DAI-DSS FAIRWORK KNOWLEDGE BASE AT USE CASE SITE

D5.1

Editor Name	Rishyank Chevuri (Jotne Connect)
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EXECUTIVE SUMMARY

This document is Deliverable D5.1, which focuses on the FAIRWork Knowledge Base at the Use Case Site. The deliverable encompasses the results of Task T5.1 "Modelling FAIRWork for Production Processes" and Task T5.2 "Creating FAIRWork Knowledge Base". The document needs to be seen in the context of the FAIRWork objective to provide a decision support system that (a) integrates digital twins to optimize the overall production process according to multiple parameters, and (b) democratizes decision making granting human worker and machines a say during decision making. The project combines (a) model-based approaches to transparently design, simulate and improve decision making, (b) a co-creation laboratory using models and physical experiments as communication media to all actors and, (c) reliability indication of data and AI algorithms.

This deliverable serves as a public demonstration of the project's progress. It provides a concise overview of the work completed in Task T5.1, which involved creating decision process models for two Use Case providers, FLEX and CRF. These models cover various use case categories such as "Automated Test Building," "Worker Allocation," "Machine Maintenance After Breakdown," "Workload Balance," "Delay of Material," and "Quality Issues." These models incorporate details about the production environment, decision-making processes, and involved actors. In this deliverable, Chapter 2 corresponds to the Task 5.1 and provides a comprehensive overview of the methodology employed for decision process modeling in the FAIRWork project, as well as the tools utilized to implement these models. Additionally, there is information provided on how to access these models for demonstration purposes. Section 2.1 delves into the methodology of decision process modeling within the specific context of the FAIRWork project. It outlines the steps and approaches taken to develop effective decision models that can enhance decision-making processes. This section provides insights into the iterative nature of the modeling process, emphasizing the need for clear understanding of a problem, identification of concrete decisions, and relevant decision parameters and aspects.

Section 2.2 focuses on the tools utilized to implement the decision process models in the FAIRWork project. It discusses the technological infrastructure leveraged to create these models effectively. The section highlights the utilization of modeling techniques, such as BPMN 2.0, to ensure consistency and compatibility across different decision trees and scenarios. Furthermore, Section 2.3 and 2.4 provide an overview of the decision process models developed specifically for the end users of the FAIRWork project, FLEX and CRF. These sections also present the relevant data inputs to facilitate decision-making.

Concurrently, task T5.2 focused on collecting and storing the data and decision models required for each Use Case scenario to establish a common Knowledge Base. The Knowledge Base is built on internationally available open standards, with the ISO 10303 (STEP) standard for data exchange serving as the foundation for the developed repositories. The Knowledge Base provides REST APIs that enable data access and exchange. Furthermore, the deliverable includes the demonstration of the Knowledge Base through figures presented in chapter 3, showcasing the preliminary project setup, and data accessing methods using REST API and also providing information on the demonstrator videos that are made to show the data accessing and sharing capabilities of the Knowledge Base.

The contents of this deliverable will contribute to "D5.2 DAI-DSS Infrastructure and Setup Report at Use Case Site" and "D5.3 Demonstration Report of FAIRWork with DAI-DSS", scheduled for M20 and M36, respectively. These subsequent deliverables will further adapt the Knowledge Base to suit the specific needs of the use cases.

PROJECT CONTEXT

Workpackage	WP5: Demonstration of FAIR Work at Use Case Site
Task	T5.1,5.2
Dependencies	WP3, WP4

Contributors and Reviewers

Contributors	Reviewers
Aleassandro Cisi (CRF) Roland Sitar (FLEX) Marlene Mayr (BOC) Magdelena Dienstl (BOC) Rishyank Chevuri (Jotne Connect)	Herwig Zeiner (JR) Gustavo Vieira (MORE) Damiano Falcioni (BOC)

Approved by: Robert Woitsch [BOC], as FAIRWork coordinator

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LIST OF ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
AI	Artificial intelligence
ANN	Artificial neural networks
API	Application program interface
BPMN	Business Process Model and Notation
CAD	Computer aided design
CE	cognitive-emotional
DAI-DSS	Democratized AI decision support system
DHS	Digital Human Sensor
DMN	Decision Model Notation
EDM	Express data manager
EIP	Enterprise Integration Pattern
FIPA	Foundation for Intelligent Physical Agents
GUI	Graphical user interface
HLD	High level design
HTTP	Hypertext Transfer Protocol
IT	Information technology
IIOT	Industrial internet of things
IOT	Internet of things
ISB	Intelligent sensor box
ISO	International Organization for Standardization
JSON	JavaScript Object Notation
KPI	Key performance indicator
LLD	Low level design
MAS	Multi Agent System
ML	Machine Learning
NLP	Natural Language Processing
OGSi	Open Service Gateway Initiative
OPC-UA	Open Platform Communications - Unified Architecture
PLCS	Product Life Cycle Support
PLM	Product Lifecyle management

PSI	physiological strain index
QA	Quality assurance
RDF	Resource Description Framework
RDL	Reference data library
REST	Representational State Transfer
RL	Reinforcement Learning
SDAI	Standard Data Access Interface
SDLC	Software development life cycle
STEP	Standard for the Exchange of Product model data
TCP	Transmission Control Protocol
UI	User interface
URI	Uniform Resource Identifier
WP	Work package
XML	Extensible Markup Language

1 INTRODUCTION

1.1 Purpose of the Document

This document provides an overview of the current state of the Decision process models and data storage and exchange for the FAIRWork project. It includes detailed flow charts that illustrate the decision-making processes associated with each use case scenario, highlighting the specific data required to support those decisions. Additionally, the document describes the setup of the DAI-DSS Knowledge Base, which serves as a repository for collecting and storing relevant data related to the use case scenarios. This Knowledge Base is designed as a Data Lake, allowing for flexible storage and retrieval of data. The document outlines the structure of the project within the Knowledge Base. To facilitate access and extraction of information from the Knowledge Base, the document presents the utilization of REST API functions. These functions provide a means to retrieve data from the Knowledge Base, enabling seamless integration with other systems and applications. Through these API functions, users can access and retrieve the information they need to support their decision-making processes.

Furthermore, the document presents the data sharing capabilities of the Knowledge Base by demonstrating its integration with the Olive Framework[1]. Where several examples in form of videos are presented to illustrate how web micro services provided by the Olive framework can access data from the Knowledge Base, showcasing the practical application of the data sharing capabilities.

Overall, this document offers a comprehensive overview of the decision process models, data storage and exchange, and the utilization of the Knowledge Base for the FAIRWork project. It emphasizes the importance of leveraging the available data to support decision-making and demonstrates the practical implementation of accessing and sharing data through the REST API functions.

1.2 Project Introduction

Manufacturing companies are to face challenges more than ever to international competition in the modern world due to advancements and incorporation of Digital technologies like AI and Robotics in production lines. Different objectives can be used for production system optimization, it might cover all technological components, including the use of robots, machines, AI, or it can apply to the improvement of processes and systems using important criteria like the number of workers, the number of stations, the line's balance between stations, and others. All these criteria may be employed in the optimization process to govern the process depending on some decisions. All optimization tasks need evaluation of the performance of process, machines, workers. The most common way used in most of the manufacturing companies to evaluate the production systems are Key Performance

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[1] https://www.adoxx.org/live/olive

Indicators. These indicators show the performance of the process in all needed aspects. These indicators in business have the preferable value which is a target of process performance. Decisions are made based on these measurable performance indicators to control the process in relation to cost, expected efficiency and energy consumption. The main challenge is that these decisions overlap or are in conflict with each other.

Most of the production processes are complex, thus there is a high likelihood that the decisions made lead to unwarranted result. Additionally, decision-making in the modern production environment results in a great deal of uncertainty due to the lack of knowledge about something or lack of precision data. This is crucial because, in case of complicated production processes, the choice about the process' desired performance is not clearly stated. This makes it difficult to determine with precision if a method's assistance can provide managers with the chance to grasp the situation's entirety and base decisions on objective information. Based on the situation presented above, making a fast and good decision is important to make the profitability and effective business in the world of customization and short lead times.

Current automated and hierarchical structured production processes can only insufficiently deal with the upcoming flexibilization. To tackle this complex production setting we are introducing a decentralized AI system by "democratization" of decision making in production processes, where all relevant stake holders are involved. The proposed Democratic AI-based Decision Support System (DAI-DSS) finds the appropriate decision for a concrete situation during production. Each human or technical actor is represented by an agent who negotiates based on the status provided by the digital shadow and twins. The future situation is predicted by AI algorithms for each individual actor considering the modelled Knowledge Base that defines each negotiation strategy. A multiple optimization algorithm finds the most appropriate solution considering the needs of all involved human and technical stakeholders.

FLEX has been selected, both providing a complex combination of human, AI, robots, and data, acting as a role-model for flexibilization and optimization of production processes, and aiming to consider energy efficiency and workforce safety, production efficiency, and workload management in their decision making. The two use cases with complex cyber-physical smart and data driven processes are:

(1) The car manufacturer CRF, need to optimize the throughput between two succeeding production lines where automatic lines, static and mobile robots, and human workers with and without machines are cooperatively working together.

(2) The design and manufacturing company FLEX wants to speed up and improve the programming of manufacturing robots for low volume production. The cooperative production by humans and robots is influenced by factors like energy consumption for moves, machine hours, safeness of cooperating workers within the co-working area, selection, and tooling of grippers in combination with production plan and the required flexibility in low volume production.

To address the issues in the use cases FAIRWork will use proposed Democratic AI-based Decision Support System (DAI-DSS) to optimize the production process. The overall objective of the DAI-DSS is shown in Table 1 below.

Table 1: Democratic AI-based Decision Support System (DAI-DSS) Objectives

Democratic AI-based Decision Support System (DAI-DSS) Objectives	
Speed-Up the Configuration of complex Decision-Making: Models speed up the configuration and maintenance.	Having at least 5 pre-defined decision models in the Knowledge Base
Enable Compliance in Decision-Making by approved Models: Using methods and tools to approve decision models	Use approved models in Knowledge Base in 100% of decisions
Improve the Co-creation Capabilities: Using physical laboratories enabling participatory and user-centered design.	Include advanced laboratory-based evidence in 100% of approved models

FAIRWork brings "Human, AI, Data and Robots" together, by introducing: (a) Design Decision Models and assess if those models are "appropriate / fair", (b) decentralize the decision-making, by representing involved – human or technical – actors within a Multi Agent System and configure each agent with previously approved decision models, (c) broaden the view to optimize the production process, by also introducing social and energy related parameters to the existing technical and business related aspects. These will be identified and valuated in a participatory and user-centered design process. This enables a more balanced decision-making in complex situations, as the flexibility opens-up "space for maneuverer".

The goal is to change the present production process's decision-making to cooperative decision-making so that human workers may trust the decisions made regardless of whether they were made by humans, artificial intelligence (AI), or in a hybrid fashion. The DAI-DSS focuses providing support for making decisions in the production process under uncertainty, strong dependencies on unknown future events, affecting the balance of work between humans and machines, and affecting the overall success of the production process while using the available data with "best effort" in frequently a very complex and conflicting situation for human decision makers.

1.3 Document Structure

This deliverable is structured as follows:

- **Chapter 1:** this section introduces the project objectives with focus on the main goals and problem statement, and contains a short summary describing the intended purpose of the deliverable
- **Chapter 2:** Describe about decision process models and how it is used for FAIRWork use case scenarios and list the required data for each use case scenario

- **Chapter 3:** details the setup of the Knowledge Base. It gives an overview of how information and data will be structured and stored along with a description of the REST API interface and how this can be used to interact with the model and the data contained in it.

- **Chapter 4**: summarizes the content of this document and provides the conclusion.

2 DECISION PROCESS MODELLING

In this section, the use case scenarios are specified through the decision process models. For the DAI-DSS, the decisions involved are critical to better understand the problem settings the responsible decision-makers face. Thus, in section 2.1, the methodology for modelling the decisions is presented. In 2.2, access to the modelling environment and the decision process models is demonstrated. The last two sections, 2.3 and 2.4, cover the FLEX and CRF use case scenarios and a detailed description of the identified decision process models involved per scenario. These sections also include the required data requested for the use cases.

2.1 Methodology of Decision Process Design

Based on the application scenarios and business process model that were covered in Deliverable 2.1, a more detailed understanding of the involved decisions for building a DAI-DSS is required. Thus, identifying concrete decisions, including relevant decision parameters and aspects, is necessary. Figure 1 shows the methodology how the decision process modelling was approached in FAIRWork. Currently, the focus lies on step 4 the specification and detailing of the initial defined use cases, as highlighted. The previous three steps concerning the preparation of the use case domains, the scenario development and the Process Landscape Design served as foundation for performing this step. Like the business processes, the Business Process Modelling technique was applied by using BPMN 2.0 as a modelling standard to draw the decision trees involved in each of the prior defined use case scenarios. The decision models are an additional step to concretize the use case requirements and to ease the identification of relevant aspects and information for experts to decide. Based on the decision trees, a joint base fosters the technical alignment and discovery of services, especially of AI services suitable for supporting a specific decision aspect or the whole process.
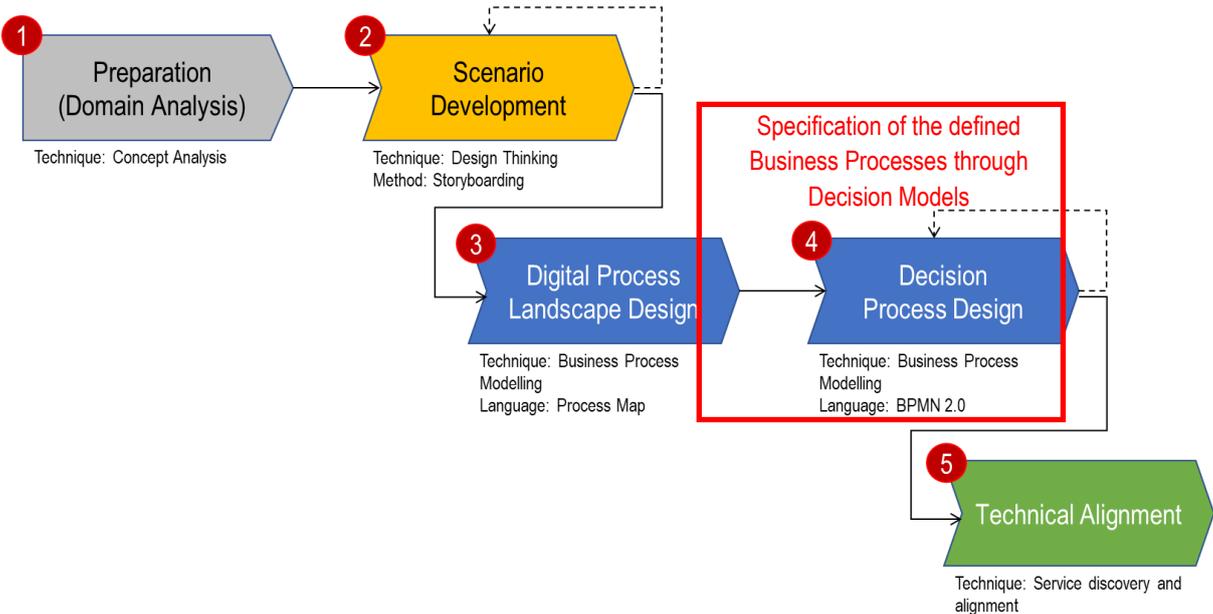
Figure 1: Methodology for designing Decision Processes

Due to the high preciseness of the decision models, recurring interviews and workshops with domain experts and the relevant decision-makers were required. Additionally, previously defined data requirements were considered to better understand what parameters are involved in the decision and where the specific piece of information may be found. Three main questions are relevant in preparing the decision model:

1. Who is the relevant decision-maker?

2. What should be the outcome of the specific decision-making process?

3. Which aspects and parameters must be considered to find a solution?

Thus, by keeping those three questions in mind, a final decision model per application scenario could be approached. The decision process models are created in the online modelling environment ADONIS. For demonstration purposes the modelling environment and the public space for accessing the models are introduced in the next section.

2.2 Accessing the Decision Process Models and Tool

There are two tools to be introduced within this deliverable for demonstration purposes. First a description of the modelling environment ADONIS and on how to use the tool is given. Then the FAIRWork website is depicted for accessing and downloading the described decision process models.

2.2.1 Process Modelling Environment

ADONIS, a cloud-based modelling platform, is used as the FAIRWork process modelling environment. It is a framework built on the ADOxx meta-modelling platform and is compliant with the BMPN 2.0[2] standard. It is used for the initial business processes and the finally derived decision process models per the defined use case scenario. In order to access the modelling tool, ADONIS evaluation credentials must be requested first from faq@adoxx.org, then the environment can be accessed via https://fairwork-sp103940.boc-cloud.com/main.view#0. The Login page is illustrated in Figure 2.
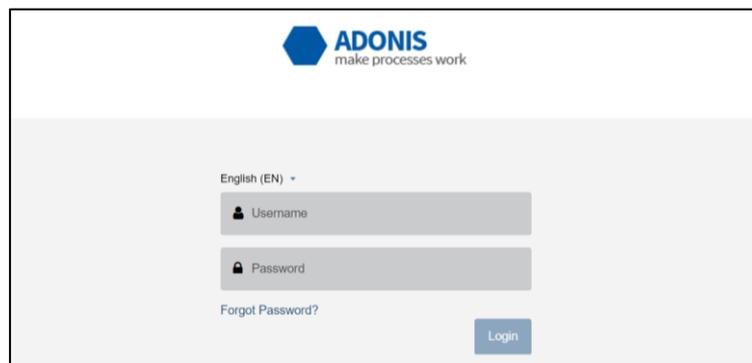
Figure 2: Adonis Login page

As ADONIS is a full business process management suite that incorporates three main features 1) "Design & Document" 2) "Control & Release and 3) "Read & Explore" as seen in Figure 3. The first capability concerns the design, the second allows to review and release of processes and the third is used for reading and checking the correctness of the processes. For the following demonstration of the tool the focus lies on the design of the decision processes, hence feature "Design & Document" must be chosen. In Figure 4 the three sections are shown.
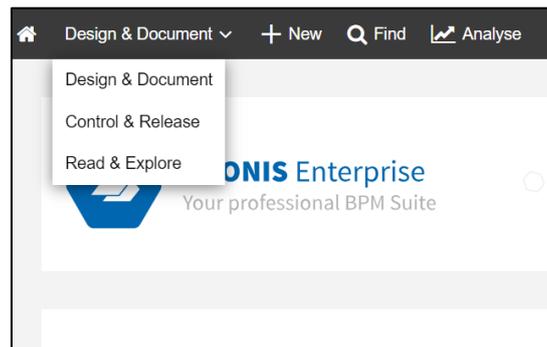
Figure 3: Main Features of Process Modelling Environment

By navigation through the "Find" button, all models and objects can be explored in the modelling environment. The existing process models are depicted in a folder-tree structure and can be visualized. Additionally, new processes can be created directly in the target folder. This step is shown in Figure 4.
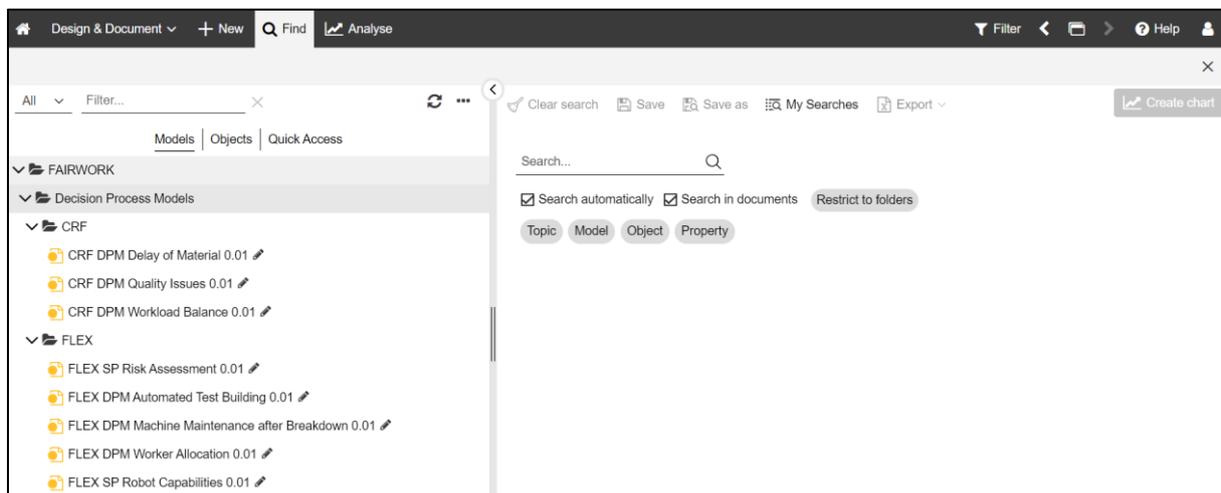
Figure 4: Searching, selecting, and creating processes in the modelling environment

