Engineering IoT-based Software Systems for Forestry: A Case Study

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***Abstract*—The Internet of Things (IoT) is a rapidly growing technology that offers huge possibilities for optimizing processes and increasing productivity in various domains. The IoT technology connects software services, devices, various types of sensors, and machines to the internet and enables real-time data collection, analysis and sharing. However, ensuring the quality of the IoT is a complex challenge for software engineers and requires new development skills, as well as coordination of third party service providers. In this case study, we use embedded single case design with two Internet of Things experiments to study the quality factors in IoT system implementation. The research problem of this study is: How quality aspects should be taken into account while designing and implementing IoT-based software systems for forestry inventory management? The main contribution of this paper is to present lessons learnt from two experiments with different monitoring targets: liquid level monitoring and continuous mass monitoring of oil canister pallets. Both IoT experiments were performed in facilities of the second largest forest harvesting company in Finland.**

***Keywords*—Internet of Things; software system; software engineer; sensor; ICT quality.**

I. Introduction

The Internet of Things (IoT) is a fast-growing network of interconnected devices that exchange data and enable a wide range of applications. From smart homes and cities to industrial automation and intelligent machinery, the IoT has the potential to transform our lives, workplaces, communication and processes. However, implementing IoT systems is not a straightforward task even for experienced software engineers. Building IoT-based software systems of high quality requires careful planning and integration of various technologies, devices, services and sensors together.

Especially for forestry domain where actors still operate with traditional non-digital practices, IoT technology provides numerous opportunities for improvement and ways to improve productivity and increase level of automation. While forest machines involve high tech components, such as machine vision, robotics and intelligent sensors, the support and maintenance of forest machines including orders for liquids and other supplies, includes a large number of manual work activities.

Previous studies on using Internet of Things in forestry domain have mainly focused on monitoring forest assets [1], creating IoT-based systems for forest environment monitoring systems [2], improving the safety of forestry workers [3], establishing IoT-enabled plantation monitoring systems [4] and studying IoT implementation challenges in experiments conducted in rural areas [5]. However, surprisingly few of these studies focus on discussing how to ensure quality in IoT systems implementation. Identification of these quality aspects would help IoT engineers and developers to make better informed decisions on selecting IoT sensor components, services and platforms. Information on IoT quality aspects would also help IoT customers, consultants and coordinators of IoT projects to produce better quality and more accurate invitations for tender and make acquisition of IoT systems smoother.

There are several quality factors that software engineers in IoT projects should take into account. One of the most important quality aspects of the IoT is reliability. Reliability means that various IoT devices, sensors, software services and platforms must work together seamlessly to deliver accurate and timely data. In Finland, poor network coverage is a real challenge [6], especially in eastern and northern parts of Finland. Network failures can lead to significant consequences, such as loss of data, severe information security breaches, and unavailability of systems. Thus, it is critical to ensure that all IoT components are reliable and no weak links shall exist in the infrastructure. Additionally, when an IoT service is running in the operation phase, the service provider should provide frequent reports on the service quality which is part of a broader service-oriented philosophy [7].

Information security is another important quality aspect related to the IoT technology. While increasing amount of data is exchanged over the internet, security breaches have become a significant concern in Internet of Things projects. Cyberattacks may be performed even through very standard IT components, such as web cameras [8].

Fortunately, large cloud service providers have addressed security concerns of IoT, established security controls by using IT governance frameworks, such as COBIT [9], created security roadmaps and cybersecurity reference architectures [10] and presented mechanisms for ensuring secure access control, authentication of various types of devices and detecting potential security vulnerabilities and providing secure connections from sensors to IoT cloud services. Cybersecurity plays a very important role for IoT systems that can control critical systems or services, such as heating, ventilation, lighting and access control in smart buildings [11].

The results of this article are aimed at IoT system develop-

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ers, companies in IoT customer role, Internet of Things consultancy companies and persons responsible for coordinating IoT projects to increase their awareness of quality aspects related to IoT implementations in Finland, especially in forestry sector.

In Section 2, research methodology of the study is presented. In Section 3, case study results are presented. Section 4 is the analysis and finally, the conclusions are given in Section 5.

II. Research Problem & Methodology

This study aimed at answering the following research problem: How quality aspects should be taken into account while designing and implementing IoT-based software systems for forestry? The forestry domain was selected because it has a large financial impact in Finland. We admit that oil and gas industries may be forerunners in IoT but they play a very minor role in Finland compared to forest industry. In this study, we utilized a case study research method to answer the research problem with a single case organization (Motoajo Oy, a forest machine operator from Finland) with an embedded structure involving two IoT experiments. The research problem was divided into following three research questions:

- What types of IoT monitoring needs does a forest machine operator company have?
- How quality attributes are visible in building IoT solutions?
- How IoT monitoring shall support forest operations?

