An IT-platform prototype as enabler for service-based business models in manufacturing industry

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Abstract

To an increasing extent manufacturing companies explore possibilities and opportunities of service-based business models in order to offer services that increase the value for the customer and provide higher margins than their conventional product sales. However, in most industrial cases transformations towards more service-oriented businesses are regarded as extremely challenging since the prevailing structures of conventional product sales do not support service activities. In particular data collection and analyses during product use phases are seen as key enabler to identify and tap service-based business potentials. These circumstances pressure industrial information and communication technology with new requirements to also embrace product use phases. In this context, this paper presents the development of a platform prototype in order to support manufacturing companies to move towards service-based offers of their products. The prototype contains a flexible event-based architecture to capture and analyse data which has been created during use of physical products. Finally, the prototype has been verified using simulated data from an agent-based program. The results show that the platform is able to process empirical data generated during product use phases and thus tighten the connection between manufacturing companies and their customers. In line with previous development within the agent-based modelling domain this work adds another case study where agent based models have been used as validation method for new product-service systems at pilot stage.

Keywords: information technology, business models, service-based, event-driven

1. Introduction

There has been an increasing interest in tapping the potential of service-based offers in manufacturing industry [1], especially in Swedish industry [2][3]. Both original equipment manufacturers (OEMs) and customers have become more interested in the function or capacity that a physical product is able to deliver rather than possessing the physical product. Customers appreciate service-based offers due to economic benefits, ease of access and lower environmental impact. Manufacturing companies have realized that service-based models can deliver strategic advantages and change their markets [4]. In turn there are opportunities to become market leader in their particular area or to compete with lower-priced competitive offers. However, in manufacturing industry a transformation towards more service-oriented businesses is extremely challenging since the existing infrastructure of conventional sales business does not support service activities. Infrastructures are necessary that allow for efficient collection, management and communication of information [5][6]. In particular data collection and analyses during product use phases are seen as key enablers to identify and tap service-based business potentials. With regard to information requirements and management in service-based business models knowledge gaps have been identified [7]. These circumstances pressure industrial information and communication technology with new requirements to also embrace product use phases, which means to connect to and treat customers as integral part of the manufacturing enterprise. In this scenario, this paper presents the development of a platform prototype in order to support manufacturing companies to increase their competitiveness by moving towards service-based offers of their products. This development is addressing small and medium-sized companies (SMEs) in particular given their specific needs and limited resources for development work in comparison to global companies. The prototype contains a flexible event-based architecture to capture and analyse data which has been created during use of a physical product. The verification of the prototype is based on simulated data from an agent-based program. The paper is structured as follows.

Section 2: Conceptual background and state-of-the-art
Section 3: Description of the development
Section 4: Proof of concept and visualization of results
Section 5: Conclusions

2. System architecture and event structure

This section elaborates fundamental concepts while keeping the example of a farming vehicle as a reference to give practical examples of the conceptual descriptions. Conceptually the work shown in this paper is related to developments of service-oriented architectures (SOAs) containing event-driven approach. At this point, it is necessary to emphasize that the terminology of “service” in the context of service-based business models (SBBMs) is not the same as in the context of SOAs: SBBMs constitute the scope of the presented work describing the (evolutionary) change when gradually moving from selling physical products towards selling service content, thus increasing the share of service as value proposition [1]. SOAs on the other hand are distributed software architectures containing independent applications that are able to connect and interact with each other. One major benefit of using SOAs is easier handling of integration processes with existing systems and functionalities [8]. SOAs have established themselves at business level and are expected to further spread within manufacturing industry [9]. Recently, developments in the area of SOAs have been done in manufacturing context [10], which are taken as fundament for the forthcoming description.

Bringing the advantages of SOA from business level down to product operation level requires an event-based approach. In this scenario event-driven architectures can be perceived as a more advanced SOA (event-driven SOA). In event-driven architectures event creators only need to be aware of if an event occurred, however without the knowledge about the receiver or how the event will be processed afterwards [11].

In order to make event-driven SOA applicable to SBBMs product operating states need to be defined, which then enable the definition of events. Figure 1 shows an exemplary case of a farming vehicle in use. The vehicle operating states consist of:

- Driving
- Working
- Waiting
- Planned down
- Unplanned down

The basic events which describe use cycles of a vehicle are initiated when switching from one state to another. Using a prototype-based approach [12] events are created and sent when a change from one operating state to another operating state occurs. The sent event contains information about that particular change.