Existing models can be improved, or processes can be created from scratch. For this purpose, the interface offers the possibility to utilize all BPMN objects. Due to the assistance feature provided by ADONIS, an easy drawing of connections between the elements and suggestions on the next object are given. On top of the modeling canvas,

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[2] https://www.omg.org/spec/BPMN/2.0/

functions for exporting, validating, and releasing the processes are offered. In Figure 5 the described modeling canvas can be seen. All possible object types of BPMN 2.0 are listed and it is possible to add further information into the attributes such as special types of decision gateways, durations of specific activities or responsible roles who perform a task.
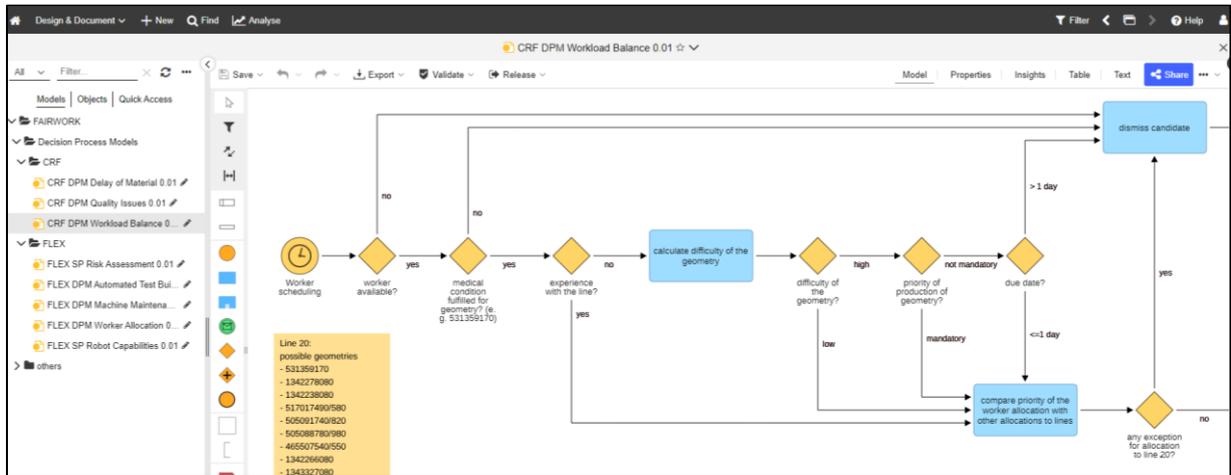
Figure 5: Process Modelling Environment canvas

2.2.2 Decision Process Models

Besides the access to the modeling environment and the proper toolkits for modelling, the decision process models can be found on the FAIRWork web page by accessing the https://fairwork-project.eu/deliverables/d5-1 .In the webpage page under Decision Process Models section the elaborated decision models can be found in a PNG or BPMN file format. The landing page and the access links are illustrated in Figure 6.[3]

Figure 6: Accessing the FAIRWork Webpage

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[3] https://fairwork-project.eu/deliverables/d5-1

2.3 Flex Use Case Scenarios

2.3.1 Automated Test building

The business process for creating automated test building is depicted in Figure 7 and starts with a new product order or the requirement for a manufacturing process update. The automation engineer oversees organizing and designing the inclusion of the robots in the manufacturing process for a given request. The program manager provides this information together with order specifics (such as the needed cycle time, quantity, and client details). Cooperative mode is the recommended method of operation for robots, but collaborative mode is also a possibility. Because there are no people involved or present in cooperative mode, the robot may move more quickly, resulting in a reduced cycle time. In collaborative mode humans need to work close to the robots and the speed and motions of robots need to be reduced such that it will be safe for the humans in the range of motion. Here the automation engineer needs to consider several aspects like safety of workers, regulations, cycle time for
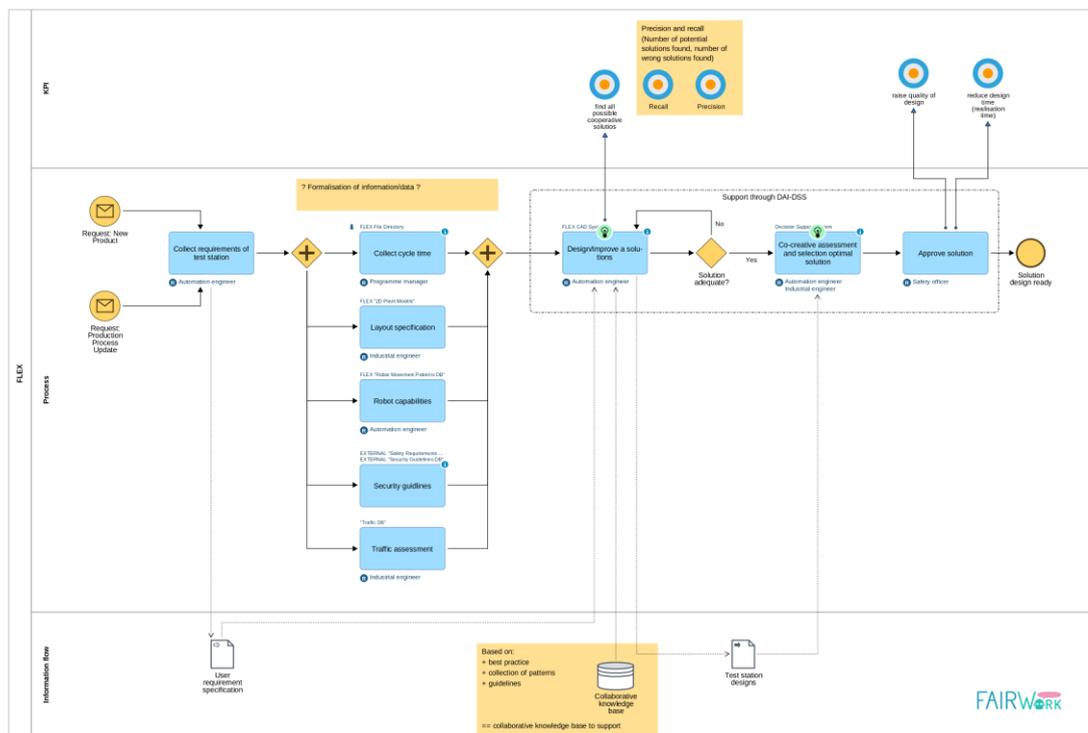
designing a solution.

Figure 7: FLEX Automated Test Building

Decision process models

Building test stations where humans and robots might collaborate involves multiple decision-makers, such as engineers, quality personnel, or program managers, and many decision aspects must be considered. Thus, three decision processes can be differentiated to break down this complexity. Figure 8 gives an overview of how the decisions can be clustered and how they connect with each other.
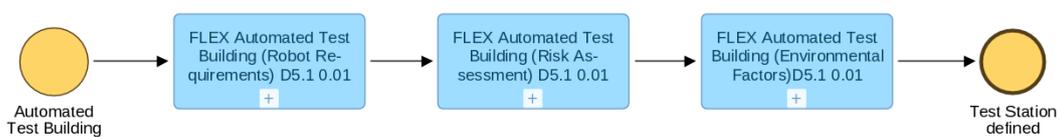
Figure 8: Automated Test Building: connection of the involved decisions

The first decision, "Robot Requirements" must be made regarding the type of robot and its capabilities and features, mainly determined by the specific product and its required process flow. The selected robot type provides information necessary for the other two decision processes, such as the reach, which defines the safety zone and the critical area around the robot. The second decision process, "Risk Assessment" addresses the level of risk that can be expected when working with the robot. This process is relevant to identifying safety concerns and risk reduction measures. The third process, "Environmental Factors," concerns environmental factors and other decision parameters to finally decide which Human-Robot Interaction modes are possible and feasible. Each decision process model is explained and analyzed in more detail below.

1. **Robot Requirements**

Deciding on a specific type of robot includes many aspects covering weight, distance, or movement requirements. Thus, the process starts with a request to build a test station for a particular product as shown in Figure 9. The first parameter that the engineers must consider is the payload that needs to be carried by the robot arm. This parameter differentiates the smaller robot types, TM5-700, and TM5-900, from the bigger ones, the TM12 and TM14. The latter two can carry up to 12 or 14 kilograms. On the contrary, in the TM5 series, the TM5-900 can only lift a maximum of 4 kg and the TM5-700 a maximum of 6 kg. This needed payload capacity is mainly defined by the type of gripper and its weight. The second important decision aspect is the definition of the maximum reach. The TM5 series can be differentiated in a reach of 900 mm maximum by the TM5-900 or a reach of 700mm maximum for the TM5-700. The reach is determined based on the distance from one robot system to another or to humans. The third aspect focuses on the desired speed of a robot. With a maximum speed limit of 1,4 m/s, the TM5-900 is faster than the TM5-700 with only a

rate of 1,1 m/s. The bigger robot types with a possible payload above 6 kg are characterized by a maximum reach of 1100 mm by the TM12 and 1300 mm by the TM14. Although the TM14 can reach further, it is slower than the TM12 with a typical speed of 1,1 m/s compared to 1,3 m/s. Besides the speed parameter, the two robots differ in their possible movement capabilities. All robot types have a total of 6 joints that allow them to navigate the available space and do their programmed operations. This is characterized by either the joint range or the joint speed of the robot arm. The radius and speed are for all joints for the TM5 type the same; thus, there is no differentiation made. Also, for the TM12 and TM14, these aspects are similar but except for joint 3's range and joint 4 and 5's speed. When a range of up to +/- 166° is required for joint 3, only the TM12 will fit. If a joint range of up to +/-163° is enough, the TM14 would be suitable for the application. The speed of joints 4 and 5 is higher for TM12 as well and can be up to 180°/s compared to 150°/s for TM14.

The first generic robot type can be chosen when applying the requirements to these robot characteristics. Each type can be further specified into four subtypes, as in the process model in Figure 9 illustrated. For example, for the generic TM5-700 robot, the subtypes entail the classic TM5-700, the TM5 X series, the TM5M-700, and the TM5M-700 SEMI. The subtypes and their differentiation are for all four generic robot types same, thus only TM5-700 is explained in the following. After the generic robot type is selected, the first aspect is to determine whether a built-in vision system is needed. This mainly depends on the product type and if the product from the previous station can be passed so that its placement concerning the outline and the facing direction never changes. If possible, the TM5 X series can be used as they have no built-in vision system otherwise, other subtypes are more suited. The next decision aspect is the controller weight, required power supply or the robot arm cable length. If the weight is 13.5 kg, the power supply is 100-240 VAC, and the arm cable length is either 3m or 12m, then again, the standard TM5-700 type must be chosen. When the controller weight is 14,5 kg, the power supply is 22-60 VCB, or the cable length is only 1,5m, then further subdivision between a SEMI 2 certified robot, the TM5M SEMI, or a non-SEMI certified TM5M can be made. The SEMI 2 certification includes safety guidelines that should be fulfilled in certain circumstances.
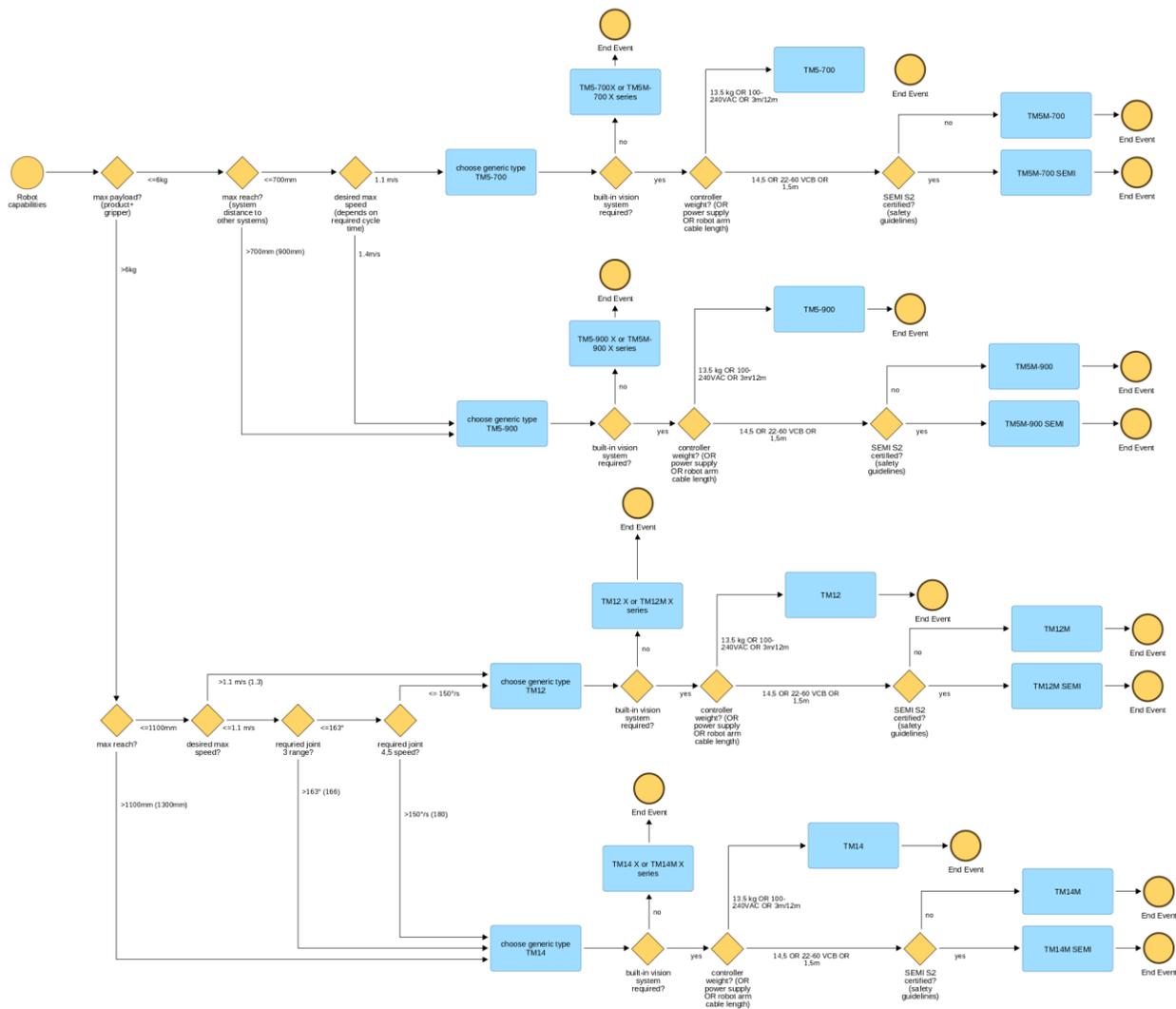
Figure 9: Decision Model of Automated Test Building - Robot Requirements

2. Risk Assessment

After the robot is selected, a risk assessment must take place. This assessment is critical as no safety issues and concerns are allowed for Human-Robot Interactions. The robot system cannot be built without proper safety measures and strategies to ensure safe spaces for humans. The risk assessment decision-making process is illustrated in Figure 10 (Refer Figure 46 for better quality image). and must be performed every time a robot test station should be built. It starts with a request to build a robot system. Then the first decision parameter that must be considered is whether hazardous substances are involved or not If yes, there is a safety risk assumed. If not, the next decision gateway must be checked. The second parameter requires information on whether humans are expected in the safety zones around the robot, which is calculated by summing up the robot's reach with 1m up to 1,5m safety distance. If it is not expected that humans will cross this zone then no risk is faced at all, otherwise it must be checked if it is likely that the critical zone referring to the reach area around the robot is crossed. If no crossing is expected, there is no risk. If yes, the next crucial parameter is to determine at which height the robot is operating and with which part of the human body an interaction is likely to happen. If the operating height affects the head region, there is, again, directly a risk associated. If the robot interferes with the neck-to-pelvis region, a differentiation regarding the type of interaction, static or transient contact, is necessary. Static contact takes more than 5 seconds, and a maximum force level is defined for each specific body part. If this level is exceeded, risk is directly associated, otherwise there is still a potential risk as humans are in the critical zone, and interaction with the robot is expected. For transient contact shorter than 5 seconds, the force and pressure level of 2 m/s cannot be exceeded. If this value is exceeded, there is again a risk indicated, and otherwise, also, a potential risk arises due to the Human-Robot interaction. A warning that the safety concerns must be checked and improved is given for potential risk. Risk-mitigating measures must be taken when a threat is identified, like force or weight limitation. If no proper strategy for the safety of humans can be made, the robot system is not allowed to be built.
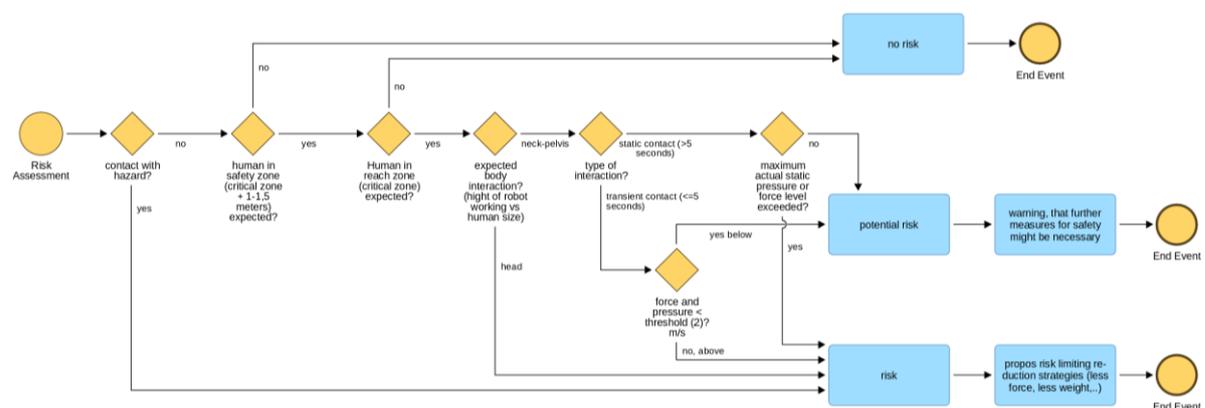
Figure 10: Decision Model of Automated Test Building - Risk Assessment

3. Environmental Factors

Based on the robot type, the outcome of the risk assessment, and an evaluation of risk mitigation strategies, a decision on which kind of Human-Robot interaction can be made. The decision-making process in Figure 11 (Refer Figure 47 for better quality image) considers other factors arising from space limitations in the production halls and product details. The decision starts with a parameter that can be defined after the previous decision process. If the safety aspect of working with cobots cannot be ensured, then the industrial robot must be chosen directly. Otherwise, whether the automated test building concerns a new or existing product must be checked. For new products, the engineers create multiple drafts for the given space in the hall, and the customer can choose according to his preferences. He can define the way of interaction and the cycle time. The challenge for the engineers is to improve the current test station activities and designs for existing products. Therefore, the next relevant decision aspect is whether humans were involved in the past. If there were manual tasks required, it is likely that the robot cannot fully substitute the human. Hence, cobots are the better option. If no humans were involved, the next aspect is to check the area around the robot system. If it is very open where humans can easily enter, then again, the cobot variant is the better-suited one. If there is no open area around, but a human directly at the nearby working station, the cobot solution is preferred. The next decision parameter considers the human traffic close to the robot system. If there are paths for workers where higher human traffic is expected, such as an entrance to the hall, cobot solutions are the preferred option unless other measures to counterbalance this are taken. If the human traffic is low, but there is still a high possibility that the safety zone (reach length of the robot and the safety distance) is crossed, then again, the cobot solution should be chosen.
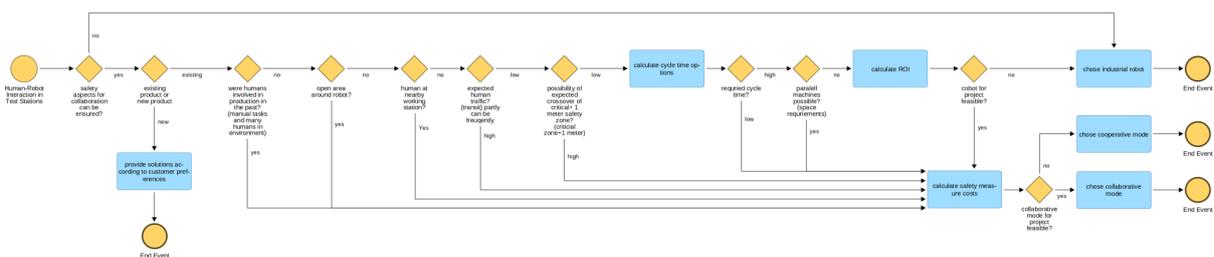
Figure 11: Decision Model of Automated Test Building - Environmental Factors

If the probability of crossing this zone is relatively low, the cycle time options must be calculated and discussed with the customer. If high cycle times are preferred, it must be checked if parallel robot stations are possible, including the space considerations in the hall. If parallel systems are possible or a lower cycle time is accepted, the cobot systems would be suitable. If no parallel machines can be used but still higher cycle time is required, a Return on Investment (ROI) calculation is made. This is necessary to determine what would be feasible for the company. If the cobot system is feasible, the preferred option for the company is the cobot system. To decide which type of cobot interaction is the better choice depends heavily on the safety measures that must be taken and their cost. If the safety

measures and their costs for cooperative interactions are more feasible, this Human-Robot Interaction is chosen. Otherwise, the collaborative approach should be selected. When the ROI is higher for industrial robots, this robot mode is directly elected for the Automated Test Building

Data Requirements

For each Use case scenario, the required data is listed in tabular format as shown in Table 2. Alongside the process models, it provides a concise summary of the data required for decision-making, as described in the Figure 7. The table's headers are described as follows:

- **Data required:** Required data for the use case scenario listed in decision process models.
- **Data source:** How this data is generated or stored (Simulations software, database, planning software, SAP etc.).
- **Format :** Excel, PDF, docx, STEP Files, etc.
- **Frequency:** How frequently this data is generated or updated (daily, weekly, monthly).
- **File:** list of files that are provided for each data required.

