Monitoring and control framework for business processes in ubiquitous environments

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***Abstract*—Business processes in production and logistics need to be monitored in order to comply with official regulations, to schedule and plan the production or transport route, to ensure quality and find errors, but also to optimize the process itself. Often this monitoring needs to be done in real-time, e.g. to be able to see a potential error and take corrective actions in time. To monitor only traditional Key Performance Indicators might not be sufficient though as automatization in production and logistic environments advances, the number of sensors and actuators increase and make the systems more ubiquitous but also more complex and the focus of costumers moves from pricing and quality to environmental aspects. This paper presents an architecture of a process-oriented monitoring and control framework which uses visual process models to cope with the complexity of these systems and combines it with sensors and actuators. This way, processes and process steps can be monitored in detail by enriching sensor data with process information to enable detailed analysis, such as energy consumption in production or the maintenance of a cool chain in logistics. The architecture will be explained with the help of a realistic scenario from the food-supply-chain domain.**

Keywords—business processes, monitoring, sensors, process-oriented

I. Introduction

There are different reasons why companies need to monitor and control their business activities and processes: official regulations, the planning of the production or logistic processes, finding and correcting errors during the activities' execution, using the monitoring data to optimize the process or to increase resource-efficiency. One way for the companies to monitor these activities is to identify important goals and success factors and use them to define Key Performance Indicators (KPIs), such as produced items or number of orders. These KPIs are monitored in order to find errors and deviations from the original planning, so that the company can react effectively and dynamically on the market. One approach to monitor KPIs is Business Activity Monitoring (BAM), which focuses on monitoring and control of business processes and activities in real-time [1][2].

There are other values than KPIs which are interesting to monitor though, even if they are not directly connected with the success factors of a company, such as energy consumption during single process steps, CO_2 emission or the wearing-out of machine parts. The latter is a concept used in predictive maintenance in order to prevent downtimes and therefore save money. The data gained from monitoring energy consumption during single process steps can be used to optimize the process and therefore reduce costs. But there is another important factor to consider: for European citizens environmentally-friendly products become more and more important. A survey published by the European Commission[1] indicates that 77% of the interviewees "are willing to pay more for environmentally-friendly products if they were confident that the products are truly environmentally-friendly" and in comparison to 2009 there was an increase of 25% of people who stated that environmental impact is more important than the price. Therefore optimizing energy consumption and reducing the CO_2 emission can help to sell products or services. There are other advantages when monitoring single process steps: it can identify errors and therewith help localizing them more precisely within the process in contrast to general monitoring.

Monitoring single process steps means that the steps of a process are actually known and ideally documented. There are different possibilities to monitor a process, but also several requirements: The system shall be easy to understand and configure for non-engineers. There shall be visualization for the process and for the monitoring part. Overall it is to reduce the complexity which is inherent to production and logistic systems. It is to include different sources, e.g. legacy systems and production systems. Also sensors and actuators as sources and means of interaction need to be considered as they become more present in production and logistics as the internet of things and services advances, information technologies become more ubiquitous, and production floors and logistic processes become more interconnected and intelligent. This trend also manifests in the idea of industry 4.0, which describes a fourth industrial revolution based on cyber-physical systems [4]. Looking at the concepts and plans in the Industry 4.0 context, we can see that similar problems as described above are addressed. In [4] it is suggested that the complexity of products and production systems increase due to increasing functionality, individualization of products, and integration of different disciplines. Models are to be used to reduce this complexity, not only during planning, but also during runtime, to monitor production and to predict failures and wear-outs of machine parts.

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[1] http://ec.europa.eu/public_opinion/flash/fl_367_en.pdf, 11.01.2016

In order to achieve the above goals to have documented and monitored processes and also reduce the complexity by using models, we model the process and use these models to monitor and control the real process with the help of process engines connected to sensor networks or IT systems. There are several reasons to model processes with the Business Process Model and Notation (BPMN): BPMN standardized by the Object Management Group (OMG); it is widely used in industry; it can be executed by a process engine; and it was designed as a means of communication between different roles such as software architect and business analyst [5] and therefore is understandable also for non-engineers.

This paper describes the architecture of a developed framework for monitoring and control based on business processes. The concept of processed-oriented monitoring has already been verified for a production line of an automobile manufacturer [3]. This paper describes a use case in logistics, or to be more precise in food traceability, for explaining the architecture in order to show that the framework can be used in the logistics domain as well. The rest of the paper is structured as follows: chapter 2 shortly presents the state of the art. Chapter 3 describes a use case for the application of monitoring and control with the help of business processes. Chapter 4 describes the architecture of framework to implement and run such a monitoring system and chapter 5 summarizes and gives an outlook on future work.