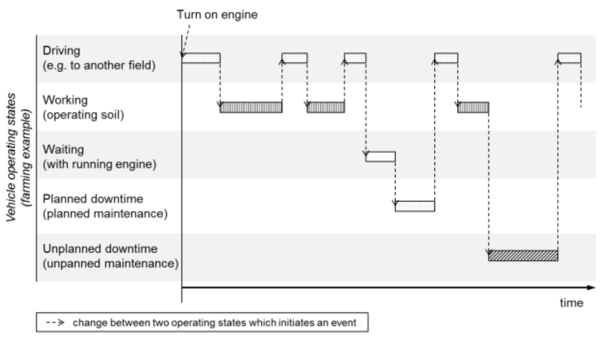


Figure 1: *Exemplary vehicle operating states including changes between these states*

The structure of an event can then be defined as follows based on [13]:

$$e = < id, t, AV> \quad (1)$$

where

e = the event that is being sent
id = unique identification number (format: integer)
t = timestamp (format: yyyy-mm-dd hh:mm:ss)
AV = set of attribute value pairs to describe the event being sent (format: $attribute_1$: $value_1$, …, $attribute_k$: $value_k$)

In order to benefit from these basic (raw) events in the context of service-based businesses they need to be enhanced and aggregated to enable decision-making through the use of service performance measures (SPMs). Thus, raw events are enhanced with additional information by appending further sets of attribute value pairs AV' for which AV' ∈ AV is valid. This enhancement functionality is called *fill*. Returning to the example of farming equipment, an additional enhancing attribute pair during the course of operating soil on a field could be the outside temperature provided through an external database.

For aggregation purposes events that have been created and sent while changing states can be used to create new events (i.e. events can be "folded"). In this process a function called *fold* transforms a sequence of events *s* into one new event e=fold(*s*). As a result of folding transformations SPMs such as downtime, uptime per machine (farming equipment) can be quantified for a given time period, thus enabling detailed analysis about utilization and maintenance efforts. Depending on the attributes included further SPMs can be calculated.

3. Development of an IT-platform prototype for service-based businesses

Figure 2 shows the data flow of platform prototype for SBBMs taking farming equipment as an example.

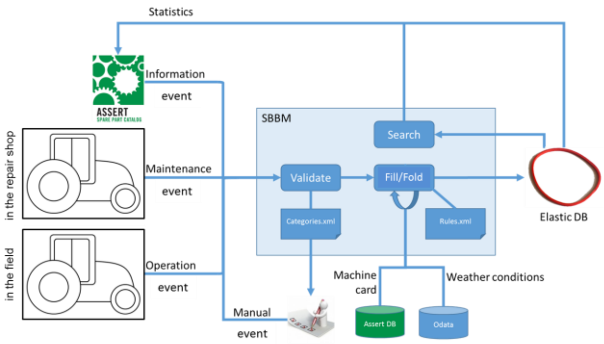


Figure 2: *Data flow using an example from farming equipment (tractor)*

Various types of events are collected, categorized and validated. The main categories operation, maintenance, information and manual contain subcategories. Subcategories for operation events consist of e.g. operating, driving, waiting, while subcategories for maintenance events consist of preventive and reactive maintenance. Preventive maintenance in this case signals a planned maintenance activity (planned downtime) and reactive maintenance signals an unplanned maintenance activity (unplanned downtime). Additionally, information events in the form of order events (e.g. the placing of spare part orders) are considered and associated with symptoms identified during maintenance. For this purpose Assert is used, which is an online spare part catalogue. Lastly, manual events from service personnel are included (e.g. through servicing activities).

Within the SBBM-frame all events are categorized based on the aforementioned sources. In the following step events are enhanced through a fill function using data from existing internal (Assert DB) or external (public) databases. The internal database provides additional machine-specific data, such as data from the machine card (model ID and machine ID). An external database adds further context-relevant attributes such as the weather condition during time of farming operation (e.g. temperature).

Moreover, fold functions are used to create new events for SPM calculation and visualization. In this example, a fold function is triggered by the event of the type *reactive maintenance*, thus initiating a query for the identified machine ID. The result of this machine-specific query is a fold event containing data about all failures, maintenance efforts as well as existing spare part orders for that particular machine (screenshot shown in the following section 4, right-hand side of Figure 5). Practically, a fold function is realized via a set of context-specific rules (see rules.xml in Figure 2).