Table 2: Required data for Automated Test building.

S.no	Data required	Data source	Format	Frequency	File
1	**Collect cycle time**	User requirement specification	PDF	Frozen	NND00041259-100.pdf
2	**Layout specification**	AutoCAD software	DWG	Depends on products requirement	Fertigung_20220826.dwg
3	**Robot capabilities**	Specification	PDF	Frozen	i837_collaborative_robotos_ datasheet.pdf
4	**Security guidelines**	ISO /TAS 16066 Standards	PDF	4 to 5 years	080_roboter.pdf 05-ISO-TS15066-status.pdf Thomas pliz.pdf
5	**Traffic Assessment**	Simulation or estimation	Manual Estimation	Manual Estimation	Manual Estimation
6	**Test Station designs**	From Project folder. Secured drive	STEP, Excel, DOCX, PDF	Frozen	FTS X-Wide SARA_Programming 36x. step

1. **Collect cycle time**

The user requirement specification describes all necessary requirements on a manufacturing equipment for a dedicated product and the file Contains of operative, qualitative, safety and functional targets and required cycle times.

2. **Layout drawing**

All areas where it is not possible to deploy equipment are taken into consideration in the layout drawing, including emergency corridors, transportation routes, etc.

3. **Robots Capabilities**

The files contain the collaborative robot specifications and various grippers details. The robot specification contains information like max payload(kg), Reach(mm), Joint Range and Joint speeds for each robot. These are some of the important parameters which need to be considered when selecting a particular collaborative robot in a test station.

4. **Security guidelines**

These documents detail every aspect of a system or component's requirements, design, behavior, or other features in a thorough, accurate, and verifiable manner. They also frequently outline the methods for verifying whether these requirements have been met.

5. **Test station Designs**

The finer features of the equipment that make it suitable for operation are specified in equipment specifications, which are written documents or manuals that specify the process of manufacture, power requirements, fabrication techniques, and other factors. To prevent equipment breakdowns, an engineer needs to have a firm grasp of the equipment requirements.

2.3.2 Worker Allocation

The second scenario concerned with worker allocation is shown in Figure 12. Allocating workers is required either before the shift begins or during the production when workers can't continue to work due to different reasons. The challenge in both cases is determining the appropriate action of finding a suitable replacement for the unavailable worker. The first step is finding a suitable replacement, who is currently available and who has the required training to work on the machine. Each line has a "screenplay" that outlines the required abilities for operators, which must undergo a training to be capable in performing this "screenplay".

The process starts by receiving a message that a work shift is cancelled due to a sick leave or another unexpected incident. Checking current workers availabilities and asking for the required "screenplay" to find who are available. The workers' competencies are compared with the "screenplay". At the same time production plan must be considered. Additionally, it's crucial to assess the fairness factor and take worker preferences into
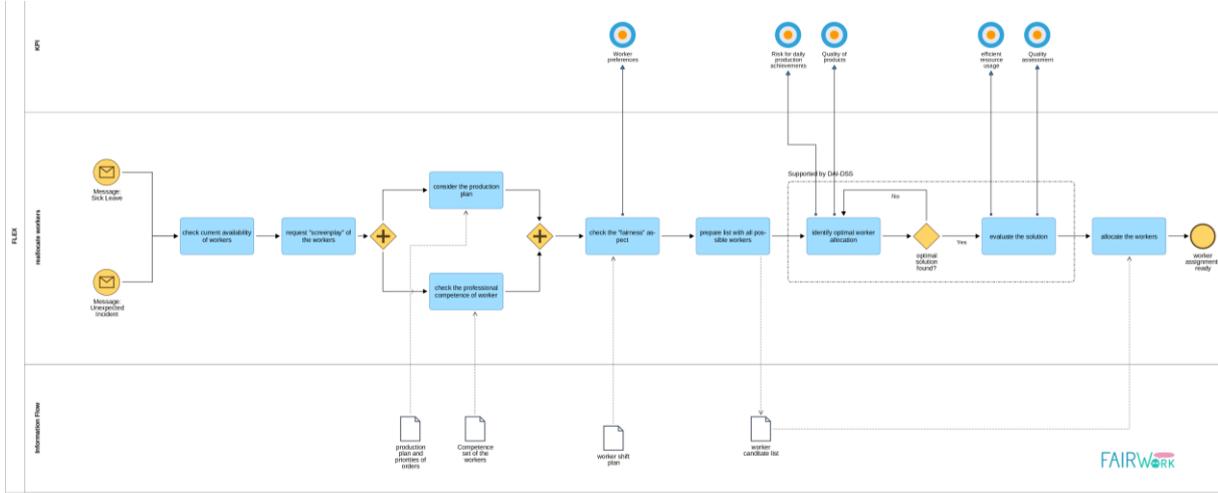
account when reallocating resources. The best worker allocation is then determined after compiling a list of all possibilities. A risk assessment for not meeting production targets and a check on whether product quality requirements can be met should be included in this process.

Figure 12: FLEX Worker Allocation

Decision process models

The task of worker rescheduling takes place when unexpectedly an operator shift is canceled. The corresponding program manager must then check if a suitable alternative can be found and allocated by keeping the goal of minimizing the impact on production in mind. The decision-making process for worker allocation is illustrated in Figure 13 (Refer Figure 48 for better quality image) and starts with the message that a worker cannot attend. The first aspect to check is the order's due date and priority at the understaffed line. If it has a low priority, no rescheduling is necessary otherwise, the aspect of availability of workers at the plant is essential. If there are no workers available, then no rescheduling is possible. If yes, it must be checked whether the worker already performed an 8-hour shift. The worker cannot be rescheduled if 8 hours of work were completed already. When a worker has not reached the maximum working hours, the current allocation of the worker to a job and the job's delivery deadline are essential. When the delivery is less or equal to 1 day, the worker cannot be used as the current order must be finished soon. If the due date is more than one day, the next crucial aspect is the proper training to operate on the understaffed line. If the training is not given, the worker cannot be allocated if the training was performed, the type of worker must be checked. In the best case, another operator is found for replacement as he can be rescheduled directly. If not, other job positions like engineers or maintenance personnel who performed the same training cab be rescheduled, but higher-level training can also be used in the worst-case scenario. To allocate other job positions for working as an operator, the acceptance of these

employees is essential to consider. As they are not employed for this kind of work, their agreement for allocation is required, otherwise rescheduling is impossible.
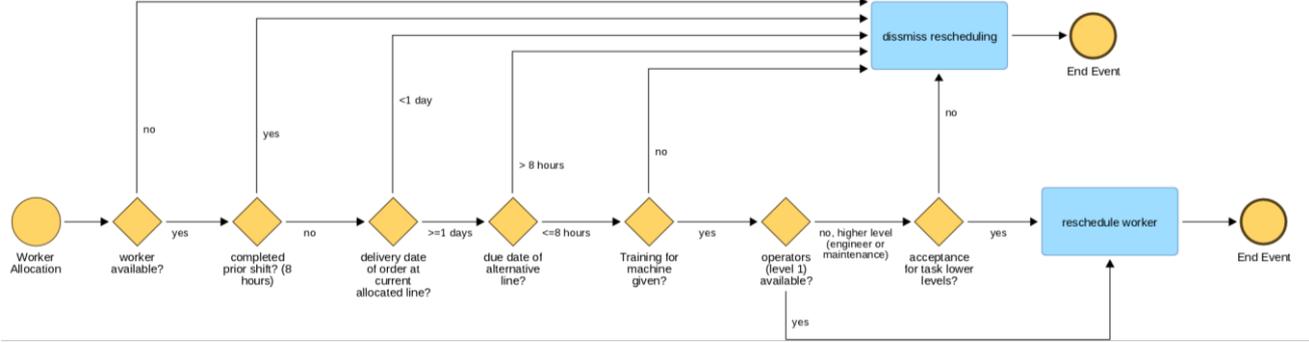
Figure 13: Decision Model of Worker Allocation

Data Requirements

The Table 3 presented alongside the process models provides a concise summary of the data required for decision-making, as described in the Figure 12.

Table 3: Required data for Worker Allocation.

S.no	Data required	Data source	Format	Frequency	File
1	Production plan and priorities of orders	Cronet /FLEX Flow	XMLS	Real time	Annex FF9 SamplesFTS2SaveRes.zip, FF_Standard.docx
2	Competence set of workers	Workday	XLSX	Fixed	Meine_Ubersicht.xlsx

1. **Production Plan and Priorities of orders**

The production plan serves to determine and secure the human, material, and technical capacities in the long and medium term. It only contains the planned production figures in aggregated form (e.g., series) and for longer production periods. The production plan is the basis for creating production programs in which the individual product variants are precisely specified and scheduled to the day. It should support in decision where it has the least influence to allocate worker from one production line to another where a worker suddenly fails.

2. **Competence of workers**

This file is recorded to ensure that every worker has proper training on operating specific equipment or following specific processes. It serves as a documented record indicating that a worker has undergone the necessary training required to work on a particular station or handle specific tasks. The purpose of maintaining such records is to prioritize safety, efficiency, and compliance within the workplace. It is a vital component of the decision-making process, enabling to prioritize safety, productivity, and regulatory adherence while assigning workers to appropriate stations or tasks.

2.3.3 Machine Maintenance after Breakdown

The machine maintenance scenario is shown in Figure 14. In this scenario a ticket is raised in the ticket system when a machine malfunctions. To ascertain if it was a straightforward human error or a technical problem, a technician will come to the machine. If it's an operator failure, the issue can be quickly fixed; if not, the failure database must be reviewed to determine if the issue is already known. Issues that are known to exist in the database are resolved by initiating the relevant solution procedure.

If the issue is a novel kind, it will likely take longer to fix, and all available technicians must be contacted to find a fix for the issue as soon as possible. While the technicians seek to find a solution, countermeasures must be determined and put into place by rescheduling to other machines and reallocating the workforce while taking the production schedule into account. If the rescheduling operations are doable, they need to be carried out, and the production schedule must be modified. The new production plan must allow for the effective use of resources, permit the creation of items of the same quality, and fulfill orders on time. The new production plan must provide efficient resource usage, enable to production of same quality products, and fulfil the orders within the deadlines.
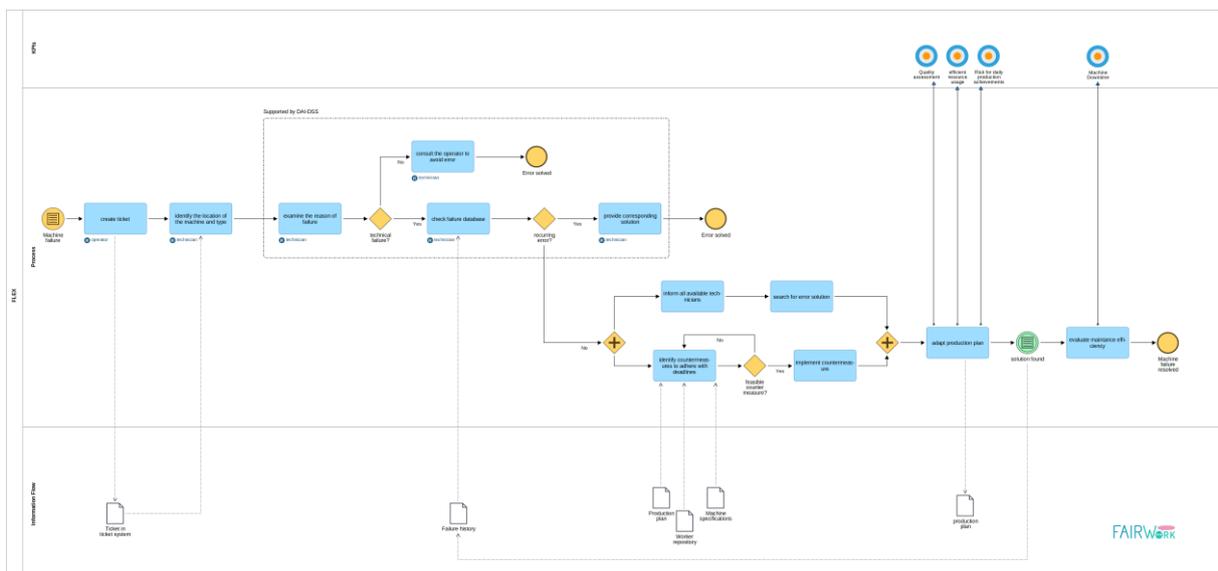
Figure 14: FLEX Machine Maintenance After Breakdown

Decision process model

The decision process for finding a good strategy after a machine breakdown is illustrated in Figure 15(Refer Figure 49 for better quality image). The process starts with a new ticket in the ticket system. Then the first aspect which the maintenance must check is whether an unknown error occurred or not. If this is the case, the error type is directly associated with an unknown and uncertain maintenance time. When the error is known, it must be determined if it is a relatively simple error, such as an operator or software error, or if it is coming from a different source of error. Thus, if it is from a different source, the specific error type is analyzed. It can be either a simple error Y or a rather severe error X. Did the simple error occur, the error is attributed to category A, meaning that it should be resolved soon. The production should be stopped until maintenance is finished. If failure X is identified, there must also be considered if multiple errors caused the defect. Did only error X occur, category B for single severe errors is determined. For category B errors, where the maintenance could take some time, it must be checked whether production on a backup line is possible. If it is feasible, then the order is allocated to another line. Otherwise, the production must be stopped. If multiple errors arise, it would be attributed to category C. Errors of category C take longer to be resolved. Thus like the unknown error category D, the orders should be rescheduled to other lines.
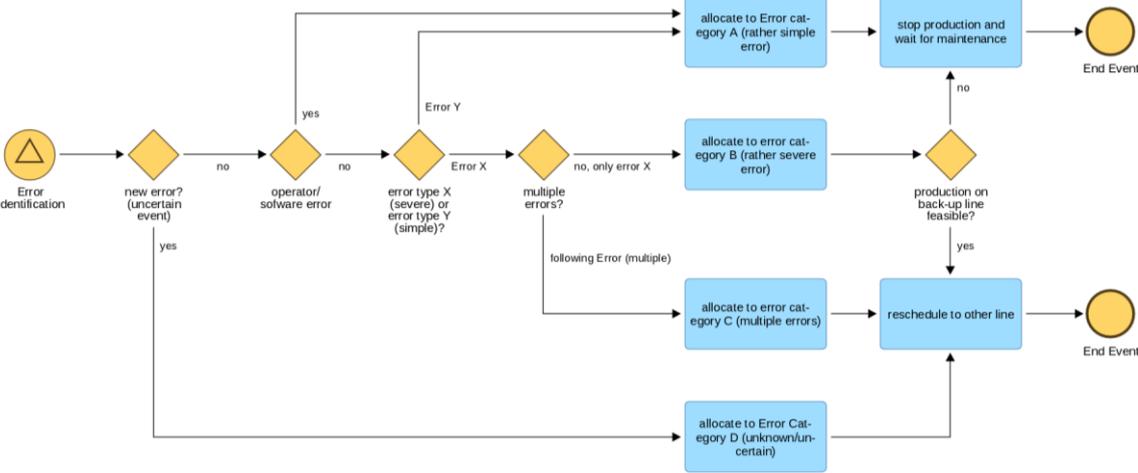
Figure 15: Decision Model of Machine Maintenance after Breakdown

Data Requirements

The Table 4 presented alongside the process models provides a concise summary of the data required for decision-making, as described in theFigure 14: FLEX Machine Maintenance After Breakdown Figure 14.

Table 4: Required data for Machine Maintenance after Breakdown.

S.no	Data required	Data source	Format	Frequency	File
1	**Failure history data base**	IsproNg	XLSX,PDF	Daily	DekTqlineA-Cronet.xlsx, DekTQlinieA_IsproNG.pdf
2	**Production plan (and priorities of orders)**	Cronet /FLEX Flow	XML	Real time	Annex FF9 SamplesFTS2SaveRes.zip, FF_Standard.docx
3	**Worker repository**	Workday	XLSX	Daily	Operator_presence.xlsx
4	**Machine specifications**	Ispro ng	PDF	Fixed	Betriebsanleitung_Ublox_Flasher_Cobc.pdf, 11454897DE.pdf
5	**Information about the ticket**	Operator	PDF	Daily	DekTQlinieA_IsproNG.pdf

1. **Failure history data base**

It is a database where all previous machine failures are compiled and saved along with details on potential troubleshooting. The files are samples of data from machine failures with different error codes.

2. **Production plan (and priorities of orders)**

This was explained in the earlier scenario worker allocation.

3. **Worker Availability**

In the workday tool, one can check the availability of people. It's a real time recording by entering and leaving the factory. This information is needed to decide if a worker is available for re-allocation.

4. **Machine Specification**

This document contains all technical information, including user manuals, spare parts lists, drawings, wiring diagrams, pneumatic diagrams, etc. This is not a decision-making document, but it should assist with maintenance or fixing a problem.

5. Ticket system

With the ticket system, an operator can open a ticket for any machine-related problem, which triggers maintenance actions to examine the equipment's status.