The case study can be defined as ”an empirical inquiry that investigates a contemporary phenomenon within its real-life context” [12]. The real life context refers to daily operations management of a forest machine operator company. Figure 1 shows the context of this study.

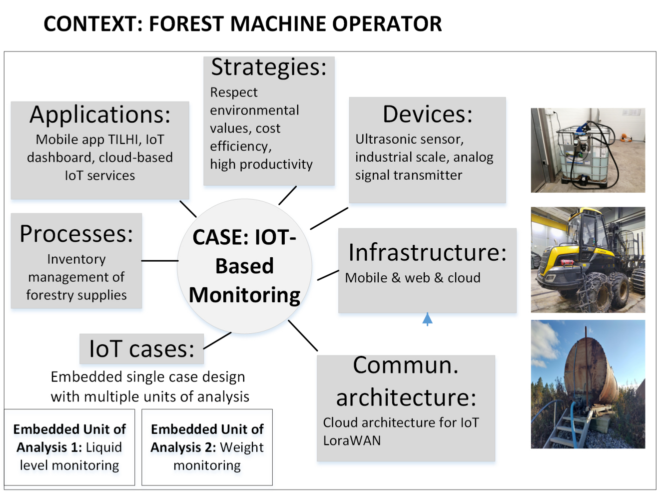

Fig. 1. The context of the case study.

A. Case Organization

Our target organization Motoajo Oy (SME) is a forestry contractor company located in Nurmes, Eastern Finland. The company is Finland’s second largest harvesting company. Motoajo operates as a family-owned company with 51 forest machines and 81 employees. Additionally, the company has in possession 3 Volvo transport trucks, 2 Volvo excavators, 1 wheel loader, 5 MB Sprinter light trucks and 64 Pick-up trucks. Regarding the staff, there are 35 harvester operators, 28 forwarder operators, 2 transport truck drivers, 3 excavator operators, 5 mechanics and 8 management staff. Reliable inventory management and order management of liquids and other supplies for forest machines are critical business functions for Motoajo. Forest machines cannot operate without these liquids and supplies and even short operational outages may cause remarkable costs for the company.

During the case study, the research team including the authors of this paper collaborated with various Motoajo employees but especially foreman, CEO, financial administrator and development manager. The collaboration occurred in joint digital experiment workshops, work meetings on preparing the experiment handbook, experiment status reporting meetings (Motoajo, AIKA DIH, DIH-World coordinator), joint webinars and seminars (2 DIH community days, 2 other regional dissemination events on digital transformation).

Digital Innovation Hubs (DIH) [13] are one-stop shops that help companies, especially SMEs and start-ups become more competitive with regard to their business/production processes, products or services using digital technologies. The funding for the first IoT case was received from the 1st call of experiments of DIH-World project (funded by Horizon 2020). The idea for the second IoT case was identified in the continual improvement workshop that was organized at the end of the first IoT case.

B. Data Collection Methods

Qualitative data for this case study were collected by using multiple sources of evidence between August 2021 - May 2023. Most of the data were captured while visiting Motoajo’s facilities (main storage in Nurmes, Finland as well as remote storage areas). The following sources of evidence were used:

- Documentation: IoT device specification for Tekelek tank alert sensor (ultrasonic), Enless Wireless Transmitter product specification, supporting documentation sent by IoT providers during the bidding process of weight monitoring system, safety instruction documentation of diesel exhaust fluid and log marking colour.
- Archival records: Data records (JSON) from the IoT provider, online forms for truck drivers and forest machine operators (triggered by QR codes in containers), LoraWAN data conversion Excel sheet by Enless Wireless.
- Interviews/discussions: Online meeting discussions with 9 Internet of Things providers, live discussions in Solver X reverse pitching event in April 19th, 2023, interviews with CEO of Motoajo, project discussions during work meetings with foreman of Motoajo, phone discussions with CEO.
- Participative observation: digital experiment work meetings, several field visits to case organization’s facilities, such as the main storage area, the remote

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storage area, a logging site in Nurmes, Finland; participative observation in DIH webinars and dissemination meetings related to Green and Digital Forest Service Management experiment.

- Physical artifacts: Artifacts related to case 1 included Tekelek ultrasonic sensor module, various types of liquid containers, such as a portable fuel container, a fungicide container, plastic Intermediate Bulk Containers (IBC) containing log marking colour and diesel exhaust fluid. Artifacts related to case 2 included oil canister pallet, industrial scale PCE RS 2000 by PCE Instruments and Enless Wireless Analog Transmitter.
- Direct observations: Monitoring forest machine operational work in logging site (January 11th, 2022)

C. Data Analysis

Data analysis of this study was performed by case comparison technique with two units of analysis. The case comparison analysis technique [14] is a common way to compare and analyze data from multiple cases. Our units of analysis were two different types of Internet of Things experiments. The first experiment focused on liquid level monitoring and the second experiment on weight monitoring.

