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D5.5 - Human-Machine-Interfaces for direct interaction with the factory environments I

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Index:

1 Executive Summary

This deliverable presents the first results of the task T5.3 which is about the development of inter- and intra-factory human-machine-interfaces which enables users to interact with the COMPOSITION system. The HMI design is driven by initial requirements collected in both, WP2 (D2.1) and WP5 activities. For the initial GUIs, the use cases defined in D2.1 were considered; however, their prioritization was changed after the T5.3 started. This is why use cases of higher priority might not always have HMI drafts of highest detail.

Based on a research on the role of HMIs in the Industry 4.0 environment, general requirements for HMIs in the manufacturing context have been collected. As described in section 3, such requirements are for example web capability, responsive design, interfacing communication services, and context sensitivity. A brief summary of HMIs which are already applied in Industry 4.0 process and production monitoring was added in order to demonstrate how decent systems can support workers accomplishing their tasks. Additionally, the applied technology showed what is already being applied and delivered initial input for the right choices of context-aware devices and their potential.

The methodology is described in section 4. Several design methods offered by the applied user-centered design framework, for example interviews, guided tours through the factory floors, scenario thinking, storyboards, activity analysis, and prototyping allowed for further basic functionality and user requirement elicitation, situation analysis and grouping, as well as the development of initial prototypes for decent HMIs. Doing this, three major factory scenarios were identified: alarm situations, navigation or logistic tasks, and basic observing and analytic tasks. Those situations have been documented in order to find the best fitting devices for task-relevant HMIs on the COMPOSITION test sites.

Section 5 and 6 report on the initial interfaces of different fidelity levels. Therefore, wireframes, screenshots from digital mockups, as well as basic functionality diagrams are shown. Additionally created interaction flow diagrams, detail views for GUIs, alternative interfaces such as mobile and / or desktop are presented in the appendix of this deliverable.

Finally, next steps, the main achievements, and the influence of the presented work on other work packages are presented in section 7.

2 Introduction

2.1 Purpose, context and scope of this deliverable

This deliverable provides an overview of the initial results of task T5.3 Advanced Human-Machine-Interfaces for Direct Interaction with Real-World Objects. The purpose of task T5.3 is the development of work-task oriented user interfaces that support people in CPSs. T 5.3 is one of five subtasks of work package 5 – Key Enabling Technologies for Intra- and Interfactory Interoperability and Data Analysis.

Due to the early state of the project, presented results will provide a first overview of the interfaces to be developed as COMPOSITION progresses. The main focus of this deliverable lies on identifying and developing relevant interaction scenarios, devices, data, and work-tasks that allow for the application of COMPOSITION HMIs. The results of these actions will be input for further work done in WP2 and are presented as initial paper prototypes, wireframes, visions and story boards. The initial HMIs are to be refined and evolved iteratively as the project proceeds following a user-centered approach (UCD).

2.2 Content and structure of this deliverable

This deliverable describes the initial drafts of HMIs developed for intra- and inter-factory scenarios described as a part of the COMPOSITION project. As depicted in Figure 1, intra-factory use cases focus on the value chain and are addressing processes inside the factory, whereas inter-factory use cases handle processes among multiple stakeholders, thereby concentrating on the supply chain. Section 3 will briefly introduce the state of the art of HMIs in the context of Industry 4.0. While section 3.1 focuses on research topics and design guidelines up the foundation for the methodology further described in section 4, a general analysis of interfaces and interaction techniques applied in the industry 4.0 environment is described in section 3.2. Besides the adopted design process, a short overview of the methodology used throughout the development of the presented results as well as initial results of conducted user research methods is given in section 4.

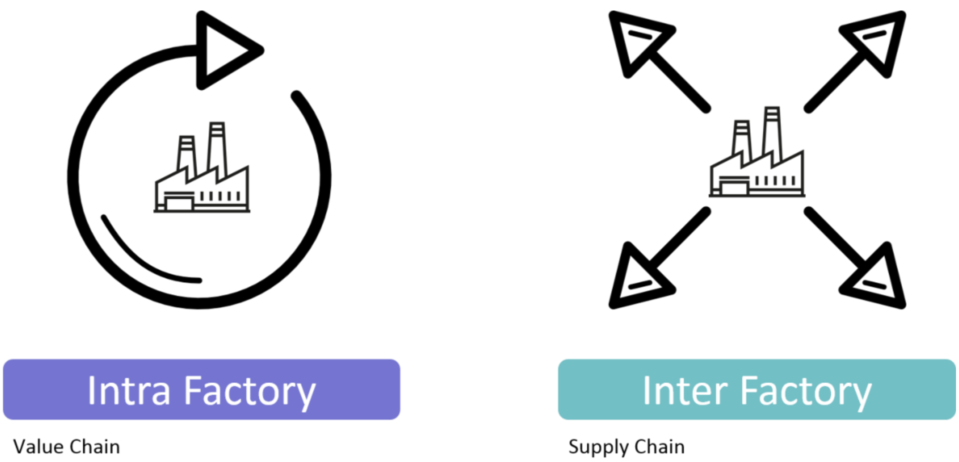

Figure 1: Intra-factory vs. inter-factory

The wireframes, interfaces, visions and other results shown in the Sections 5 and 6 have been developed in close collaboration with the COMPOSITION pilot and technical partners. Section 5 focuses on the intra-factory scenarios described in D2.1 Industrial Use Cases for an Integrated Information Management System. In line with a general vision for the intra-factory use cases, matching interaction techniques and concepts for the available devices will be briefly introduced. The developed interface prototypes will be described according to the use cases defined in D2.1. Section 6 is structured in a similar way and focuses on the inter-factory scenarios and use cases, mainly on the developed marketplace further described in the deliverables D6.3 COMPOSITION Marketplace I and D6.4 COMPOSITION Marketplace II developed in WP6 – COMPOSITION Collaborative Ecosystem. Finally, section 7 introduces achieved results, next steps and points out the work packages affected by the presented work.

3 Research

The following section briefly introduces the state of the art of HMIs in the context of Industry 4.0. While section 3.1 focuses on research topics and builds up the foundation for the methodology further described in section 4, section 3.2 provides a brief overview of specific HMI implementations.

3.1 The Role of HMIs in Industry 4.0 Environment

Industry 4.0 depicts a vision of interconnected, integrated processes, information, and communication of mostly self-managed systems within factories, which will challenge the future role of humans in manufacturing. With machines and processes becoming more and more autonomous, “more complex manufacturing scenarios will become manageable” (Gorecky, Schmitt, Loskyll, & Zühlke, 2014). This will require a worker to take over the role as supervisor of systems and processes as well as deploying the production strategies (Gorecky,et al., 2014).

The shifted focus of human tasks will render nowadays mostly stationary workplaces as being obsolete as it will require more flexible on-site as well as remotely “constructive planning activities” (Gorecky, Schmitt, Loskyll, & Zühlke, 2014).

Resulting from the Industry 4.0 vision, Schreck (Schreck, 2014) formulates basic requirements for HMIs in future factory environments that should be fulfilled:

- Web capability based on HTML 5.0 and Java Script to allow device agnostic support for all possible platforms;
- Responsive design to support all sorts of user- and task specific GUIs;
- OPC-UA as server and client to allow for unlimited connectivity between different systems and platforms[1]
- Distinct functionalities to process complex data structures for the realization of job management, maintenance management, etc.[2]
- Interfacing email and social web services for task notifications[3]
- Support of easy conceptualizing of task relevant interfaces through automation technicians

Gorecky et al. further introduce the following requirements (Gorecky et al., 2014). In their opinion, future HMIs

- should provide access to a multitude of different components and sites via mobile user interfaces (1:m access)
- need to be able to deal with the raising system complexity
- have to be able to reveal components’ positions
- have to be context-sensitive to display relevant information to the mobile worker (see e.g. (Seissler, Breiner, Schmitt, Asmelash, & Koelsch; Schillit, Adams, & Want, 1995)[4]

With respect to Schreck’s general requirements it is important to emphasize that the HMIs developed in COMPOSITION will not be used for direct interactions with the operating machines. Instead, they will allow users to query for information and observe machine and production states and communicate with the COMPOSITION IIMS. Therefore, the main purpose is the visualization of collected data, the presentation of suggested behavior, the interlinkage of information from different sources, and the support of causal research tasks. This is the main reason why not all of the general requirements of Schreck can be applied for the HMI

[1] this requirement will not be relevant for HMIs in COMPOSITION since the connectivity layer does not feature direct interaction with machines
[2] the level of importance of job management in COMPOSITION is currently not yet defined; however, job management is expected to be out of scope for COMPOSITION
[3] Social web services might be out of scope of COMPOSITION; however, some type of communication is expected and therefore will be included in the HMIs
[4] The role of context-sensitive or context-aware HMIs in COMPOSITION has not been defined, yet

development. However, following the already collected user requirements, the resulting interfaces will be web-based, responsive (or at least multi-device supporting), task-oriented and interfacing with some communication technology, for example email.

Due to the amount of available data and the complexity of workers' tasks, HMIs have to be reduced to the needed minimum of information in order to be intuitively usable. The goal of such HMIs should not be to present all available data, but all required information for a user to fulfill his tasks. Following this premise, Walter points towards HMI design principles that should be applied for interfaces in the industrial environment (Walter, 2017) to maximize their usability:

- Anything that doesn't add value should not appear on the screen.
- Ease the burden on the user's eyes by reducing contrast between foreground and background elements and restraining your use of saturated colors.
- Designers should spatially group related objects and elements to allow the user to perceive the whole as a single unit of information.
- Optimize your product experience for the target environment and be ruthless about removing unnecessary user-interface elements that don't add value.

Furthermore, Walter emphasizes the importance of starting from a user's mental model when it comes do designing interfaces, instead of focusing on the capabilities of data and machines. This aligns well with the human-centered design process (UCD) (International Organization for Standardization, 2010), which is further described in section 4.

3.2 Applied HMIs in Industry 4.0 Process and Production Monitoring

Industry 4.0 paradigms are present for several years which means that there are several commercial and scientific solutions for different scenarios in an interconnected shop floor. Some of them are presented as follows:

ProGlove's Mark (ProGlove, 2017) is a smart glove that supports the picking and packing process in Industry 4.0 factories. The glove is equipped with a long-live battery and supports wireless connection with the factory systems. When a button is pressed, the ProGlove allows the user to scan barcodes. Acoustic signals give feedback if the process was executed correctly. This device allows the worker to save time by rendering the process of picking up a specific scanning device as unnecessary. However, the ProGlove is very specifically specialized for manual scanning processes, which are currently not being part of the COMPOSITION scenarios.

Figure 2: Mark, a smart glove that is capable of scanning barcodes and emitting aural feedback (ProGlove, 2017)

As an outcome of the project WatchOut (Gottwalles, 2016), a smartwatch HMI for interacting remotely with machines in an Industry 4.0 factory was developed. The described use case is depicting a scenario in which a worker is able to remotely change the recipe of cocktails produced by an assembly line after being notified about quality issues. The project was executed to demonstrate how smartwatches can be applied in an industrial context, explicitly pointing to two benefits:

1. Notifications received on smartwatches can be read hands-free; the disturbance of the currently executed task performed by a worker is therefore being reduced to a minimum. Additionally, the worker can decide using a gesture if the notification is urgent and therefore needs immediate interference with the process, or if he can address the issue later.
2. If the issue is urgent, the worker can remotely address the issue – in this case by changing the recipe of a cocktail using an easy smartwatch application. The smartwatch application is depicted in Figure 3.

The project demonstrates that smartwatches can be applied successfully in alarm situations when human interaction is required to solve an (upcoming) issue.

Figure 3: Hands-free interaction with notifications and production processes in the manufacturing environment using smartwatches (Gottwalles, 2016)

MachineMetrics offers a software bundle featuring multiple functionalities, such as job performance monitoring, downtime and quality tracking, performance reporting, machine analytics, remote machine monitoring, real-time dashboards, etc. (MachineMetrics, Inc., 2017). As depicted in Figure 4, the software platform supports multiple devices, for example tablets, TV monitors on the shop floor, laptops and smartphones. Their HMIs mainly address COMPOSITION relevant fields, such as analytical and observing tasks (see section 4.3). The input and output devices are mainly touch-based, contextual information can be displayed on monitors close to the machines. Notifications in case of machine failures are sent out via text and email.

Due to its holistic dashboard approach, the presented solution is very interesting. However, the application scenarios in COMPOSITION are more expansive, for example by addressing maintenance planning and bottleneck handling.

Figure 4: Multi device support (MachineMetrics, Inc., 2017) as software bundle

MANTIS (MANTIS Consortium, 2017) is a project funded by the ECSEL Joint Undertaking and the European Union's Horizon 2020 research and innovation programme and focuses on cyber-physical systems based proactive collaborative maintenance. Throughout the currently still running project HMIs for controlling and visualizing data also in the manufacturing environment are developed by implementing a dashboard approach. In Figure 5, such a customizable dashboard is shown which provides information about system alarms and measured sensor data. The dashboard is designed to allow for a quick overview of all running processes in the factory environment. Its adaptability ensures the user and task relevance for the signed-in worker. The modular widgets can be activated either by the worker himself, or by context based information.

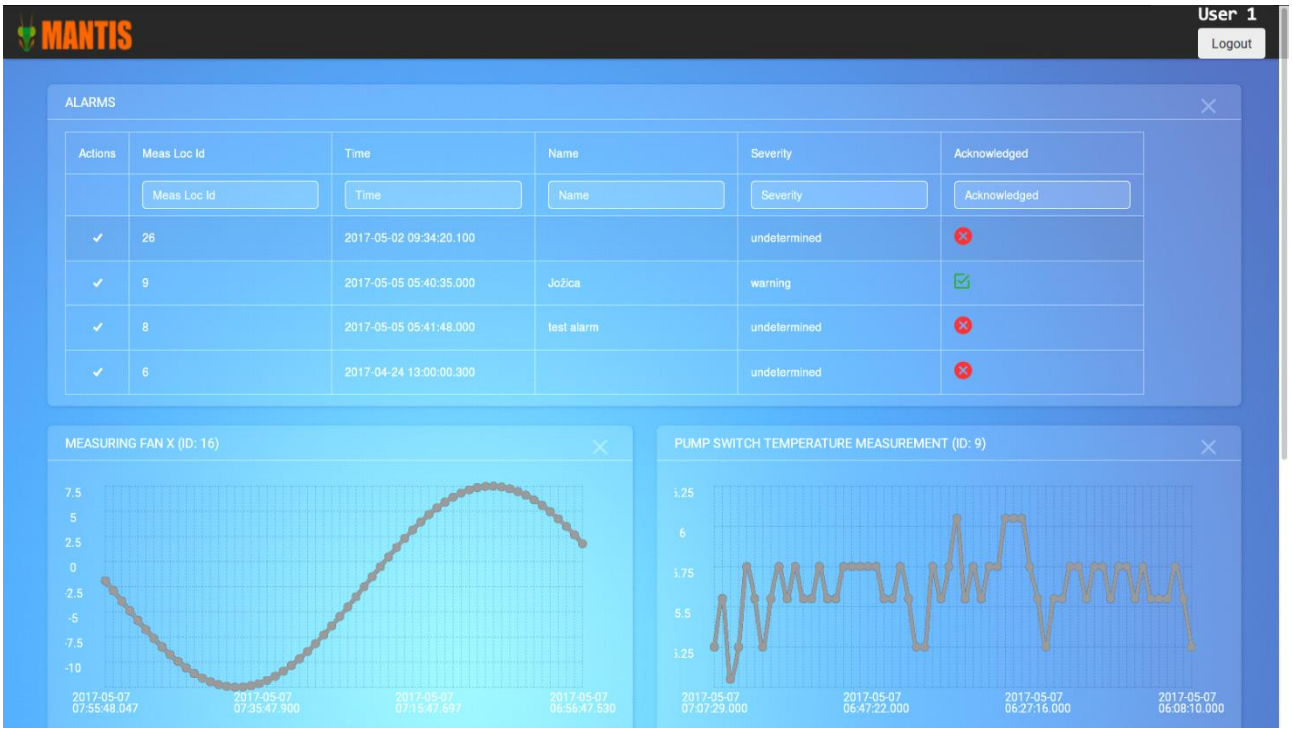

Figure 5: First version of a web-based HMI of the MANTIS project (MANTIS Consortium, 2017)

The presented HMIs emphasize a general premise in interaction design: good interfaces try to solve concrete problems and support the user in efficiently solving problems. A general outcome from the presented HMIs is that:

- mobile interfaces are best used when a worker has to move on the factory floor and needs to be notified in case an alarm situation occurs or his task needs to be updated. This interaction type becomes powerful if urgent issues can directly be addressed in a follow-up interaction without the necessity to abandon the current task, e.g. by changing a machine configuration, adapting the order of process steps or changing one's behavior.
- custom-build HMIs like the ProGlove's Mark are very limited in their functionality, but therefore extremely powerful if applied in their specific problem domain. However, adapting highly specialized HMIs for other issues might not result in satisfying results.
- general monitoring and analytical tasks are best performed on input devices offering enough screen size to display necessary information. Personalization of the provided information is important and can be solved using different approaches, such as location-based information, authentication systems paired with user rights management, etc. Those interfaces become flexible if multiple devices and screen sizes as well as interaction modalities are supported.