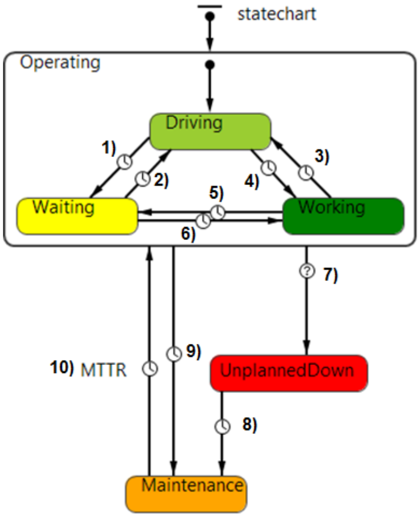


Figure 3: *Statechart of an agent-based model for simulating industrial vehicles*

The rationale of creating new fold events based on the rules template consists of the following three steps:

1) Identification of the trigger (e.g. a particular subcategory of event)
2) Testing of pre-defined condition(s) (e.g. is a specific set of SPMs exceeding a threshold)
3) Initiation of a new event (fold) with all relevant data, if the test performed at 2) has been positive

All events are finally stored in a search database called ElasticSearch [14] enabling fast text search. The fast search supports quick calculation steps and visualization of relevant statistics. Search results and queries are finally shown on a graphical user interface as part of the Assert user interface.

4. Proof of concept and visualization of results

4.1 Simulation setup

Since the project scope did not include an industrial case company at the point of development a simulation program has been used in order to generate data to test the prototype's functionality. An agent-based simulation program based on Anylogic 7.2.0 has been written, which is operating in Java SE.

Agents are representations of entities which are able to take decisions or act, by which it is interacting with its environment [15]. Formally, agent based models are represented by states, rules and actions. A state is a specific collection of parameters defining an agent [16]. If agents change from one state to another or if agents are meant to carry out actions a description of rules is required. Rules in this context can be understood as logical rules which may contain mathematical formulations.

Two fictional examples have been assumed in order to generate context-specific data. Figure 3 shows the underlying statechart and Table 1 the corresponding data input used in the agent-based program to the model behaviour of industrial vehicles. In the software of Anylogic statecharts are used to describe event-driven and time-driven behaviour of agents. In Figure 3, the boxes (states) are connected with arrows (transitions) defining time and the state the vehicle agent is in as well as the conditions under which that vehicle agent will transit to another state. Table 1 gives an explanation about each of the states and transitions including a description of actions for vehicles.

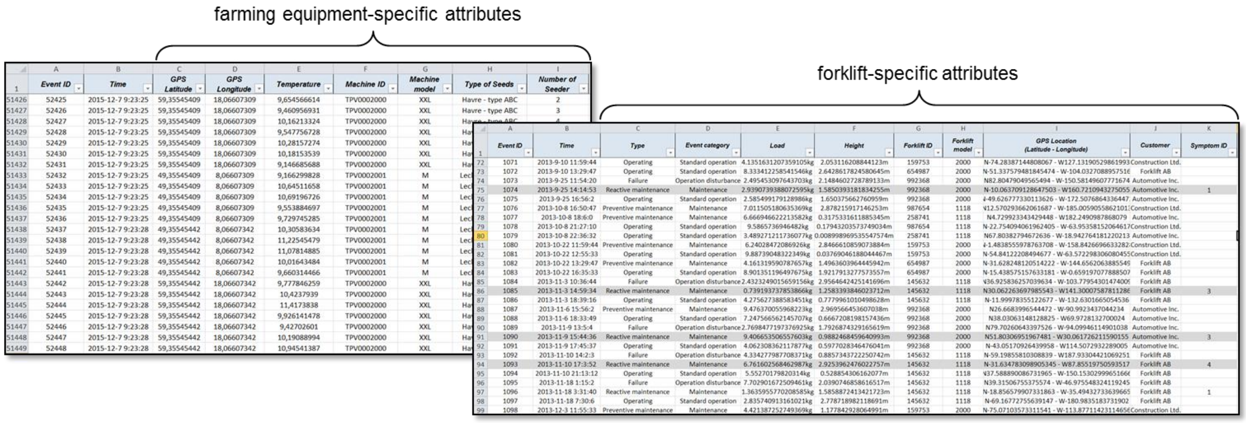
Table 1: *Generic state variables of an industrial vehicle*