2.4 CRF Use Case Scenarios

2.4.1 Workload Balance

The workload balance scenario is shown in Figure 16 and the describes a scenario for finding a good workload balance. The process is triggered by an event which makes an allocation or reallocation of workers when necessary (e.g., planning the weekly production, a change in the production lines, etc.). The start event is followed by two parallel tasks, where one concerns availability of the operators and the other the production plan. The production plan specifies the production requirements (e.g., requested number of parts) and influences how many people are needed to fulfil all orders in time. Before assigning people to certain lines or positions, their availability and their capabilities need to be checked by accessing a database. Capabilities of operators include passed trainings, skills, and medical conditions. After all input data is collected, the allocation of workers is done in two stages, where both stages should be supported by the decision support system.
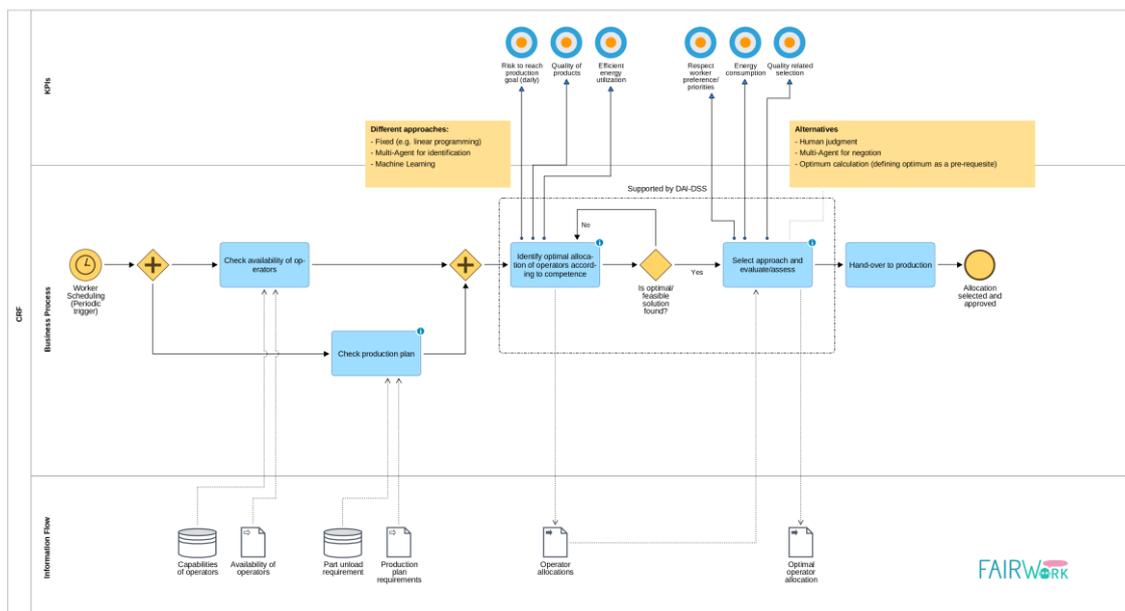

Figure 16: Workload Balance

Decision process model

Starting from the defined business process as seen in Figure 16, the decision tree for allocating a worker to a specific line and geometry is derived and illustrated in Figure 17 (Refer Figure 50 for better quality image). The relevant decision maker is considered as the UTE (e.g., translated in Elementary Technological Unit) Head.
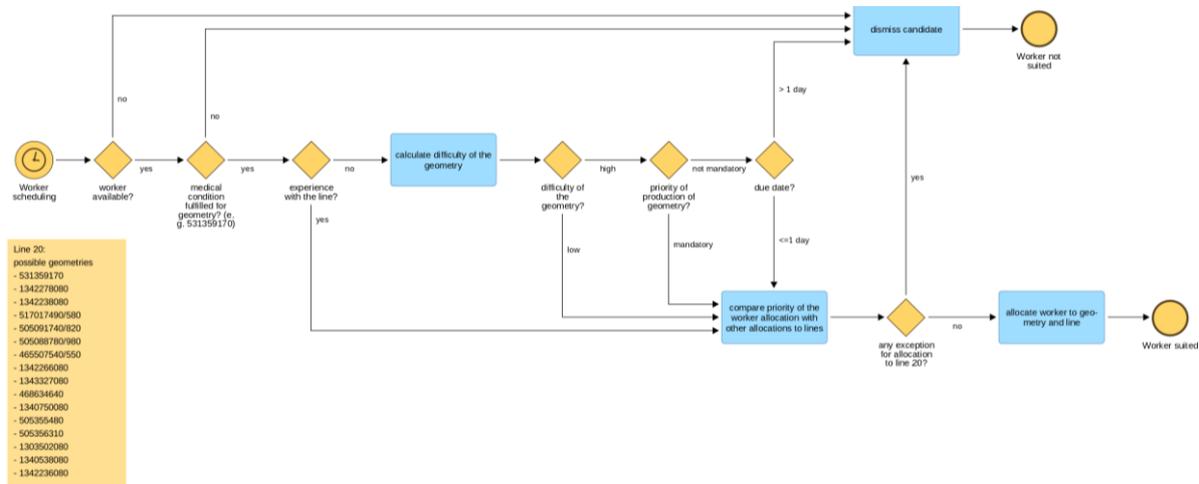

Figure 17: Decision Model of Workload Balance

The decision process occurs periodically as soon as workers must be scheduled to a line producing a specific geometry. One specific line can produce multiple geometries, this example process concerns the geometries that are produced on line 20. As soon as the process is triggered, the first relevant aspect that must be checked by the decision-maker is whether a worker is available or not on that day. The second crucial precondition for allocating a worker is the information about the medical condition that must be fulfilled by the stevedore for lifting the specific geometry from the line. If one of the first two decision gateways are answered with "no", the analyzed worker must be dismissed as a candidate for the geometry and the line. If both prior conditions are fulfilled the experience of the worker with the line and geometry must be identified, as workers should be taken who already know how to handle the geometry. If there is no prior experience given, then a difficulty calculation is made, as these kinds of workers preferably should only be allocated to easy geometries. The difficulty calculation is very individual and depends on the NOISH index considering aspects such as weight, size, the production speed of the geometry as well as the age and gender of the worker. The difficulty is low when the NOISH index indicates a value below a threshold, and it is high when the index is in a critical zone around the threshold. The last two decision parameters concern the priority and urgency of producing a geometry. The priority is determined through a specifically set deadline marked as "mandatory," meaning the product must be produced until this day, and there cannot be any exception. If it is "not mandatory", the geometry production may be postponed. However, if there the general due date is less than 1 day, the geometry must still be produced, although not considered "mandatory". In the last step, there must be a comparison with the other geometries and lines to which the worker could be allocated and determine which job has the highest priority to schedule the worker. In general, there are two solutions that the decision-maker can decide either to add the worker to the production line and geometry or not.

Data Requirements

The Table 5 presented alongside the process models provides a concise summary of the data required for decision-making, as described in the Table 5.

Table 5: Required data for Workload balance.

S.no	Data required	Data source	Format	Frequency	File
1	**Capabilities of operators**	Software (SGA)	XLSX	Weekly	2_Stevedore suitability.xlsx
2	**Availability of operators**	Software (SIPERT)	CSV	Daily (on shift starting)	1_Presence_of operators.csv
3	**Part unload requirement**	Software (SGPP,Siemens)	XLSX	Fixed values	7_Production Cycles.xls, (+ Legende L.X.xls)
4	**Production plan requirements**	Software (SGPP,Siemens)	XLSX	Daily	6_Scheduled orders.xls (+ table_02.xls)
5	**Logistic information regarding (containers, forklifts, storage area)**	Software (SGPP,Siemens)	XLSX	Daily	3_List of Stamping Parts.xlsx, 5_Inventory of container.pdf, 4_Inventory of raw and finished materials.xls

1. **Capabilities of operators**

The reference file is the Table 5 ,**2_Stevedore suitability.xlsx** is the file that contains information on the adequacy of a stevedore to manipulate geometries (in relation to ergonomic rules and medical data). This file refers to the box "Check availability of operators" into the workload balance decision model, we need operators that can manipulate the programmed geometry.

In the excel file starting from row 10 there is the list of stevedores. The column heading "Sap Code" [C10] is equivalent to the "IdSap" of the file **1_Presence of operators.csv**, preceded by the letter "F". The column "**Ute membership**" [A10], contains an indication of the normal location of the workers. In fact, the workers are assigned to particular UTEs, where they normally work, but they can be moved to other UTEs, if suitable. Whether a stevedore is suitable or not, is linked to data contained in the column "**Associated Restriction Codes**" [E10].

From the column [G] onwards, there various geometries. For example: " C111-09-UTE1-1067-(04) - Lin.9-161-6701036560-CRUSC-INF-G-SX ", where:

- UTE1: Reference UTE
- Lin.9: Reference Line
- 6701036560: Drawing number of the geometry
- CRUSC-INF-G-SX: Short description of the geometry

The intersection of the operator's line with the geometry column determines its suitability. If there is a laughing smiley the operator can be used. The other symbols indicate that, in general, it cannot be used or advice from the medical room is needed. The file considers just UTE1 and UTE4 (not consider the UTE 8, called medium presses, that produce small secondary parts, which are stored in very large containers).

2. Availability of operators

The file **1_Presence_of operators.csv** collects the list of people present in the plant (registered in the system using the badge). In this case the refer to the box workload balance decision model is "Check availability of operators". It includes not only the stevedores, but all the personnel who must register themselves using the badge. The most significant column is "IdSap" [K]. The value (8 digits) represents the unique code associated to the worker. Sometimes, in other files, the code appears preceded by the letter "F" (so "F" and 8 digits).This file gives the information of people present in the plant on the given day which can be used for better worker allocation.

3. Part unload requirement

The reference file is the excel **7_Production Cycles.xls.** This file is particularly containing complex information. For each geometry, it has been indicated the geometry drawing number, and operations necessary to produce it present in the file. So, we will have as many lines as the expected operations. The column of our interest is the column "number of workers" [AN] that indicates how many workers are employed in each operation. The number of line conductors is fixed and equals to 2, while the number of stevedores is variable for each geometry. The reference operation for the unloading of the lines is the one of type W, that is "**FAT.FISIOL**". So, the number of stevedores is reported in this cell.

A series of excel files is supplied (**Legende L.X.xls**), which summarize significant data of the individual lines (where the X can assume the values: 5, 7, 9, 11, 16, 17, 18, 19, 20, 24). These files are compiled manually based on the raw files provided by the SGPP system by SIEMENS and are used by line employees because they are easy to consult. In this set of files, the number of stevedores needed for each geometry is shown in the column OP [T]. These data is used into the box" Check availability of operators" of the workload balance decision model.

4. Production plan requirements

The file **6_Scheduled orders.xls** contains the order list. First, we have the column "**Disegno**" [B] which contains the geometry drawing number, then we have the column "**Cliente**" [C] which represents the

customer code. Then information is collected on the quantities of each geometry that need to be produced for a given customer. These data are collected in the columns from [AB] onwards, in particular:

- "Last quantity shipped" [AB]: it's the number of components shipped last time
- "ANT. RIT." [AC]: it indicates whether production is ahead or behind schedule
- "QTA S" [AD]: it's the quantity planned for the current week (residual)
- "QTA S+1" [AE]: it's the quantity planned for the next week (week +1)
- "QTA S+2" [AF]: it's the quantity planned for the week +2
- "QTA S+3" [AG]: it's the quantity planned for the week +3
- "Month schedule" [AH]: it's the total quantity for the current month
- "First forecast" [AI]: it's the prevision for the next month

Based on the information contained in this file, the production manager compiles a summary diagram (**table_02.xls**) in which is reported the scheduled production for each line. In the table, the columns represent the time axis, day after day. Each day consists of 2 shifts. For each geometry that must be produced, 4 summary data are reported: the identification number of the geometry, the target number of components to be produced, the MDR (acronym that stands for "means of collection") and the code of the expected raw material. This data is used into the box" Check production plan" of the workload balance decision model.

5. Logistic information regarding containers, forklifts, storage area

Regarding the containers expected for each geometry, the raw data file is the excel **3_List of Stamping Parts.xlsx**. In column we have:

- "PART NUMBER" [C]: drawing number of the geometry
- "ACTUAL RACK CODE" [F]: code of the container
- "QT ACTUAL per Rack" [H]: number of components in a container
- "Container weight" [I]: weight in Kg of the empty container
- "Part weight" [J]: weight in Kg of a single component
- "Full container weight" [K]: weight in Kg of a full container

The availability of the containers in plant warehouses is reported in the file **5_Inventory of container.pdf**. This sheet is not digitized but is printed and filled in by hand every morning. It is the inventory of the containers present in the warehouse divided by line (it is the reference line to produce the component they contain).

Regarding the storage areas, raw data are reported in the file **4_Inventory of raw and finished materials.xls**. The file contains information about the quantity of raw materials and finished products (identified by drawing number), present in storehouses:

- QTA'. MAG. EST. [O]

- QTA'. MAG. Giro Lavoro [Q]
- QTA'. MAG. Stampaggio [R]
- QTA'. Giro Lavoro Lastratura [S]
- QTA'. MAG. Lastratura [T]

This information is considered into the box" Check availability of operators" of the workload balance decision model, because to produce a geometry not only personnel is needed, but also raw materials and containers (in addition to the volumes already produced and in warehouse)

2.4.2 Delay of Material

The scenario delay of material delivery is illustrated in Figure 18.This scenario starts with incoming orders with corresponding order specifications. The first step is to identify the amount and type of needed raw materials by using information about the level of inventory in the warehouse as well as a procurement list in case material is not yet stored. In this step material turnover rates might be calculated and used for information about material usage within the company. When there is not enough material stored at the warehouse, the procurement strategies must be adapted to these circumstances, as optimal warehouse management could prevent material shortages. If there is enough supply, identification of the line capacities and a ranking of the orders according to their priorities takes place. Also, the expected duration of one order is an important indicator for the allocation to the machines.

The optimal assignment to specific lines is done by the UTE head (Elementary Technological Unit) and this person request the material from the logistic manager for delivery of material to the required line. If there is delay in receiving material due to shortage or other reasons the UTE head needs to reconsider the production plan to avoid downtimes. This could be preparing the line for different production by changing the machines stamps and reallocation of workers to the production lines.

Figure 18: CRF Business Process Delay of Material

Decision Process models

The decision-making process for the Delay of Material scenario can be split into two decisions. First, the pre-production process, where a production delay might be caused, and second in the post-production phase through problems when loading the truck inefficiently for a shipment to the customer Figure 20 (Refer Figure 51 for better quality image). Thus, the consequence that the customer receives his orders late can be due to a shortage of required materials, causing a delay in the production of an order or a delay in the shipment of a specific geometry.

The first decision process, as seen in Figure 19, causing a delay in production, starts with an incoming order with multiple geometries. Each geometry must be checked first to see if the required raw material is available. If yes, then the next step is determining whether the correct container is available at the plant. If this is also fulfilled, the last aspect is the availability of the specific line where the geometry can be produced. These three conditions must be met, otherwise there is no production possible, and another geometry must be produced instead. It is important to note that each geometry requires a specific type of container for transport, and one sort of raw material is necessary to produce the geometry. Also, besides the possible backup lines, only one production line is used for the specific geometries.
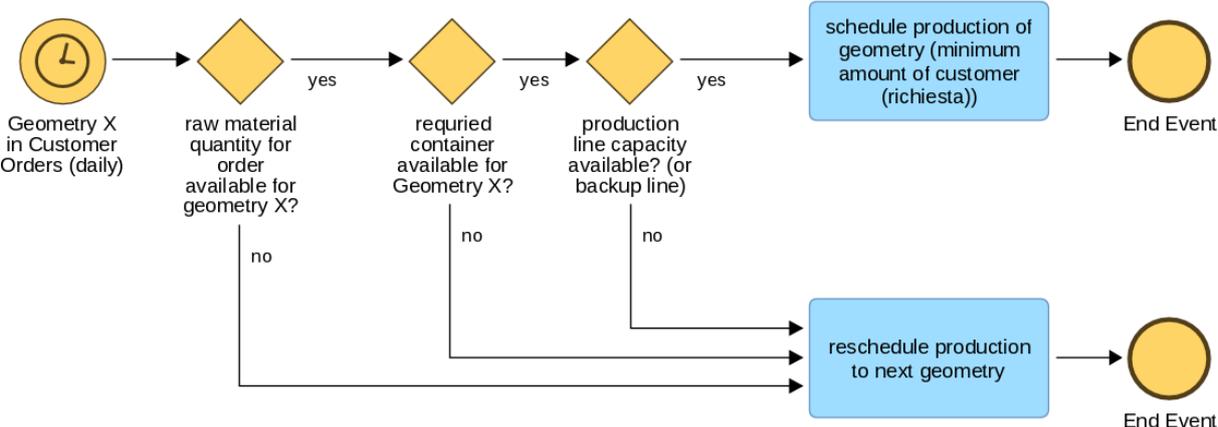

Figure 19: Decision Model of Delay of material pt.1

The second decision-making process must consider the whole order of the customer, which must be shipped daily. For this decision, the crucial part is determining the optimal truck type for the shipment and how to load them so that all order geometries can be shipped accordingly. The process starts with the due date of the required shipment. First, it must be checked if, for each geometry, the number of container efficiency parameters is fulfilled, otherwise no shipment of the geometry can take place. If this condition is fulfilled, the containers must be added to the truck, and it is checked whether the truck has an acceptable saturation so that the free capacity of the truck is minimal in the best case. If free space is available or the saturation is low, other truck types can be chosen. If the other truck types can offer better saturations, one of them is selected and shipped. If no better saturation can be achieved, it must be considered to send additional geometries in advance. When additional geometries can be added to the truck, the shipment occurs as planned. If this is impossible, the customer must be contacted and asked whether the shipment can be postponed. If this is not an option for the client, the

shipment must take place even, and higher costs are expected for the plant. If the customer accepts, the shipment can be postponed.
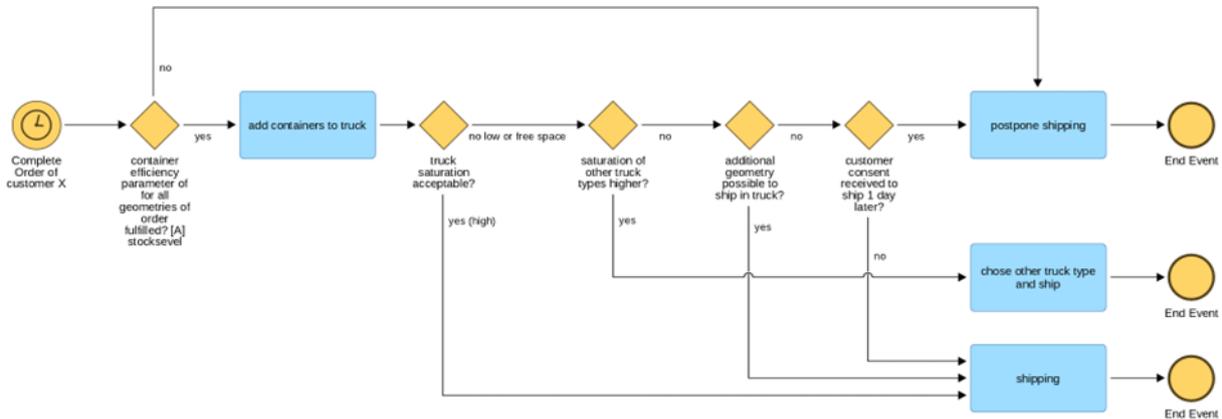

Figure 20: Decision Model of Delay of material pt.2

Data Requirements

The Table 6 presented alongside the process models provides a concise summary of the data required for decision-making, as described in the Figure 18.

Table 6: Required data for Delay of Material.

S.no	Data required	Data source	Format	Frequency	File
1	**Order specifications**	Software (SGPP,Siemens)	XLSX	Weekly	6_Scheduled orders.xlsx
2	**Inventory list of material**	Software (SGPP,Siemens)	XLSX	Daily	4_Inventory of raw and finished materials.xlsx
3	**Material needs for certain orders**	Software (SGPP,Siemens)	XLSX	Fixed values	7_Production Cycles.xls, (+ Legende L.X.xls)
4	**Priorities of orders**	Manually filled in	XLSX	Daily (based on production planning)	table_02.xls

5	**Capacities of production lines**	Software (SGPP,Siemens)	XLSX	Weekly	8_Cno.xls
6	**Components shipment**	Manually filled in	XLSX	Daily	11a_LOADING LIST SEVEL.xls, 11b_STOCK SEVEL.xls

1. Order specifications

The reference file is the excel **6_Scheduled orders.xlsx** already explained in the section "Workload Balance" of this document.The file refers to the box "check the details of the order" into the delay of material decision model.

2. Order Inventory list of material

As anticipated in the previous section the file **4_Inventory of raw and finished materials.xlsx** contains information on the level of raw materials in the warehouse. The file refers to the box "identify the needed type and calculate the number of raw materials" into the delay of material decision model. In the column "DISEGNO" [C] is reported the drawing number of the component, in this case the raw materials. In column [G] there is the "Unità di misura" that means "Unit of measure", for raw materials is the weight "KG". Then in the warehouses in columns [O], [Q], [R], [S] and [T] is reported the quantity that is present in each. The file is updated at the end of each day.

