Personalization in a Paper Factory

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Abstract. The purpose of this work is to explore the potentialities of a personalization platform in industrial settings. We report on a case study in the paper factory domain, in which the industrial aspects identified with relevant experts through interviews have been simulated and connected with a personalization platform. A first user test has been carried out with a representative set of users, which has provided useful and encouraging feedback in terms of the potentialities of the approach in industrial settings.

Keywords: End User Development, Internet of Things, Industry 4.0.

1 Introduction

Today's industrial environments are becoming highly dynamic, with shorter product life cycles and delivery times, requiring increased levels of innovation and customization. Such requirements call for rapidly responding systems that can adjust to required changes in processing functions and production, and meet customization demands on a timely basis. Industry 4.0 is the current response to these complex scenarios: by combining different technologies and software, it aims to enable seamless and flexible production, thus signifying the disruptive power of digitalization in industrial plants. For instance, thanks to the Internet of Things (IoT), a key enabling technology of Industry 4.0, the way in which operations and processes are carried out is radically changing. What in the past was 'closed' inside factories, stored in different local 'data silos' (i.e. one for each machinery producer), and managed using devices based on proprietary/non-standard communication protocols (which kept them rather isolated and inflexible), now is increasingly handled through more standard approaches, promoting easy connectivity and interoperability between the devices, sensors and actuators available in firms. This will offer unprecedented access to real-time data on products and processes, and more informed decisions taken across the whole enterprise (from technicians, to front-line operators to top managers), potentially leading to continuous factory optimization.

In the manufacturing sector, while the availability of up-to-date information at all levels (i.e. from technical processes, to individual equipment components, to associated production and business processes) for a better factory control is becoming paramount [17], turning this vision into reality is extremely challenging. Not only because in these contexts there is a plethora of processes, IoT assets, information sources and up-to-date as well as legacy machines to manage, but also because the integration, maintenance, and control of software is usually responsibility of Information Technology (IT) experts. Therefore, when manufacturing workers identify that a change is needed to the software controlling some processes (e.g. because in a specific situation a different behavior is needed), they strongly depend on the IT department to implement it. However, current software development cycles are not always able to respond quickly to the dynamic needs of factories, then this situation could introduce significant delays and increase costs. Thus, it is becoming clear that applications whose behaviour depends on context cannot be completely “hard-coded” at design time by professional developers, since they cannot predict all the possible situations of use and whether the results produced will actually be meaningful, as they often lack the knowledge that usually only domain experts have. This scenario seems a suitable application area for End-User Development (EUD), which aims to provide domain experts with effective tools to build solutions to the problems they face every day, by empowering them to develop and iterate autonomously on needed customizations without including IT experts at each stage.

In the context of IoT-based applications, EUD approaches that exploit the trigger-action paradigm have demonstrated particularly promising [9, 2], thanks to their compact and intuitive structure which directly links dynamic events or conditions of the current context to actions to execute when the rule is triggered. Several applications from the academic and industrial fields have shown that the trigger-action paradigm could be easily understood also by people without specific programming skills [15], since its use does not require specific algorithmic knowledge, or abilities in the use of complex programming structures: users have just to specify the rules that indicate the desired effects (e.g. in terms of changes to the state of devices, appliances and user interfaces) when specific situations occur. Such approaches have been applied to different domains ranging from rehabilitation [14], robotics [16], smart homes [4], Ambient Assisted Living [10], and finance [5]. However, to the best of our knowledge, so far industrial contexts have been considered only in a limited manner with regard to EUD themes.

In this paper, considering the increasingly emergent trend of Industry 4.0 we focused our attention on applying a EUD trigger-action approach to an industrial scenario in the paper sector, to investigate to what extent the concepts associated with this approach could be found suitable for addressing current issues in such Industry 4.0 scenarios, and easily exploited by domain experts for personalizing the behaviour of a factory according to events and situations occurring in it. The contribution of this work is to show how a solution based on trigger-action rules can be used to make such personalization easier for people who are not professional software developers. In order to show this, we extended an existing EUD platform to support triggers and actions relevant in an industrial context and then we assessed the solution through a remote usability study in which real experts in the considered sector had to specify relevant rules. We also provided participants with the possibility to see the effects of the interactions with the EUD tool, by executing some rules using simulated prototypes.

The structure of the paper is as follows. In the next section we describe related research, then in Section 3 we report on some interviews with stakeholders, which have been carried out to identify relevant requirements. In Section 4 we describe the case study considered, while in Section 5 we detail the solution to support experts of this domain to personalise their applications. In Section 6 we describe a user study that we carried out involving relevant stakeholders in the paper sector, also providing a discussion of the main results gathered. Then we conclude, describing our future plans in this area.