Entity	*State variable / type*	*Value / Range / Distribution*
Vehicle agent		
Vehicle ID	Integer	Integer of 6 digits
Transition	1) Timeout	uniform: 0,2-0,5 hrs
	2) Timeout	uniform: 0,5-1 hrs
	3) Timeout	uniform: 3-4 hrs
	4) Timeout	uniform: 0,2-0,5 hrs
	5) Timeout	uniform: 3-4 hrs
	6) Timeout	uniform: 0,5-1 hrs
	7) Conditional	if *capability to operate* ≤ 0
	8) Timeout	normal: 0,5-3 hrs
	9) Timeout	8 weeks
	10) Timeout	normal: 1-15 hrs
Wear out factor	Double	0,033
Capability to operate	Double	0 - 1
Spatial and temporal unit		
Temporal unit	time step (day)	Simulation time
Spatial unit	spatial unit (m)	random

In order to simulate unplanned breakdowns a specifically defined function is used: For the duration that an agent is in operating state (i.e. driving, waiting or working) the variable *capability to operate* is reduced by the *wear out factor*. If the capability to operate has reached the value of zero transition 7) is triggered (Figure 3). After every maintenance activity the variable *capability to operate* is set to one.

4.1.1 The farming case

In line with the Figure 1 it is assumed that one farming vehicle operates in three distinct states (driving, working, and waiting). When not operating, the farming vehicle is assumed to be under maintenance (state: Maintenance). The state of maintenance can be either reached through a planned maintenance schedule directly from operating or through an unplanned breakdown. It should be noted at this point that the primary purpose of the agent-based program is the generation of context-specific data for testing purposes of the IT-prototype.



	Event ID	Time	GPS Latitude	GPS Longitude	Temperature	Machine ID	Machine model	Type of Seeds	Number of Seeder
51426	52425	2015-12-7 9:23:25	59,35545409	18,06607309	9,654566614	TPV0002000	XXL	Havre - type ABC	2
51427	52426	2015-12-7 9:23:25	59,35545409	18,06607309	9,460956931	TPV0002000	XXL	Havre - type ABC	3
51428	52427	2015-12-7 9:23:25	59,35545409	18,06607309	10,16213324	TPV0002000	XXL	Havre - type ABC	4
51429	52428	2015-12-7 9:23:25	59,35545409	18,06607309	9,547756728	TPV0002000	XXL	Ha	
51430	52429	2015-12-7 9:23:25	59,35545409	18,06607309	10,28157274	TPV0002000	XXL	Ha	
51431	52430	2015-12-7 9:23:25	59,35545409	18,06607309	10,18153539	TPV0002000	XXL	Ha	
51432	52431	2015-12-7 9:23:25	59,35545409	18,06607309	9,146685688	TPV0002000	XXL	Ha	
51433	52432	2015-12-7 9:23:25	49,35545409	8,06607309	9,166299828	TPV0002001	M	Lec	
51434	52433	2015-12-7 9:23:25	49,35545409	8,06607309	10,64511658	TPV0002001	M	Lec	
51435	52434	2015-12-7 9:23:25	49,35545409	8,06607309	10,69196726	TPV0002001	M	Lec	
51436	52435	2015-12-7 9:23:25	49,35545409	8,06607309	9,553884697	TPV0002001	M	Lec	
51437	52436	2015-12-7 9:23:25	49,35545409	8,06607309	9,729745285	TPV0002001	M	Lec	
51438	52437	2015-12-7 9:23:28	49,35545442	8,06607342	10,30583634	TPV0002001	M	Lec	
51439	52438	2015-12-7 9:23:28	49,35545442	8,06607342	11,22545479	TPV0002001	M	Lec	
51440	52439	2015-12-7 9:23:28	49,35545442	8,06607342	11,07814885	TPV0002001	M	Lec	
51441	52440	2015-12-7 9:23:28	49,35545442	8,06607342	10,01643484	TPV0002001	M	Lec	
51442	52441	2015-12-7 9:23:28	49,35545442	8,06607342	9,660314466	TPV0002001	M	Lec	
51443	52442	2015-12-7 9:23:28	59,35545442	18,06607342	9,777846259	TPV0002000	XXL	Ha	
51444	52443	2015-12-7 9:23:28	59,35545442	18,06607342	10,4237939	TPV0002000	XXL	Ha	
51445	52444	2015-12-7 9:23:28	59,35545442	18,06607342	11,4173838	TPV0002000	XXL	Ha	
51446	52445	2015-12-7 9:23:28	59,35545442	18,06607342	9,926141478	TPV0002000	XXL	Ha	
51447	52446	2015-12-7 9:23:28	59,35545442	18,06607342	9,42702601	TPV0002000	XXL	Ha	
51448	52447	2015-12-7 9:23:28	59,35545442	18,06607342	10,19088994	TPV0002000	XXL	Ha	
51449	52448	2015-12-7 9:23:28	59,35545442	18,06607342	10,94541387	TPV0002000	XXL	Ha	