4 Methodology

Designing relevant interfaces and their interaction requires a structured development process. Therefore, this section describes the user-centered design framework (International Organization for Standardization, 2010) and its application in the COMPOSITION environment.

UCD is a framework of processes and methods which is not limited by the use of specific interfaces and technologies. This allows for a flexible adaption to all sorts of user needs and tasks as well as limitation induced by the working environment. Figure 6 depicts the UCD framework as an iterative process consisting of 4 phases. During the development cycle, multiple iterations are executed in order to adapt to changing user needs, requirements, limitations and problems that might occur as the project develops. Such iterations can happen between any phases in the process, but are usually triggered after evaluation.

1. **Understand**
   Understand and specify the context of use; this phase also identifies user groups and their needs by directly involving end-users and stakeholders
2. **Specify**
   Specify requirements based on previous analysis; This phase requires filtering the gathered requirements according to priority and feasibility and can generate input for tasks in WP2, specifically for the deliverables D2.5 and D2.6 Lessons Learned and updated requirements report I and II
3. **Prototype**
   Produce minimal feasible design solutions to meet requirements; prototyping is used to portray and visualize knowledge which was gained from the previous phases Understand and Specify
4. **Evaluate**
   Evaluate design against requirements; Similar to stage 1, this stage usually involves gathering direct user feedback

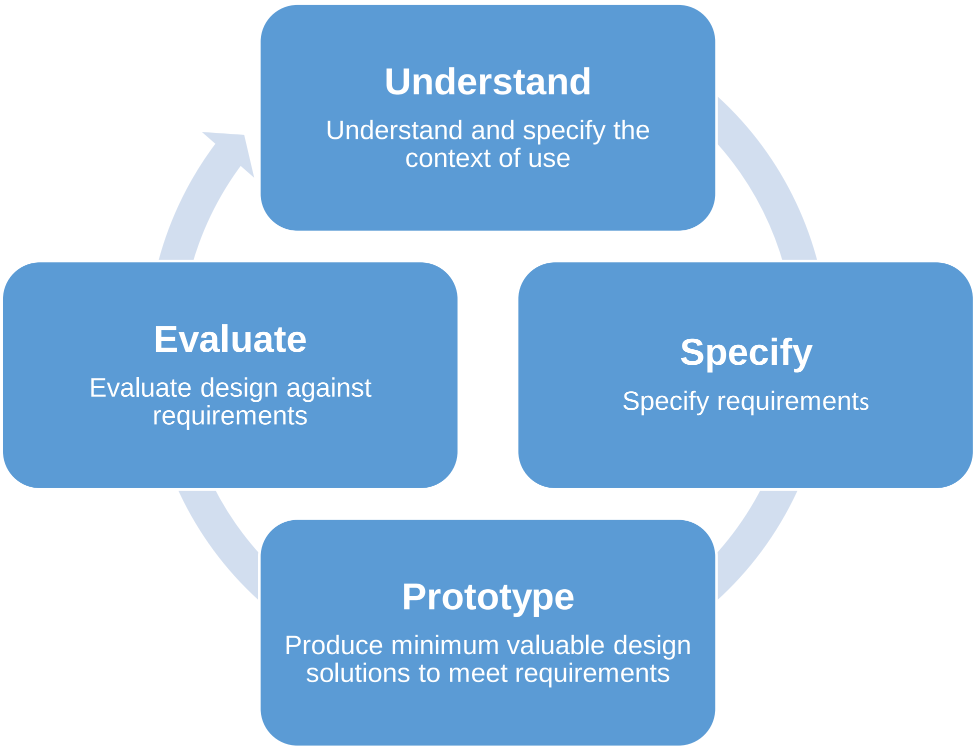

Figure 6: The UCD process adapted from (International Organization for Standardization, 2010)

This process is also applied for evolving the prototype fidelities described in section 4.2. The iterative application of understanding, specifying, prototyping, and testing ensures the interfaces' alignment with user requirements as well as up-to-date requirements which are being documented on the platform Jira (see D2.2 Initial requirements specification for more information).

4.1 Methods for requirements gathering

The UCD process offers multiple methods which are built on close interaction and discussion with users. This ensures the best possible information and feedback gathering from a human perspective as well as their relevance for the user work-tasks. The choice of applicable methods during the development phase is influenced by multiple factors, such as available users or resources, technical or law restrictions, user expertise, etc. Many methods can be applied in the phase "understand" as well as the phase "evaluate" and are chosen with respect to the desired outcome (e.g. knowledge gathering, prototype evaluation) as well as the available resources.

In COMPOSITION, a diverse set of methods was and will be applied. The most used ones during the work presented in this deliverable are listed below.

- **Semi-structured interviews and questionnaires of different users**
  Those are questionnaires and interviews that consist of both, close-ended (e.g. yes, no) and open-ended questions. Interviews and questionnaires were conducted mostly online during telcos and with the use of suitable tools.
- **Guided Tours**
  The demonstrator partners KLE and BSL offered guided tours around their shop floor to allow for better understanding of the local working situation. Those tours were partially documented with photographs.
- **Scenario thinking**
  To generate new ideas, tasks as they are executed right now were imagined and discussed in an environment with new technology, such as augmented reality (AR) glasses, tangible interfaces, wall touch screens, smartphones, tablets, etc.
- **Storyboards**
  Users had problems imagining themselves operating a mostly autonomous system, such as the agent-based marketplace. To better communicate the ideas and identify misunderstandings concerning processes, used or future technology, interaction possibilities etc., some of the uses cases defined in D2.1 were illustrated as storyboards. An example of such a storyboard is depicted in Figure 7.
- **Activity Analysis**
  Co-creation with workers and process-owners; listing and describing tasks and worker roles present in the pilot partners' processes
- **Prototyping**
  Developing rapid prototypes to elaborate understandings and ideas about a certain task or problem; prototyping is also involved in the design process described in Section 4.2

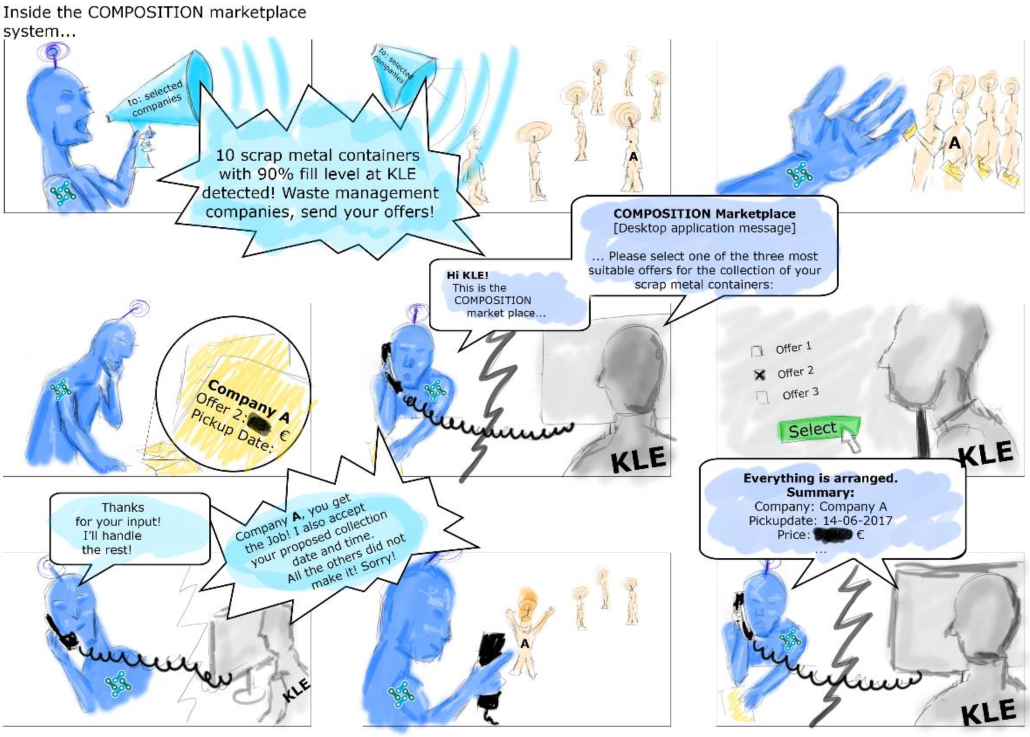

Figure 7: Storyboards were used as use case illustrations eased the communication during workshops and discussions. Here, the storyboard for UC-KLE-4 from the agents' point of view is shown.

4.2 Design process

Following the iterative UCD process, the COMPOSITION interfaces are developed in three fidelity levels, low (low-fi), medium (mid-fi), and high (hi-fi):

1. **Low-Fi Prototypes**
   Those prototypes are developed rapidly with primitive tools, such as paper sketches, scribbles, etc. Because low-fi prototypes are cheap in terms of time and cost, they are used at the very beginning of the design process, mainly to generate and communicate ideas and provide first approaches of possible ways to interact with systems and devices. Low-fi prototypes are mostly static.
2. **Mid-Fi Prototypes**
   The most promising low-fi prototypes are then further developed into mid-fi prototypes. This might involve software tools such as balsamiq (Balsamiq Studios, 2017), moqups (S.C Evercoder Software S.R.L., 2017) or Axure (Axure Software Solutions, Inc., 2017). Mid-fi prototypes are already able to show information flows by mimicking page navigation (e.g. clickable PDF).
3. **High-Fi Prototypes**
   High-fi describes prototypes that are almost finalized interfaces with applied graphical design, fully modelled transitions (animation, gestures), etc.

The transition between fidelity stages is done after the evaluation of the prototype in question. This evaluation should be done in close collaboration with end-users. This cannot always be accomplished; therefore, an evaluation was at least done together with project responsibles from the test-sites in question. With respect to the project's stage and the state of requirements elicitation, the presented results in the sections 4 and 5 are mostly low- to mid-fi prototypes and are to be further developed iteratively as the project evolves.

Presented features are based on user requirements documented on Jira and presented in the deliverables D2.2 Initial requirements specification (M6), D2.5 Lessons Learned and updated requirements report I (M15), and D2.6 Lessons Learned and updated requirements report II (M28).

4.3 Devices and their Application Environments

The use of devices is often limited by safety regulations affording special dress codes, e.g. protective gear (glasses, gloves, …), technical limitations such as signal interference with the machines distributed in the factory environment, as well as other environmental factors such as lightning, movement, temperature, etc.. In the best possible case, supporting interfaces do not require special attention, do not introduce new process steps and diminish the cognitive load for users. To ensure the best possible HMI solutions in terms of applicability, usability and task orientation, relevant tasks for different worker roles and situations in the pilot partners' factory environment have been analyzed. Building on the findings in section 3 as well as the identified situations resulting from user workshops, three identified situations in the COMPOSITION environment are listed as follows, intertwined with matching devices and technologies which promise the best possible support for individual user needs.

- **Alarm situations**, which can occur if a machine breaks down and needs immediate attention, important decisions need to be taken, or urgent information has to be passed. In the described situations workers might be assigned to a fix working station or spread over the factory floor. If the user's location can be narrowed down to specific areas, stationary public displays / wall screens for delivering visual feedback (blinking visual elements combined with more detailed information). Wearable (Mann, 2013) or portable display devices (smart watches, wrist bands, smartphones, tablets…) can be used if the location of the required user is unknown. Attention seeking notifications can also be transmitted on purely tactile-based devices, such as vibrating wristbands. The application of voice or sound-based interfaces is limited due to the noise level on the factory floor. Alarm situation notifications require special attentions with respect to override and update regulations as well as selecting adequately points of contacts, devices, etc. (USA Patentnr. US 7233781 B2, 2007).
- **Navigation or logistic tasks**, which should not distract people from their actual activity, such as driving, picking, placing, etc. using a forklift. To allow users to stay focused on their surroundings instead of the task-supporting device, information has to be delivered in a way that the additionally induced cognitive load is kept to a minimum. Several devices can be applied, combining voice interfaces, augmented reality and head-up displays, etc. The applicability of smart watches, smartphones and tablets highly depends on the task complexity as well as potential travel speed and needs to further be evaluated. In already conducted studies, augmented reality interfaces performed superior compared to other display modalities when it comes to outdoor navigation performance, visual attention, cognitive load and situation awareness (Mendeica, Kun, Paek, & Palinko, 2011), (Davis, 2006). However, there are still further studies necessary to investigate on the superior modality for indoor navigation as the superiority might only be perceived (Rehman & Cao, 2015).
- **Basic observing or analytic tasks**, such as process monitoring, material tracking, failure analysis or quality inspection require the combination of multiple data sources to allow for information gathering and analysis. Until now, those tasks have mostly been described as being not collaboratively executed. This affects the size of applied devices as well as input modalities. The most fitting equipment seem to be operated by a single person and a medium to big output device, such as desktop PCs, interactive walls, etc.

Especially stationary computers and smartphones are already used in some of the described scenarios. Hereby, the preferred way to communicate is via call or email. This user preference should be taken into account for designing the final interfaces. However, according to Gorecky et al., due to a shift of responsibilities and tasks for workers, stationary workplaces will lose their significance in the future industry 4.0 environment compared to today's situation. This will highly influence HMIs for on-site and far distance applications in a manufacturing context (Gorecky, Schmitt, Loskyll, & Zühlke, 2014). With respect to the state of the requirements, for now, the development of HMIs will focus on devices already in use, such as big screens or wall displays, smartphones and desktop applications and will further investigate on how to optimize the support of current work tasks by combining data and enhancing the usability of applications.

5 Intra-Factory HMIs

The intra-factory HMIs are being developed in joint workshops with Kleemann and Boston Scientific and intertwined with efforts from Nextwork. Intra-factory use cases and HMIs focus on processes inside the factory. First results are presented in the following sections.

Based on the project review propositions in July 2017, the intra-factory use cases of COMPOSITION have been prioritized as described in Table 1. Because of the preferences being changed after the initiation of the interface designing task (M5), the detail of the presented interfaces below is not completely conformant with the importance ranking of the different use cases. This will be addressed as the project evolves.

The prioritization levels are as follows:

- Tier 1: Very high overall priority to be implemented by M18
- Tier 2: High overall priority, parts to be implemented until M18
- Tier 3: Medium overall priority, not to involve until M18

With Boston Scientific producing pace makers and Kleemann manufacturing elevators, two different domains are to be analyzed concerning their user requirements and HMI demands. However, use cases belonging to the same scenario also require similar functionalities when it comes to presented information. This is very important for scaling the resulting interfaces and potentially adapt them to similar processes in other domains. Exceptions are UC-BSL-4, which describes a fully automated process and might not even involve HMIs, as well as UC-KLE-4, which describes a navigational task and features indoor location as well as route optimization.

Table 1: Prioritization of the intra-factory use cases

Tier	Use case ID	Name	Scenario
1	UC-BSL-2	Maintenance Monitoring	Predictive Maintenance
	UC-KLE-1	Maintenance Decision Support	
2	UC-BSL-3	Component Tracking	Material Management
	UC-KLE-2	Delayed Process Step	
	UC-BSL-5	Equipment Monitoring	Production Floor Monitoring and Visualization
3	UC-BSL-1	NC Monitoring	
	UC-KLE-3	Scrap Metal and Recyclable Waste Transportation	Material Management
	UC-BSL-4	Automatic Solder Paste Touch Up	Automatic Data Conversion

Since the goal is to create a system general enough to be applicable to various scenarios but specific enough to satisfy the user needs analyzed in the test sites, the lowest common denominator of requirements and working situation scenarios for the overall system was investigated and is presented in Table 2. The resulting requirements will be included in the documentation platform Jira and described in D2.5 (M15).

Table 2: Similarities and differences in basic requirements and working situation scenarios for the shop floor HMIs

Functionality	Kleemann	Boston Scientific
Basic System Requirements		

Content adapted to different user roles	X	X
Read-only access	X	X
Dashboard for a general overview over all use cases[5]	-	Limited (UC-BSL-5)
Notifications[6]	X	X
Real-time display of information	X	X
Limitations		
Protective glasses	Limited	X
Protective gloves	Limited	X
Other protective gear (hair and beard masks)	-	X
High level of noise on the shop floor	X	X
Technology usage		
Stationary PC access	X	X
Public displays / wall screens	-	X
Smart phones	X	Limited
Tablets	X	X
Smart glasses	X	NA
Smart watches	-	NA

Building on the results presented in Table 2, the resulting system shall be accessible using mobile devices (smartphones and tablets), stationary PCs (laptops, desktops), as well as wall screens or public displays. The content of those screens shall be configurable or at least tailored to predefined user roles in a way that presented information is always relevant for the operating worker. This could be realized by developing widgets, which can be added to or deleted from screens by either admins or the user itself, depending on the roles and rights management of the HMI screen administration. Widgets allow a modular and freely configurable placement of information needed for specific tasks and can be seen as autonomous information components. However, it still needs to be specified how modular the HMIs developed in COMPOSITION should be and how freely users are allowed to configure the information they receive, in case a freely configurable interface is a user need.