2 Related Work

According to [1], the application domain of business and data management is one of the most frequent in which End User Development or End User Programming techniques have been applied (24% of total). This is also because it was the historical domain where the idea of tailoring digital artefacts by end users at use time was born, by exploiting spreadsheet programming [3]. An interesting recent work [12] describes a systematic literature mapping study analysing the main EUD strategies used by organizations, as well as the benefits and barriers to their adoption. The benefits they identify can be classified into human factors and organizational factors, whereas the barriers can be related to people, processes and technologies. In particular, on the one hand, support for decision-making, reduced dependence on IT, increased end-user productivity and increased end-user satisfaction are the most mentioned benefits of EUD adoption. On the other hand, lack of training for end-users, lack of support for end-users and the need for technological support were the most cited barriers.

In the business domain, a common approach is to use workflow-based technologies to define and execute business processes, with established standards being BPEL and BPMN. However, such approaches focus just on business process, whereas Industry 4.0 settings are typically more complex, as they involve a variety of heterogeneous physical IoT devices, digital resources, services and activities, which can change their course based on events occurring on them or in the operator's context. As an attempt to bridge the gap between physical IoT devices and business processes, [8] suggested employing process models to define the process layer of IoT applications and enact them through a process engine. However, while workflow-based approaches facilitate the integration of different systems, they require quite strong programming skills, so being unsuitable for unprofessional developers.

A key component of Industry 4.0 is its human-centricity, which Romero et al. [13] concretized in the *Operator 4.0* concept. It refers to smart and skilled operators of the future, who will be assisted by automated systems providing a sustainable relief to their physical and mental stress, and enabling them to better leverage on their creative skills without compromising production objectives. The authors propose an Operator 4.0 categorization, arguing that one operator could incorporate one or several others, differentiated between: Super-Strength Operator (e.g. using exoskeletons), Augmented Operator (e.g. using augmented reality tools), Virtual Operator (e.g. using a virtual factory), Healthy Operator (e.g. using wearable devices to track well-being), Smarter Operator (e.g. using agent or artificial intelligence for planning activities), Collaborative Operator (e.g. interacting with cobots), Social Operator (e.g. sharing knowledge using a social network) and Analytical Operator (using Big Data analytics).

Fogli and Piccinno [7] highlight that there is a gap between what Industry 4.0 promises, and how Operators 4.0 will be called on to change their work practice, suggesting that the integration of EUD with Industry 4.0 enabling technologies might help workers to evolve more smoothly into the various types of Operator 4.0. For instance, Super-Strength Operator can be included in Augmented Operator by assuming exoskeletons as a form of augmentation that must be (physically) personalized to the user, while Smarter, Healthy and Social Operators can be embraced in IoT Operator, who, through EUD, should be able to manage the entire IoT ecosystem. Thus, the enabling technologies of Industry 4.0 should be tailored to the work context and the type of operator *by users themselves*, supported by suitable EUD tools developed according to meta-design [6], as it not only focuses on technologies, but can also sustain the cultural transformation needed to address the future complexity of workplaces.

Other examples that focused on EUD applied to industrial environments involve robotics. While robots have not yet become commonplace in homes, collaborative robots work with humans in factories with increasing frequency. In [16] the authors introduce Robot Blockly, a block-based programming interface for a single-armed industrial robot, showing that novices with no prior programming experience successfully wrote programs to accomplish basic robotics tasks. However, as acknowledged by authors themselves, it was just a preliminary investigation in the potential of block-based programming for industrial robots. Recent commercial automation platforms such as IFTTT or Zapier also allow users to integrate different IT systems in an easy and flexible manner, without having programming skills. However, they typically allow users to define rather simple rules, and have been just limitedly considered for integration in business scenarios so far (e.g. Zapier integrates Customer Relationship Management).

In sectors such as the manufacturing industry, tailoring issues have been addressed even less till now. To this regard, Wieland et al. [17] propose MIALinx, a lightweight and easy-to-use integration solution for SMEs using *if-then* rules that connect occurring situations in manufacturing environments (e.g. machine breakdowns) with corresponding actions (i.e. an automatic maintenance call generation). To this goal, MIALinx connects sensors and actuators according to rules defined in a domain-specific and easy manner, to enable rule modelling by domain experts. In their approach, rules involve available sensors and actuators in the current production environment, and they are then transformed to be managed and executed using existing rules engine (e.g. Jess or Drools). In a more recent paper [11] the user interface of MIALinx has been presented. It was installed and tested in an industrial plant and in a lab dedicated to research on future working places: first test results show that it usually takes less than 30 seconds to create a rule after a short introduction (less than 5 minutes). However, no further details on these tests are provided in [11[to fully appreciate the validity of the solution. To sum up, by analysing the state of the art there is a lack of solutions that apply EUD approaches in an Industry 4.0 manufacturing context (paper factories in our case), also gathering feedback from real stakeholders. This work aims to contribute to fill this gap.