	Event ID	Time	Type	Event category	Load	Height	Forklift ID	Forklift model	GPS Location (Latitude - Longitude)	Customer	Symptom ID
72	1071	2013-9-10 11:59:44	Operating	Standard operation	4.1351631207359105kg	2.053116208844123m	159753	2000	N-74.28387144808067 - W127.13190529861993	Construction Ltd.	
73	1072	2013-9-10 13:29:47	Operating	Standard operation	8.333412258541546kg	2.6428617824580645m	654987	2000	N-51.337579481845474 - W-104.0327088957516	Forklift AB	
74	1073	2013-9-25 11:54:20	Failure	Operation disturbance	2.495453097643703kg	2.1484602728789133m	992368	2000	N82.80479049565494 - W-150.58149607771674	Automotive Inc.	
75	1074	2013-9-25 14:14:53	Reactive maintenance	Maintenance	2.9390739388072595kg	1.5850393181834255m	992368	2000	N-10.063709128647503 - W160.7210943275055	Automotive Inc.	1
76	1075	2013-9-25 16:56:2	Operating	Standard operation	2.585499179128986kg	1.650375662760959m	992368	2000	N-49.626777330113626 - W-172.5076864336447	Automotive Inc.	
77	1076	2013-10-8 16:50:47	Preventive maintenance	Maintenance	7.011505180635369kg	2.878215917146253m	987654	1118	N12.570293662061687 - W-185.0059055862101	Construction Ltd.	
78	1077	2013-10-8 18:6:0	Preventive maintenance	Maintenance	6.666946622213582kg	0.3175331611885345m	258741	1118	N4.729923343429448 - W182.2490987868079	Automotive Inc.	
79	1078	2013-10-8 21:27:10	Operating	Standard operation	9.5865736946482kg	0.17943203573749034m	987654	1118	N-22.754094061962405 - W-63.95358152064617	Construction Ltd.	
80	1079	2013-10-8 22:36:32	Operating	Standard operation	3.489271211736077kg	0.008998969535547574m	258741	1118	N67.80382794672636 - W-18.942764181220213	Automotive Inc.	
81	1080	2013-10-22 11:59:44	Preventive maintenance	Maintenance	6.24028472086926kg	2.8466610859073884m	159753	2000	N-1.4838555978763708 - W-158.8426696633282	Construction Ltd.	
82	1081	2013-10-22 12:55:33	Operating	Standard operation	9.887390483223349kg	0.03769046188044467m	159753	2000	N-54.84122208494677 - W-63.572298306080455	Construction Ltd.	
83	1082	2013-10-22 13:29:47	Preventive maintenance	Maintenance	4.161319590787657kg	1.4963603964445942m	654987	2000	N-31.628248120514222 - W-144.6562063885549	Forklift AB	
84	1083	2013-10-22 16:35:33	Operating	Standard operation	8.901351196497675kg	1.9217913277573557m	654987	2000	N-15.438575157633181 - W-0.659197077888507	Forklift AB	
85	1084	2013-11-3 10:36:44	Failure	Operation disturbance	2.4323249015659156kg	2.9564642425141696m	145632	1118	N36.925836257039634 - W-103.7795430147400	Forklift AB	
86	1085	2013-11-3 14:59:34	Reactive maintenance	Maintenance	0.739193737853866kg	1.2583393846023712m	145632	1118	N30.062263697985543 - W141.3000758781128	Forklift AB	3
87	1086	2013-11-3 18:39:16	Operating	Standard operation	4.275627388583451kg	0.7779961010498628m	145632	1118	N-11.99978355122677 - W-132.6301665054536	Forklift AB	
88	1087	2013-11-6 15:56:2	Preventive maintenance	Maintenance	9.476370055968223kg	2.969566453607038m	992368	2000	N26.6683996544472 - W-90.9923437044234	Automotive Inc.	
89	1088	2013-11-6 18:33:49	Operating	Standard operation	7.247566562145707kg	0.6667208198157436m	992368	2000	N38.03063148128825 - W69.9728132700024	Automotive Inc.	
90	1089	2013-11-9 13:5:4	Failure	Operation disturbance	2.7698477197376925kg	1.7926874329165619m	992368	2000	N79.70260643397526 - W-94.09946114901038	Automotive Inc.	
91	1090	2013-11-9 15:44:36	Reactive maintenance	Maintenance	9.406653506557603kg	0.9882468459640993m	992368	2000	N51.80306951967481 - W30.061726211590155	Automotive Inc.	3
92	1091	2013-11-9 17:45:37	Operating	Standard operation	4.062308362117877kg	0.5977028346476041m	992368	2000	N-43.05170926439958 - W114.5072932289005	Automotive Inc.	
93	1092	2013-11-10 14:2:3	Failure	Operation disturbance	4.334277987708371kg	0.8857343722250742m	145632	1118	N-59.19855810308839 - W187.93304421069251	Forklift AB	
94	1093	2013-11-10 17:3:52	Reactive maintenance	Maintenance	6.761602568462987kg	2.9253962476022757m	145632	1118	N-31.634783098905345 - W87.85519750593517	Forklift AB	4
95	1094	2013-11-10 21:13:12	Operating	Standard operation	5.55270179820314kg	0.528854306162077m	145632	1118	N37.588890086731965 - W-150.1530299651666	Forklift AB	
96	1095	2013-11-18 1:15:2	Failure	Operation disturbance	7.702901672509461kg	2.0390746858616517m	145632	1118	N39.31506755375574 - W-46.975548324119245	Forklift AB	
97	1096	2013-11-18 3:31:40	Reactive maintenance	Maintenance	1.3635955770208585kg	1.5858872413421723m	145632	1118	N-18.856579907331863 - W-35.494327336396655	Forklift AB	1
98	1097	2013-11-18 7:30:6	Operating	Standard operation	2.835740913161021kg	2.778718982118691m	145632	1118	N-69.16772755639147 - W-180.9835183731902	Forklift AB	
99	1098	2013-12-3 11:55:33	Preventive maintenance	Maintenance	4.421387252749369kg	1.177842928064991m	159753	2000	N-75.07103573311541 - W-113.8771142311465	Construction Ltd.	