3. Material needs for certain orders

Also, in this case the reference file is the excel **7_Production Cycles.xls** (and the simplified summary files for each line **Legende L.X.xls**). In terms of material necessary to produce a given geometry, in addition to the raw materials, we point out the molds listed in these files. Also, in this case the reference box of the delay of material decision model is "identify the needed type and calculate the number of raw materials"

4. Priorities of orders

The priority of the orders is indicated exclusively in the summary table **table_02.xls**. The priority of producing a geometry derives from the comparison between the quantity requested by the customer and not fulfilled (file **6_Scheduled orders.xlsx**) and the quantity present in the warehouse (file **4_Inventory of raw and finished materials.xlsx**). The file refers to the box "assign the order to a timeslot at a line" into the delay of material decision model.

5. Capacities of production lines

Historical data on the capacity of a line to produce a geometry is reported in the file **8_Cno.xls**. CNO is an Italian acronym that means net hourly cycles. The file reports how many components (for each geometry) are

produced in one hour from a historical point of view. The file refers to the box "assign the order to a timeslot at a line" into the delay of material decision model. The file contains following headers:

- LINEA [A]: it's the number of the line
- MODELLO [B]: is the car model for which the component is intended (not important)
- DISEGNO [C]: it's the drawing code of the geometry
- DENOMINAZIONE [D]: it's the short name of the geometry
- CNO [E]: it's the number of pieces historically producible in an hour

The difference between CLO and CNO, i.e., between gross ("Lordi") and net ("Netti") pieces that can be produced in one hour, is caused by two factors:

- Stops necessary for production: for example, to clean the molds, evacuate scraps and other small necessary scheduled maintenance. We can also here considerate the pauses for the operators.
- Unscheduled stops: normally micro-stops or breakdowns that require unexpected maintenance

6. Components shipment

Another critical and important aspect of the process is the ability to ship components to the customer to fulfill the order. The file **11b_STOCK SEVEL.xls** contains the components to be sent to the SEVEL plant in a particular day. Below there is an explanation of the columns:

- DISEGNO [E]: is the drawing number of the component (geometry)
- DENOMINAZIONE [F]: short description of the component
- RICHIESTA [G]: is the quantity requested for the shipment
- GIACENZA ORE 6 [D]: is the total quantity of components of that type in stock at 6:00 in the morning into the warehouse
- Mdr [B]: is the code of the container for that geometry
- Q-TA X MDR [I]: is the number of components that a container can contain
- PESO LORDO [J]: is the gross weight (empty container + components) of a fully loaded container, expressed in kilograms
- [A]: means that this type of container is normally shipped in multiples of 3

The file **11a_LOADING LIST SEVEL.xls** contains additional info divided by container:

- DISEGNO [A]: is the drawing number of the component (geometry)
- DENOM [B]: short description of the component
- Cod.Cont [G]: is the code of the container
- Qta cont. [I]: is the number of components that a container can contain
- LA [J]: is the length of one side of the container in mm
- LE [K]: is the length of the other side of the container in mm
- H [L]: is the height of the container in mm

- Dinam [N]: is the number of containers that can be stacked on top of each other during transport (dynamic mode)
- Peso Unit.kg. [O]: is the weight in kilograms of a single component
- VolM3 [P]: is the volume of the container in cubic meters
- Tara [R]: is the weight of the empty container
- PESOTOT [T]: is the gross weight (empty container + components) of a fully loaded container, expressed in kilograms

The goal is to optimize the placement of the containers in the trucks, respecting their dimensions and capacity. Considering for example the data of a truck called MEGA:

- Height: 2.800 mm
- Width: 2.400 mm
- Length: 13.600 mm
- Capacity: 26.000 kg

Into the first file are indicated the parameters to evaluate the load of the trucks:

- [K37]: is the load saturation index
- [K39]: is the unused length (in meters) compared to the maximum length of the truck

The second file contains the shipping forms (with the parts list for each truck) and other indicators:

- [H7]: is the capacity saturation percentage (i.e., the kilograms of the load compared to the maximum capacity of the truck)
- [J7]: is the percentage of volume saturation (i.e., the cubic meters occupied by the load compared to the maximum volume of the truck)

These files refers to the section "Delay of shipment" of the delay of material decision model, the reference box is "add containers to truck".

2.4.3 Quality Issues

The scenario "quality issues" is a recurring process of quality checks and is illustrated in Figure 21. It is either necessary for testing the quality of products that are produced after a line was set up for a new geometry and before production on full capacity or takes place during the ongoing production on a random sample basis. If a new geometry is produced the line must be set up and all necessary components for the line must be checked and prepared. The first molded products are then produced and checked for any quality issues. If the quality standards are fulfilled the product goes into full production. When the quality requirements are not met the deficiencies must be improved and the line must be adapted. The quality check is made by visually analyzing any surface defects on the part and based on the defects a categorization of the severity and type of defect is determined and if the defect can be rectified by the rework different ways of reworking the products are evaluated

and then the products are reworked manually. If the rework not possible or feasible the products must be discarded.
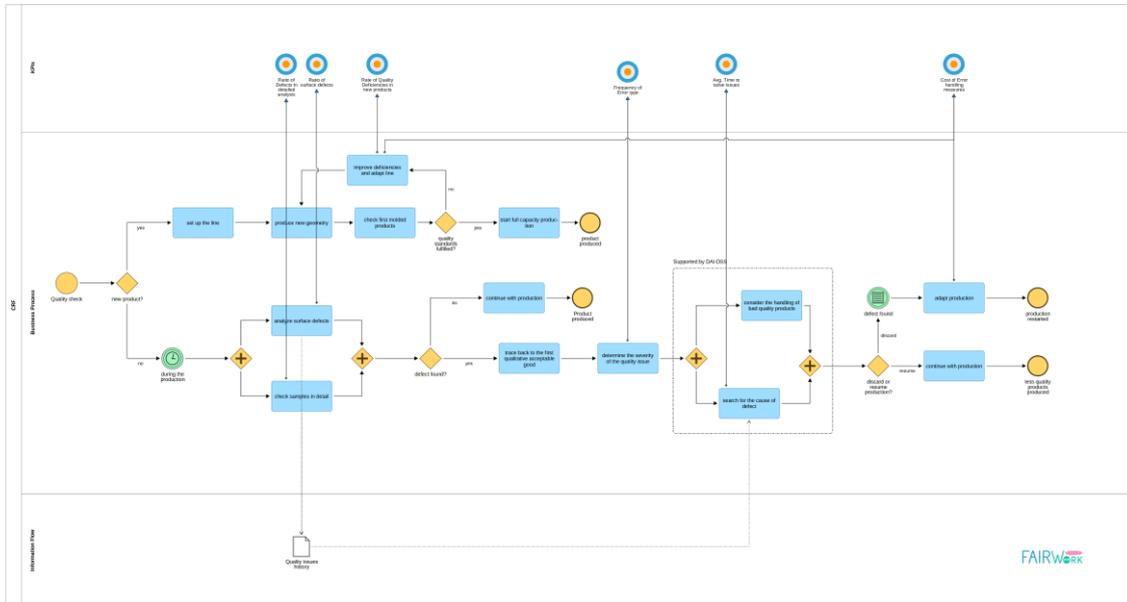

Figure 21: CRF Business process Quality Issues

Decision process model

The business process model of Figure 21 is further specified in the decision-making process shown in Figure 22 (Refer Figure 52 for better quality image) which determines whether a product can be reworked, shipped with lower quality or must be discarded and reproduced. The relevant actors and decision-makers is the quality personnel in the Quality Corners.
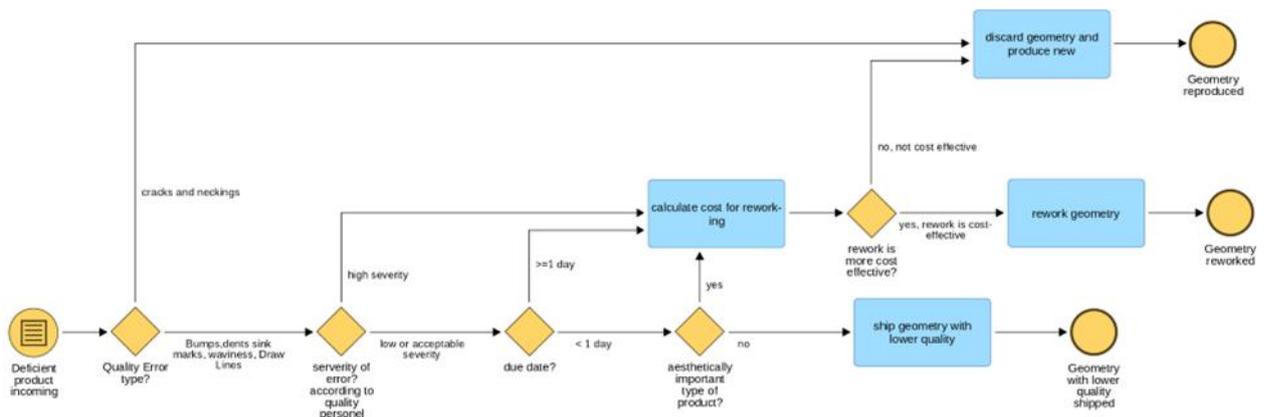
Figure 22: Decision process for Quality Issues

The process starts as soon as a geometry with deficiencies is produced and identified. First the type of quality error is determined, which can be of 7 types: cracks, necking's, bumps, dents, sink marks, waviness and draw lines. The first two types of namely cracks, and necking's are not repairable at all and must be reproduced directly. The rest of the types of errors can be reworked depending on the concrete severity of the identified

quality issue. The level of severity for the geometry can only be determined by the quality personnel examined and is based on their experience. If the quality issue is characterized by major deficiencies, it is considered as high severity, and a cost calculation for reworking the product must be made. The cost of rework is compared to the cost of producing a new product, and the more cost-effective option is chosen. The cost calculation includes the total cost for all defective pieces and the estimated time for rework in comparison to reproducing the geometry.

If the severity of the quality issue is acceptable or the urgency of shipping is low, and the aesthetical importance of the geometry must be checked. If the due date is less than 1 day the geometry is perceived as urgent, and it must be shipped as soon as possible. Unless the geometry is not aesthetically important meaning that the quality issues does not affect the product, it can be shipped with lower quality. Has it a high importance as an aesthetical component, rework to an acceptable quality or reproduction is required depending again on the cost effectiveness. Is the due date equal or higher than 1 day then again, the decision depends on a cost comparison.

Data Requirements

The Table 7Table 6 presented alongside the process models provides a concise summary of the data required for decision-making, as described in the Figure 21.

Table 7: Required data for Quality Issues.

S.no	Data required	Data source	Format	Frequency	File
1	**Waste and Rework data**	Software (SGPP,Siemens)	XLSX	Daily	9a_Waste document.xlsx, 9b_Rework.xlsx

1 - Waste and Rework data

Whenever a component (or rather a container with n components) is discarded, a discard document is produced and posted on the container. The list of these documents is collected in the file **9a_Waste document.xlsx**.The translation of the column headers is:

- Cod. Disegno [E]: it's the drawing code of the geometry
- Data registrazione [H]: date and hour in which the discard document has been produced
- Numero bolla scarto [I]: progressive number of discard document
- Quantità scarto [J]: number of components discarded
- Causale movimento [K]: code of the reason why the components were rejected (they can be rejected due to production start-up, technological tests, damages, quality reasons, etc.)

As in the previous case, a similar document is also produced for components intended for repair (rework). Consider the file **9b_Rework.xlsx**, the translation of the column headers is:

- CODICE QUALITA' [B]: it is the code that represents the type of defect found
- UTE [C]: it's the UTE of origin of the components
- LINEA [D]: it's the line of origin of the components
- DENOMINAZIONE [E]: short description of the geometry
- DISEGNO [G]: drawing number of the geometry
- PRODOTTI [H]: number of components produced
- N° PEZZI RIPARARE [I]: number of components to be repaired
- % RIPARARE [J]: ratio of components to be repaired on total ones produced

Note that a component sent for repair (reworked) can be repaired and become of acceptable quality, or it can be rejected and therefore appear in the waste document. Both files are updated at the end of each day. They correspond to the reference box of the quality issues decision model "analyze surface defects".

3 DATA STORGAE AND EXCHANGE IN KNOWLEDGE BASE

This chapter provides an overview of the setup of Knowledge Base that will be used for the FAIRWork project use cases.

3.1 Introduction to Knowledge Base

This section will provide a brief introduction to the EDMtruePLM and ISO 10303 standards which helps to store the required data. The DAI-DSS Knowledge Base is the main data repository used in the DAI-DSS architecture. It is where all data required to be processed or analyzed is imported to and stored. It is also where results from decision makings are collected and stored. Other components within the framework use the interfaces offered by the DAI-DSS Knowledge Base to retrieve or add data. The Knowledge Base is implemented with the EDMtruePLM application. EDMtruePLM has a functionality to implement digital twins and digital shadows for physical assets where the asset's life-cycle data is stored and can be accessed by other DAI-DSS components.

The EDMtruePLM tool as the basis for the Knowledge Base was explained in detail in the deliverable "D4.1 DAI-DSS architecture and initial documentation and test report ". Section 3.4 in D4.1 provides information related to internal architecture of the PLM module, providing information on the web client, and digital twin representation. Section 3.4.4 goes in further detail regarding the dependencies to the larger DAI-DSS framework. The matter of interfaces and interoperability is further discussed in section 3.4.5. For additional information on the Knowledge Base, please refer to D4.1, section 3.4.

3.1.1 ISO 10303

The standard ISO 10303, "Product data representation and exchange", also known as STEP, "Standard for the Exchange of Product Model Data" is the standard with the widest scope of industrial data interoperability. The standard is developed by ISO/TC 184/SC 4[4], "Industrial data". ISO 10303 consists of hundreds of standards. Those that are exposed to the industrial end users for solving their data interoperability are called Application Protocols (AP). Some of them are in daily use world-wide, especially ISO 10303-242 (AP242)[5], "Managed model-based 3D engineering" and its predecessors AP203[6] and AP214[7]. To make an application interoperable its native data need to be converted to, for example, the AP242 data model. The converted data may then be transported to one or many receiving applications in ISO 10303 formatted files. Most design engineers use this method today

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[4] https://www.iso.org/committee/54158.html
[5] https://www.iso.org/standard/66654.html
[6] https://www.iso.org/standard/44305.html

to exchange CAD data. The scope of STEP, however, in general and even of its subset in AP242 is much wider than only CAD.

As explained, the Knowledge Base for the project is a data repository based on the open standards ISO 10303. An ISO 10303 based application, EDMtruePLM, will be used as a digital cloud repository for the FAIRWork Use Cases. The ISO 10303 based application complements in scope and functionality with comprehensive PLM systems, such as, Windchill by PTC[8] and Teamcenter by Siemens[9], which are used by large system integrators in the domains of automotive, aeronautics, and space. It will support and pursues the goal to "help organizations in coping with the increasing complexity and engineering challenges"[10], but with a focus on addressing challenges that the extension of the lifecycle beyond product development into product operation bring along, such as:

- Provide a project collaboration solution for all relevant types of product lifecycle data, such as CAD, CAE, CAM, CAT, ILS etc.,
- Address data interoperability in a heterogeneous application environment,
- Support data longevity.

Therefore, the open standards-based repository puts a strong emphasis on data interoperability and data longevity. It accepts data from heterogeneous applications and gives access to end-user data in the openly available ISO 10303 format, STEP. All product data are merged and consolidated into a unified and standard-compliant repository to enable overall configuration management.

3.2 Description of Project structure in the Knowledge Base

This section presents the current setup of the Knowledge Base and the created Project structure for FAIRWork Use cases. This current instance of the Knowledge Base can be accessed using the URL: https://fairwork.jotne.com/EDMtruePLM/#/home. The instance is secured behind a firewall requiring a VPN. In this secured instance all the sensitive data related to the use cases are stored.

Furthermore, there is an additional instance of the Knowledge Base with public access where it contains the replica of the main project data repository, but the sensitive information is protected, and the user has read only access to the project structure. This instance can be accessed using the URL https://demo.jotne.com/EDMtruePLM/#/home which takes to the login page as shown below in Figure 23. Further details are provided in the Annex A.

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[7] https://www.iso.org/standard/43669.html
[8] https://www.ptc.com/en/products/windchill
[9] https://plm.sw.siemens.com/en-US/teamcenter/
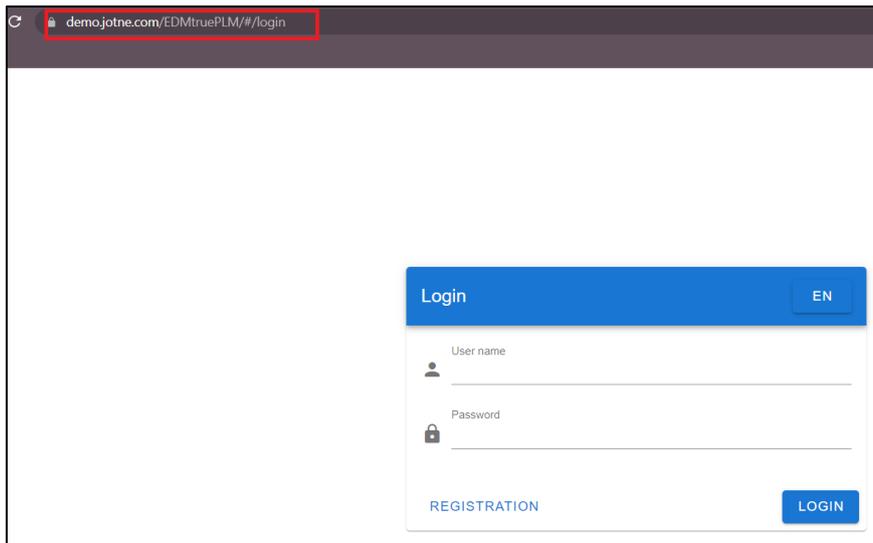[10] https://bombyxplm.com/what-is-plm/

Figure 23: Demo login page

The setup of the Knowledge Base and the process of populating it with the necessary data will be explained in subsequent subsections. The Knowledge Base is structured in a FAIRWork_Project root node. For each of the Use Cases, separate breakdown elements are created within this model, as depicted in Figure 24.

These breakdown elements serve as containers within the Knowledge Base where the relevant data for each Use Case can be stored and accessed. By organizing the data in this manner, it becomes easier to manage and retrieve the specific information related to each Use Case. The unstructured data can be stored in these elements as files, allowing for the storage of diverse types of information.

Additionally, the use of a "reference data definitions" section in the Knowledge Base enables the configuration of elements with properties or attributes of data entities. In this way, structured data can be stored within the elements by creating properties specifically designed to hold structured information. This can be used for modelling digital representation of physical entities in the Knowledge Base.