3 Domain Analysis and Requirements Elicitation through Interviews

We interviewed stakeholders of the paper sector preferably having a managerial view, to identify relevant requirements, to better understand current practices and challenges, and to identify events and actions relevant for customization. They were recruited from the network of the members of a project funded by the Tuscany Region (Italy). Initially contacted by phone, they received via email a brief introduction and a document on personal data processing and informed consent, to fill in and sign. Interviews were remotely conducted on: *i) Information on stakeholders* (user's age, gender, familiarity with technology, experience in the sector, role/tasks) and their *companies* (goals, size); ii) *Adoption of IoT/Industry 4.0 and currently used methods; iii) Relevant events/sensors*; *iv) Relevant actions/actuators*; *v) Challenges (*e.g. aspects that pose problems, situations to improve). We involved 5 subjects (1 woman; AVG age=51.2; SD=3.8; Min=45; Max=55), overall quite familiar with technology, and working in companies all located in the Lucca area, one of the largest Italian districts in this sector.

Stakeholders. One stakeholder (M, 52) is responsible of the IT department for a company (300+ workers in Lucca) that builds undulators (the machines producing undulated cardboard, typically used for packaging). Another one (M, 53) works in a paper mill (200+ workers in Lucca) producing undulated cardboard: he has 37+ years of experience in this sector, currently managing safety. Another stakeholder (F, 45) is the IT director of a paper mill (200+ workers only in Lucca). Another one (M, 51) is the administrator of a small transport company (~40 people): his activities range from managing warehouses, customers, to administration and even safety. The last one (M, 55) is the General Director of a paper converting company (~65 workers in Lucca).

Adoption of IoT/Industry 4.0 technologies. In the firm producing undulators, they already use predictive maintenance. The paper mill producing undulated cardboard is technologically heterogeneous: modern and legacy equipment co-exist, with several costly machines, difficult to replace. Also, they do not strongly leverage on Industry 4.0 technologies yet. Even the idea of using web TVs (already available in some plants) to send messages to operators was hindered by the top floor for security reasons. In the transport company, they recently purchased a trolley which updates automatically the warehouse's inventories by "firing" barcodes on items; to move goods, they also have elevator carts which automatically register entry/exit via barcodes. The other stakeholder working in a paper mill also reported that Industry 4.0 adoption is still at an early stage: while they already use many sensors, they would eager to have further support such as predictive maintenance or self-correcting equipment. They have both 'old' machines (dating to the '80s, for which they use sensors to "retrofit" them), and newer ones measuring i.e. paper humidity, strength, and grammage (a measure of paper 'thickness', used to define different paper types). The stakeholder working in the transport company reported that they would like to have sensors to detect risky situations (i.e. when ground personnel are not properly separate from forklifts), which currently is not the case. The paper converting company just started adopting Industry 4.0: one of their newer lines has its composing machines (i.e. winders, cutters) connected with the management system, thus operators can get data in real-time. They are also installing a predictive maintenance system.

Events. In the company building undulators, relevant events include monitoring the quality of the produced equipment and the production speed. In one paper mill, situations to detect include the characteristics of the produced board (cameras and sensors are already used to control starch, glue, humidity), anomalies (i.e. unglued sheets), number of produced items, temperature of the equipment. In the other paper mill, relevant events include e.g. the consumption of raw material (in terms of e.g. water, steam, starch) and also its quality (i.e. humidity, amount of contained ashes or plastic). The situations to monitor reported by the stakeholder working in the transport company include controlling cost/revenue ratio (i.e. they would like to suitably handle more up-to-date information, whereas now reports are sent every 3 months), and whether activities are carried out in accordance with safety regulations. In the paper converting machine company, relevant aspects include those related to machinery (i.e. state, production speed, temperature), paper grammage, number of tears in paper rolls, roll length and diameter.

Actions. In the company producing undulators, actions include those that operate on parts of the equipment (i.e. cylinders, pistons, valves, servomotors). Alarms or notifications are sent in case of anomalies, or when the equipment is poorly working. In paper mills, notifications are sent to users in case of anomaly via sounds or lights, or using monitors on the lines. Also, one of the most serious alarms is issued when a machine stops, while warnings occur e.g. when the "recipe" currently used (i.e. the mixture of ingredients used to produce a particular product) is going to change. In the paper transport company, audible or visual alarms are already sent in "man-down" situations (by using dedicated devices), or to personnel on moving carts (who may not see well their surroundings). However, the user points out that it is important to limit such alarms to truly risky situations. This was also confirmed by the stakeholder working in the paper converting machine company, who reported that while acoustic and flashing signals are already used to highlight anomalies, often such alarms do not correspond to truly dangerous situations, thus in such cases it is needed that human operators check them.

Current Challenges and Personalization Scenarios. In the firm producing equipment for papermaking there is the challenge of improving the satisfaction of operators, whose tasks nowadays are often reduced to rather passive roles (i.e. visual monitoring), as well as improving factory efficiency (i.e. increasing production while decreasing the need of maintenance stops). Also, to supervise production, the IT team developed an application providing the company with real-time data about the equipment they produce, and their customers with various reports about the equipment they use, also allowing them to modify autonomously specific parameters according to their needs (by acting on a database), without the need of manufacturer's intervention. For paper mills, one challenge is to avoid paper breaking (depending on the contract, there is a maximum number of admitted tears in the same paper roll). When this situation occurs, they have to avoid both customer's 'downgrading' of the product (due to too many 'joints' in the same roll) and wasting material. In particular, in these situations she would like to set that e.g. dispensers (feeding the line with the ingredients) automatically stop, and specific warnings reach concerned people with associated reporting of the problem. She also would need more sensors on the lines, to improve checks *in-line* (i.e. in real time), and not *off-line* (i.e. in laboratories), as it occurs today. In the paper converting machine company, a challenge is enhancing the quality control: currently the data about e.g. product defects or equipment efficiency come on a sample basis and at a later stage (since machines work in a continuous cycle), while they would need them continuously, to enable suitable prompter reactions. The stakeholder working as a safety officer in a paper mill mentioned several scenarios that can benefit from personalisation: their undulators need to be configured based on dynamic plant's factors (e.g. internal temperature, humidity); he also would like to get real-time info on trucks' flow at plant's gate to send tailored navigation info to concerned drivers.