5.1 Interface Prototypes

As already described in section 4, the presented initial interfaces have been developed in iterative cycles, starting from sketching, paper prototyping and wire framing to semi-interactive click dummies. To keep the document short, only the latest versions of the HMI drafts are being presented.

[5] The current trend is to not have a general overview dashboard (e.g. general control penal), but overview dashboards for each use case or corresponding areas, e.g. Material Handling dashboards in the material handling area for Boston Scientific. This needs to be further evaluated as the project evolves.

[6] Based on the current state of analysis, there is no situation in which a worker has to immediately interfere with the process when an issue occurs, which means that there are no time critical notifications to be sent. For Boston Scientific, such a notification could be realized as a report that can be downloaded on request or is sent out via email based on adaptable schedules.

Before the development of UC-BSL-5, there was no need for having a general overview dashboard. However, this might be introduced later on the project. Figure 8 shows a schematic representation of the current state of the expected information hierarchy. However, this scheme is only based on requirements from Boston Scientific and still needs to be discussed in detail. Additionally, the overview dashboard could integrate information from the market place system, such as bidding process updates, new offers, new messages etc. This still needs to be evaluated since it has not yet been in the focus of T5.3.

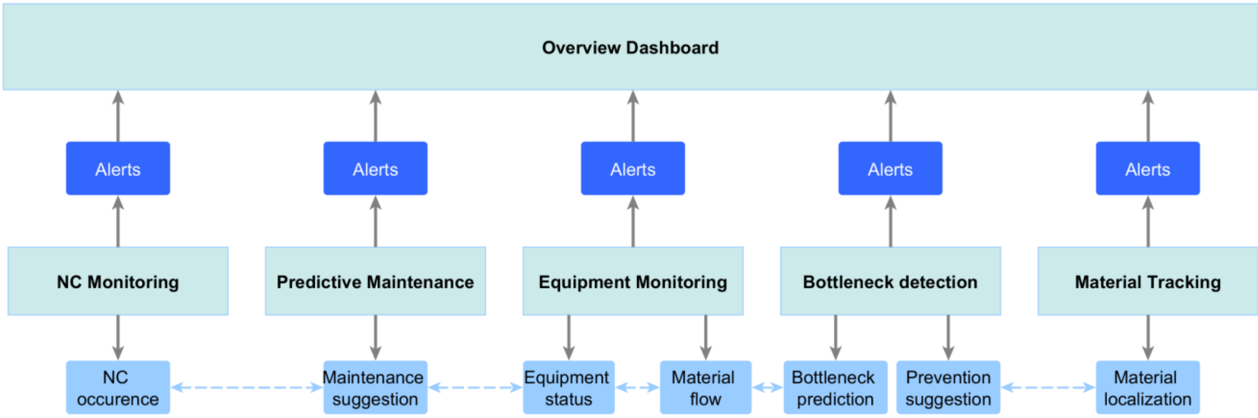

Figure 8: Possible information relationship between different use cases for a global intra factory overview dashboard

5.1.1 Predictive Maintenance (UC-BSL-2, UC-KLE-1)

The basic functionalities of the predictive maintenance dashboard are described in Figure 9. The system should be able to send out alerts using a communication channel, e.g. email. Additionally, the alerts shall be displayable on the dashboard itself. Sensor data needs to be displayed synchronous to real-time data and could vary according to the machine or parts to be observed: While Boston Scientific is focusing on noise levels of fans, Kleemann monitors for example the energy consumption of motors. This also indicates that the amount of monitored devices and machines might vary and therefore requires a flexible visualization.

An important feature for maintenance decisions is the estimated life time[7], which also triggers alerts and notifications when the prediction exceeds a certain, predefined threshold. The boundaries for those thresholds should be adaptable for the end user. Maintenance suggestions should also pay attention to estimated remaining life times of other parts of the system and suggest replacing them whenever it makes sense.

[7] Life time can be defined as likelihood to break down in a preset time frame, for example 3 weeks; 3 weeks is the time needed for Boston Scientific to reorder parts

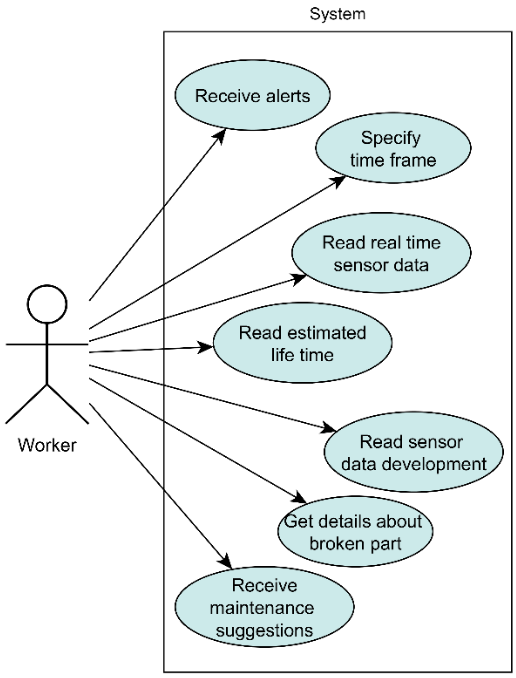

Figure 9: Basic functionality of the predictive maintenance dashboard

The dashboard prototype depicted in Figure 10 still needs to be adapted to also fit for Kleemann's use case. However, many of the requirements are already fulfilled:

- **Alerts:** Alerts are being displayed in the top row or sent out to specific users. They are sorted according to the estimated remaining life time of the concerned fan (shortest = left, longest = right). The top row displays a collection of all alerts (red and yellow) for all ovens in the production line (or several production lines) and is horizontally scrollable. Detailed information about the part causing the alert state can be accessed by selecting the corresponding screen element in the alerts list.
- **Monitored machines**: All ovens to be monitored are listed here. This list is vertically scrollable. The list is sorted according to the amount of alerts as well as the state in which the oven is. An oven is in the state „red", if at least one of its fans is in the state „red". An oven is in the state „yellow" if at least one of its fans is in the state „yellow" and none of its fans is in the state „red". If all fans are in state „green", an oven is also in the state „green".
- **Over-time representation of fans (sensor data development)**: Per oven, all fans in alert state „yellow" or „red" are also displayed on a time line. The time line reaches from the past 6 weeks to the estimated future 6 weeks (time frame to be defined). Only fans which are already in alert state (or will soon be) are listed on this view to reduce the amount of information to the minimum needed.
- **Settings menu:** The Settings menu depicted in Figure 11 allows for configuring the screen content and alert behavior, for example by defining thresholds for alert states.

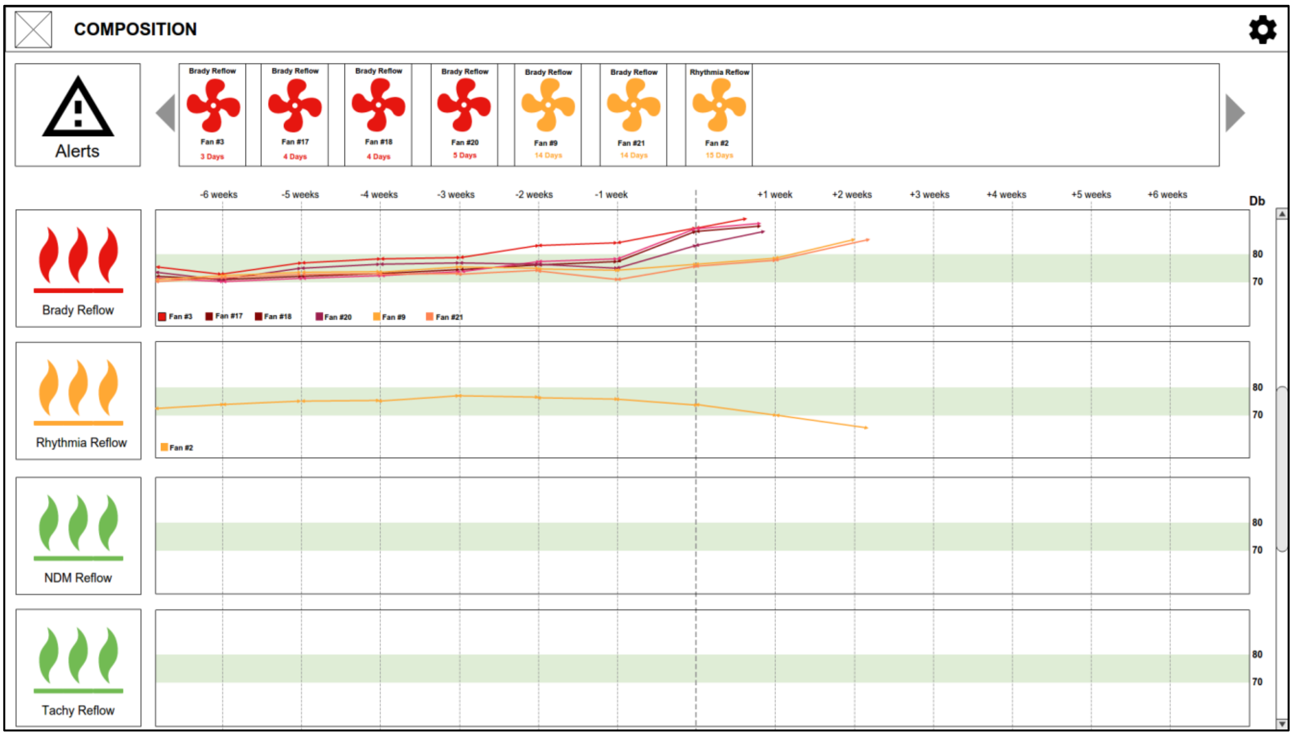

Figure 10: 3rd iteration of the click-dummy for Boston Scientific's predictive maintenance dashboard, available online at https://app.moqups.com/vkrauss/tTwFkVWrEE/view

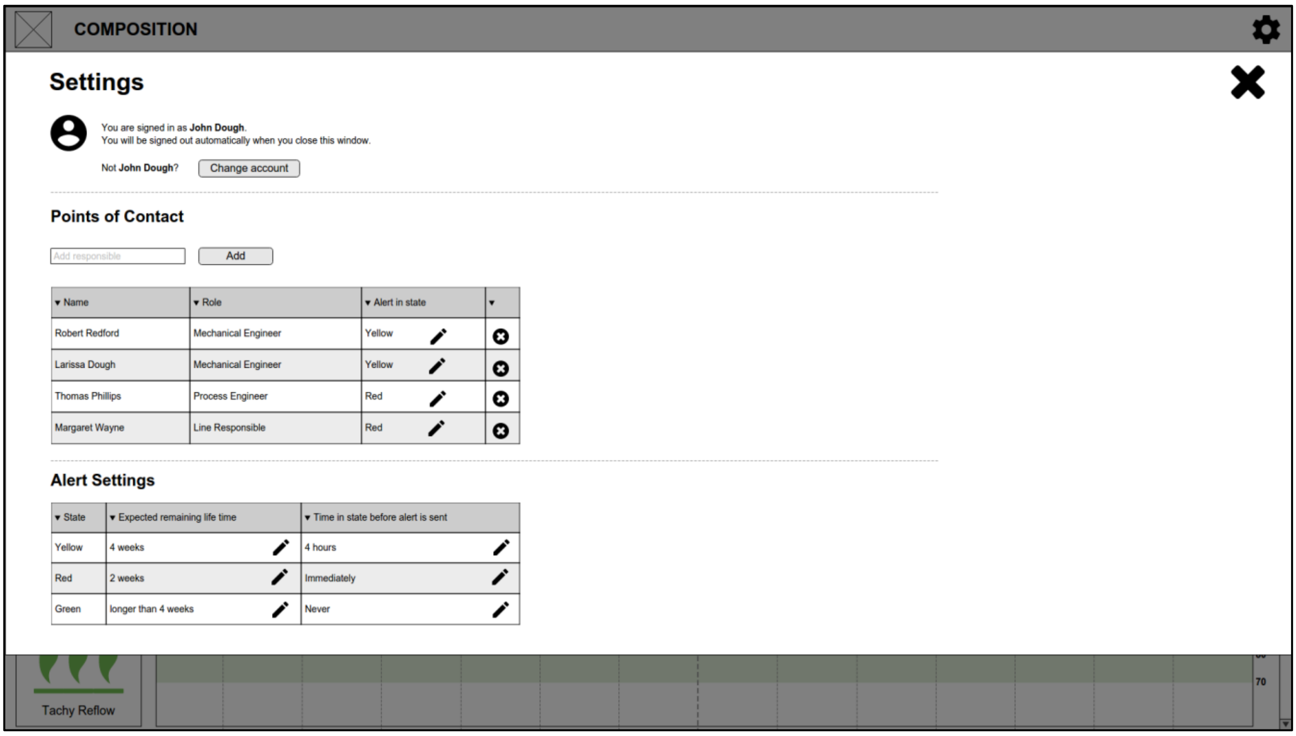

Figure 11: Settings menu for the predictive maintenance dashboard

An interaction flow diagram explaining the navigation within the features of the screen is attached to the Appendix 11.1 of this document.

With respect to KLE-1 use case, the situation might be a little bit different: here the machines involved are big polishing tools, which are monitored in terms of temperature, vibrations and energy consumption. Those sensors' data are the very output that must be real-time showed to the workers, maintenance planners, and managers. This environment fits well to the dashboard depicted in Figure 9, because in principle is similar to the other use case: monitored machines and over-time representation of the data development will be adapted into something appropriate to the type of the output (i.e. charts); the alerts will be displayed and sent out following similar rules than the previously mentioned ones, and a setting menu to configure contents to be displayed will be still necessary.

5.1.2 Material Management (UC-BSL-3, UC-KLE-2, UC-KLE-3)

The two material management use cases are focusing on different aspects and therefore require different interfaces.

Boston Scientific is focusing on tracking material to retrieve lost batches from the shop floor. The realization of this use case is highly depending on how components can be tracked since the usage of active sensors is limited. This might induce problems, such as determining where material was lost, what its current location is and where it should be at the moment. This use case was discussed after D2.1 has been published and still needs to be updated. However, the current state is that only material (containers, subassemblies) that deviate from the normal production paths shall be tracked by having a sensor attached to them. This situation occurs if material has to be sent to quality inspection. It might happen that material is forgotten to be scrapped or reintroduced into the production process. The basic functionality of this scenario is summarized in Figure 12.

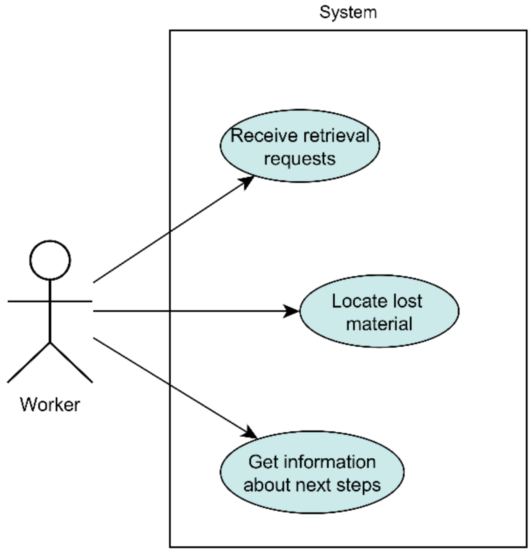

Figure 12: Basic functionalities of the lost material dashboard

As depicted in Figure 13, active sensors allow lost material to ask for being retrieved from the shop floor if they have not been moved for a certain time threshold. This call for retrieval can be displayed on a big screen (similar to the alerts of UC-BSL-2 described in section 5.1.1 and as depicted in Figure 14) and sent out as a notification using e.g. email.