Figure 4: *Excel-file extract after two simulation runs taking farming equipment (left) and forklift (right) as example*

In one simulation run two tractors are simulated in parallel planting seeds across a field. In doing so, each of the two tractors operates a number of seeders that place a seed into the soil keeping a defined distance between the planted seeds. Each time a seed is placed in the soil an event is created sending GPS coordinates, temperature at the time of seed placement, machine ID, machine model, type of seed planted and ID of the seeder that is planting the seed. The simulation time has been configured to be 18 hours on one day i.e. from 6:00 am in the morning until 12 pm, without breaks. More than 90.000 events have been generated and saved in an excel file (left hand side of Figure 4).

4.1.2 The forklift case

With the same statechart as shown in Figure 3 and used in the farming case, a small fleet of six forklifts has been simulated for the duration of three years. Events are generated when switching to and from the state "Operating" and "Maintenance". At the end of the simulation run roughly 330 events have been generated including data about type of event, event category, load and height of the forklift, forklift ID, forklift model, GPS location, customer and symptom (in case of unplanned maintenance). A data extracts for the forklift case is shown on the right hand side of Figure 4.

4.2 Visualization of results

The data obtained from the simulation runs is inserted in the prototype platform in order to test the platforms functionality to execute operations, such as filling, folding and storing of events in the database correctly. For the farming case a GPS view is generated in the graphical user interface showing average temperature at the positions of seeds at the time of placing the seed in the soil (Figure 5, left hand side). For the forklift case the history of one single forklift is visualized showing the unplanned downtime per month in hours including the symptoms at the (unplanned) maintenance. Furthermore, eventual orders that have been initiated are listed (Figure 5, right hand side)

5. Discussion of results

Both test runs have been operated without any severe problems. Technically, it was possible to retrieve the necessary information rapidly and to present it in the graphical user interface. The content showed a correct reflection of the data generated by the simulation runs. It can therefore be concluded that the prototype is sufficiently mature for an industrial case providing real-time data.