To sum up, while the companies where the interviewees work are overall at an initial stage in adopting Industry 4.0/IoT for various apparent reasons (i.e. investments needed to replace machines/infrastructure, difficulties in managing IoT-related security issues), their managers seem well aware of the opportunities that these technologies could bring to them in terms of e.g. having an integrated, real-time view of the system to enable continuous optimization. In this scenario, the proposed personalization approach targeting non-technical people (like them) was judged particularly relevant and indeed concrete personalization scenarios came up during the interviews, which also provided useful information for the design of our solution in the considered domain.

4 The Case Study Considered

The case study focuses on a paper factory. Paper production is basically a process in which a fibrous raw material is first converted into pulp, which is then converted into paper. To this aim, wood chips are first processed so that the unusable part of wood (i.e. lignin) is separated from useful fibres (i.e. cellulose), which are broken up through water within 'pulpers' to produce pulp, the main ingredient of paper. Pulp then feeds a continuous "paper machine", together with the other ingredients that define the "recipe" used to deliver a specific product (e.g. 'paper' is distinguished from 'carton board' since it has a lower basis weight or 'grammage'). Paper machines are endlessly moving belts that receive a mixture of pulp and water and make excess water drain off (by suction, pressure, or heat). The continuous paper sheet (called 'web') coming out of this machine is wound onto an individual spool, to become a 'parent reel' (or 'jumbo roll', see Fig. 1). Since the reel width is fixed for each paper machine, next, another machine (a 'winder') cuts the reel into rolls of smaller diameter, using as little material as possible to minimize trim losses. For cut-sheet paper products, rolls are loaded onto a 'sheeter', which unwinds them and slices the paper into sheets of desired size, which are then wrapped and loaded onto vehicles for shipment to customers/distribution centres. While jumbo rolls are the output of paper mills, they in turn represent the input of paper converting companies, which transform them into e.g. napkins, envelopes, tissue.

Figure 1: A paper machine with jumbo rolls in the foreground (from VOITH)

5 The Architecture of the Solution

To address the requirements identified in the paper domain we extended an existing platform [9] previously applied to other sectors (i.e. smart home, Ambient Assisted Living), to support the triggers and the actions relevant to the industrial context considered. The architecture of the solution is shown in Figure 2. The idea is that the applications used by a worker to control and manage the paper factory (i.e. for monitoring the production, for acting on parts of the production equipment, for managing emergency situations within the plant, for supporting data analysis and reporting), should be able to adapt their behaviour in a context-dependent manner, reacting to the events occurring in the surrounding context, and applying the actions specified in rules defined by 'end user developers', who, in our case, are mainly experts in the paper sector.

The Rule Editor is the EUD tool they should use to specify such behaviour, following a trigger-action paradigm. Once rules are created via the Rule Editor, those that the user wants to consider for actual execution in the current context are sent to a module called "Rule Manager", which subscribes to another module, the Context Manager, to be informed when relevant events occur in the current context. More specifically, the Context Manager consists of a Context Server receiving the context updates, and several Context Delegates, which are lightweight software applications able to communicate with sensors and appliances to receive info about their state, and consequently forward such information to the Context Server, by exploiting REST-based calls on HTTPS. In our solution, since it was problematic to perform the experimentation in a real industrial setting, two simulators have been developed to simulate the occurrence of events and actions, respectively (further details will be provided later on in this section). The Context Manager receives the data coming from sensors, and stores them in a uniform format used for all the devices, appliances and machines belonging to the considered context. The applications in turn subscribe to the Rule Manager to be informed when an action should be carried out. Whenever an event specified in a rule occurs, the Rule Manager receives a notification from the Context Manager, selects the actions associated with the triggered rule and sends them to the subscribed applications. The applications have to interpret the received actions, then sending via MQTT the associated commands to the devices, appliances, actuators involved in the actions. This in some cases could also involve additional roles (e.g. a message is sent to another factory worker).