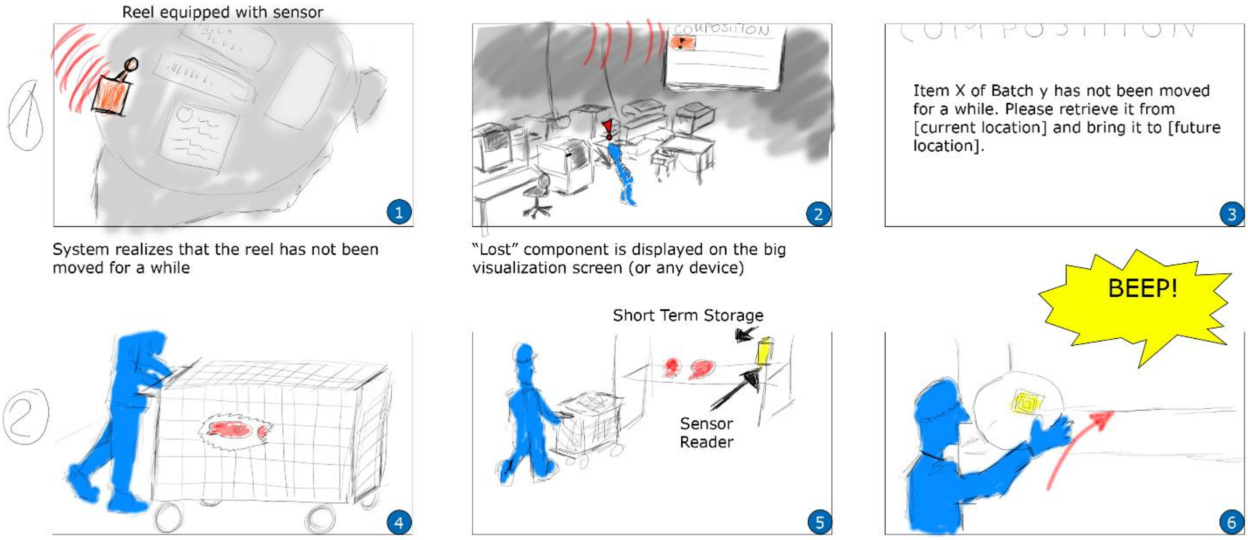

Figure 13: Possible realization of material tracking based on passive and active sensors

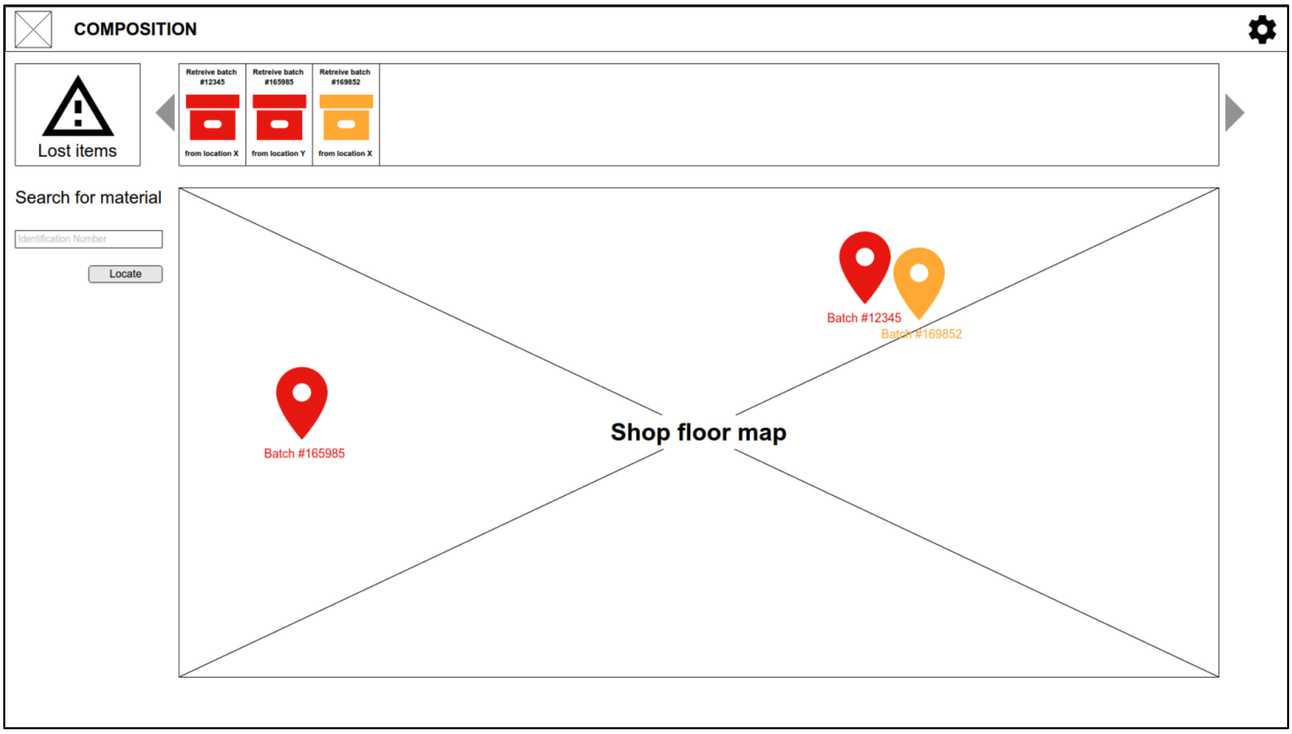

Figure 14: Draft of the material tracking desktop application; lost items requesting for pickup are listed in the top row, their current location is displayed on the shop floor map

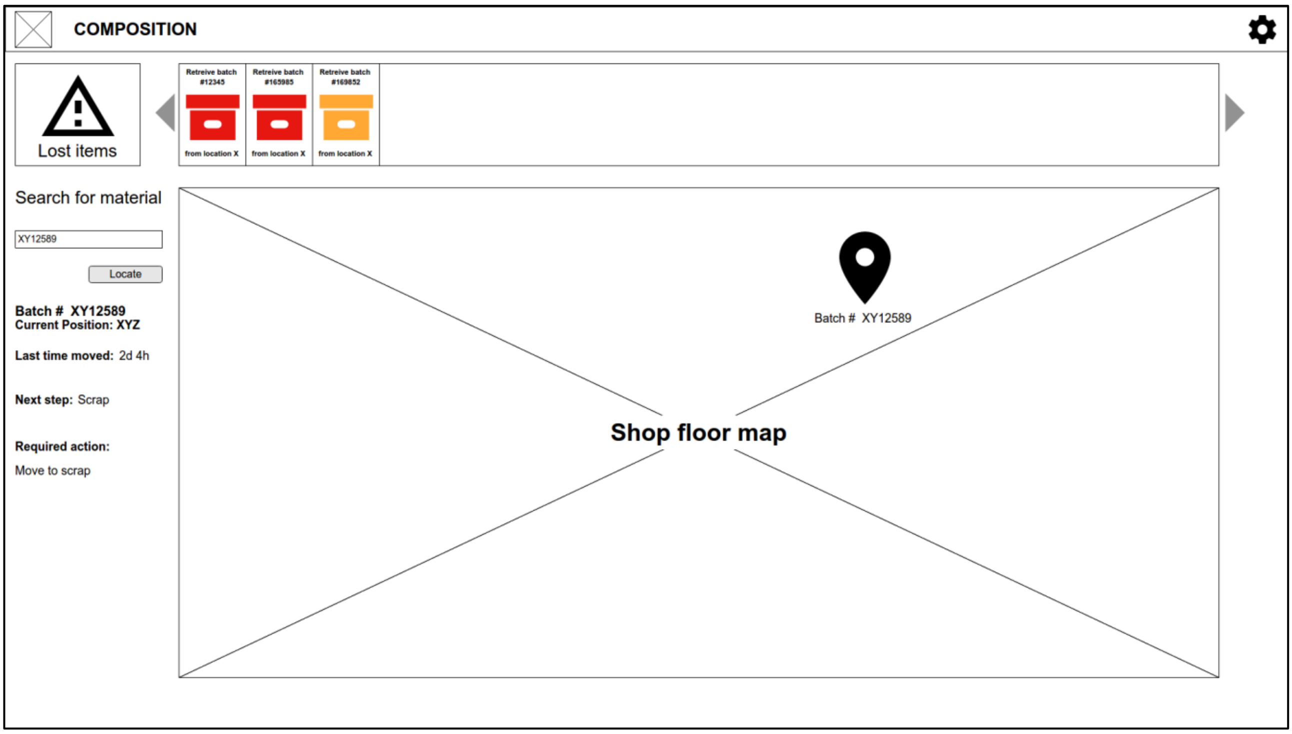

Figure 15: Draft of the material tracking desktop application; additional information as well as the current position of material that was directly searched for is displayed

If the current location of material can be determined, workers can directly search for specific batches by typing in a tracking number (see Figure 15). Mobile HMI drafts can be found in Appendix of this document. However, this use case needs to be further specified to determine what will technically be possible before HMIs are further developed.

Kleemann is facing problems with bottlenecks occurring on machines due to manual transportation or shortage on personnel. If a bottleneck is predicted or has already occurred, the dashboard shall warn the worker and deliver removal suggestions. Additionally, more detailed data about the currently processed order shall be accessible, such as the amount of orders, order numbers with the clients' names, order characteristics, delivery date per order, standard time per order after the bottleneck, etc. The basic functionality is visualized in Figure 16.

Figure 17 envisions a possible graphical representation of bottlenecks in the process context. The machines have three different bottleneck states:

1. The green state indicates that everything is going according to the production plan
2. Yellow or orange states indicate that a bottleneck is very likely to occur at the machine
3. Red indicates that a bottleneck is currently happening at that machine and needs immediate interference

At the current state of the project, there are no detailed HMI drafts available, yet. This will be handled as the project evolves.

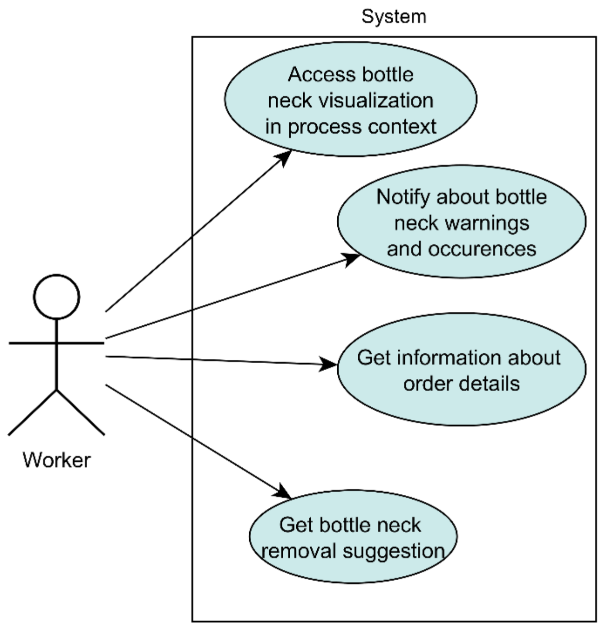

Figure 16: Basic functions of the bottleneck detection dashboard

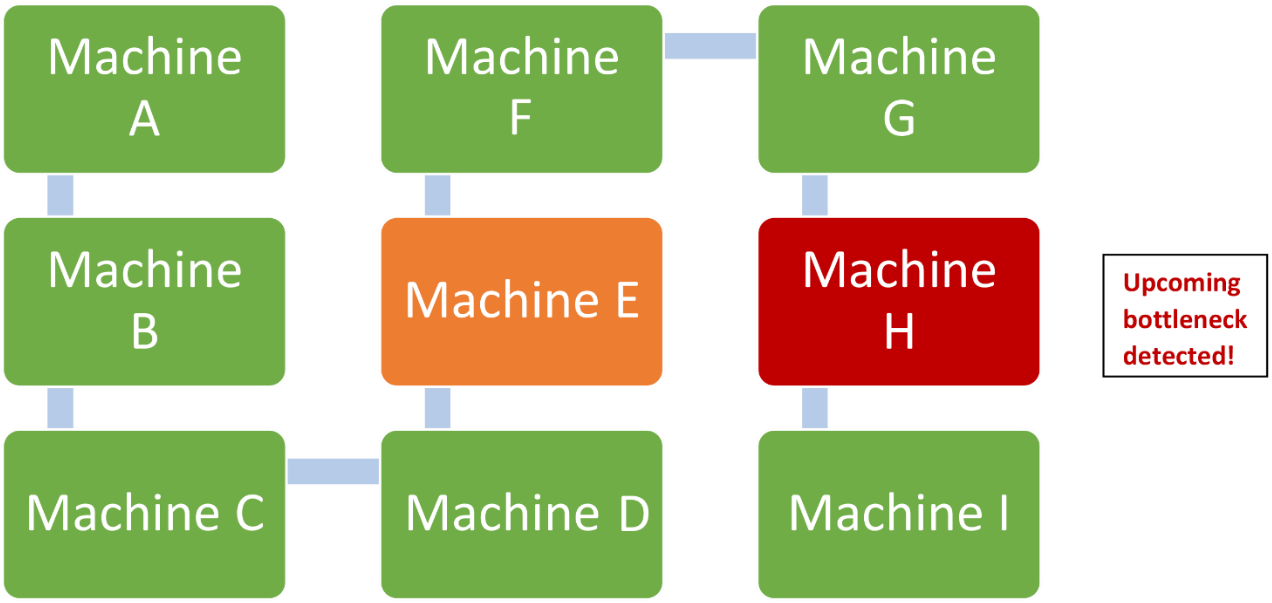

Figure 17: Sketch of bottleneck warnings and occurrences visualization in the process context (UC-KLE-2)

For UC-KLE-3, which is about monitoring the fill levels of bins distributed over the shop floor (scrap metal & recycled waste), the consortium is willing to do an assessment of commercially available technologies to see what potentially could be used; to date the only applications where there is something similar for retail checkouts and automotive vision systems. The HMI will reflect the kind of devices that will be adopted for this use case, and, with respect to those, there will be different ways to show the data coming from the environment (e.g. charts, images, etc.). In order to trigger the system reaction to request the emptying of the bins, a decision support system might be involved (for an automatic process), or, for instance, buttons can be added to the HMI, in correspondence to bins that operatives can push when they see the bin is nearly full. Due to protective gloves worn by workers, touch-based displays might not be the optimal solution. This will be part of future user workshops.

At the current state of the project, there are no detailed HMI drafts available, yet. This will be handled as the project evolves.

5.1.3 Production Floor Monitoring and Visualization (UC-BSL-1, UC-BSL-5)

The use case UC-BSL-5 Equipment Monitoring is a very new use case that still needs to be specified in detail. However, first drafts of a desktop application are available that displays NC information jointly with the equipment status. The basic functions of this use case are visualized in Figure 18 and need to be further specified as the project evolves.

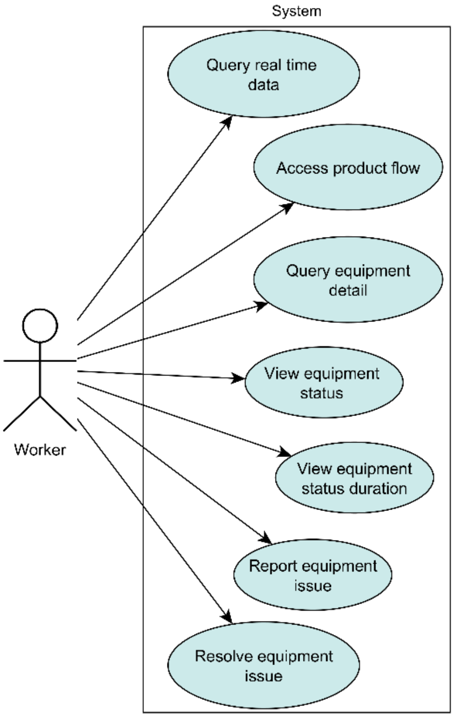

Figure 18: Basic functionalities of the equipment monitoring use case

As Figure 8 already indicates, there might be data from other use cases that could be relevant or influence the information displayed for equipment monitoring, such as predicted maintenance or NC production data described in UC-BSL-1. First interface drafts were created before the use case was newly defined. UC-BSL-5 will be documented in detail in updated versions of D2.1 as well as D2.5 (M15) and D2.6 (M28). Figure 19 and Figure 20 show how a joint information screen of equipment monitoring and predictive maintenance could be realised as well as the benefit gathered from it. Besides the current machine state indicated in red (current equipment stop), yellow (expected equipment failure due to mechanical parts failure) and green (everything working according to plan), historical data about equipment performance, throughput, and downtime reason could enhance the maintenance itself by supporting issue analysis and reason detection. Required data and task supporting information will further be investigated in future user workshops.