II. STATE OF THE ART

There are many different monitoring systems available on the market for logistic and production environments, which mostly monitor KPIs. In case of production they surveil produced items and reject ratio, or overall equipment effectiveness (OEE). There are also applications which monitor energy consumption of machines to reduce peak loads and adjust energy intensive production processes. In logistics KPIs might include transport times or GPS coordinates. However, these approaches do not tap the full potential of cyber-physical systems and analysis possibilities based on process information.

In literature there are other approaches though, such as combining complex event processing (CEP) with Business process management. CEP is used to gain knowledge from low-level events by analyzing them and combining them to new events [7][8]. In [9] a framework is described which combines business process execution and complex event processing in order to detect possible problems and delays in packet delivery, so that appropriate measures can be taken. [6] describes an approach called Event Driven Manufacturing Process Management which includes Event Driven Architecture, Complex Event Processing and Business Activiti Monitoring into process models. A process engine executes process models, finds complex events and then throws them so that other running applications can handle them. At the same time KPIs can be measured and calculated. This approach is lacks the explicit combination of sensor data with process data though, which will be included in our work.

Another alternative found in literature is the extension of a process modelling language like BPMN or the Business Process Execution Language (BPEL) and extend them to include certain concepts, such as BAM [2] or Wireless Sensor Networks (WSN) [17], but besides the need to adapt or develop an appropriate process engine to be able to execute the process, the process models itself become more complex and harder to understand.

III. EXAMPLE USE CASE

The replenishment of perishable goods is a domain where increased process transparency and more accurate process modeling can help exploit considerable efficiency reserves. An example are fresh food supply chains where both time limits and requirements regarding ambient conditions (temperature, humidity, exposure to light, etc.) have to be observed. Due to the fact that limited information is available about individual entities taking part in the process as well as individual events within the processes, guaranteed compliance with quality requirements (typically freshness, absence of contaminants) calls for wide safety margins to be applied [13]. This, again, implies losses due to discarding products that are suspected to be no longer compliant with the requirements. Moreover, fresh food supply chains have stringent real-time aspects that are often poorly addressed due to sub-optimal decisions (e.g., dispatching, stock keeping) made in the absence of sufficient process information. To make things more difficult, fresh food supply chains are also characterized by the co-existence of participants of vastly varying size, technological ripeness and understanding of business and material handling processes. Therefore, a solution improving process transparency in a fresh food supply chain must be accessible to a wide spectrum of participants to the degree their form of participation requires. Another aspect related to transparency is the traceability requirements specific to the food industry. As of today, “one-up-one-down” approaches are common practice (i.e., each participant keeps records of immediate predecessors and successors in the supply chain), however, national or cross-border end-to-end traceability services are now in the process of being rolled out due to the general vulnerability of “one-up-one-down” techniques [16]. While such global services will transcend organizational and national borders [10][11][12], their function will likely be limited to safety assurance, unambiguous assignment of responsibilities, and some simple additional functionalities—it is thus foreseeable that food supply chains will handle additional data for their internal process analytics, and simplified derivatives will be passed on to the global traceability services [16].