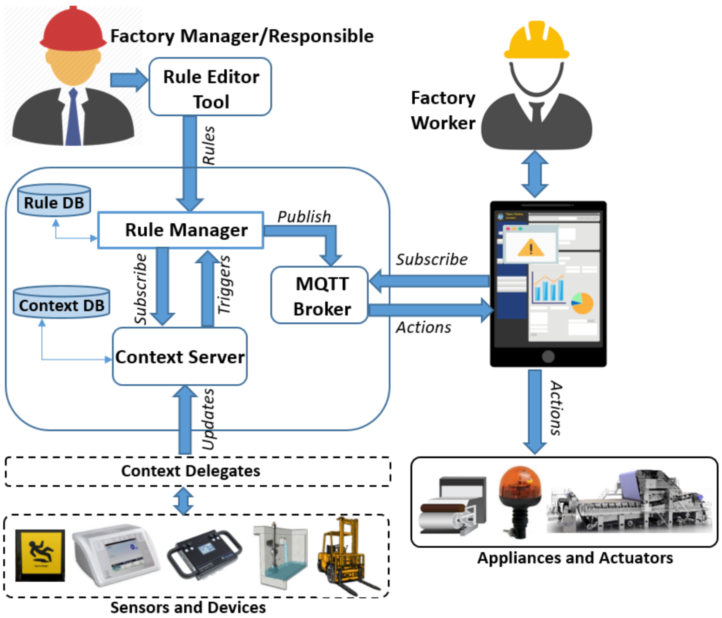

Figure 2: The Platform Architecture

As mentioned before, we also developed two simulator prototypes. The one dedicated to events simulated situations occurring on production lines (by using it, the user can monitor the state of the production lines and also change relevant parameters associated with its composing equipment i.e. the weight of paper trim losses detected at the end of the production cycle), and also the occurrence of emergency situations (such as the 'man-down' alarm, which in real scenarios is typically issued by dedicated devices that detect worker's falls). As for the actions, on the one hand the simulator provided a view of the factory, which included elements such as coloured semaphores highlighting specific situations on production lines (i.e. a red semaphore indicates a situation that needs further attention). Actions such as sending alarms/reminders via email/SMS were not simulated, but actually supported by the prototype.

5.1 The Tailoring Environment for the paper industry domain

The Rule Editor supports trigger and action selection by displaying the available ones organised in logical hierarchies that can be configured according to the needs of he considered domain. In this case the configuration considered, as reference, an exemplary paper mill. The triggers refer to three contextual dimensions (*User*, *Technology*, *Environment*), while the actions considered state changes of factory appliances, or the generation of reminders and alarms. In particular, in this case study the *User* dimension covers aspects associated with workers, who can be of three types: managers, front-line operators (working 'on the floor'), and technicians (i.e. those in charge of equipment maintenance). Their specification is refined into "Physical aspects" and "Position". The first one is to identify situations where workers are moving or not (such as the well-known "Man-Down" event). The current position of users can be specified in absolute terms (via GPS) or according to some "points of interest" within the factory (e.g. "Raw Material Warehouse", "Production Line 1", "Pulper").

The *Environments* element is refined according to key environments/departments of the factory (e.g. Raw Material warehouse, Finished Product warehouse, Production Department, Offices). All are characterised by typical environmental properties such as light level, noise, smoke, pollution, humidity. In addition, warehouses also have 'Entry Speed' and 'Exit Speed', namely the rate at which raw material (resp.: finished product) enters/exits a warehouse, and also the "capacity" currently reached in each warehouse (i.e. empty, almost empty, almost full, full). The warehouses can be internal or external, according to whether they are managed within the company or not.

Regarding the *Technology* dimension, the following elements have been considered: Pulper (the machine that produces pulp from cellulose), Desiccator (which dries excessive water from the paper web), Weight Scale (at the end of the production cycle, it measures paper trim losses), Elevator (the cart moving materials within the plant). Of course, we also considered Production Lines as another key technology. All of them have the following attributes: "Efficiency" (a value in percentage terms, defining the efficiency of the equipment) and "Status" (whether the equipment is working, in pause or is stopped). The Production Lines (see Figure 3) consider additional aspects: Entry Speed (the speed at which raw material is consumed), Exit Speed (the speed at which the final product is delivered), Jumbo Roll Weight (the weight of the reel produced at the end of the production cycle), Paper Grammage (the basis weight of the paper), Paper Waste (the paper trim losses measured by the weight scales at the end of the production line), and Order Type (the type of "job" currently managed by the production line, refined in terms of Type of Customer and Type of Product Requested, thus specifying the customer who commissioned a specific order and the type of product requested).

Actions have been refined into Alarms, Reminders, and actions on the Production Lines. Alarms and Reminders are refined basically using the same fields: the text to send, the notification mode (i.e. mail, SMS, push notification), repetition times, and the recipient (i.e. a phone number or a mail address depending on the notification mode). The other actions aim to change the state of a line (stop, start, pause), or change the light of the semaphore associated with the production line (red, green, yellow), and also modify the recipe used for feeding the production line.

Finally, to more properly cover the needs of the considered domain, in the Rule Editor we enabled different "views" of the hierarchies of triggers and actions, depending on the type of user who accesses it. Indeed, access to the Rule Editor also implies the possibility to have the control of particular equipment/machinery of the company, which of course must be allowed only to specific roles. Thus, beyond the “responsible” role (who can access the whole hierarchies) there is also an “external operator” role, who can access only a portion of triggers and actions, namely those operating on the specific entities this role can manage (i.e. a subset of warehouses). Finally, rules can also be shared with others, using a public rule repository.

