NLU is the part of Rasa Open Source that performs Natural Language Understanding (NLU), including intent classification and entity extraction.
NLU Component #	An element in the Rasa NLU pipeline (see Pipeline) that processes incoming messages. Components perform tasks ranging from entity extraction to intent classification to pre-processing.
Retrieval Intent#	A special type of intent that can be divided into smaller sub-intents. For example, an FAQ retrieval intent has sub-intents that represent each individual question the assistant knows how to answer.
REST Channel#	A messaging channel used to build custom connectors. Includes an input channel, where user messages can be posted to Rasa Open Source, and the ability to specify a callback URL, where the bot's response actions will be sent.
Response / Template / Utterance#	A message that an assistant sends to a user. This can include text, buttons, images, and other content.
Rules#	Special training data to specify rule-like behavior, where a specific condition always predicts a specific next action. Examples include answering FAQs, filling Forms, or handling Fallbacks.
Slot#	A key-value store that Rasa uses to track information over the course of a conversation.
Story#	Training data format for the dialogue model, consisting of a conversation between a user and a bot. The user's messages are represented as annotated intents and entities, and the bot's responses are represented as a sequence of actions.
TED Policy#	Transformer Embedding Dialogue Policy. TED is the default machine learning-based dialogue policy used by Rasa Open Source. TED complements rule-based policies by handling previously unseen situations, where no rule exists to determine the next action.
Template / Response / Utterance#	A message template used to respond to a user. Can include text, buttons, images, and other attachments.
Tracker#	Rasa Open Source component that maintains the state of the dialogue, which is represented as a JSON object listing the events from the current session.
User Goal#	The overall goal that a user wants to achieve, e.g. looking up the answer to a question, booking an appointment, or purchasing an insurance policy. Some tools refer to the user goal as the "intent," but in Rasa terminology, an intent is associated with each individual user message.

Word embedding / Word vector#	A vector of floating point numbers that represent the meaning of a word. Words that have similar meanings tend to have similar vectors. Word embeddings are often used as an input to machine learning algorithms.
-------------------------------	--

9.7.2 Relation to Graph DB

On this page you see a more commonly used relational database model of the Diversey context, on the next page this is translated to a abstract of a graph database.





Creating GraphQL Queries - GRAPHQL_SERVER

GRAPHQL_SERVER:

For making a query you will need to do two things in the GRAPHQL_SERVER repo. Each query needs a schema.py file (or you are able to use existing ones) and resolve method with a cypher query in the resolver.py file

Schema

Each query will need a schema to define the class of the query and its variables (**please note that these variables should be named the same as your neo4j labels/properties**). It contains both a class for the query and query type.

This typically looks like this:

```
# GraphQL Example Schema

from typing import List
import graphene
import neomodel

class ExampleType(graphene.ObjectType):
    """
    A class to represent an example in graphql schema.
    Attributes

    example (str): the example that should be performed
    """
    #These are the variables that you want to extract from neo4j could be labels,
    relations or properties
    #If one of the variables is required eg for a MATCH it should be set to True
    variable1 = graphene.String(required=False)
    variable2 = graphene.String(required=False)
    variableN = graphene.String(required=False)

class Example(neomodel.StructuredNode):
    """
    A class to represent the Example nodes in the graph database.
    Attributes

    Example (str): the example that should be performed
    """
    #Same as the graphene strings but now for neomodel, make sure the variable nam
    es are the same
    variable1 = neomodel.StringProperty(required=False)
    variable2 = neomodel.StringProperty(required=False)
    variableN = neomodel.StringProperty(required=False)

    @staticmethod
    def query_test_list(max_entries: int = None) -> List:
```

```

"""
Query a list of example nodes from database.
Filter when arguments provided.
    properties:
        test (str): the example that should be performed
    Returns:
        test (List): list of example nodes with properties
"""

# Create an empty list to append objects to be returned
example_list = []

# Retrieving the node (properties) directly from the neo4j database
example_list = Example.nodes.all()

return Example_list

```

It is recommended to just copy a schema.py file that is most close to what you want to create and adapt it.\

Resolver.py

In the resolver.py file you will need to do three things, refer to the schema, create a variable to save your query result and create a method with your cypher query

Refer to your schema like this at the top of the file:

```

from server.schema.example import Example, ExampleType

```

In the query class define the variables of your query (**please note that these variables should be named the same as your neo4j labels/properties**), again if the variable is required it should be set to True.