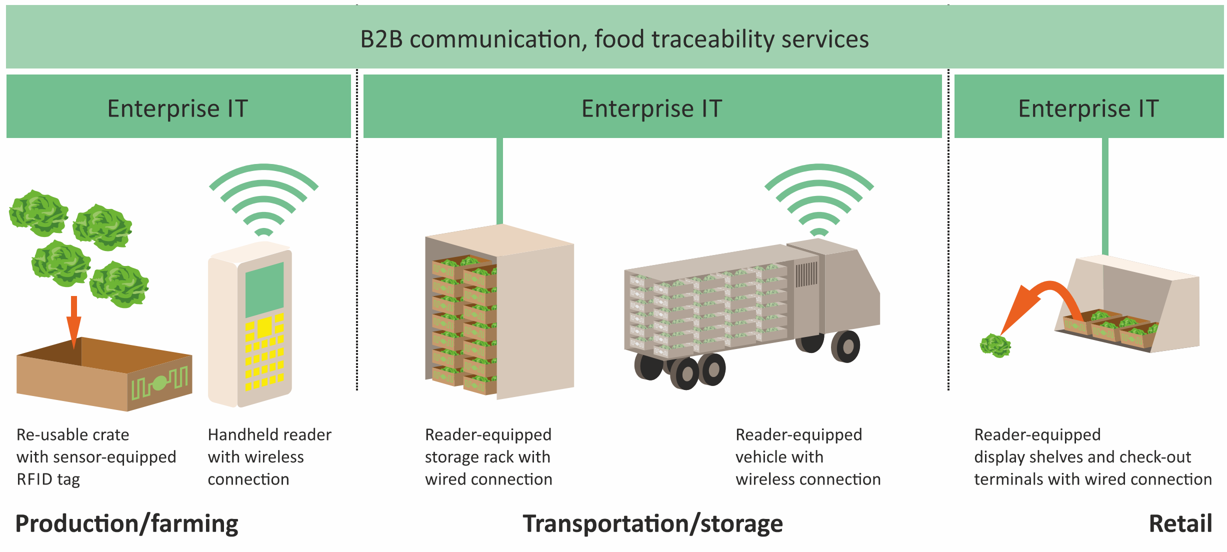

Figure 1 Track-and-trace components used in the material handling processes of the scenario outlined in Section III

The use case described here combines the tracking of (re-usable) logistics assets and goods that pass through the network in a flow-through manner—some classification schemes of track-and-trace practices refer to this approach as *asset-based tracking of goods*. Fresh food is often transported in crates that are convenient to handle by personnel, or stacked for more efficient handling when suitable machinery is present. Typically, such crates can be made re-usable if their material and geometry allow cleaning and disinfection—this makes them suitable for the permanent installation of sensor-equipped RFID tags that provide both measurement data and unique identity, enabling in-depth transparency of both material streams and handling conditions.

Crates and attached tags retain their identity during their life span in the supply chain, however, the identity of material transported in the crates is updated upon packing or unpacking operations. Fresh food being typically low profit margin and low per-unit cost commodities, it is not expected that all types of goods in the supply chain receive their own physical unique ID carrier (these are likely to be one-way low-cost bar codes if any are used [16]), nonetheless, their virtual representation in the underlying information system will be broken down to unique items or lots associated to specific re-usable assets.

RFID reading devices (transceivers) connect to the next hierarchical level in the track-and-trace infrastructure, i.e., transceiver nodes equipped with one or more RFID readers, pre-processing, user interface for on-site handling personnel, and communication capabilities towards the rest of the IT infrastructure. A transceiver node can either be mobile (e.g., mounted on a truck or installed in a container), or stationary (e.g., a storage bay in a warehouse).Transceiver nodes can also have other peripherals attached, e.g., wired sensors or GPS receivers. Messages sent by the transceiver node are status information regarding the material/assets (own ID, crate IDs, sensor information) and the crew in contact with the node (truck driver ID, handling personnel ID). Messages received are low-level instructions regarding contained material (move to destination, pack, unpack, discard, check) and crew (authorization feedback, calling for more/different crew, etc.)

At smaller supply chain participants, transceiver nodes can connect to a stand-alone site/fleet management server. Larger supply chain members, on the other hand, have an elaborate enterprise IT infrastructure already in place. Transceiver nodes can, then, be integrated into the system by coupling them to middleware or to a message broker that connects to the rest of the enterprise IT system. In both cases, records for global traceability services are generated by dedicated adapters in the higher levels of the IT infrastructure, having much in common with B2B data exchange. Possible ways of integration into a full-fledged enterprise architecture will be presented in Section IV.

A complete farm-to-fork process (from producer to retail) for fresh products (e.g., raw lettuce not requiring further processing before reaching the end consumer) would then look roughly as follows: (1) Material is packed into the assigned crates. This occurs in the operating range of a transmitter node which registers the crate ID and sends appropriate messages initiating the assignment of the given lot of products to the crate detected. (2) The packed crates are then picked up by the next member in the supply chain and begin to move, possibly over several intermediate stages of storage, redistribution and transport. During this process, the mobile transceiver node installed in the truck sends up-to-date status information to the stand-alone server or middleware of the operator of the node where interpretation of the data in view of known demands and capacities, as well as issuing of commands as needed, is taking place already at higher abstraction levels (application and analytics layers in Figure 3). Decision mechanisms can be very complex if the entire potential of transparency is to be exploited [15]—for example, a given truck-load of vegetables can be directed to different distribution or storage sites, depending on freshness estimated by available information on handling conditions and time. (3) Towards the end of the supply chain, material streams may ramify due to the