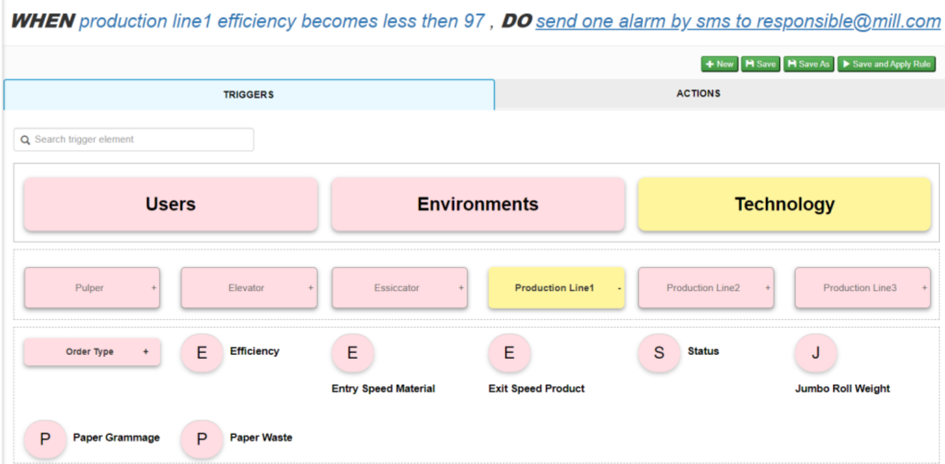

Fig. 3: The Rule Editor for the considered domain

6 User Study

The goal of the test was to get feedback from real stakeholders on the potentialities of the platform and the approach. The test was remotely conducted. Potential participants were recruited from the network of the members of a Regional project, trying to involve non-technical personnel (i.e. heads of departments, managers). They were first contacted by phone/email to ask for their willingness to participate. Then, they received an email detailing the test structure (also including info on the processing of personal data and the request for informed consent), its objectives, and main functionalities of the Rule Editor and of the simulators (also with a short video). We sent them also the tasks, the links to the tools and the simulators to use for the test (with associated credentials), and to the online questionnaires to fill in anonymously after the test: the SUS Questionnaire, and further ad-hoc questions about the approach and the tool. The metrics considered were errors (how many and of which type), and task success categorised as it follows: complete success: the user has not made any mistake; failure: the user gave up or did not complete the task; minor problems: the user made one or two errors; major problems: the user made more than two errors. We considered an error a difference between the rule defined by the participant and its correct specification. Possible errors on trigger specification are: i) use of an event instead of a condition and vice versa; ii) use of a trigger element other than the one expected (i.e., use a trigger that involves the "dryer" element instead of one involving the "pulper"); iii) selection of an incorrect attribute within a trigger (i.e. instead of specifying "inside" an environment (i.e. a department) specify "outside" it; iv) inclusion of an additional trigger, not required by the rule; v) a missing trigger. Except for the first type (which deals with the event/condition distinction, peculiar to triggers), similar types of errors were considered for actions.

6.1 Tasks

Tasks were identified to allow users to evaluate different aspects of the approach (trigger/action composition, events vs. conditions), and were proposed according to increasing difficulty levels (progressively asking to do more, and respecting more constraints).

- *Task1*: Write in your own words 2 rules you consider relevant in the paper sector.
- *Task2*: Using the Rule Editor, build a rule that you consider significant, containing 1 trigger and 1 action. Save the rule as "task2".
- *Task3*: Using the Rule Editor, build a rule you consider significant, containing 2 triggers (combined through AND or OR), and 1 action. Save the rule as "task3".
- *Task4*: Using the Rule Editor, specify: "As soon as the temperature of the Production Dept. exceeds 30 degrees while the operator is within it, send an alarm SMS to 0011223344". Save the rule as "task4".
- *Task5*: Using the Rule Editor, create two rules:
  - *Task5.1* As soon as paper waste on Production Line1 turns out to be less than 30 kg, a green light is turned on. Save it as "task5_1".
  - *Task5.2* In situations in which the weight of paper waste on Production Line 1 turns out to be equal or beyond 30 kg, a yellow light turns on and an e-mail is sent to your mailbox. Save it as "task5_2".

  After creating Task5's rules, users had to activate them in the Rule Editor, use the event simulator to set the context in which the rule is triggered, then check that the executed actions (displayed in the action simulators) were those expected.