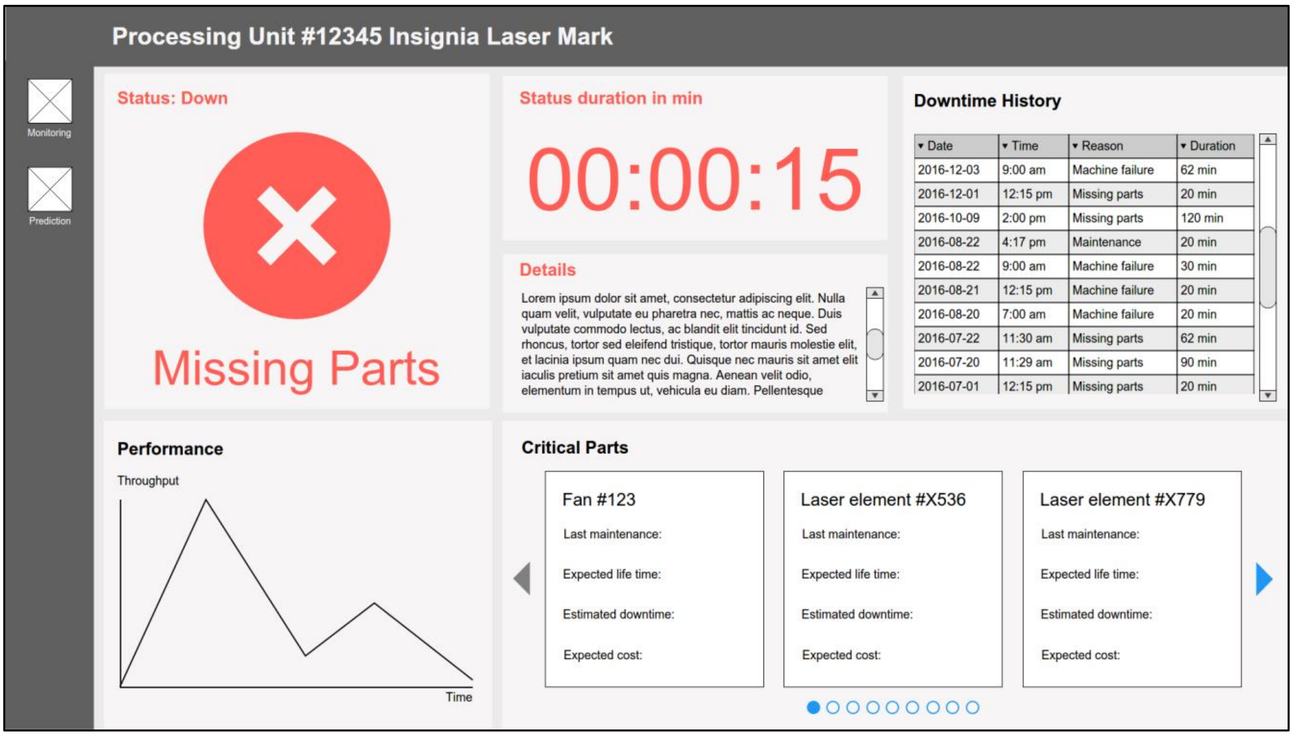

Figure 19: Equipment detail screen with downtime, state reason (missing parts), status history and maintenance monitoring predictions

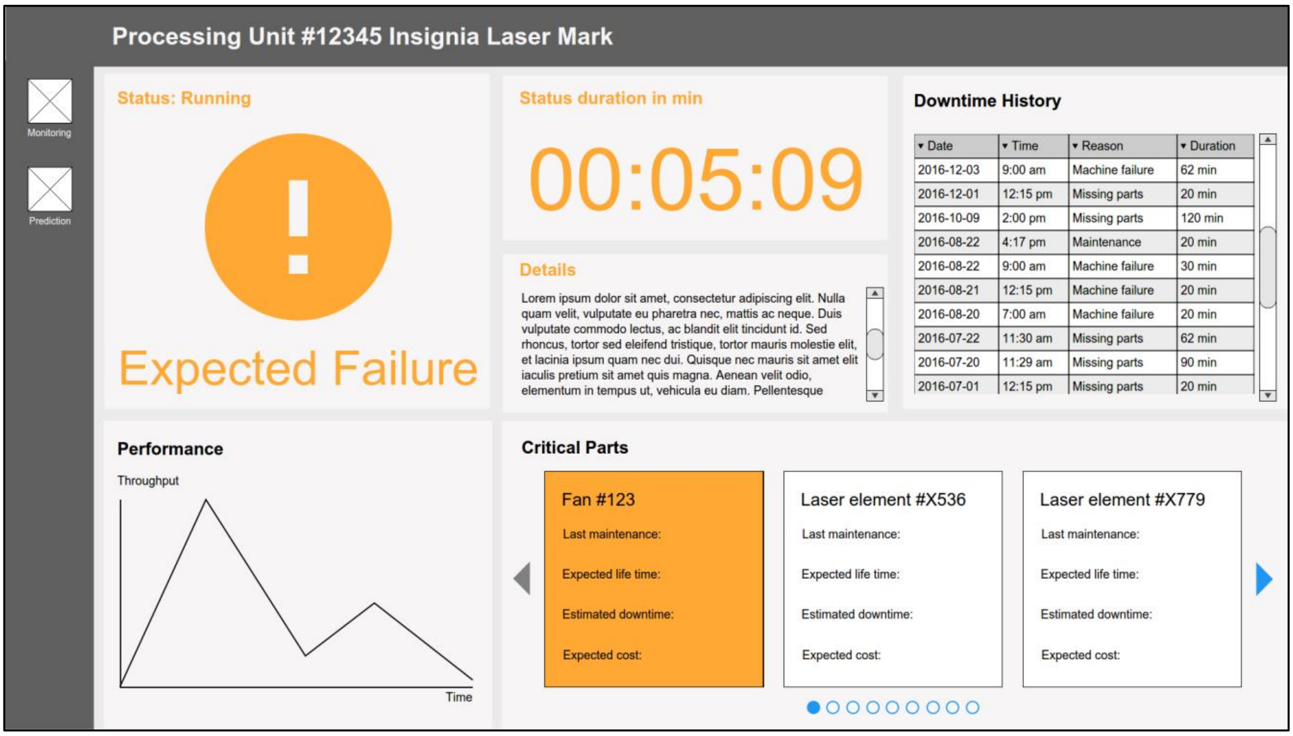

Figure 20: Possible solution for predicted maintenance data and the reason for equipment failure

UC-BSL-1 NC monitoring describes the easier analysis and monitoring of non-conformances or defective parts. NCs occur if a product is rejected from a machine or identified as being defective / non conformant during quality inspection. The NC monitoring system shall ease the process of analysis and failure searching as well as being able to determine if an NC is due to production failure, machine failure or if a higher NC rate is caused by an inspecting worker, e.g. the worker has higher quality demands than others and therefore detects more NCs.

The so far collected basic functionalities of the NC monitoring system are visualized in Figure 21. In general, the NC monitoring use case can be split in two phases: General overview phase and detailed analysis phase. It is still not completely clear how the NCs can be visualized in a usable and task oriented way to support workers involved in this use case. The NC monitoring and reporting process itself is complex and a decent documentation has not yet been acquired. However, this will be tackled as the project evolves.

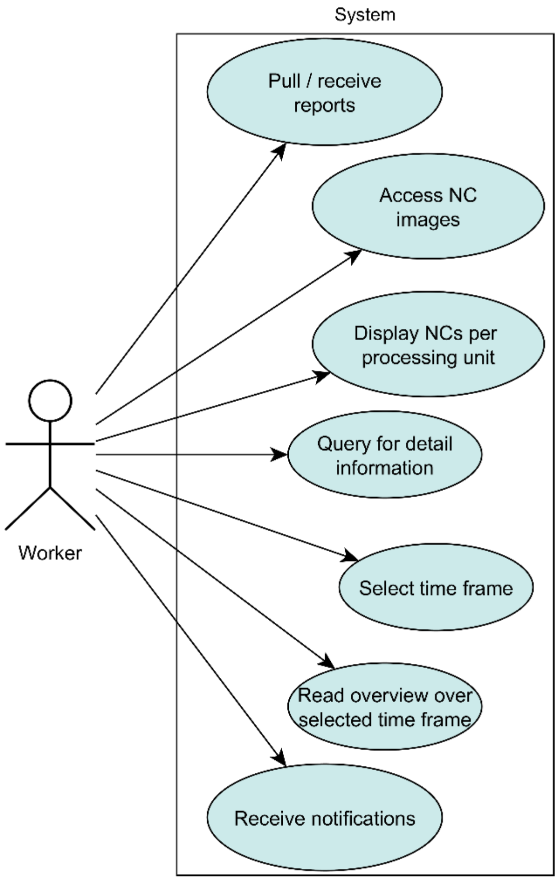

Figure 21: Basic functions of the NC monitoring use case

Figure 22 visualizes a dashboard with joint NC monitoring, equipment monitoring and process monitoring information. However, this early draft of a possible interface is already deprecated since NC monitoring is not done per machine, but per processing unit, which can be described as a machine bundle. A mobile version of an NC monitoring only dashboard is attached to the document in Appendix 11.3 and also online at https://app.moqups.com/vkrauss/xb88A6dR3b/view.

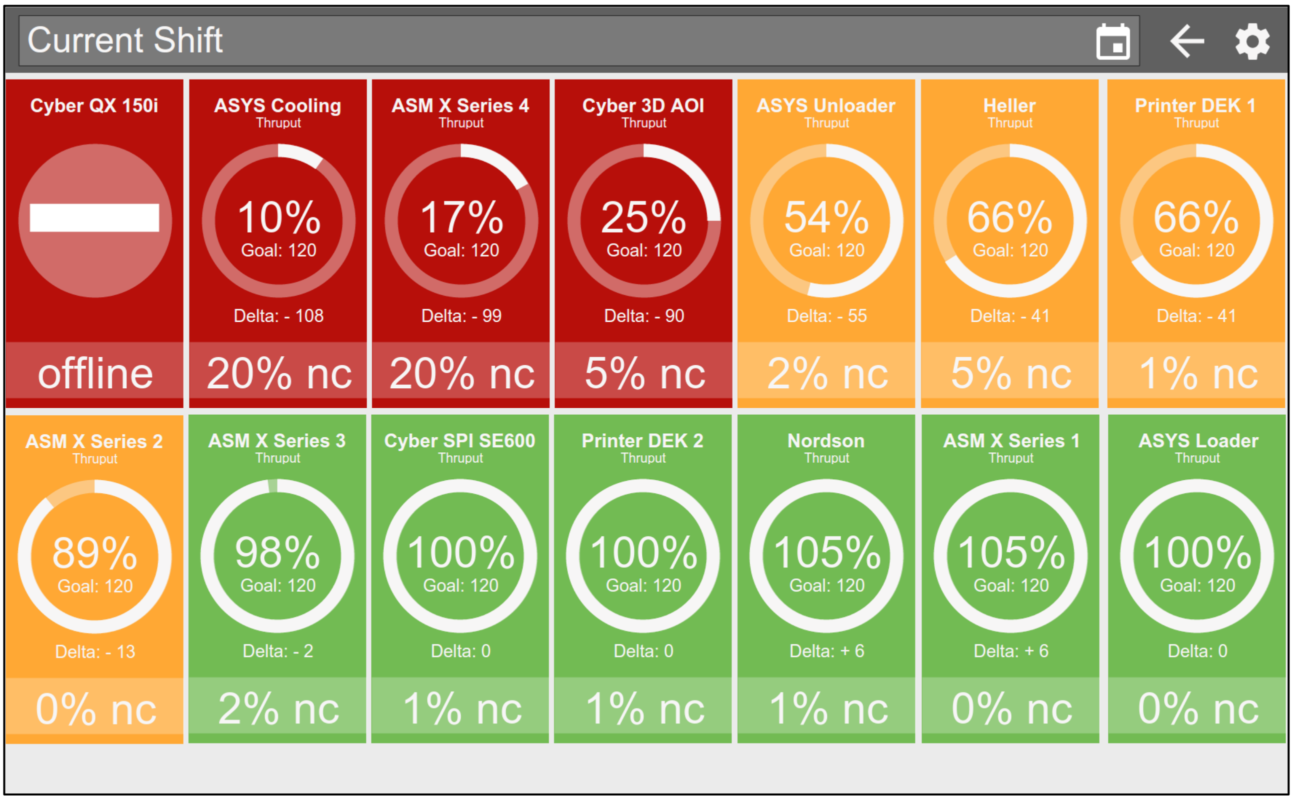

Figure 22: Machine status overview dashboard paired with production data as well as NC monitoring information; this is deprecated since NC is not being monitored per machine, but per production unit (machine bundle)

6 Inter-Factory HMIs

Many of the inter-factory use cases in COMPOSITION are addressed by the market place system (see D6.3 (M20), D6.4 (M34)) which is to be implemented in WP6. Only view interfaces are at least partially covered by the HMI task, for example fill-level notifications. Therefore, the inter-factory HMIs are developed in close collaboration with the partner ISMB, who is the main responsible for the market place system. FRAUNHOFER supports with initial requirements elicitation for HMIs as well as interface concepts and design drafts to ensure the fulfilment of requirements, such as COM-108 (see D2.2 (M6), D2.5 (M15), and D2.6 (M28)). However, the implementation of the marketplace interfaces is part of WP6 and does not involve the Human-Machine-Interfaces task. Therefore, the market place system is only briefly discussed in this section.
The HMIs described in section 6 will nevertheless focus on HMIs for the market place system as it might affect how notifications are sent out and being received by the end user.

Table 3 lists the inter-factory use cases according to their prioritization level described in section 5.

Table 3: Prioritization of the inter-factory use cases

Tier	Use case ID	Name	Scenario
1	UC-KLE-4	Scrap Metal Collection Process	Scrap Metal Management
	UC-KLE-5	Scrap Metal Bidding Process	
	UC-KLE-6	Determining the Price for Scrap Metal with ELDIA acting as Logistician	
2	UC-ELDIA-1	UC-ELDIA-1 Fill-level Notification – Contractual solid recyclable waste management	Recyclable Material Management
	UC-ELDIA-2	UC-ELDIA-2 Fill-level Notification – Contractual wood waste management	
	UC-ATL-3	Searching for Recommended Solutions	Software Distribution
3	UC-ATL-2	Searching for Solutions	
	UC-ATL-1	Selling Software / Consultancy	
	UC-KLE-7	Ordering Raw Materials	Supply Chain Management
	UC-ATL/NXW-1	Integrate External Product into Own Solution	System Connection over Marketplace
	UC-NXW-1	Decision Support over Marketplace	

6.1 Devices

The market place is a mostly autonomously acting, agent-based system that mainly interacts with human users if a decision needs to be taken or settings concerning the agents' behavior have to be adapted. As long as this human interaction is missing, the concerning process is paused for the user's company. In the worst case this might result in losing a job. As depicted in Figure 23, the market place system should therefore be accessible from various devices, such as smart phones, tablets and stationary desktop PCs. Notifications might be send as in-application message or email. Based on user workshops, email is therefore the preferred medium which is also being required as input channel for system adjustments. Corresponding interface drafts are presented in Figure 25, Figure 26 and Figure 27.

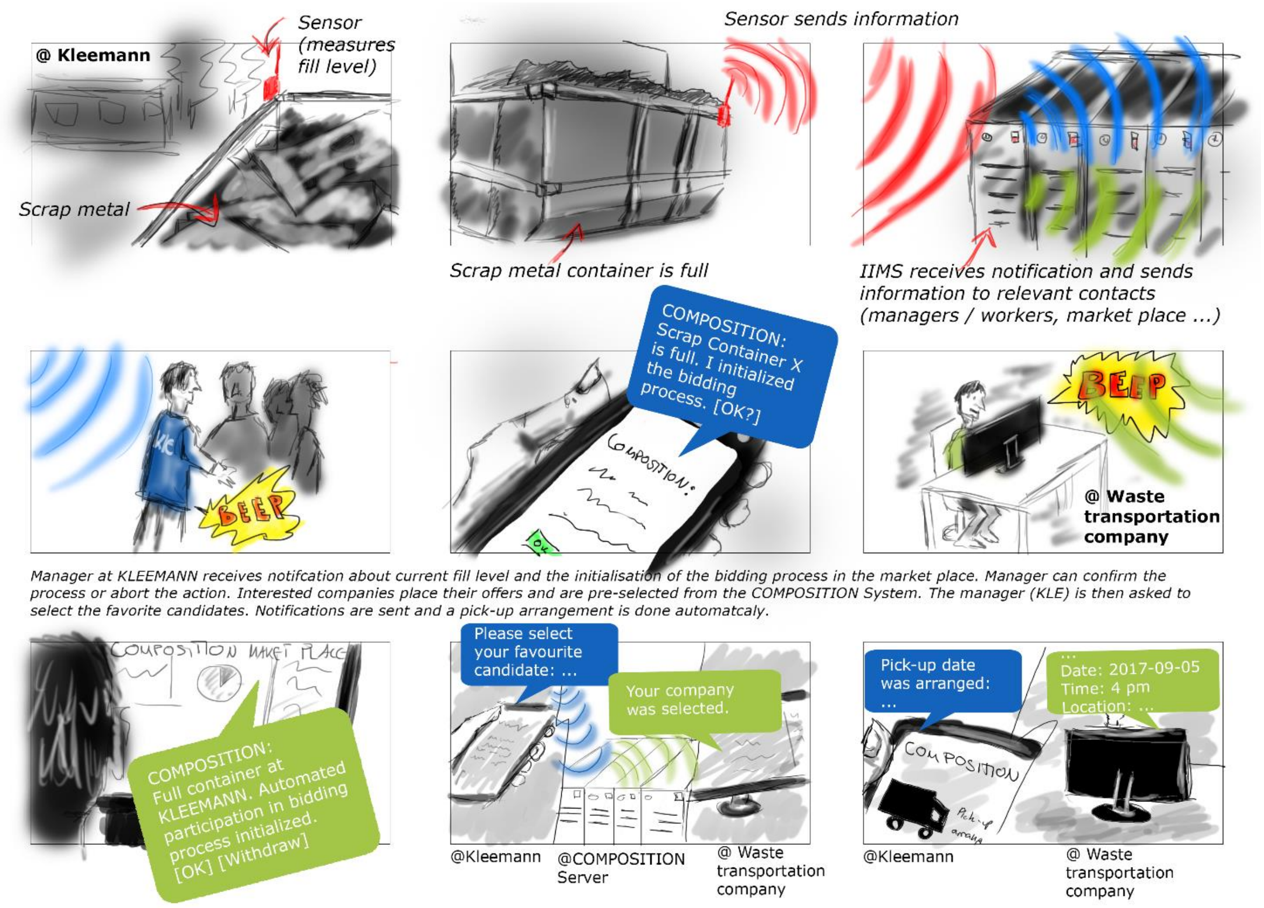

Figure 23: Story board describing UC-KLE-4

As Figure 24 shows, the market place system itself offers a huge set of interaction. Administrative tools such as agent management, user administration, offer settings, etc., allow users to manage their own company's presence on the system. Additionally, users can register on market places from other companies and receive notifications concerning new offers, bidding processes, contractual information or market place invitations. A rating system is planned to be included to allow for the rating of companies and their offers. A black- or whitelist which can be set up by company administrators with corresponding rights ensures that the automated process of matchmaking will always take the best rated companies into account. A search functionality enables to easily find products or market places.