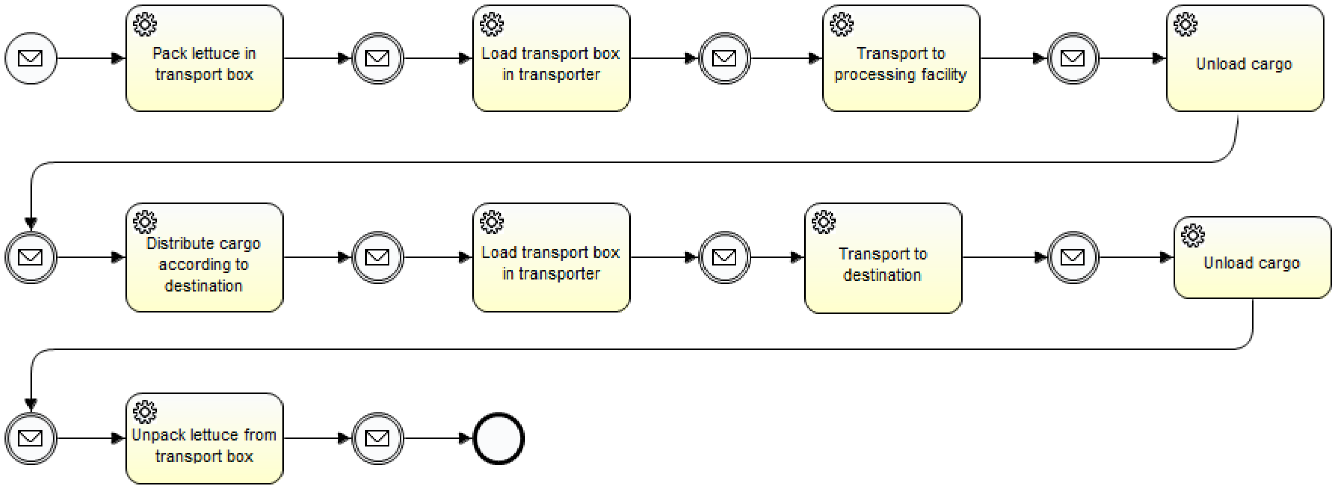

Figure 2 Simplified lettuce transport process

distributed nature of retail chains and individual retail points. The fragmented structure of redistribution and retail narrows down the focus on individual orders, and typically, little is communicated between parallel replenishment paths about capacity or stock shortages, as well as stock in storage facing expiry. In a more transparent supply network, spare capacities or stock could be subject to negotiation on a B2B level, and sufficient transparency of processes towards unbiased intermediaries (facilitation services) would enable useful "shortcuts" or mitigation actions preventing losses at minimal risk of disclosing confidential business information. (4) At some point on the way to retailing, the individual goods are unpacked from the crates—this has to occur in the range of a transceiver node to automatically dissolve the product-to-crate association, or some other logging process must be introduced as a substitute. If the crate serves as a display case, this last step can also occur simultaneously with retail/check-out processes. Figure 1 gives a brief summary of the types of track-and-trace components used in the use case outlined above.

IV. Architecture

The framework is organized within a layered architecture as depicted in Figure 3. The lowest layer is the data layer, where data is being collected, for example from sensor networks, transceiver nodes, manufacturing execution systems, or logistic software. In case of our scenario, this means that we have transceiver nodes equipped with one or more RFID readers at the places where the transport boxes are packed, unpacked, loaded or unloaded (see Figure 2). During transport there are GPS receivers and sensors measuring transport conditions (e.g. temperature, humidity). Information about the route such as weather or traffic can as well be included as average mileage.
The data is then sent through the communication layer, e.g. through a MQTT message broker or a middleware, to the application layer, containing the application logic and the business process engine. The business process engine executes the model of the process which is being monitored, in our use case the one displayed in Figure 2. Sensor events from RFID readers trigger the start of a new activity within the process, e.g. when the RFID tag is read during loading the transporter. When the transport crate is first scanned, a new process instance will be started. The application logic will combine events from other data sources with the information of the process and stores in the data base or forwards it to an analytic component. If there are any deviations from the original plan, they can be detected and counter measures can be taken. For example, if the cooling system does not work correctly and there is a danger that the cooling chain will interrupted, the transport can be rerouted to a nearer destination (for simplicity reasons this is not depicted in the business process in Figure 2). The analytics layer can then calculate reports from the data which might be interesting for the supply chain participant. Information about the processes, the process instances and the reports can then be displayed in a human friendly manner on the dashboard in the interface layer.
It is possible for different supply chain participants to only have the data layer and maybe the communication layer implemented in their systems as long as there is one overall instance monitoring and analyzing the data. It is also possible to divide the monitoring responsibility of the process among supply chain participants as long as there is sufficient transparency of the overall process.
Besides the different architecture layers there are tools which help with the developing of the application: modelling tools for modelling the business processes and the domain and a mapper which helps to connect the data sources to the process steps of the business process. The resulting models are used in the application layer as input for the application: the process model in the business process engine and the mapping of data sources and process steps in the application logic.
There is also a simulator under development [3] which consists of a transformer, a business process engine and the simulation logic. As the data sources such as temperature sensors, are not modelled as part of the business process, there will not be any simulated data for these data sources in a