6.2 Participants

The test user group is made up of real users (i.e. experts in the paper sector), familiar with using web applications, but no additional skills were required. Six participants were involved in the test (1 woman), all different from those involved in the interviews. Before the test, the participants had never used the applications to test in the trial. The average age of the participants was 45.3 years (min = 40; max = 53, SD = 4.7). Three participants have a high school Diploma, 2 users have a Master's Degree (one in Physics, another in Aeronautical Engineering), the latter has a Bachelor's degree in Electrical Engineering. Three participants declared to have no knowledge of programming languages, the others had limited/low knowledge, one user declared to have good knowledge of industrial programming languages. All users have good familiarity with the web. Their companies range from the production of tissue, to production of paper converting machines, to developing services for automation/industrial applications. Most of them have 50-250 employees, one company has more than 500 employees. One user is the head of the company's IT department, another is the sales manager for machine components; another participant deals with the sale of spare parts, another with the planning and coordination of maintenance and warehouse management, another deals with solutions for predictive maintenance, the last user is responsible for company's quality and safety. Most users have more than 10 years of experience in the paper industry, with 50% having more than 15 years. 5 users never used any tools for customizing applications before the test (one user mentioned the Voith OnCare tool).

6.3 Results

In Task1 users were asked to report two rules in natural language, which they considered significant. Examples of rules created are: If number of knife cuts = X, send to maintenance the following text "number of knife cuts = X, blade change required; If the traffic light associated with the line signals a reel deviation>10 kg, send a warning via email; If a man-down is detected, call the safety officer. If reel diameter = 10m, send message to production asking to change the reel". By analysing the rules, users generally exploited a rather simple structure (one trigger, one action). Three out of the 6 involved users referred to man-down scenarios in their rules, whereas the actions were generally of notification/alarm/warning type. Task2 required to build a (1 trigger, 1 action) rule the user considered significant (from Task2 onwards users were required to use the Rule Editor). All the rules built by users included sending an alarm as an action. Three rules correctly included an event trigger whereas in the other rules a condition trigger was used: the latter, when combined with an instant action (i.e. sending an alarm), would result in repeatedly sending the notification, a situation that does not always correspond to a desired one. However, all users at maximum experienced minor problems with Task 2. Example of rules are: IF operator is laying down, DO send one alarm by mail to sistema@company.com; When production department temperature becomes more then 40C, do send 3 alarms by mail to maintenance@mill.com; When production line1 efficiency becomes less than 80%, do send one alarm by SMS to 123456789. Task3 required to build a rule containing 2 triggers (combined through AND or OR), and one action. Examples of rules created were: i)When production department smoke becomes more than 100 AND operator is near production_line_1, do send one alarm by SMS to 123456789; ii) When production department noise becomes more than 98 OR production department humidity becomes more then 95, do send three alarms by mail to manager@mill.com; iii)If production line2 paper grammage is 17 AND production line2 paper waste is more than 10, do send alarm by mail to quality@farm.com. Most of the times the AND operator was used to combine the triggers, only twice the OR was used. Alarm type notifications were included as an action type, while the most used types of triggers were of Environment type and of User type. Most users completed Task3 successfully, in the worst cases with one or two errors, and no failure was reported. In Task 4 the majority of users (66.7%) experienced minor problems or successfully completed the task. For Task 5.1, all the users either experienced minor problems or successfully completed it. Task 5.2 was the most affected by errors: however, it was the most complex one, as it required both the specification of a structured rule (2 triggers, 2 actions) and its actual execution (using the simulators). Across all the tasks, the error in which conditions and events were used incorrectly was the most frequent one (38.2% of the total), followed by the one in which an attribute different from the one expected was used (23.5%). The average of the global values obtained by SUS (i.e. the average level of satisfaction of the sample) was 68.8, thus denoting a more than acceptable usability. Additional questions were included to collect feedback on other aspects of the solution presented. Some questions (Q1-Q5, see Figure 4) involved providing a score using a scale from 1 to 7 (1 = not very useful / appropriate; 7 = very useful / appropriate), and also a motivation for it. The other questions gathered qualitative feedback e.g. on the most positive and negative aspects of the approach, and willingness to adopt it. As it can be seen from Figure 4, overall users appreciated the usefulness of the approach. A user stated that since it is not possible to program "a priori" all the events occurring in a complex industrial environment such as a paper mill, a dynamic handling like the one proposed is extremely useful. Two users particularly appreciated its usefulness for managing safety and production: one noted that the control of the variables manipulated by production processes well suits with a trigger-action logic to promptly act on critical situations through corrective actions. Another user highlighted, as one of its main advantages, that the approach can benefit numerous aspects of the management of a paper factory, from handling anomalies and emergencies to quality control and logistics. Both the hierarchy of triggers and of actions were overall well received, although some suggested further expanding the available choices. The description of the rules in natural language was appreciated by the users, one of them stated: "*Those who specify the rule behaviour are often unskilled users, then the use of natural language simplifies rule understanding*". One highlighted that this can be useful to make the rule behaviour more easily understandable also to people different from the ones who created them, thereby serving as a useful communication mean. For the event/condition distinction, they judged it “clear and concise” and “simple to use”. However, when it came to actually exploit it within rules, it seems that not all of them completely grasped it, as well as the importance of the impact that a misuse of it could have at rule execution time.