This should look like this:

```

example = graphene.List(
    ExampleType,
    variable1 = neomodel.StringProperty(required=False)
    variable2 = neomodel.StringProperty(required=False)
    variableN = neomodel.StringProperty(required=False))

```

Then for the method the name is of importance, it should be named exactly like the, in this case, graphene.List above. Be sure to always test the cypher query in neo4j first so you are certain it give to output you need.

This example shows a query to retrieve all example nodes from neo4j:

```

@staticmethod

```

```

#This method name should always be named the same as the list defined above in
the query class
def resolve_example(root, info) -> List:

    #Cypher query
    results0, meta = neomodel.db.cypher_query(
        "MATCH (example:Example) RETURN example")

    example_list = [Example.inflate(row[0]) for row in results0]

    return example_list

```

This example shows a query to create an example node on neo4j:

```

@staticmethod
#This method name should always be named the same as the list defined above i
n the query class
def resolve_create_example(root, info, variable1, variable2, variableN) -> Str
:

    #Cypher query, note that the first variable before the ":" is the property
name in neo4j
    results0, meta = neomodel.db.cypher_query(
        "CREATE (n:Example {variable1: " + repr(variable1) + ", variable2: "
+ repr(variable2) +
        ", variableN: " + variableN + "})"
    )

    #No need to return anything as this posting
    return []

```

Don't forget to remove, rebuilt and run the graphql image in the docker everytime you update something

Creating GraphQL Queries - Cognitive advisor (rasa + actions)

On the RASA side you set up the basic conversational flow as you normally would so you start with building an intent and an action. Don't forget to retrain your NLU model otherwise it will not work.

In the NLU file:

```

- intent: example
  examples: |
    - examplesentence1
    - examplesentence2

```

```
- examplesentenceN
```

In the stories (or rules) file:

```
stories:  
- story: example path  
  steps:  
  - intent: example  
  - action: action_Example
```

Following this you have to create an action in one of the action.py files that will trigger the method of the query (Please mind the spelling and capitals in the variables, actions and methods)(see last part of this wiki). This specific action retrieves variables from the Neo4J database and utters a message with these variables:

```
class ActionExample(Action):  
  
    def name(self) -> Text:  
        return "action_Example"  
  
    def run(self, dispatcher, tracker, domain):  
  
        example_variable = get_Example()  
  
        dispatcher.utter_message("This example line show the first variable " + example_variabel[0] +  
            " and the second one " + example_variabel[1] + " and the Nth variable " +  
            example_variabel[N-1])  
  
        return []
```

To be able to communicate with with GraphQL you need to have the following in order in the graphql_queries.py files to be able to connect to GraphQL (should be fixed if you use the git_lab versions):

```
container_name = config.get_endpoint("graphql").get("container_name", "")  
container_port = str(config.get_endpoint("graphql").get("container_port", ""))  
routing_parameter = config.get_endpoint("graphql").get("routing_parameter", "")  
  
graphql_url = f"http://{container_name}:{container_port}{routing_parameter}"
```

In the same file you can now create the GraphQL queries **Please make sure these names are the exact variable names as on the GraphQL server:**

```
def grapgql_get_Example() -> Any:  
  
    query = (''query {  
                Example{  
                    variable1  
                    variable2  
                    variableN
```

```

        }
    }'''

client = GraphQLClient(graphql_url)

try:
    result = client.execute(query)

except URLError as e:

    log.warn('Error while executing GraphQL query.')
    log.warn(f"Reason: {e.reason}")
    log.warn(f"Endpoint: {client.endpoint}")

    result = {
        "errors": [
            {
                "error_response": "url_error",
                "service_name": "GraphQL"
            }
        ]
    }

return result

```

For rasa to be able to use the variable the `graphql_helpers.py` file is used. In this file you create a readable return value for the rasa action

```

def get_Example() -> Dict[Text, Text]:

    example= grapgql_get_Example()
    objects = json.loads(example)
    variable1 = objects['data']['Example'][0]['variable1']
    variable2 = objects['data']['Example'][0]['variable2']
    variableN = objects['data']['Example'][0]['variableN']

    example = [variabel1, variable2, variableN]

    return example

```

At this point you should have everything up and running and you are able to test if it works in rasa shell!

9.8 Code

For the code you can contact me via jeroenschunselaar@gmail.com to get access to the Github page