This approach allows for a combination of structured and unstructured data storage within the project structure. Unstructured data can be stored as files directly within the elements, while structured data can be stored within the properties or attributes of the elements. This flexibility ensures that the project structure can effectively handle various types of data required by Use Cases or AI services.
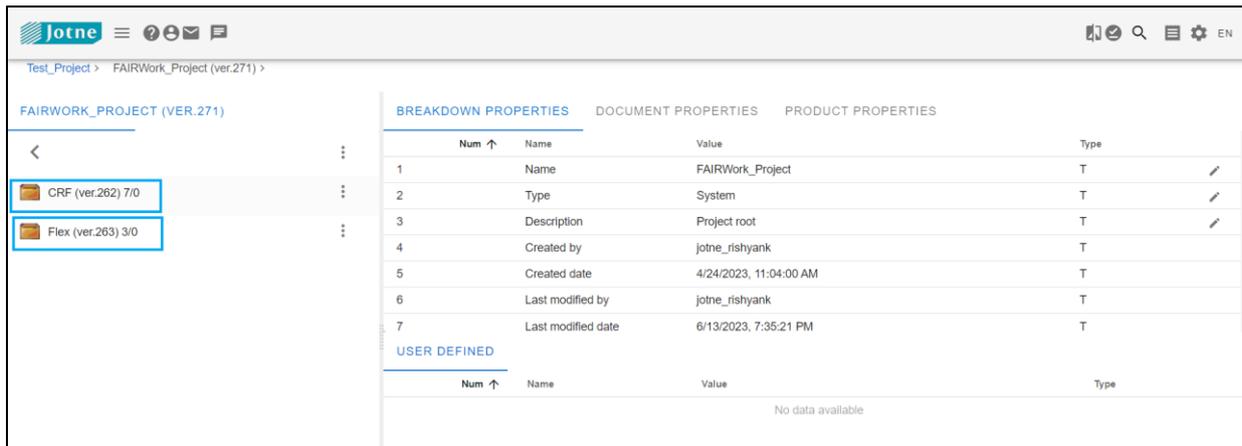
Figure 24: Knowledge Base Breakdown structure

3.2.1 Flex Use Case

The Decision process models are described in section 2 of this deliverable for the FLEX Use case scenarios and the required data is outlined in corresponding tables. Based on the provided information, breakdown elements are created in the Knowledge Base to store this data. The names of these elements are listed as follows:

- Automated Test Building
- Machine Maintenance
- Worker Allocation
- Decision models

Figure 25 displays the structure of the created elements in the Knowledge Base. The subsequent subsections describe the building of the required knowledge for each use case scenario. However, it's important to note that the data and initial project structure of the Knowledge Base are subject to change and evolve based on the data collected and the needs of the AI Services and the use cases. The required decision process models for the FLEX usecases are stored in the breakdown element "**Decision models**".

Figure 25: Elements for each FLEX use case scenario

3.2.1.1 Automated Test Building

In the automated building scenario, based on Table 1, the required data is collected and stored in the corresponding breakdown elements which is shown in Figure 26. These elements have both structured and unstructured data representation.

The breakdown element related to robot capabilities is created based on collaborative robot specifications. This element "robot capabilities" further contains child nodes (elements), which contain various collaborative robots with their specifications. These specifications are obtained from the **i837_collaborative_robotos_datasheet.pdf** and using reference data definitions the elements are modeled with this specification as set of properties which is shown in Figure 27. To enable access to the data within these elements, each element is assigned a REST API endpoint.

This allows other AI services or applications to retrieve the data from these elements programmatically. The security guidelines element has associated PDF files, which are described in Table 1. These PDF files contain relevant information related to security considerations. Furthermore, the other relevant data are archived as files in the breakdown element.
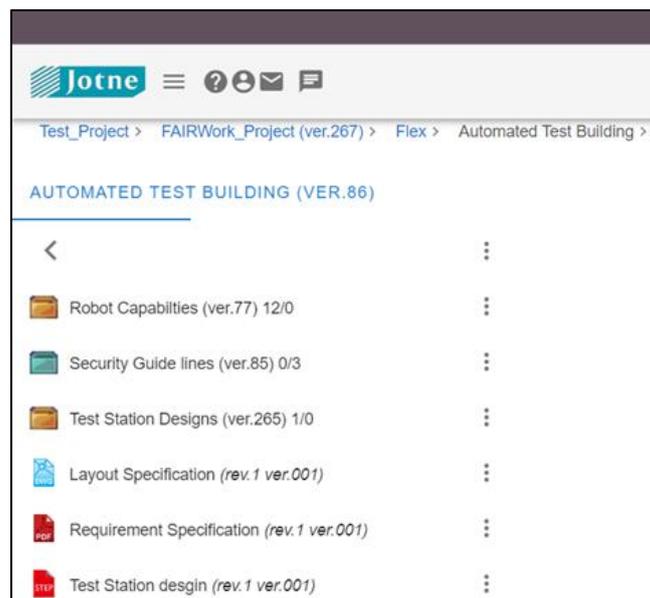
Figure 26: Breakdown of data for the Automated Test Building use case
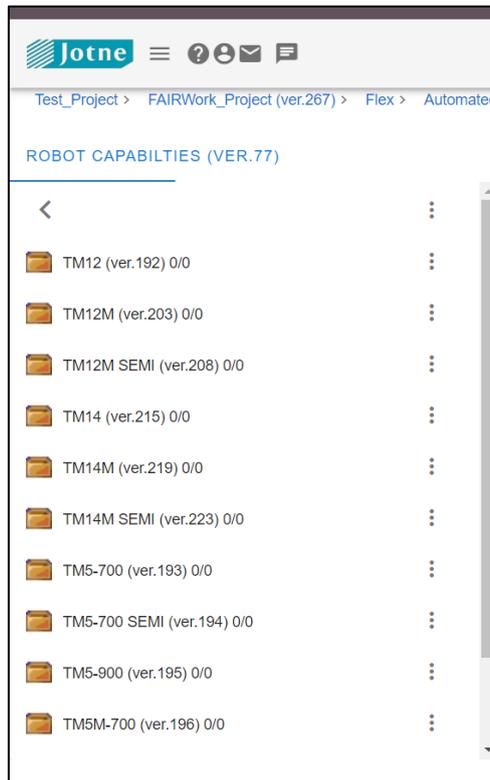
Figure 27: Robot capability

The Figure 28 here shows the break down element with name TM5-700 and its properties. The Knowledge Base provides functionality to update or access these data values using REST API or the user can user the GUI interface provided by the PLM. Furthermore, these elements have been configured with aggregate properties to stores sensors information to demonstrate the capability of knowledge Base to store IOT data.

Figure 28: Example of robot capability for TM5-700

3.2.1.2   Machine Maintenance

The machine maintenance element contains two types of data are stored: the error log from machines and safety manuals. This information is visually represented in Figure 29. A breakdown element with aggregate properties that can hold aggregated machine errors is set up in the Knowledge Base based on the error log csv file that was obtained from the use case owner. These properties are designed to capture and store the summarized information about machine errors. Figure 30 provides a visual representation of this breakdown element structure and the properties created to store the aggregated machine errors.

To enable real-time updates of the error logs, a REST API endpoint is used. This allows for the continuous streaming of error logs into the Knowledge Base. By utilizing this streaming capability, the error log information can be constantly updated and accessed by other AI services.

The availability of this information allows other AI services to analyze the error codes and provide suitable solutions based on the specific errors encountered. By accessing the error log data through the REST API endpoint, these AI services can leverage the information stored in the Knowledge Base to offer appropriate solutions or recommendations.

Figure 29: Breakdown of data for the Machine Maintenance use case

Index	APNRIST	AGAKNR	ATIST	ETIST	AGRUECK_BEARBDAUERMELD	STOERGRUND	BEZEICH	KOMMENTAR	AGSTOERKZ	STOER_1	Dauer ([h])	Line_Cat	Time_CAT	LINE_CAT_TIME
100001	LINE/A	471U32551	3/1/2023, 2:57:19.0 AM	3/1/2023, 3:13:22.0 AM	0.011145833	2100	Pastendruck		1	2	0.2675	A_2	D	A_2_D
100002	LINE/A	471U32551	3/1/2023, 3:26:28.0 AM	3/1/2023, 3:30:44.0 AM	0.002962963	2100	Pastendruck		1	2	0.071111111	A_2	B	A_2_B
100003	LINE/A	471U32551	3/1/2023, 3:32:19.0 AM	3/1/2023, 3:50:56.0 AM	0.012928241	2100	Pastendruck		1	2	0.310277778	A_2	D	A_2_D
100004	LINE/A	471U32551	3/1/2023, 3:54:02.0 AM	3/1/2023, 4:01:03.0 AM	0.004872685	2100	Pastendruck		1	2	0.116944444	A_2	C	A_2_C
100005	LINE/A	471U32551	3/1/2023, 4:05:53.0 AM	3/1/2023, 4:21:48.0 AM	0.011053241	2100	Pastendruck		1	2	0.265277778	A_2	D	A_2_D
100006	LINE/A	471U32551	3/1/2023, 4:46:24.0 AM	3/1/2023, 4:51:56.0 AM	0.003842593	2100	Pastendruck		1	2	0.092222222	A_2	C	A_2_C
100007	LINE/A	471U35968	3/1/2023, 8:06:40.0 AM	3/1/2023, 8:15:57.0 AM	0.006446759	2100	Pastendruck		1	2	0.154722222	A_2	C	A_2_C
100008	LINE/A	471U35976	3/1/2023, 8:40:30.0 AM	3/1/2023, 8:57:06.0 AM	0.011527778	2100	Pastendruck		1	2	0.276666667	A_2	D	A_2_D
100009	LINE/A	471894646	3/1/2023, 12:30:54.0 PM	3/1/2023, 12:34:10.0 PM	0.002268519	2100	Pastendruck		1	2	0.054444444	A_2	B	A_2_B
			3/1/2023	3/1/2023										

Figure 30: Error log data

3.2.1.3   Worker Allocation

Figure 31 displays the breakdown structure created to store relevant data for the worker allocation scenario in the Knowledge Base. This data includes information such as worker availability, skill sets, and other relevant details necessary for the allocation process. The competence set of workers, which contains information about their training, is represented by a breakdown element. Figure 32 visualizes the breakdown element representation of this competence set. It is important to note that the training information of employees is protected by masking or anonymizing sensitive information. This ensures the privacy and security of employee data while still retaining the necessary details for worker allocation purposes.

The operator presence information date is depicted in Figure 33. This data set is created for representation purposes and contain dummy data. During the later stages of the project, it is expected that a similar type of data set will be obtained from the use case owner. This data set will provide actual daily information about worker presence for each shift, facilitating the worker allocation process based on up-to-date information.
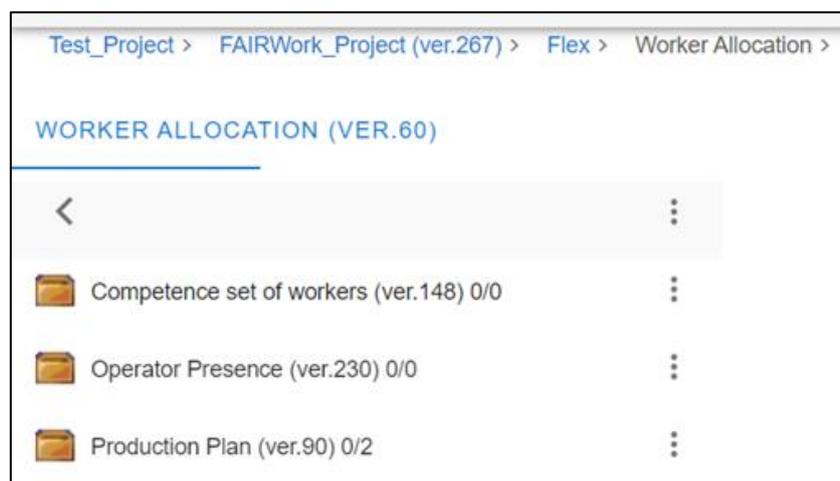

Figure 31: Breakdown of data for Worker allocation use case scenario.

Representation of the aggregate property

Index	Name	Course name	Content type	Enrollment status	Enrolled on	Completion	Closing date and time	expiration date	Participation status	valuation	score	record type
10001	108285	CAP Automation Fundamental Level Module 5 (English)	digital course	Enrolled	5/13/2023, 12:00:00.0 AM	Completed	5/13/2023, 2:38:35.0 PM	5/13/2023 14:38	Don't track	Passed	0	enrollment
10002	108285	CAP Automation Fundamental Level Module 4 (English)	digital course	Enrolled	5/13/2023, 12:00:00.0 AM	Completed	5/13/2023, 11:18:27.0 AM	5/13/2023 11:18	Don't track	Passed	0	enrollment
10003	108285	CAP Automation Fundamental Level Module 3 (English)	digital course	Enrolled	5/13/2023, 12:00:00.0 AM	Completed	5/13/2023, 10:55:25.0 AM	5/13/2023 10:55	Don't track	Passed	0	enrollment
10004	108285	Global Employee Privacy Policy	digital course	Enrolled	11/2/2022, 12:00:00.0 AM	Completed	11/2/2022, 12:11:21.0 PM	11/2/2022 12:11	Don't track		0	enrollment
10005	108285	CAP Automation Fundamental Level Module 2 (English)	digital course	Enrolled	9/23/2022, 12:00:00.0 AM	Completed	9/23/2022, 9:52:06.0 AM	9/23/2022 9:52	Don't track	Passed	0	enrollment
10006	108285	CAP Automation Fundamental Level Module 1 (English)	digital course	Enrolled	9/21/2022, 12:00:00.0 AM	Completed	9/21/2022, 1:57:51.0 PM	9/21/2022 13:57	Don't track	Passed	0	enrollment
10007	108285	CAP Automation fundamental level	program	Enrolled	9/17/2022, 12:00:00.0 AM	Completed	5/13/2023, 2:38:35.0 PM	5/13/2023 14:38	Don't track		0	enrollment
10008	108285	CAP Automation fundamental level	program	Enrolled	8/31/2022, 12:00:00.0 AM	Completed	8/31/2022, 1:11:48.0 PM	8/31/2022 13:11	Don't track		0	enrollment
10009	108285	Introduction to FLEXible Work (Inactive)	digital course	Enrolled	6/30/2022, 12:00:00.0 AM	Completed	6/30/2022, 2:04:53.0 PM	6/30/2022 14:04	Don't track		0	enrollment
10010	108285	Compliance Matters: Importance of Software Compliance	digital course	Enrolled	6/8/2022, 12:00:00.0 AM	Completed	6/8/2022, 12:41:26.0 PM	6/8/2022 12:41	Don't track	Passed	0	enrollment
10011	108285	FY22 Annual Reflection: A Guide for Employees (Inactive)	digital course	Enrolled	6/3/2022, 12:00:00.0 AM	Completed	6/29/2022, 4:09:04.0 PM	6/29/2022 16:09	Don't track		0	enrollment
10012	108285	Leading Culture—Ways of Working	digital course	Enrolled	9/10/2021, 12:00:00.0 AM	Completed	9/10/2021, 1:37:48.0 PM	9/10/2021 13:37	Don't track		0	enrollment

Figure 32: Breakdown of data for competence of workers

Figure 33 Breakdown element for operator presence

3.2.2   CRF Use Case

The business process models for the CRF use case scenarios are described in chapter 2 of the deliverable which provides a detailed explanation of how the business processes are structured and organized within the context of the CRF scenarios. Additionally, the required data for these scenarios are outlined in corresponding tables, which likely specify the exact data elements and attributes needed to support the CRF use cases.

The available data is then best used to create breakdown structures in the Knowledge Base specifically tailored to these use case scenarios for CRF. These breakdown structures serve as a hierarchical representation of the relevant information and relationships within the Knowledge Base. They provide a structured and organized view of the data and its interconnections.

In Figure 35, a visual representation of the plant layout is depicted within the Knowledge Base. This figure provides a digital presentation of few sections of the physical arrangement of the plant or facility related to the

CRF use cases as shown in Figure 34. By incorporating this information into the Knowledge Base, users can easily understand and navigate the plant layout and its associated information.

Figure 34: CRF Plant Layout

The breakdown structure represents plant sections, specifically UTE1, UTE4, and UTE8. Each section has different line configurations, and each line can produce a specific set of geometries. In the Knowledge Base, breakdown element properties are created to represent each material and its required configuration within a line. These properties capture the specific details of how a material should be processed in a particular line.Figure 36 shows the required decision process models stored in the Knowledge Base for the CRF.
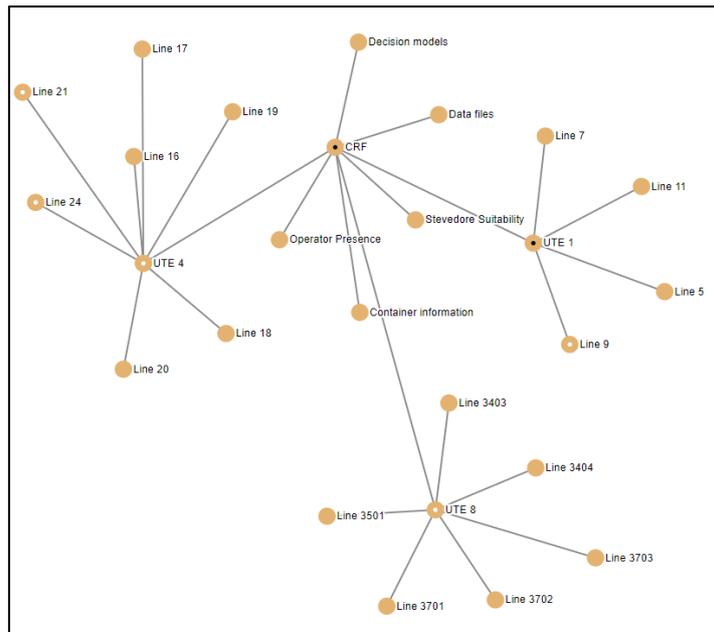
Figure 35: CRF breakdown structure in PLM

Figure 37 represents the modeled information. In the breakdown element of the figure, there is a specific line referred to as Line 5. Line 5 has child nodes, represented with material design codes. Each design code has associated properties that define the required stamping configuration for that material variation. Additionally, the properties also contain specific number of operators or personnel required to carry out the production process for that design code. This approach allows for the systematic representation and management of the breakdown structure, line configurations, material variations, and their corresponding properties in the Knowledge Base. This organized information helps in understanding the relationships between different components and enables effective planning and execution.
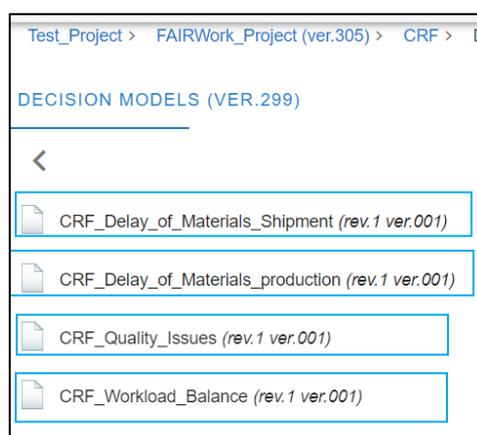
Figure 36: CRF Decision Models element

Figure 37: Line 5 and associated geomteries

Figure 38, illustrating information about containers used to store specific parts. The CONTAINER_INFORMATION, element contains various child elements related to the breakdown of parts, identified by their part numbers. The breakdown properties defined are "ACTUAL_RACK_CODE" and "Part_weight" etc. These properties provide additional details about the parts, such as the code representing the actual rack where the part is stored and the weight of the part itself. The purpose of this information is to assist in determining the appropriate container needed to store a particular part based on its geometry. By referring to the breakdown elements and their associated properties, one can find the relevant container that can accommodate the specific part.

Figure 38: Container information

3.3 Accessing Knowledge Base using REST API

In this section few examples are presented to show how the data can be accessed from the Knowledge Base with the help of REST API functions. To showcase the practical application of the Knowledge Base, a few demonstrator videos have been produced which can be found in FAIRWork webpage https://fairwork-project.eu/deliverables/d5-1 under the section Prototype Videos in Figure 6.These videos highlight the utilization of REST API functions that are made available by the Knowledge Base. Specifically, the videos focus on the integration of microservices defined using the Olive Framework, which enables seamless access to data stored in the Knowledge Base. The Olive Framework, being a microservice framework which allows to create model-aware web applications through the configuration of existing components, serves as the bridge between the Knowledge Base and external systems or applications. By leveraging the REST API functions provided by the Knowledge Base, the Olive Framework facilitates the extraction and utilization of relevant information. Part of the Olive Framework is the Microservice controller, which allows the definition of backend microservices. The defined services can then be used in the configuration environment to use data coming from the Knowledge Base in a web application.

3.3.1 Accessing robot capabilities FLEX Use case scenario

In this example it is shown how to get a TM5-700 robot capability from the Knowledge Base as shown in Figure 39.

a) Robot Specification manual   b) Breakdown structure in Knowledge Base

Figure 39: Robot specification in Knowledge Base

The following URLs are essential for accessing the required information from Knowledge base. The first URL is used to generate a token, which is a security measure to authenticate the user and authorize access to the system. This initial URL request involves providing necessary credentials or authentication details, and upon successful verification, a token is generated. Once the token is obtained, it serves as a key to access advanced search functionality within the Knowledge Base. The second URL request, utilizing the token, enables the user to perform a detailed search based on specific parameters. The search functionality is designed to locate the required breakdown element or relevant information within the Knowledge Base.