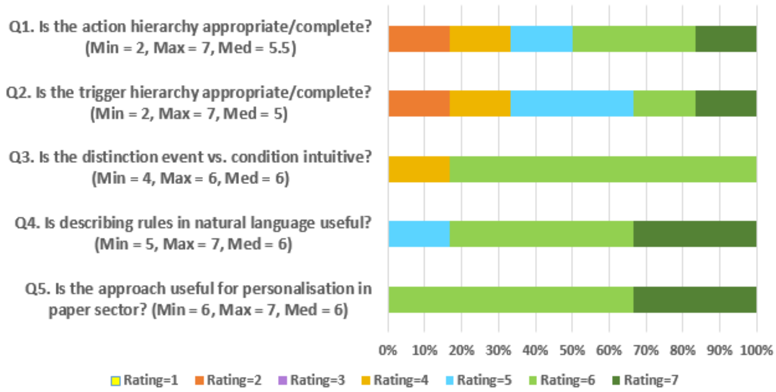

Figure 4: Chart with user ratings on some aspects of the Rule Editor Tool

Among the positive aspects of the tool (Q6), the simplicity of use and the clarity of its parts were indicated. One user reported the good potential of the solution in his own company, another user found the possibility to specify alerts through various channels very interesting. As for negative aspects (Q7), one user would have preferred more options for triggers/actions, another said that he would have preferred additional mechanism (i.e. flowcharts) for displaying rules. When asked whether in their companies they already faced similar customization needs (Q8), two users affirmatively replied: one pointed out that they are using a Manufacturing Execution System that integrates functions to send emails or feed SQL tables in a manner suitable also for unskilled users. Another one reported that they are creating a dashboard both at the management level and at the level of the single production plant to handle the underlying processes in a facilitated manner. Another user reported that they are considering this type of issues for situations such as downtime and/or emergencies. Two stated that these issues have not yet been addressed in the company. The last one is not aware of any initiative in this regard.

There was also a question about whether they would recommend the use of a tool like the one proposed in their company (Q9): four users answered positively. A user stated that the proposed tool could be a "plus" to be included in the automation package associated with the machines. Another user found the tool intuitive as it only requires the minimum level of understanding of if-then constructs. Two users stated that the tool has certainly good potential for exploitation in IoT and I4.0 scenarios and would be useful in their companies even though it should be further adapted to consider the multitude and the variety of objects and appliances that can be found in companies working in this domain. One especially found a high potential in making more understandable the policies that are in place in a factory also to not strictly technical people. Further suggestions to improve the tool/approach (Q10) were to include graphics (such as Zabbix[1], one said) to improve the monitoring view offered to users, and to provide a sort of "production line layout" where triggers are also visualised through their actual position on the machines.

7 Discussion

From the data collected it emerges that the tool was generally appreciated by users, even if the limited number of test participants does not allow generalization of the gathered data, but to consider them only qualitatively e.g. as indicative of possible opportunities and promising directions, or problematic areas encountered.

One of the positive data –and encouraging for any future development of the platform– is that, despite the participants never had the opportunity to use the tool before the test, they were able to use it with good results, also expressing high appreciation on its potentiality in the paper domain. This is especially relevant considering that the participants were real professionals, mostly senior managers operating within paper-related companies, thus having limited time available to devote to activities not strictly connected with their own work.

The proposed approach was found promising to them not only because it supports personalisation of the functioning of a complex, context-dependent system like the one typically found in companies working in this sector, and without requiring from users

[1] https://www.zabbix.com/

specific programming skills. Also because, by using rules, which are also rendered using natural language, the approach supports easy communication between different stakeholders, as it allows for externalizing the knowledge of a worker to others, and this knowledge can be easily adapted to fit other scenarios.

Also the fact that the considered approach exploits a uniform interface was particularly appreciated by them, in that it facilitates dynamic optimization of factories to the highly different aspects and scenarios that can emerge in the various involved departments, in an unifying and integrated manner. While the goal of this work was more on assessing the opportunities that introducing such approach could offer to workers in this domain in more general terms, some participants highlighted that the presented tool, while providing a promising innovative direction, should be further adapted to support the needs that can be found in real scenarios e.g. in terms of number/variety of things and appliances. One aspect to this regard would be to provide enhanced visualisations for presenting in an effective and efficient manner the multitude of sensors, things, appliances and actuators that can be available in Industry 4.0 scenarios in a way that remains usable, effective and efficient for the worker users. For instance, one option could be to provide users with the possibility to filter the hierarchies of triggers and actions, to take only the elements that are typically of interest for the considered user role. Another one could be to consider even recommending specific elements to users (i.e. when some actuators are often used with specific sensors), which can also represent interesting future work.

8 Conclusion and Future Work

The work presents the application of a trigger-action platform in the paper domain. For this purpose, a set of relevant concepts and requirements have been identified through some interviews carried out with real professionals in the paper domain, which were used to suitably configure the personalization platform for the considered sector. The approach was assessed through a user test with domain experts, which provided encouraging feedback regarding the potential adoption of the proposed approach in industrial settings. Future work will consider extending the personalization tool integrating it directly in industrial settings, also considering the possibility of further, improved visualizations (e.g. considering Augmented Reality –based techniques), as well as carrying out further empirical studies in such contexts of use.

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