The results show that it is possible to log product use data on a very detailed level as empirical evidence to quantify use patterns. Despite the effort of categorizing various event types on a case-to-case basis the obtained data is highly useful when it comes to identify potentials for service-oriented business approaches. As a result tailored solutions can be proposed including specific service level agreements. In this view also the possibility of online monitoring of product conditions becomes an additional opportunity.

Another practical aspect consists of the possibility to evaluate the condition of a product based on its entire use history to make reasonable forecasts for take-back activities and value recovery such as remanufacturing.

6. Conclusions

This paper has presented the development of an IT-platform prototype in order to support manufacturing companies and particularly small and medium-sized companies to increase their competitiveness by facilitating the movement towards service-based offers of their products.

Using event-driven system architecture the presented IT-prototype platform is able to process empirical data generated during product use phases and thus tighten the connection between manufacturing companies and their customers. The platform is able to preserve all created events during product use phases, thus making it possible to change and add calculation and analysis services. The stored events can be updated and used in future applications.

The platform prototype has been tested in an experimental environment based on data generated from an agent based simulation program. Although the used data samples are based on simulated data high potential and benefits of collecting operational data from product use phases becomes apparent. As a result of the data collection and aggregation process decision-making and optimization of equipment uptime can be supported.

In line with previous development within the agent-based modelling domain this work adds another case study where agent-based models have been used as validation method for new product-service systems at pilot stage [17][18].

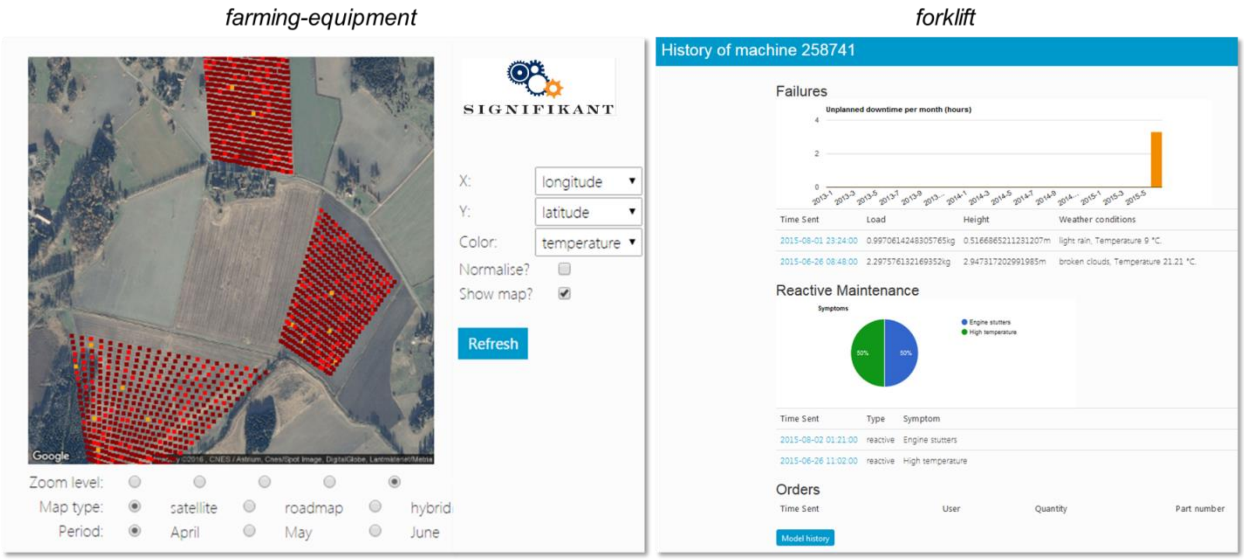


Figure 5: *Screenshots of the graphical user interface showing GPS view based on a farming example (left) and failures, maintenance efforts, symptoms and orders based on a forklift example (right)*

As a future step the presented prototype needs to be tested with an industrial case. In this context, a scale-up of data and increased numbers of decision-making rules will be necessary to enable more sophisticated identification of improved service-based propositions including service level-related contracting. Simultaneously, legal aspects of product data usage and storage need to be investigated.

Acknowledgment

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