1. **Token Generator**: https://fairwork.jotne.com/EDMtruePLM//api/admin/token

2. **Quick search method**:
   https://fairwork.jotne.com/EDMtruePLM//api/bkd/q_search/TruePLMprojectsRep/Test_Project/PHCKOZSMS1XXA0VVWE

When the second URL request is made, the system processes the input search parameters provided by the user and retrieves the corresponding data. The response to this request is returned in JSON format, a widely used data interchange format that is structured and easy to parse. JSON provides a standardized way of representing the retrieved information, ensuring consistency and compatibility across different systems and programming languages.

To visualize the response and better understand the data retrieved, Figure 40 showcases an example representation of the JSON response. This figure serves as a visual aid, demonstrating the structure and content of the JSON data returned by the system in response to the second URL request.

Figure 40: REST API JSON Response for robot capabilities

Overall, these two URLs play a crucial role in accessing the desired information, as they enable the authentication process, trigger the advanced search functionality, and deliver the search results in a structured JSON format. Further details of these API request cab be found in the swagger documentation available for FAIRWork https://fairwork.jotne.com/EDMtruePLM/swagger.html .

This example presented is further extended to retrieve the aggregated data present in the element. In this scenario, the aggregated data pertains to the sensors present in the element. These sensors gather data and

transmit it to the Knowledge Base for storage and analysis. To demonstrate the capabilities of the Knowledge Base, sample data has been created to showcase how it can store sensor data effectively. Within the TM5-700 element, in addition to the standard product specification, a new property called "Accelerometer_readings" has been created as shown in Figure 41.

Num ↑	Name	Value	Type
22	Communication	RS232, Ethernet (master), Modbus TCP/RTU (master & slave)	T
23	Integrated Camera	5M pixels, color	T
24	IO_power_supply	24V 1.5A (control box and tool)	T
25	Programming Environment	TMflow, flowchart based	T
26	SEMI S2 Certified	No	E
27	Accelerometer_readings	5 items	A

Representation of the aggregate property

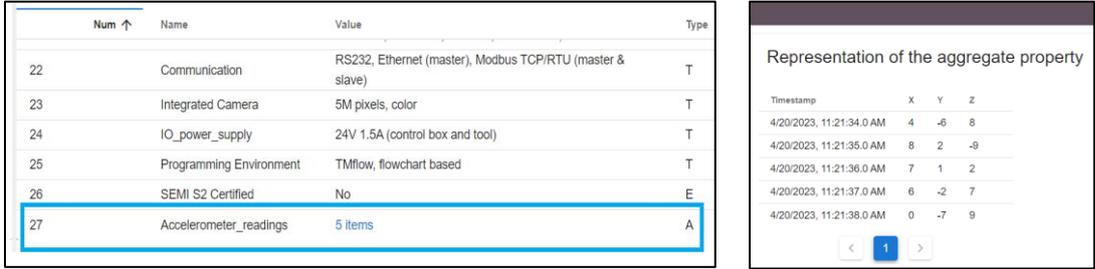| Timestamp	X	Y	Z
4/20/2023, 11:21:34.0 AM	4	-6	8
4/20/2023, 11:21:35.0 AM	8	2	-9
4/20/2023, 11:21:36.0 AM	7	1	2
4/20/2023, 11:21:37.0 AM	6	-2	7
4/20/2023, 11:21:38.0 AM	0	-7	9

‹ **1** ›

Figure 41: Sample Aggregate data for TM5-700 element

The "Accelerometer_readings" property contains several fields that capture essential information about the accelerations measured by the sensor. These fields include the timestamp, which denotes the precise moment when the acceleration data was recorded, as well as the acceleration values in the X, Y, and Z directions. By storing this information, the Knowledge Base enables comprehensive analysis and retrieval of the recorded sensor data for further processing or examination.

Overall, this extended example demonstrates how the Knowledge Base can effectively store and organize aggregated data from sensors, specifically focusing on the acceleration sensor values within the TM5-700 element. By leveraging such capabilities, the Knowledge Base provides a valuable resource for storing and accessing sensor data for a wide range of applications and analyses.

In the context of the demonstration of data accessing capabilities of Knowledge Base the video **robotcapabilities.mp4** [3] has been created, this example revolves around accessing and retrieving aggregate data from the TM5-700 element. This aggregate data represents a consolidated collection of information that has been stored within the Knowledge Base. By employing the capabilities of the Olive Framework and its integration with the Knowledge Base's REST API functions, the video showcases the seamless retrieval of this aggregated data.

Through a series of visual demonstrations, the video illustrates how the Olive Framework interacts with the Knowledge Base, making API calls to fetch the desired aggregate data from the TM5-700 element. This retrieval process enables users to access and analyze the combined information, providing valuable insights and enabling informed decision-making. Overall, the video serves as a practical example of the integration between the DAI-DSS configurator olive framework and the Knowledge Base.

3.3.2 Accessing Geometry information in CRF use case

In this example, we can see the process of retrieving the necessary configuration to generate a geometry with the design code "505469970". This information is stored in a Knowledge Base, which is depicted in Figure 37. In the Knowledge Base, Line 5 contains the relevant data about the potential set of geometries that can be produced on the line. To further illustrate this, let's take a closer look at the JSON response obtained from a REST API request in Figure 42. The response, which is displayed in the figure, provides a structured format for transmitting data. It includes key-value pairs that represent various attributes related to the requested Configuration and its associated geometry. By making use of the REST API, the system can send a request to the server, specifying the required parameters, such as the design code "505469970" as query search parameter. The server then processes this request and generates a JSON response containing the pertinent information.

```
Performing request: https://fairwork.jotne.com/EDMtruePLM//api/bkd/q_search/TruePLMprojectsRep/Test_Project/YCBE8T8QDEAYOOVF6A
status_code:  200
{'bkdn_elem_info': {'instance_id': 261993180507, 'id': '0TubsW_imHxO00IdNiWvXr', 'name': '505469970', 'quantity': None, 'versio
n_id': '143', 'description': 'PARAF.ANT.SX', 'element_type': 'urn:rdl:Test_Project:material_type', 'children_loaded': False, 'c
hildren': None, 'date_created': '2023-05-25 07:16:50', 'created_by_user': 'jotne_rishyank', 'date_last_modified': '2023-05-25 0
7:16:50', 'last_modified_by_user': 'jotne_rishyank', 'is_part': False, 'data_contents': None, 'templates': None, 'properties':
[{'name': 'urn:rdl:Test_Project:DISEGNO', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '505469970.000000', 'uni
t': None, 'action': None, 'num_val': 505469970.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:TIPO',
'value_domain': 'urn:plcs:rdl:TruePLM:Text_value', 'val': '952A', 'unit': None, 'action': None, 'num_val': 0.0, 'si_unit': Fals
e, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:PZ', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '18.0
00000', 'unit': None, 'action': None, 'num_val': 18.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:M
DR', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '1585.000000', 'unit': None, 'action': None, 'num_val': 1585.
0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:N.Part', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeri
c_value', 'val': '33.000000', 'unit': None, 'action': None, 'num_val': 33.0, 'si_unit': False, 'is_derived': False}, {'name':
'urn:rdl:Test_Project:DENOMINAZIONE', 'value_domain': 'urn:plcs:rdl:TruePLM:Text_value', 'val': 'PARAF.ANT.SX', 'unit': None,
'action': None, 'num_val': 0.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:Numero stampi 01', 'valu
e_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '851250.000000', 'unit': None, 'action': None, 'num_val': 851250.0, 'si
_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:Numero stampi 02', 'value_domain': 'urn:plcs:rdl:TruePLM:Nu
meric_value', 'val': '251.000000', 'unit': None, 'action': None, 'num_val': 251.0, 'si_unit': False, 'is_derived': False}, {'na
me': 'urn:rdl:Test_Project:Numero stampi 03', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '252.000000', 'uni
t': None, 'action': None, 'num_val': 252.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:Numero stamp
i 04', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '253.000000', 'unit': None, 'action': None, 'num_val': 253.
0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:Numero stampi 05', 'value_domain': 'urn:plcs:rdl:True
PLM:Numeric_value', 'val': '254.000000', 'unit': None, 'action': None, 'num_val': 254.0, 'si_unit': False, 'is_derived': Fals
e}, {'name': 'urn:rdl:Test_Project:Numero stampi 06', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '255.00000
0', 'unit': None, 'action': None, 'num_val': 255.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:MAT
R', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '410301.000000', 'unit': None, 'action': None, 'num_val': 4103
01.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:MATERIALE', 'value_domain': 'urn:plcs:rdl:TruePLM:
Text_value', 'val': 'AA6000 -IH E 1 X 1780 X 1230', 'unit': None, 'action': None, 'num_val': 0.0, 'si_unit': False, 'is_derive
d': False}, {'name': 'urn:rdl:Test_Project:SIMBOLO', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '630473070.00
0000', 'unit': None, 'action': None, 'num_val': 630473070.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Pro
ject:T_P', 'value_domain': 'urn:plcs:rdl:TruePLM:Text_value', 'val': 'E', 'unit': None, 'action': None, 'num_val': 0.0, 'si_uni
t': False, 'is_derived': False}, {'name': 'urn:rdl:Test_Project:FABB', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'v
al': '1.000000', 'unit': None, 'action': None, 'num_val': 1.0, 'si_unit': False, 'is_derived': False}, {'name': 'urn:rdl:Test_P
roject:OP', 'value_domain': 'urn:plcs:rdl:TruePLM:Numeric_value', 'val': '6.000000', 'unit': None, 'action': None, 'num_val':
6.0, 'si_unit': False, 'is_derived': False}], 'subdomains': None, 'is_root_of_subdomain': 0, 'is_part_of_subdomain': 0, 'permis
sions': None, 'phase': 'urn:rdl:epm-std:0', 'is_requirement': False, 'children_count': 0, 'rels': None, 'orgs': None, 'occurren
ce': None, 'occurrence_users': None, 'local_occurrence': None, 'has_shape_elements': None, 'has_child_occurrences': None, 'has_
occurrences': None, 'ids': None, 'classified_as': None, 'described_as': None, 'datetimes': None, 'persons': None, 'parents': No
ne}, 'tree_path_to_element': [261993009368, 261993009632, 261993156740, 261993156819, 261993180507], 'path': ['FAIRWork_Projec
t', 'CRF', 'UTE 1', 'Line 5', '505469970']}
```

Figure 42: JSON Response for Geometry information

Overall, this example showcases a process involving the retrieval of a configuration from a Knowledge Base and the subsequent utilization of a REST API to acquire a JSON response. This methodology facilitates access to significant information pertaining to the desired geometry. By employing this approach, the DAI-DSS configurator has been effectively configured with the necessary data to invoke the desired response from the Knowledge Base. A video demonstrating this entire process is available for reference please find **lineInfomation.mp4**[3] in the FAIRWork webpage**.** In this case, the process begins with accessing the Knowledge Base, which contains a comprehensive collection of information and data related to various configurations. The Knowledge Base serves as a centralized repository where valuable information is stored and organized. By retrieving a configuration from this Knowledge Base, specific details regarding the desired geometry can be obtained.

3.3.3   Accessing Operator Presence in CRF use case

In this example, it is demonstrated how to retrieve operator presence information from a Knowledge Base, as depicted in Figure 43. This information can be potentially utilized in a workload balancing scenario. Having access to operator availability information within the Knowledge Base is crucial, and the relevant AI services can make use of this information to allocate workers effectively. To showcase the concept, an aggregate property is created in the Knowledge Base, which represents operators' presence. This aggregate property serves as a demonstration, as the original dataset contains sensitive operator information that is not shown. The operator presence information can be obtained through the REST API services, and the response from the API request is illustrated in Figure 44. Moreover, the API requests are configured within the OLIVE platform to retrieve the aggregated data. The OLIVE platform allows for the configuration and management of these requests, enabling the retrieval of the necessary information for further analysis and decision-making. The **operatorPresence.mp4**[3] provides the required demonstration.
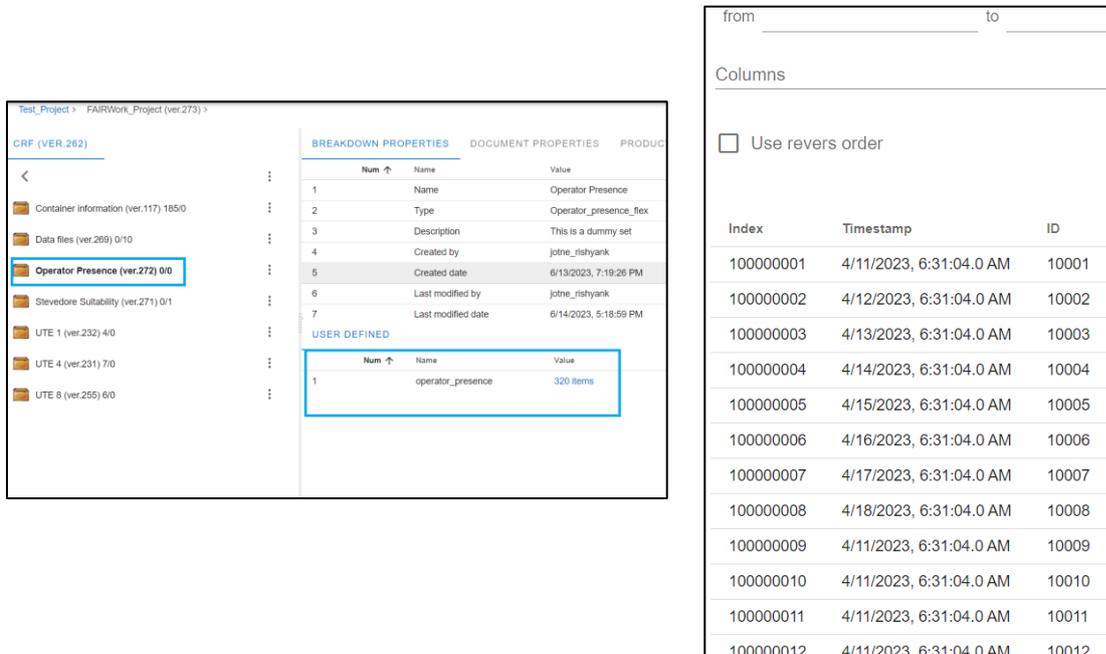
Figure 43: Breakdown structure in Knowledge Base for operator presence

```
Performing request: https://fairwork.jotne.com/EDMtruePLM//api/bkd/aggr_exp_dt/TruePLMprojectsRep/Test_Project/261993276944/
urn:rdl:Test_Project:operator_presence/6O9XN289G3FGX1OK0P
        Request (status code = 200)
[{'Index': '100000001', 'Timestamp': '2023-04-11 06:31:04', 'ID': '10001'}, {'Index': '100000002', 'Timestamp': '2023-04-12
06:31:04', 'ID': '10002'}, {'Index': '100000003', 'Timestamp': '2023-04-13 06:31:04', 'ID': '10003'}, {'Index': '100000004',
'Timestamp': '2023-04-14 06:31:04', 'ID': '10004'}, {'Index': '100000005', 'Timestamp': '2023-04-15 06:31:04', 'ID': '1000
5'}, {'Index': '100000006', 'Timestamp': '2023-04-16 06:31:04', 'ID': '10006'}, {'Index': '100000007', 'Timestamp': '2023-04
-17 06:31:04', 'ID': '10007'}, {'Index': '100000008', 'Timestamp': '2023-04-18 06:31:04', 'ID': '10008'}, {'Index': '1000000
09', 'Timestamp': '2023-04-11 06:31:04', 'ID': '10009'}, {'Index': '100000010', 'Timestamp': '2023-04-11 06:31:04', 'ID': '1
0010'}, {'Index': '100000011', 'Timestamp': '2023-04-11 06:31:04', 'ID': '10011'}, {'Index': '100000012', 'Timestamp': '2023
-04-11 06:31:04', 'ID': '10012'}, {'Index': '100000013', 'Timestamp': '2023-04-11 06:31:04', 'ID': '10013'}, {'Index': '1000
00014', 'Timestamp': '2023-04-11 06:31:04', 'ID': '10014'}, {'Index': '100000015', 'Timestamp': '2023-04-11 06:31:04', 'ID':
```

Figure 44: JSON response for Operator Presence

4 SUMMARY AND CONCLUSION

This Deliverable presents the set-up of the DAI-DSS FAIRWork Knowledge Base at the Use Case sites related to the use cases scenarios of CRF and FLEX. The use cases have a complex interaction of human, AI, robots, and machines working together in manufacturing environments. These interactions need to be optimized for better overall production rates. Starting point is the knowledge about the involved actors and the decision process in the manufacturing environment. This information is stored in the DAI-DSS Knowledge Base. It is built on internationally available open standards with focus on ISO 10303 (STEP). The standard data model of STEP serves product data representation and exchange. It is the foundation of the developed Knowledge Base repository, which stores all the required information related to the decision models to support decision making.

Following the project introduction, Chapter 2 described the process of developing decision models for DAI-DSS. The initial step defines the decision process models, followed by the specification and detailing of the use cases. The decision models were created using ADONIS, where relevant decision parameters and aspects were identified. These decision process models identify and list relevant decision-makers, the desired outcome of the decision-making process, and the aspects and parameters that must be considered to find a solution. These decision process models also play a crucial role in the technical alignment and the discovery of services, particularly AI services, that are suitable for supporting specific decision aspects or the entire decision-making process. Furthermore, the required data and knowledge artefacts for these decision models are listed, and a short description of each required data element is provided. The information on how to obtain the publicly accessible decision process models is also provided in this chapter.

Chapter 3 of the document presented the demonstration of the Knowledge Base, showcasing the preliminary project setup including the REST API access methods. The DAI-DSS Knowledge Base serves as the main repository for importing, storing, and retrieving data required for processing and analysis, as well as collecting and storing results from decision-making processes. Long-term archival of such data is facilitated by using ISO 10303 standards. Based on decision process models, the data collected from the data requirements tables from Chapter 2 is then best used to create breakdown structures in the Knowledge Base specifically tailored to the Use Case scenarios of FLEX and CRF. These breakdown structures serve as a hierarchical representation of the relevant information. Relationships within the Knowledge Base and sensitive data are anonymized or replaced with dummy data sets that provide a structured and organized view of the data and its interconnections.

To demonstrate the practical application of the Knowledge Base, demonstrator videos are available on the FAIRWork webpage. They showcase the utilization of REST API functions provided by the Knowledge Base, particularly focusing on the integration of microservices defined using the Olive Framework. The Olive Framework acts as a bridge between the Knowledge Base and external systems or applications, enabling seamless access to relevant information stored within the Knowledge Base. The Microservice controller within the Olive Framework

allows the definition of backend microservices, which can be utilized in the configuration environment for web applications to leverage data from the Knowledge Base.

Overall, Deliverable D5.1 serves as a significant milestone in the FAIRWork project, showcasing the progress made in modeling decision processes, creating the FAIRWork Knowledge Base, and providing accessible interfaces for data exchange. It lays the foundation for further development and refinement of the Knowledge Base to enhance its usefulness and applicability in the context of the project's objectives.

5 REFERENCES

References are included as footnotes in the Document

ANNEX A: PUBLIC ACCESS KNOWLEDGE BASE

Here the Information about accessing the public version of Knowledge Base is presented. The login credentials are shown in below.