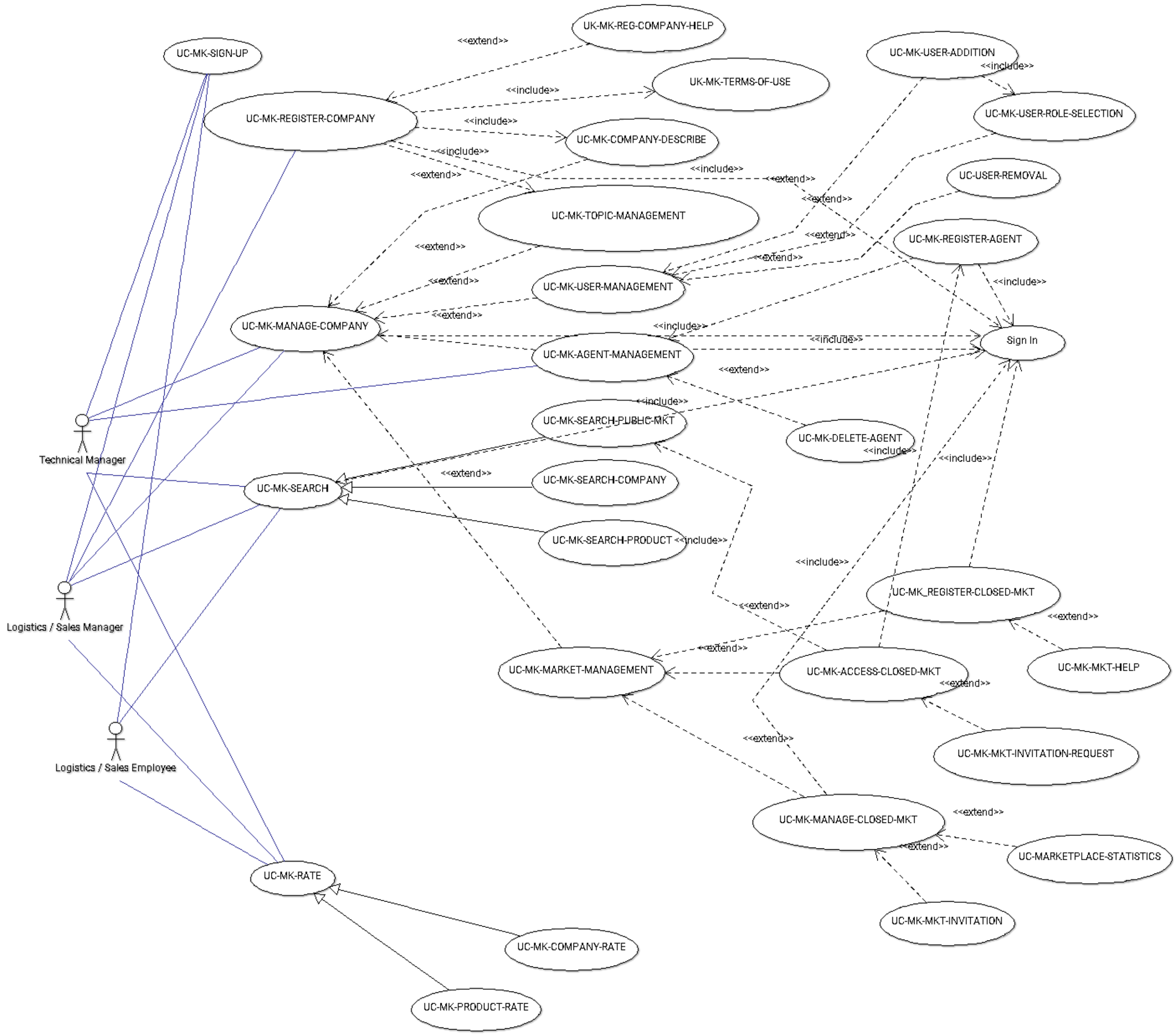

Figure 24: Functionality map of the market place system

6.2 Interface Prototypes for the Market Place System

For initial interface drafts, a subset of functionalities from the marketplace functionality map (see Figure 24) has been modelled for both, mobile as well as stationary desktop devices (see Figure 26 and Figure 27).

The mobile application (see Figure 25) focuses on describing a ping-pong action for offering and bidding using the agent-based marketplace system. Most of the interaction between vendor and bidder is cared for by the agents which need to be configured in order to step into action. On defined points in the process, the system will contact a human to ask about decisions for both, vendors and bidders. The full procedure of the bidding process is attached to this document in Appendix 11.4.

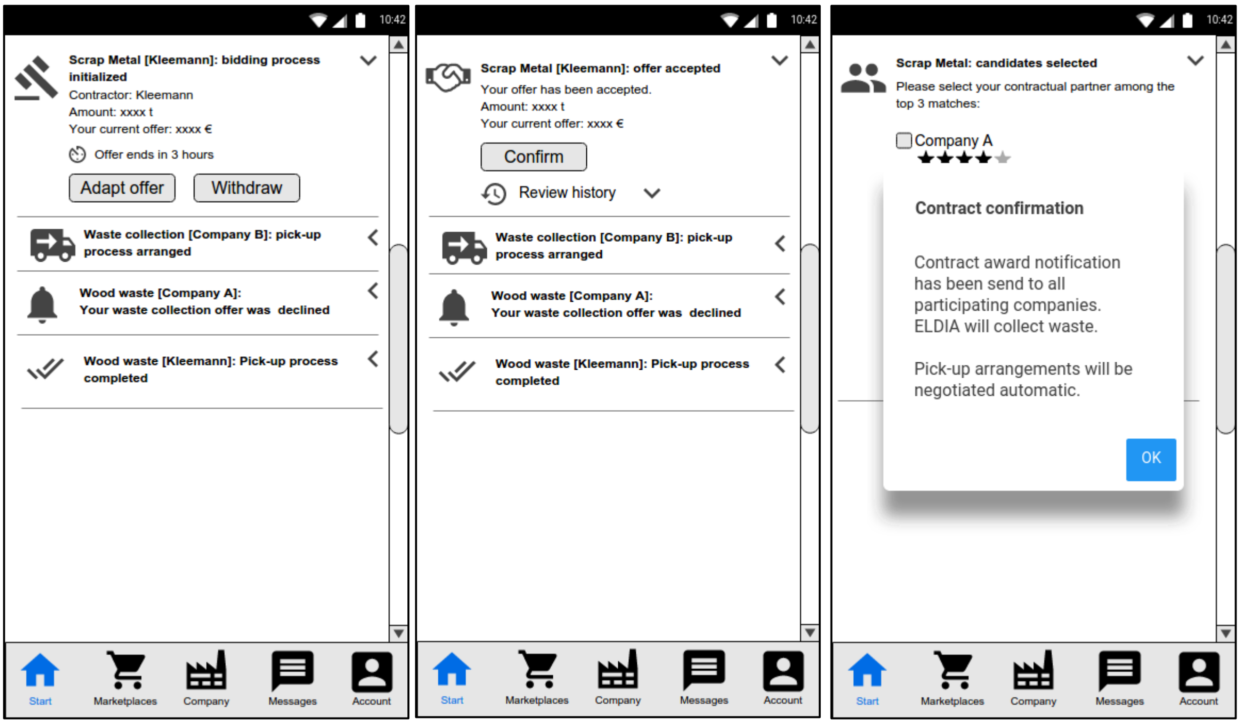

Figure 25: Initial drafts of the interface for mobile users; the complete mock-up is available online at https://app.moqups.com/vkrauss/L2Kq7DtOZQ/view; Left: automatic initialized bidding process, the agent allows the user to adapt the pre-set offer behaviour; Middle: agent informs the user about his offer being accepted; Right: vendor being informed that the bidder confirmed the process; all other participants have been notified about the result of this process

User can create market places or sign up to already existing ones. Marketplaces have different levels of access and visibility, for example public open, public closed, and private closed. Users can be invited to marketplaces or sign up directly if they own corresponding access rights. Besides various configuration functionalities, also a user management system is to be implemented and will not further be described in this deliverable. Figure 26 shows the state of the agent configuration panel as long as no agent has been set up or registered on a market place. Figure 27 demonstrates a list sorting functionality for the marketplace listings. The full set of interface drafts describing the interaction with marketplaces can be found in Appendix 11.5.

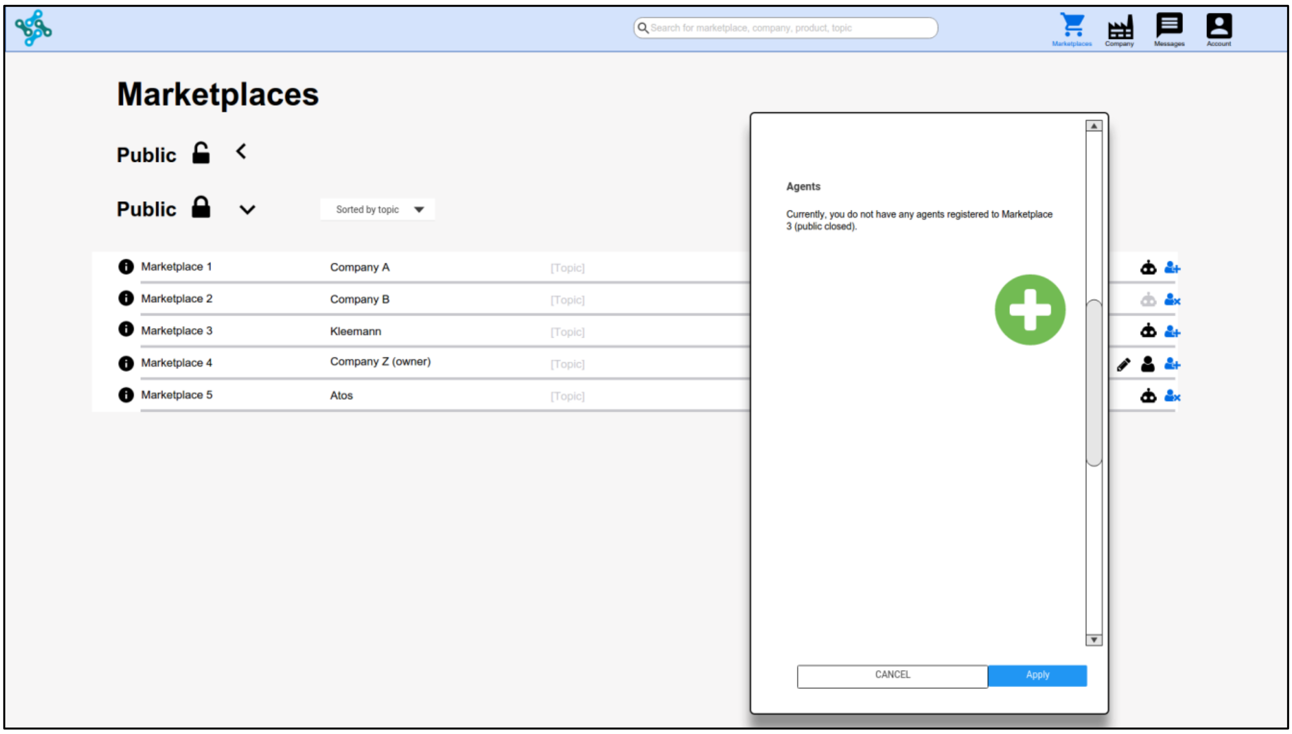

Figure 26: The market place interface should also feature a control panel for agents; available online at https://app.moqups.com/vkrauss/L2Kq7DtOZQ/view

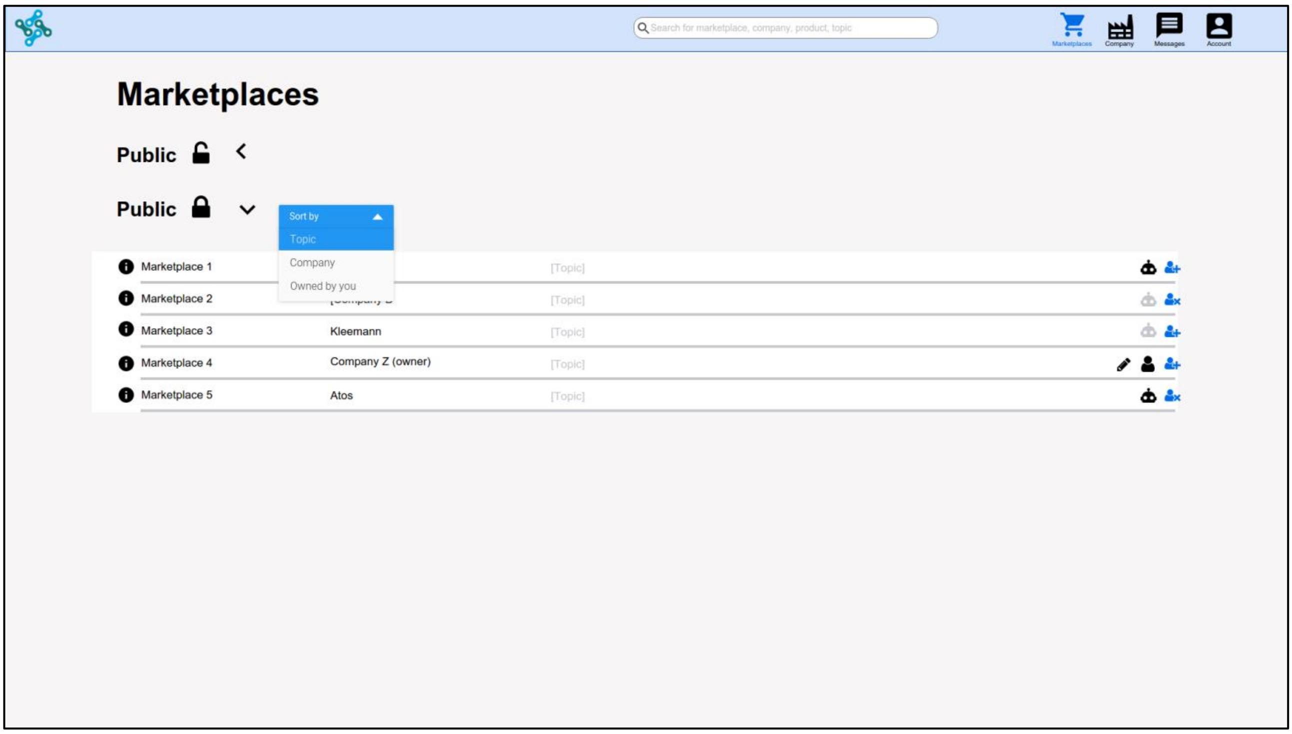

Figure 27: The market place system control panel allows the user to query public and private marketplaces as well as configuring, monitoring, bidding, etc.; available online at https://app.moqups.com/vkrauss/L2Kq7DtOZQ/view

6.3 Interfaces for other Systems

During the use case discussions and user workshops with the test site partners, other HMIs were mentioned which might be involved in some of the inter-factory use cases. UC-ELDIA-2 for example describes a waste collection process in which the route of waste collecting trucks is being updated according to the container fill levels at Kleemann. The route of drivers might be changed while they are operating their car. Nowadays, this is done by calling them on a smartphone and ask them to manually update their planned route. However, in the future this might be solved automatically by the COMPOSITION system which could be capable of updating the navigation systems of the trucks with respect to traffic. The information of the route being updated might then be communicated using voice synthesizing interfaces, as depicted in Figure 28. Currently, there are neither requirements nor specific use cases where such an HMI is relevant. Therefore, it will be neglected until the requirements and the use case prioritization might afford the implementation of such an interface.