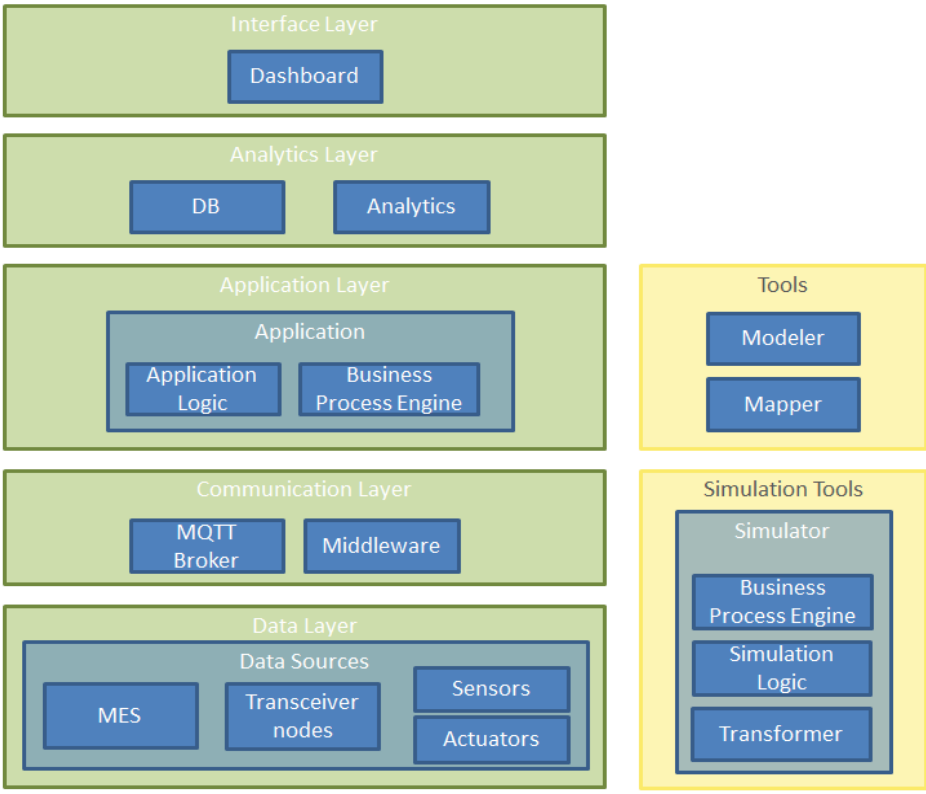

Figure 3 Framework architecture

normal BPMN simulation where parameters like number of process instances, resources such as employees, duration of an activity and costs, branching probabilities and the like can be defined. The transformer takes the business process model defined and the information which was delivered by the mapper and transforms it to process model which can simulate the missing values. This process model then can be executed by the business process engine of the simulator. Additional logic is implemented in the simulation logic component. The simulator replaces the data layer and the communication layer in a real-world environment.

V. CONCLUSIONS AND FUTURE WORK

A monitoring and control framework for monitoring business process in cyber-physical systems is being developed. In previous work it has been verified with a use case from an automobile assembly line [3]. This paper introduced the architecture of this framework as well as a use case from the logistics domain in order to show that the framework can be applied to different domains. The use case describes the transport of perishable goods, where it is important to monitor certain aspects like temperature, humidity, quantity, or location in order to make sure that the goods are transported according to traceability regulations and also to make correct dispatching and stock keeping decisions. To increase process transparency, a BPMN model of the logistics process was created. With the help of the framework, sensor readings and actuators could ensure constant monitoring and control capabilities. The architecture consists of a data layer, a communication layer, and application layer, and analytics layer and an interface layer. Not all layers are necessary for all participants in the logistic chain. Small supply chain participants may only have the data and the communication layer.

When developing and deploying the system, measures for data securities need to be taken, such as a secure data transport, secure data storages and data access control. Another aspect which needs to be considered is time synchronization in the system for correct event time stamps and robustness in case of event loss.

Next steps will include a simulation with sensor data for the described use case to see, if this solution improves upon monitoring systems on the market.

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