Username	Password
demo_user_fairwork	Mud2@eth

Furthermore, the information about the project structure can be found as shown in Figure 44
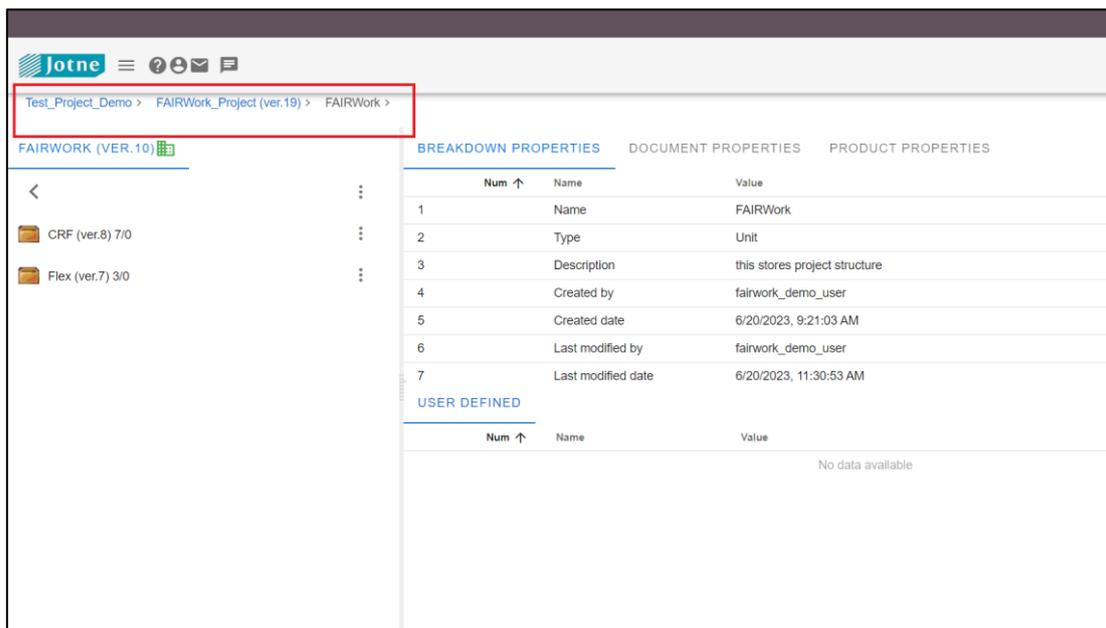
Figure 45: Project structure in Knowledge Base

ANNEX B: DECISION MODELS BETTER RESOLUTION

This section provides the figure related to the decision process models in better picture quality for FLEX and CRF Use cases
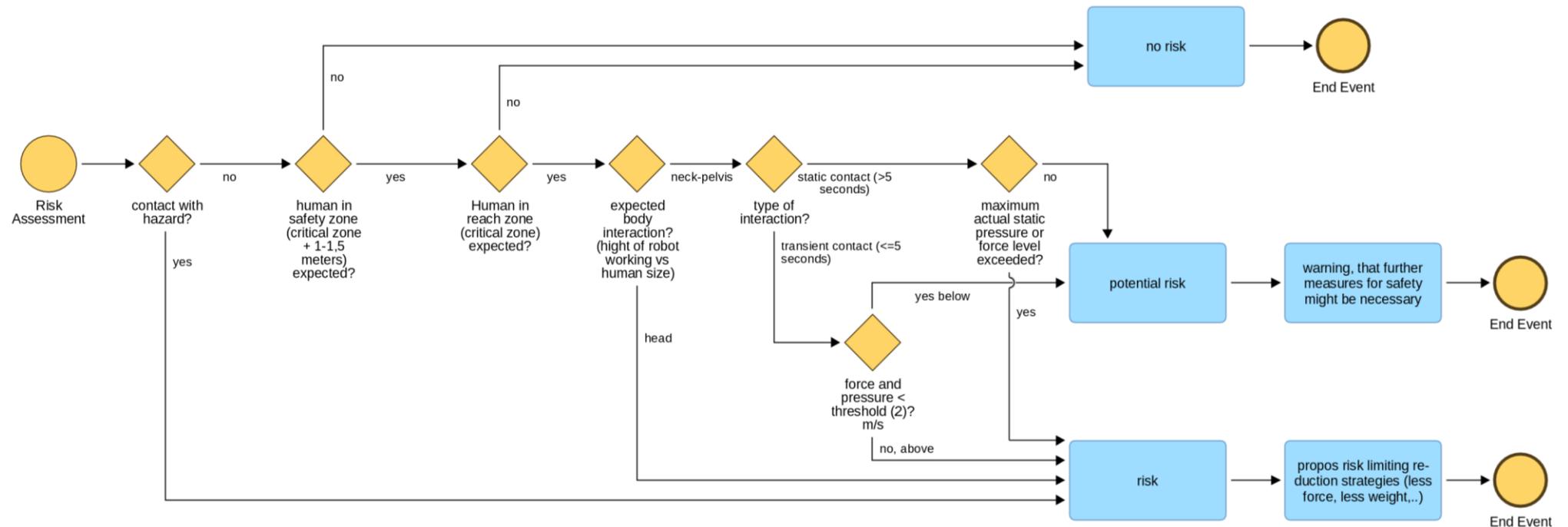
Figure 46: Decision model of FLEX Automated Test Building - Risk Assessment (Better resolution)
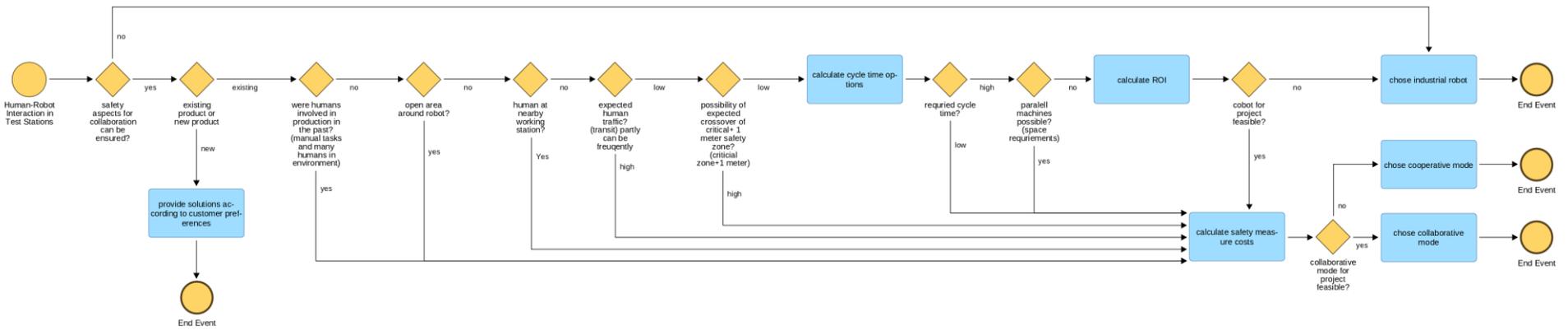
Figure 47: Decision model of FLEX Automated Test Building - Environmental Factors (Better resolution)
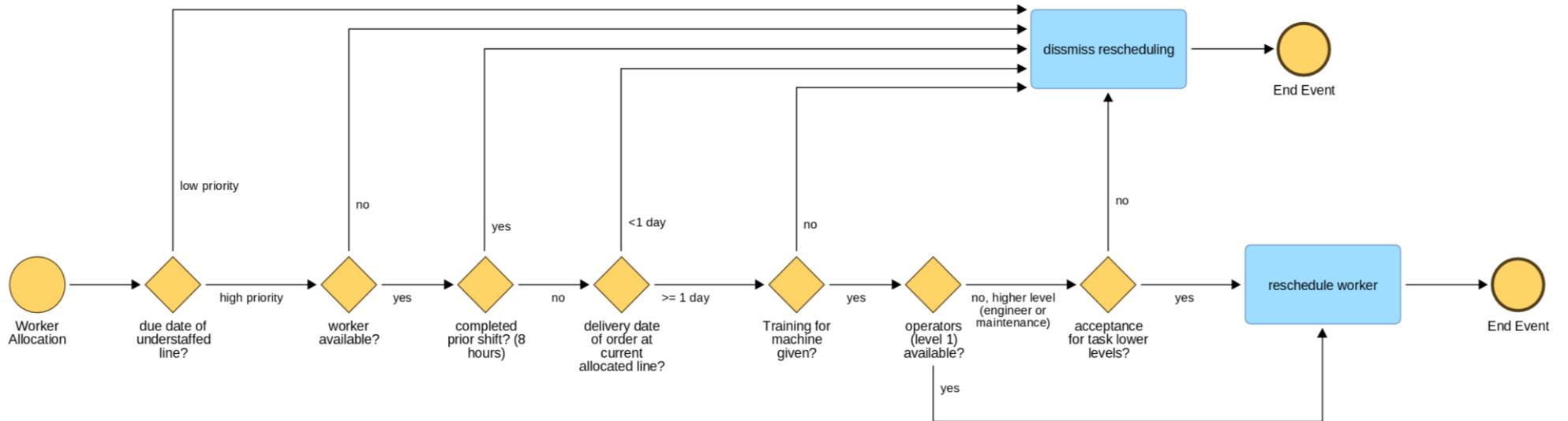

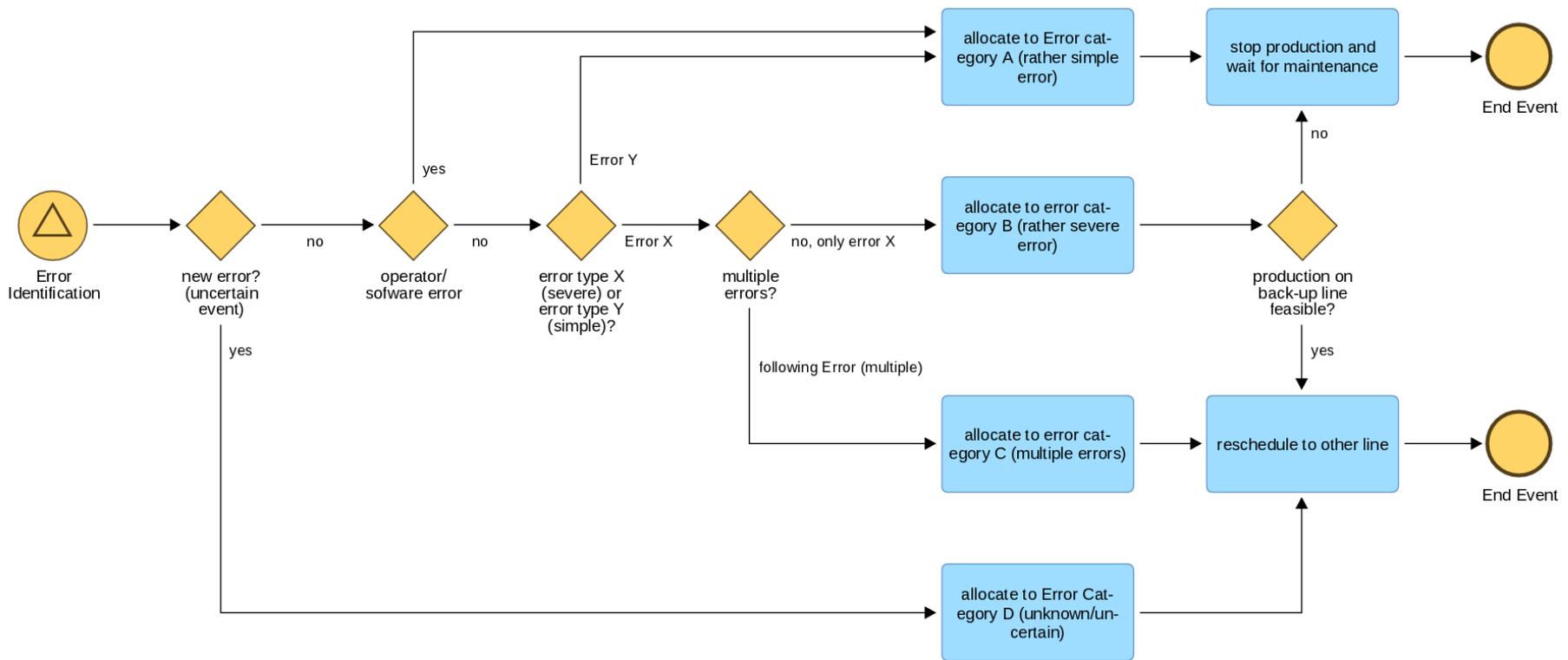Figure 48. Decision model of FLEX Worker Allocation (Better resolution)

Figure 49. Decision model of FLEX Machine Maintenance after Breakdown (Better resolution)
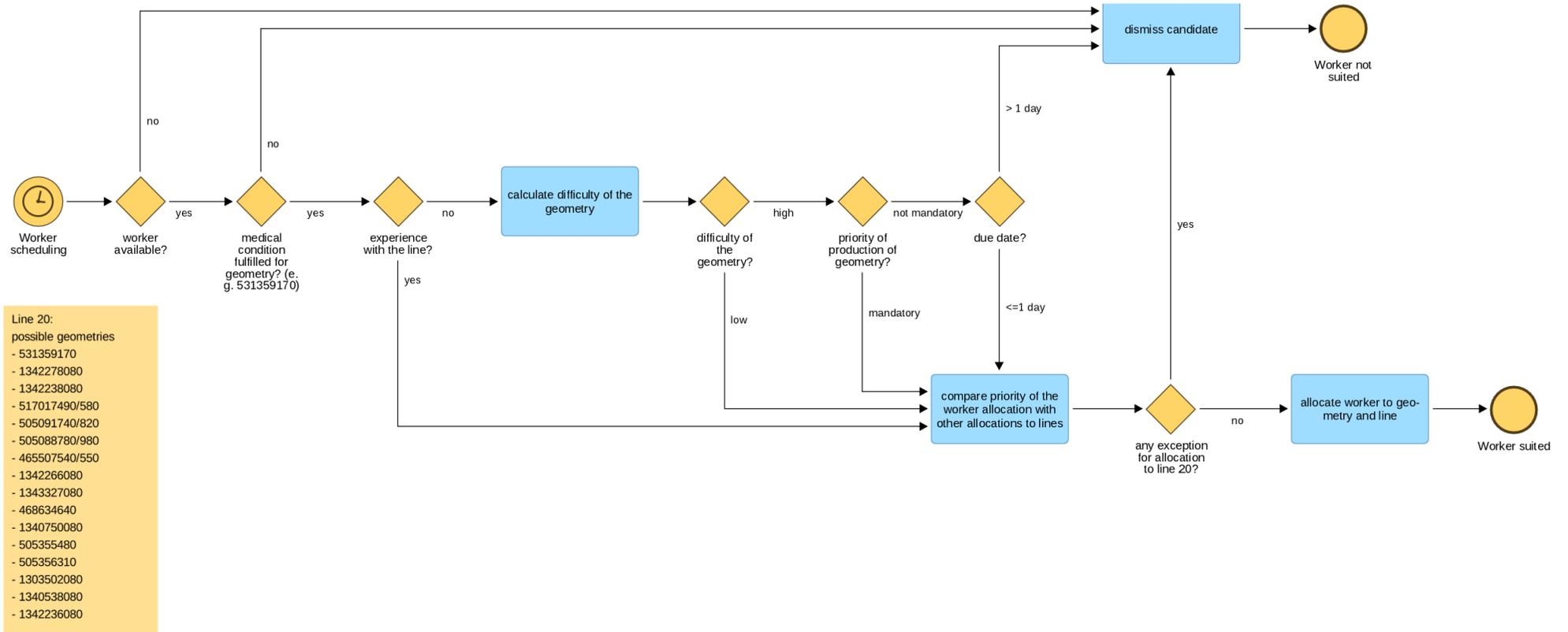
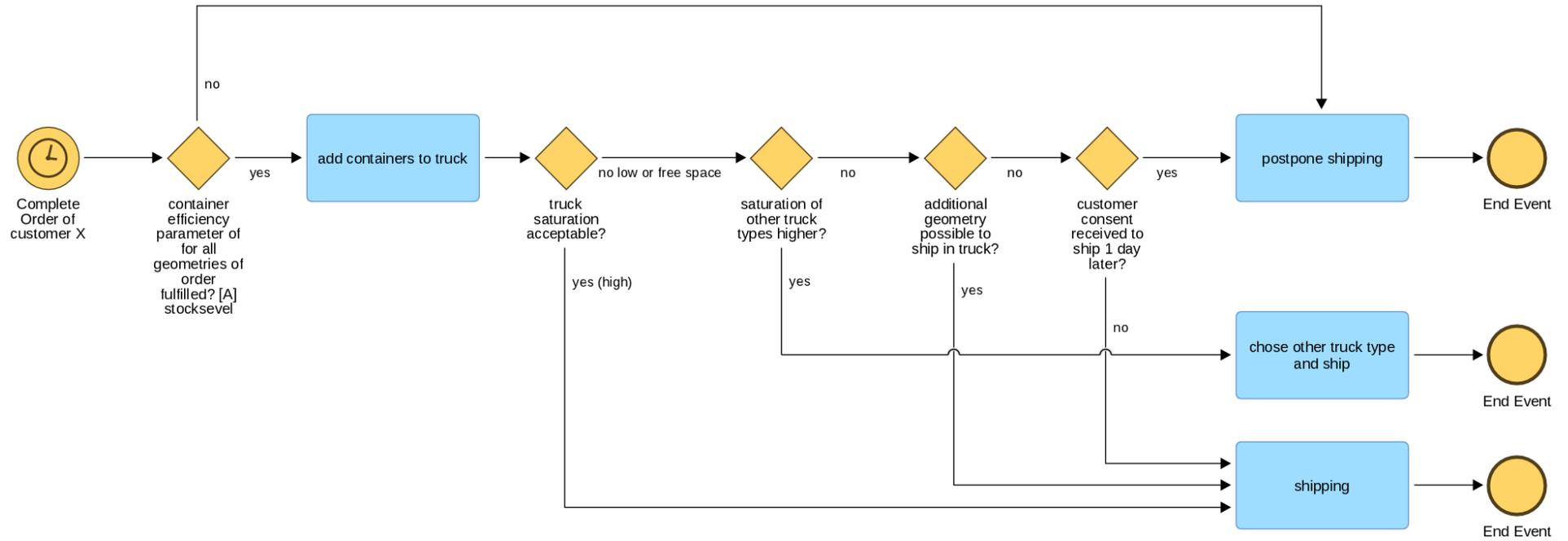Figure 50. Decision model of CRF Workload Balance (Better Quality)

Figure 51: Decision model of CRF Delay of Material pt.2 (Better resolution)
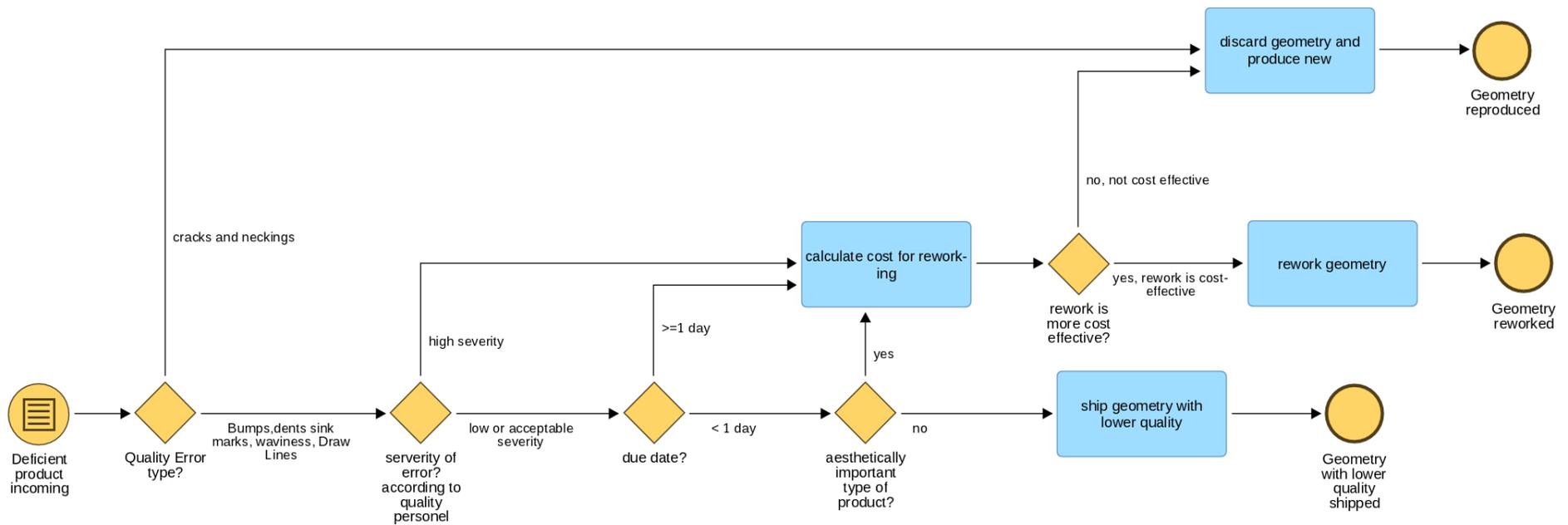
Figure 52: Decision model of CRF Quality Issues (Better resolution