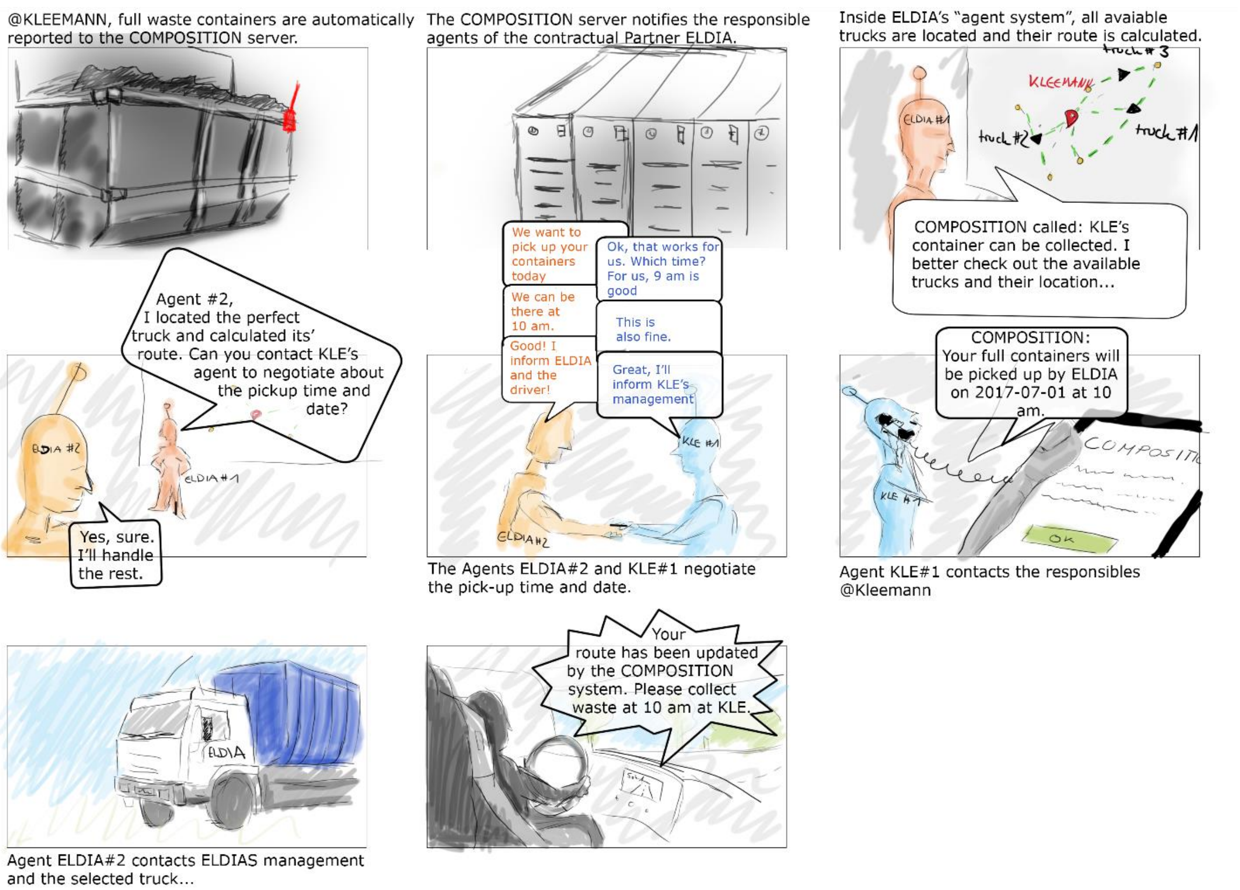

Figure 28: Story board describing UC-ELDIA-2

7 Conclusion

The work presented in this deliverable is part of WP5 task T5.3 Advanced Human-Machine-Interfaces for Direct Interaction with Real-World Objects. Initial interface drafts of different fidelity levels were presented for all intra-factory and some of the inter-factory use cases. Additionally, while working on the initial HMIs, more detailed requirements as well as a better understanding of the problems in the COMPOSITION use cases was achieved.

Both, the requirements and the achieved knowledge will be input for future deliverables of WP2, especially for updated versions of D2.1 Industrial use cases for an Integrated Information Management System, as well as D2.5 Lessons Learned and updated requirements report I, and D2.6 Lessons Learned and updated requirements report II. Initial drafts of the marketplace system as well as the achieved knowledge concerning interaction of users with the envisioned system environment will be applied in WP6, which is focusing on developing the marketplace system. Furthermore, more initial technical requirements could be collected that will be fed into WP5 and WP6. Especially the story boards developed for user workshops in T5.3 were already successfully applied in joint workshops with WP5, WP6, and WP2 partners.

The next steps will involve the more detailed analysis of use cases of tier 1 and 2 priority, especially focusing on their similarities to allow for a first prototype implementation. For identifying such basic interaction and information requirements, the applicability of the CAMELEON reference framework (Calvary, et al., 2002) needs to be evaluated. This framework allows for a structured documentation and transition of core issues into systems accessed with different devices. The result of this will be a general HMI prototype which is adaptable for specific user needs identified during co-creational and collaborative workshops.

Besides further collecting requirements, user problems and user needs, tier 1 interface drafts will be finalized and implemented; tier 2 interface drafts will be further specified in more detail. Tier 3 interfaces will be further developed if specific needs afford it.

8 List of Figures and Tables

8.1 Figures

8.2 Tables

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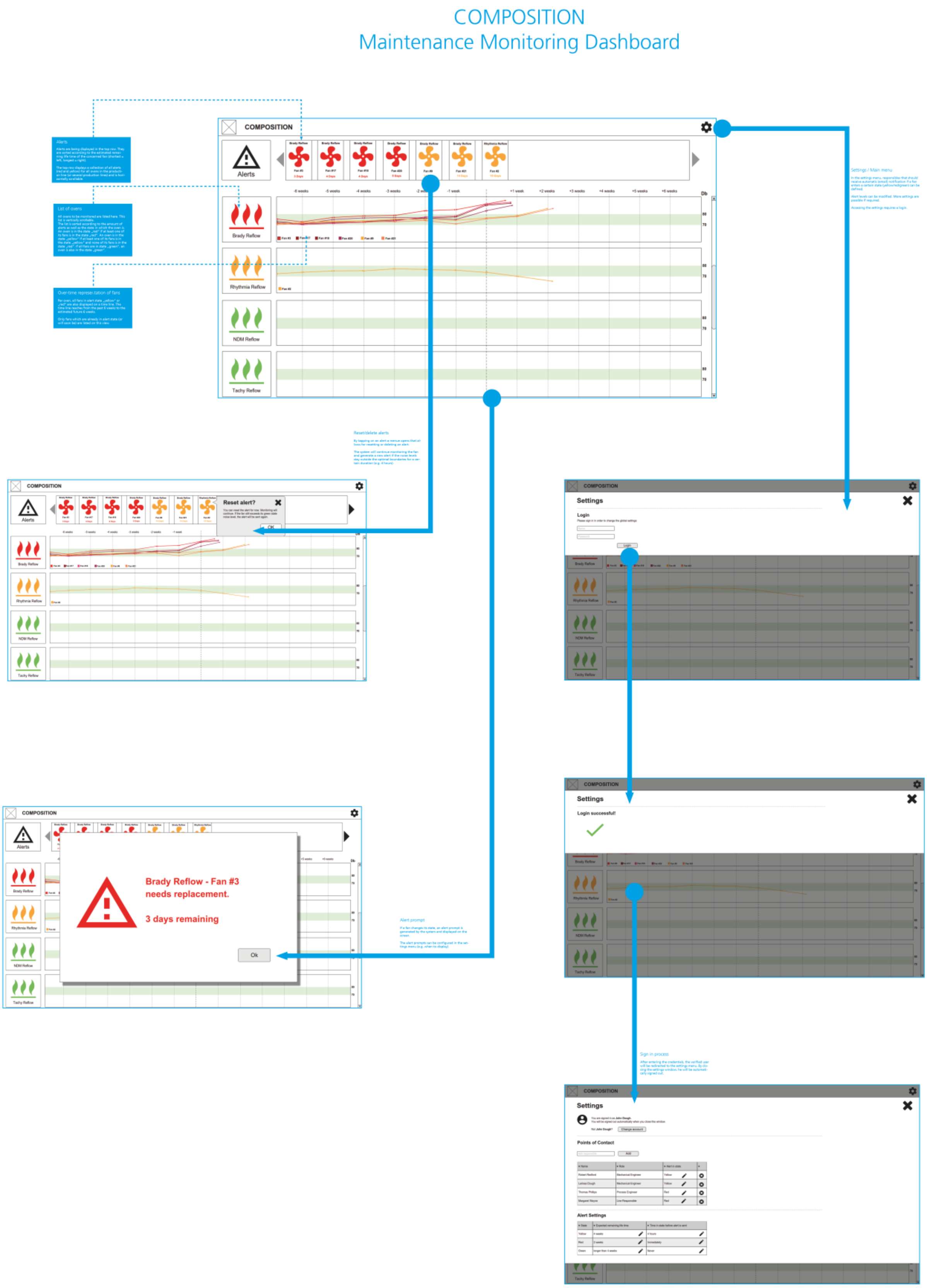
10 Acronyms

Acronym	**Explanation**
AR	Augmented Reality
CPS	Cyber-Physical System
Dx.x	Deliverable x.x
ECSEL	Electronic Components and Systems for European Leadership
HMI	Human-Machine-Interfaces
IIMS	Integrated Information Management System
Mx	Month x
NC	Non-conformance
OPC-UA	Open Platform Communications – Unified Architecture
UCD	User-centered Design
WP	Work Package

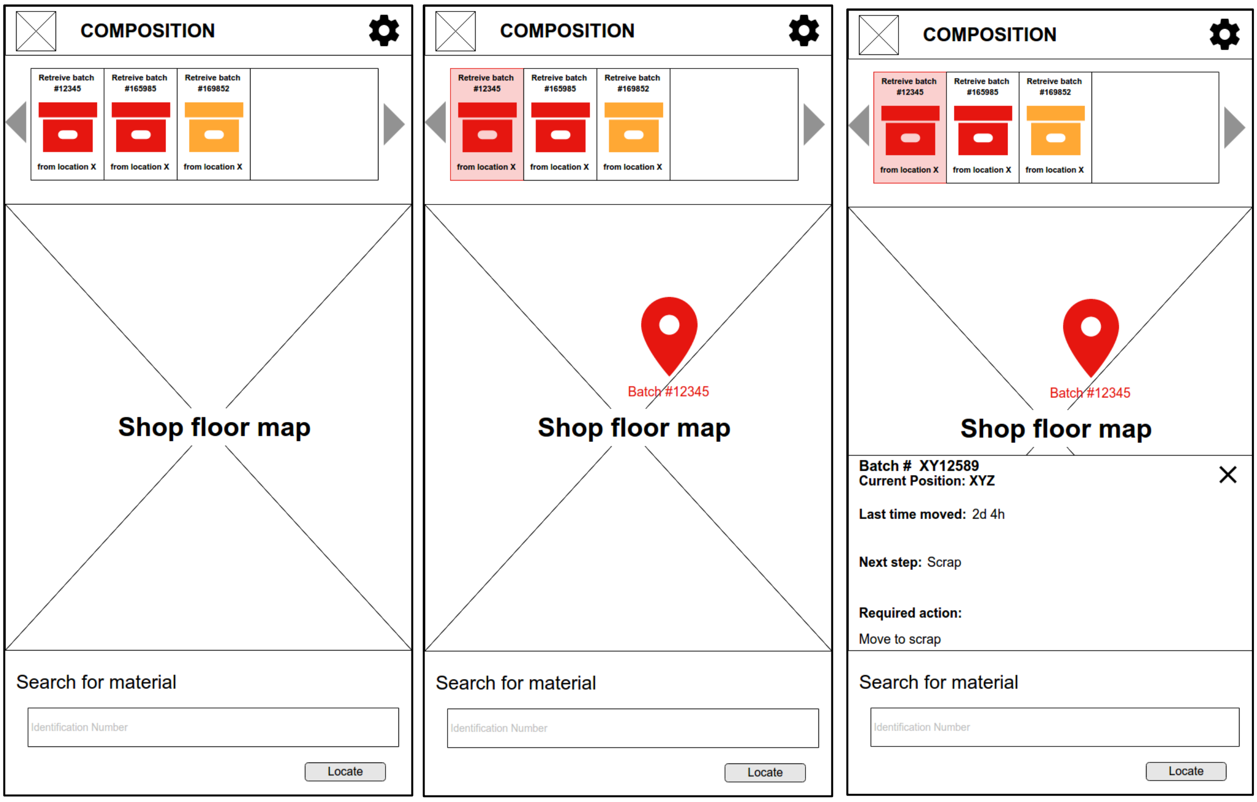
11 Appendix

The appendix presents interaction flow diagrams as well as HMI mockups and drafts for the use cases presented in the sections 5 and 6.

11.1 Interaction Flow Diagram for Predictive Maintenance



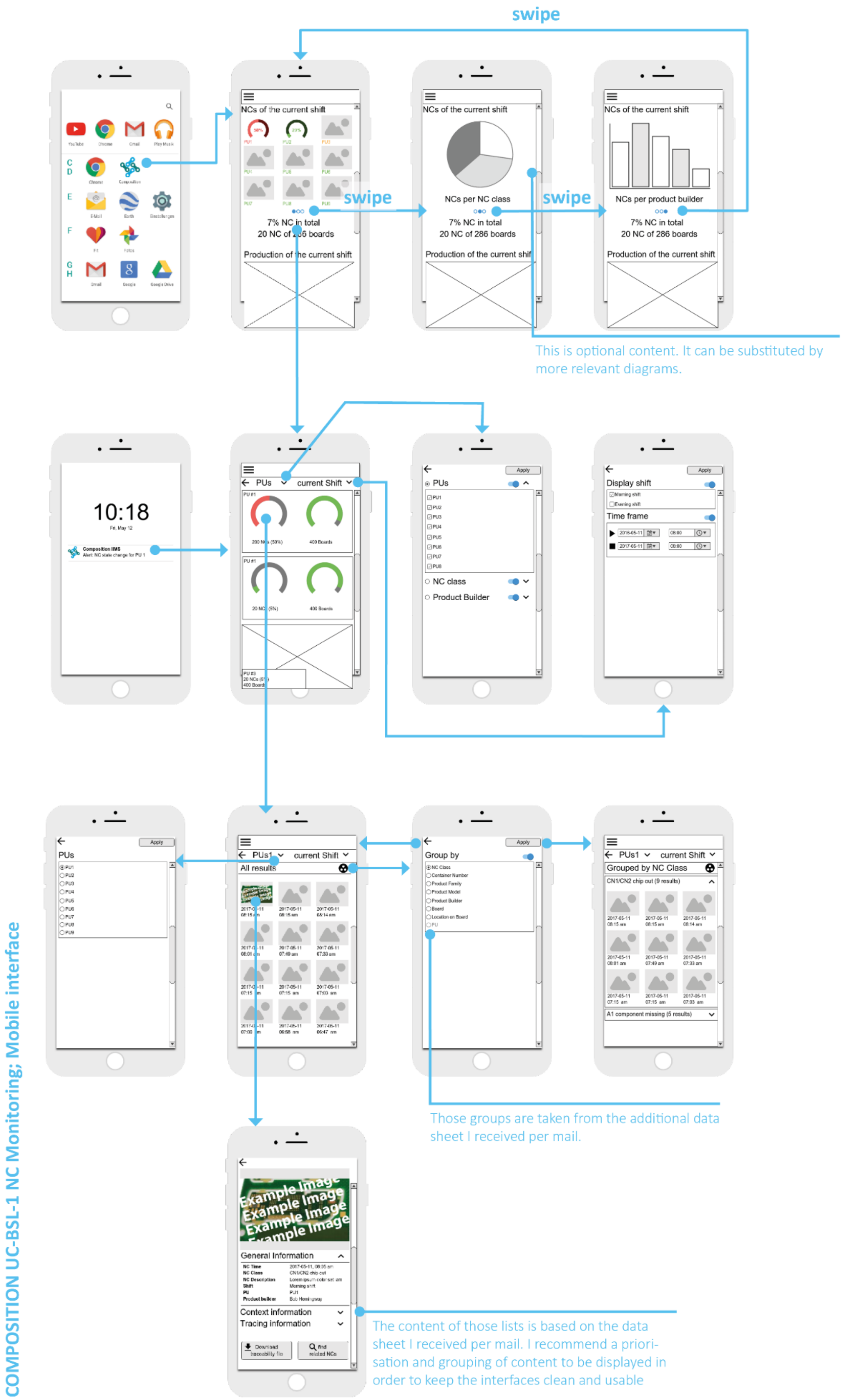
11.2 Mobile Interaction Screens for Locating and Retrieving Lost Material



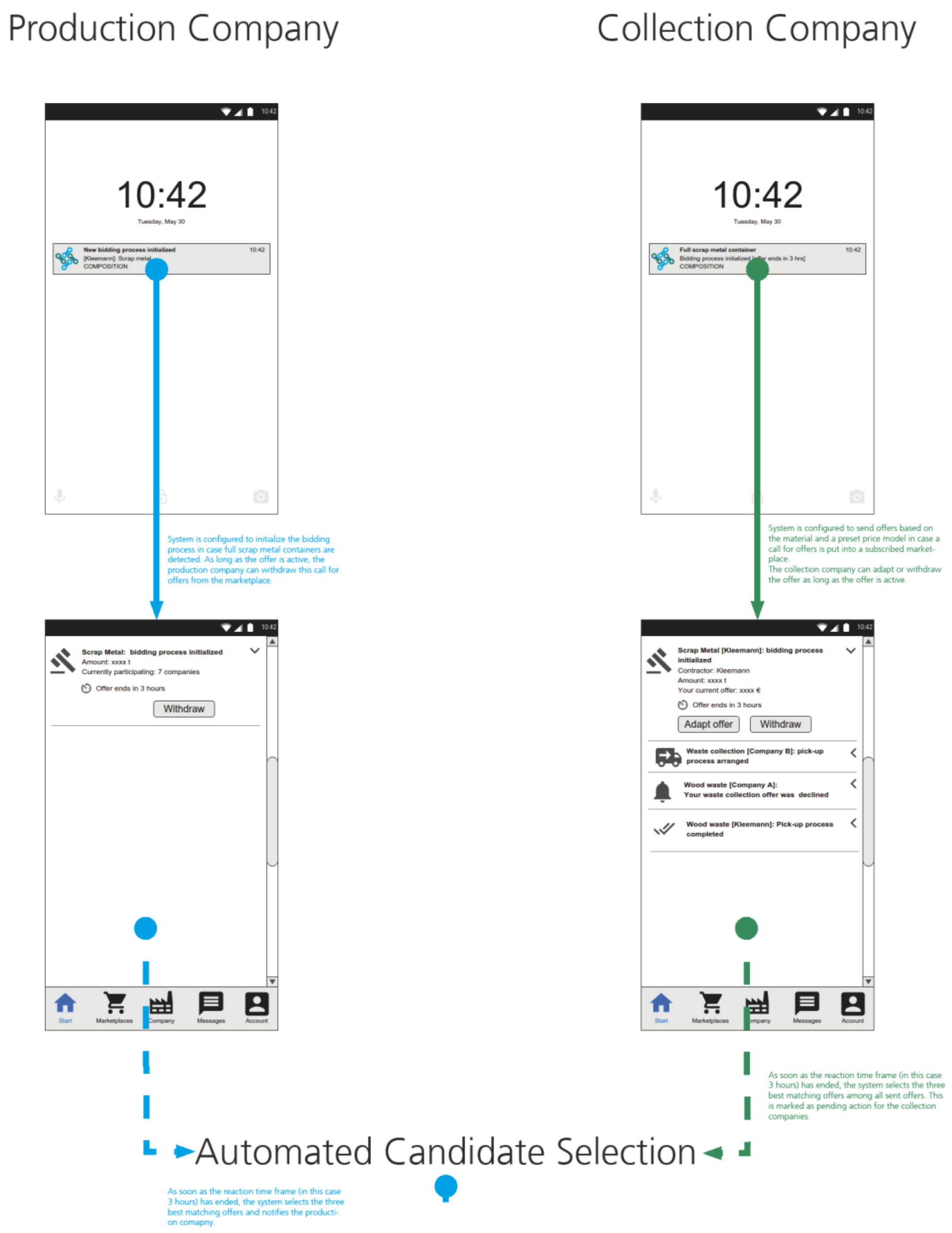
The above figures depict a scenario in which lost material has to be retrieved from the shop floor. Left: Overview dashboard; urgent lost material is displayed in a horizontally scrollable list. Middle: By selecting an item from the urgent lost material list, its position is displayed on the factory map. Right: By selecting the position icon on the map, additional information for the item to be retrieved can be displayed.

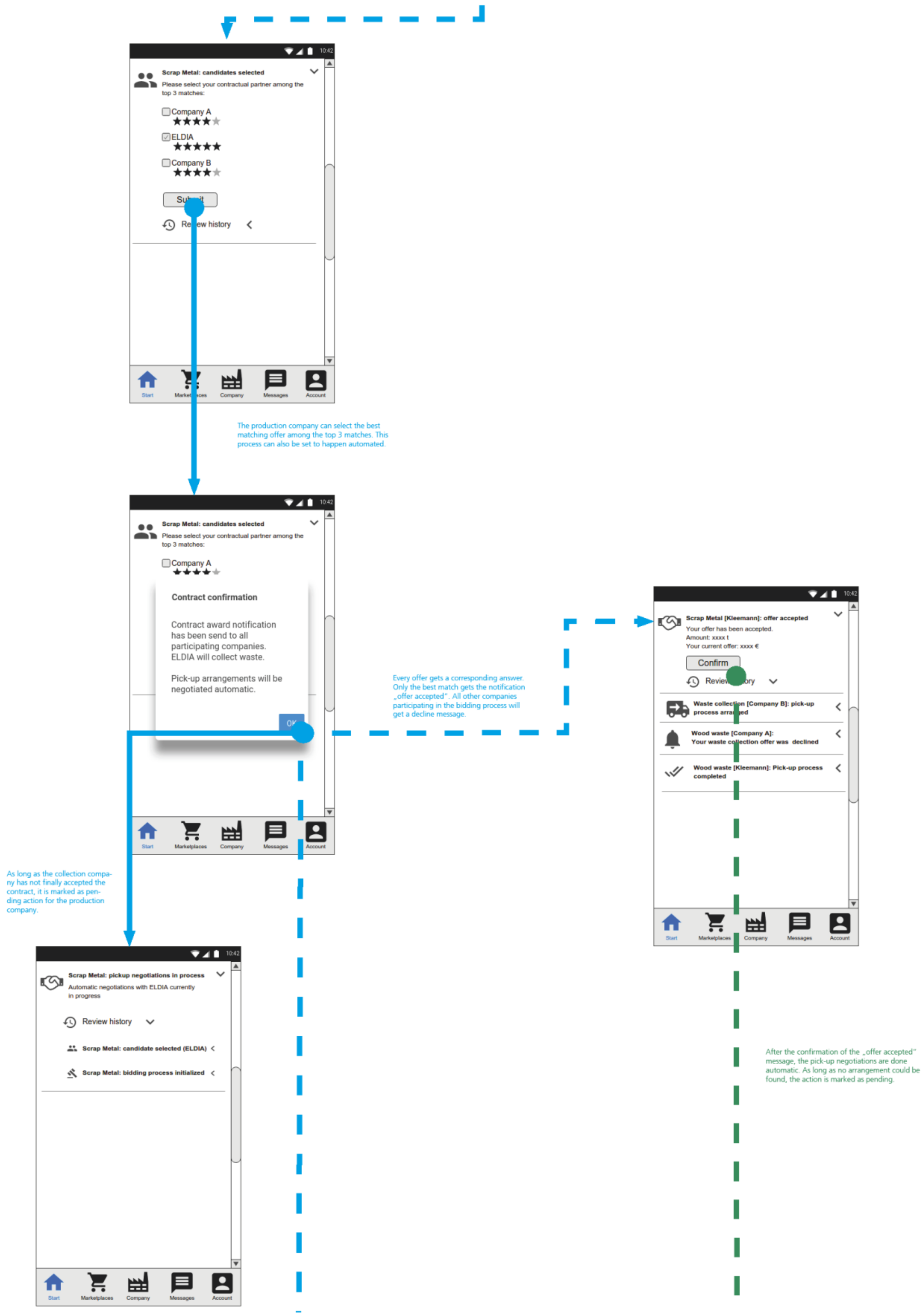
The mobile draft also supports the location of specific material by typing in a tacking number.

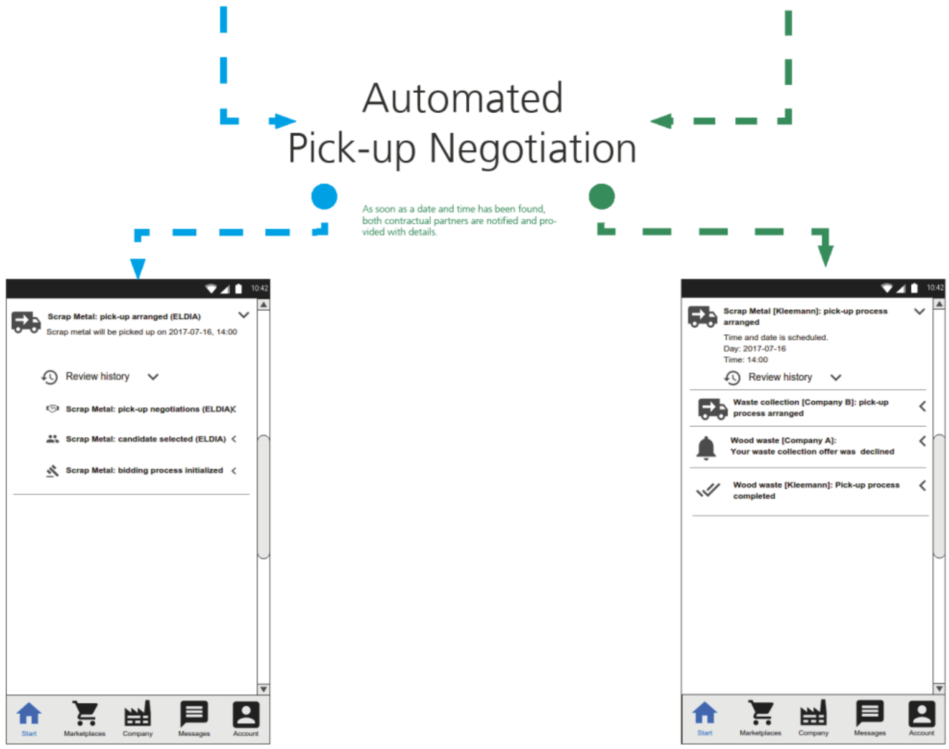
11.3 Interaction Flow Diagram for Mobile NC Monitoring



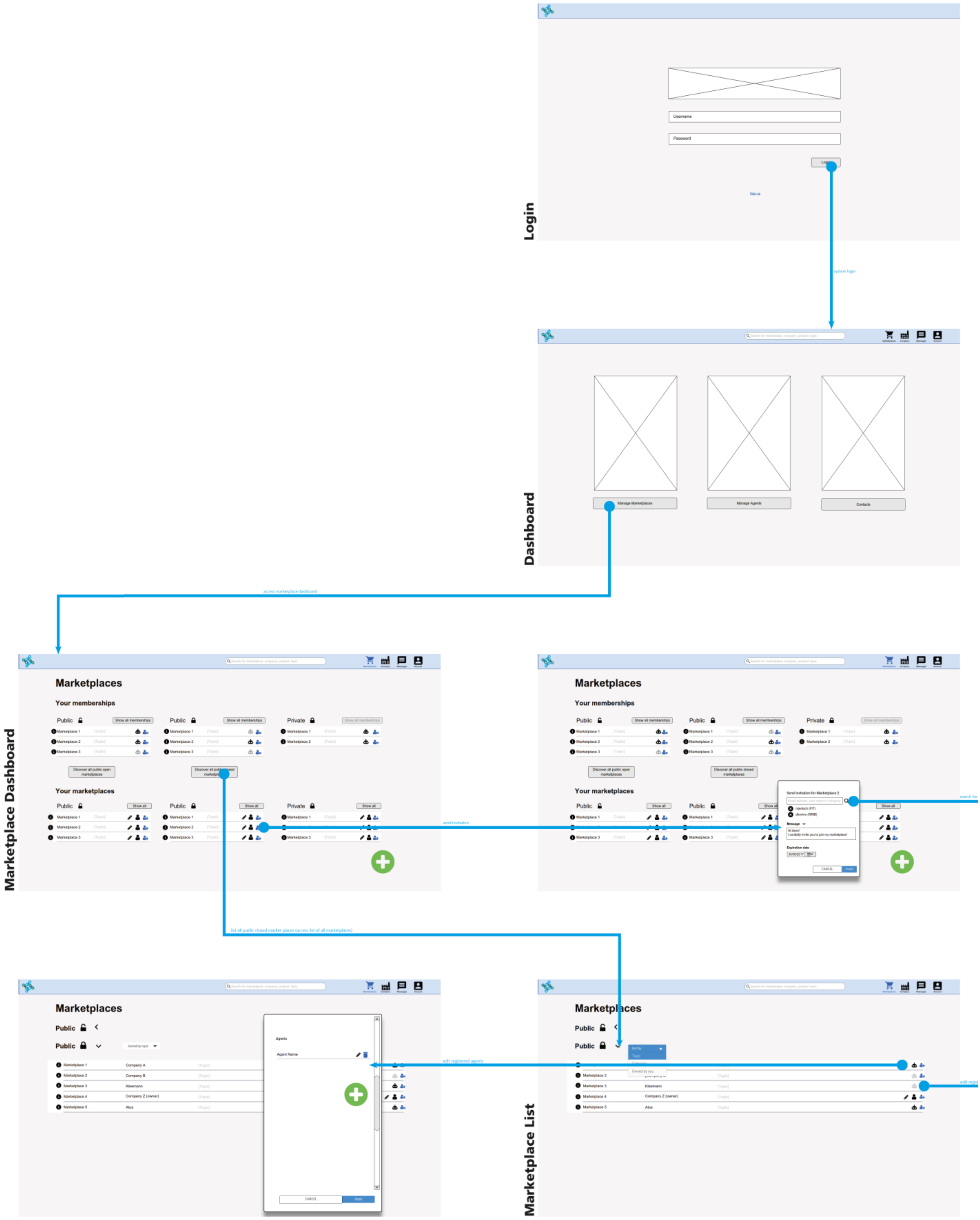
11.4 Interaction Flow Diagram for Mobile Interaction with the Marketplace System




Scrap Metal: candidates selected
Please select your contractual partner among the top 3 matches:
Company A
ELDIA
Company B
Submit
Review history
Start
Marketplaces
Company
Messages
Account
The production company can select the best matching offer among the top 3 matches. This process can also be set to happen automated.
Contract confirmation
Contract award notification has been send to all participating companies. ELDIA will collect waste.
Pick-up arrangements will be negotiated automatic.
OK
Every offer gets a corresponding answer. Only the best match gets the notification „offer accepted". All other companies participating in the bidding process will get a decline message.
Scrap Metal [Kleemann]: offer accepted
Your offer has been accepted.
Amount: xxxx t
Your current offer: xxxx €
Confirm
Waste collection [Company B]: pick-up process arranged
Wood waste [Company A]: Your waste collection offer was declined
Wood waste [Kleemann]: Pick-up process completed
As long as the collection company has not finally accepted the contract, it is marked as pending action for the production company.
Scrap Metal: pickup negotiations in process
Automatic negotiations with ELDIA currently in progress
Review history
Scrap Metal: candidate selected (ELDIA)
Scrap Metal: bidding process initialized
After the confirmation of the „offer accepted" message, the pick-up negotiations are done automatic. As long as no arrangement could be found, the action is marked as pending.


Automated
Pick-up Negotiation
As soon as a date and time has been found, both contractual partners are notified and provided with details.
10:42
Scrap Metal: pick-up arranged (ELDIA)
Scrap metal will be picked up on 2017-07-16, 14:00
Review history
Scrap Metal: pick-up negotiations (ELDIA)
Scrap Metal: candidate selected (ELDIA)
Scrap Metal: bidding process initialized
Start
Marketplaces
Company
Messages
Account
10:42
Scrap Metal [Kleemann]: pick-up process arranged
Time and date is scheduled.
Day: 2017-07-16
Time: 14:00
Review history
Waste collection [Company B]: pick-up process arranged
Wood waste [Company A]:
Your waste collection offer was declined
Wood waste [Kleemann]: Pick-up process completed
Start
Marketplaces
Company
Messages
Account

11.5 Interaction Flow Diagram for Marketplace Desktop Applications



Dashboard (new Message)