During the article writing period, the second experiment was still ongoing. The analysis was performed by two researchers that are also authors of this paper. The case comparison was based on predefined categories (=patterns) describing the nature and settings of experiments and reflecting the quality aspects of IoT.

III. Results of the Study: Engineering IoT-based Software System for Forestry

The results of this exploratory case study are presented in this section as case narratives with Situation, Task, Action, Results (STAR) approach. The STAR approach includes four steps: 1) Situation describing the context within the IoT development was performed, 2) Tasks describing responsibilities or tasks to be done in that particular situation, 3) Action describing how the task was completed or how the challenge was resolved, and 4) Results describing the outcomes or results generated by the action.

A. Situation

Case A: According to the data we received from our site visits and conversations with the case organization, we noticed that the process for refilling and retrieving liquids from containers is mostly done manually. Additionally, we observed that the online form is not consistently used by truck drivers and forest machine drivers. The primary issue is that the company lacks an accurate view of their forestry liquid inventories, which can lead to a scenario where drivers of forest machines do not receive the necessary liquids they require. Motoajo and Digital Innovation Hub AIKA Ecosystem applied and received funding for the digital transformation initiative from DIH-WORLD project around 90 Keur.

Case B: The idea for Case B, continuous mass measurement using sensor technology, was received in the end of Case A when the research team asked case organization what would be next potential improvement targets for IoT based monitoring. A joint research consortium was established to find solutions for the problem. The first research organization provided expertise on metrology (purchasing and calibration of the scale) and the second research organization took care of designing cloud services. No external regional or international funding was related to this experiment.

B. Task

Case A: The EU funding for the experiment enabled the research consortium to design, implement, test and validate the monitoring solution. When the experiments started, no sensors were used for liquid level monitoring and the company did not have sensor platform in use. Monitoring consumption was based on manual checks and required traveling to remote sites frequently (1-2 monthly visits). The expected benefits involved, first, increased productivity and quality of operations for a forest machine operator due to decreased number of interruptions in production. Significant costs are caused if a forest machine cannot operate due to lack of liquids; in worst case scenario, salaries need to be paid to forest machine drivers also when a machine does not operate and fixed costs, such as insurance fees are still running. Second, IoT based monitoring reduces costs associated to travelling to remote storage areas due to checking whether there is sufficient amount of liquids available.

Third, monitoring of containers provides more accurate and timely information on inventory in containers through real-time consumption monitoring. Fourth, the company can order refilling of containers proactively and organize pick up for waste from storage areas. Fifth, our goal was also to increase operational safety related to dealing with liquids (fungicide, AdBlue, fuel) that may also lead to decreased workload for forest machine drivers. Finally, more automated process will decrease the number of contact requests from employees to work managers due to unclear or missing liquids-related work instructions.

Case B: The main task in case B was to design a continuous mass measurement system using smart sensors and state of the art cloud services. Our goal was to place an industrial class ”scale” under the standard IBC container to continuously measure the mass of the liquid container. The public LoraWAN was selected as the data network solution because the research team had positive experiences from the first pilot.

The planned work tasks included research work to design the solution and select the components, make a build or buy decision, test and experiment the selected solution, and identify constraints in Motoajo’s warehouse environment.

C. Action

Case A: The main purpose of the action was to plan, design, implement, test and validate the IoT based monitoring system for forestry liquids including tank level sensors and install sensor modules into plastic IBC containers containing log marking colour and Diesel Exhaust Fluid. The following list contains action items from the beginning to the end of the experiment:

- Kick off for the experiment (objectives and deliverables of the experiment presented and discussed, SME and DIH plan the work to the Trial Handbook)
- Capturing user stories for the system
- Technical specification (technical features of the mobile application, technical details of IoT sensors and dashboard)
- Development (development of mobile, IoT dashboard, configuring and coding)
- User Interface design (User interface design of the mobile app, IoT dashboard design)
- User feedback (collect information from forest machine drivers and work managers, implementation of corrections and changes)
- Testing (sensor testing, data network and integration testing, testing related to alerts, agile test report)
- Deployment (deploy solution for diesel exhaust fluid and marking colour container)
- User training (train related user groups)
- Experiment closure meeting (conduct closure meeting, reflect to the experiment objectives, capture lessons learnt, plan further dissemination and exploitation opportunities)

Case B: The main purpose of the action was to implement a continuous mass measurement system. However, the monitoring target was changed to the oil canister pallet that is delivered to the warehouse or a remote storage and the goal was to find out when there are only few canisters (200 kg/1000 kg) left. The following list contains action items for the case B:

- Study the required components for the system (scale, IoT services, signal transmitter, etc.)
- Purchase and integrate selected hardware components (PCE RS 2000, Enless Wireless Signal Transmitter)
- Conduct meetings with AWS specialists to identify potential ways to implement the system
- Sign up an Open Cloud Research Environment Contract to make purchase of services smoother (however, we decided not to wait this contract to be signed)
- Establish and test the connection between the signal transmitter and Digita IoT network (this part went successfully)
- Participate in Solver X reverse pitching event in Helsinki, Finland to identify potential IoT providers for the cloud system
- Negotiate with IoT providers and initiate a public bidding process on implement the system in our own AWS subscription (we have reached this step)
- Start implementation (our next step)

D. Results: Case A

Case A: The experiment was considered successful in the case organization. As the results of Case A, the company has now an IoT-based monitoring system for liquid containers (Diesel Exhaust Fluid, log marking colour) that enables monitoring liquids in remote storage areas. The monitoring system includes a mobile application that machine drivers use when they pick up supplies and liquids from storage areas. Through the mobile application work managers are able to monitor containers and see the level of liquids. The system also enables sending alerts when most of the content in liquid containers has been consumed. Three sensor modules were installed during the experiment and according to our knowledge, the company has ordered more similar sensor modules from the IoT sensor provider in 2023.

Case B: As main results of Case B, we defined a system architecture for the continuous mass measurement system. Figure 2 shows the architecture with key system components. Based

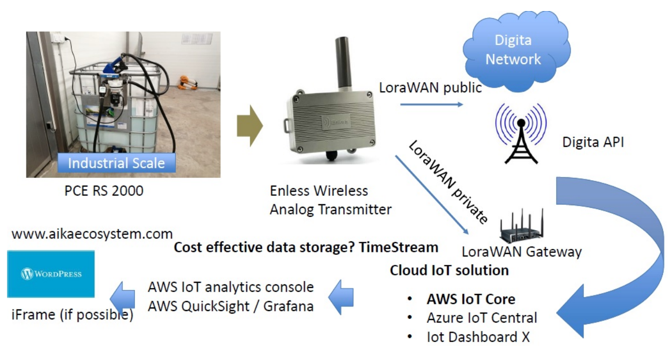

Fig. 2. The IoT sensor architecture.

on discussions with customer, data transmission frequency can be approximately one hour and the test site would be in Nurmes, Eastern Finland in Motoajo's main storage area. Our aim was to establish a system where sensor data is directed to a cost-effective cloud-based IoT environment where data is stored and a simple graph (for example, generated by open source visualization tools) is constructed. By implementing the system to our own AWS premises, we try to avoid potential vendor lock-in. The scale shall be placed on the warehouse floor and the system allows lifting goods onto the scale with a forklift. The prototype of the system is almost ready (at the time of submitting this paper) and we are preparing to deliver the system to the customer's storage facilities.

IV. Analysis

The data analysis for the study was performed by case comparison technique. The results of this exploratory case study are presented in this section according to three research questions: 1) What types of IoT monitoring needs does a forest machine operator company have?, 2) how quality attributes are visible in building IoT solutions for forestry domain? and 3) how IoT-related challenges and barriers can be solved?. In Table 1, analysis of case study results reflecting the three research questions of the study is presented.

The following lessons learnt can be identified based on our cases:

TABLE I. ANALYSIS OF THE CASE STUDY WITH TWO IOT EXPERIMENTS AS UNITS OF ANALYSIS

Category	Case A
Monitoring needs	Monitoring liquid containers Proactive orders for liquids Sending alerts on low levels Ordering refilling containers in time
Quality	Accurate view on liquid level Data conversion on distance to percent Data frequency 6 hours Install sensor to cap of container Calibration of sensors
Benefits	Check liquid levels remotely Setting alerts on critical liquid levels Proactive way to ensure availab. of liquids Provides data on liquid consumption trends May reveal container leaks
Category	**Case B**
Monitoring needs	Contin. mass monitoring Proactive orders for supplies: oil canisters Sending alerts on low levels Oil orders in time
Quality	Number of canisters 4-20 mA to kg Data frequency 1 hours Scale under pallet Calibration of scale
Benefits	Number of oil canisters Setting alerts on only few oil canisters left Enables monitoring any tangible items Consumption of oil canisters May detect that items are stolen

Lesson 1: Security is a top priority quality aspect: As IoT devices are connected to the internet, they are prone to cyber attacks. It is important to ensure that security is top priority when designing and implementing IoT solutions. In our cases, data does not control anything and IoT platform was protected by usernames and passwords. Data was sent from sensors to IoT platform and further to mobile app. The mobile app showing virtual version of the container forces users to use strong passwords.

Lesson 2: Scalability is crucial: IoT solutions may need to handle large amounts of data and devices. It is important to design solutions that can scale to accommodate growth. Regarding case A, our mobile app Alfa was running in AWS cloud to ensure scalability. In case B, we also aim at using scalable cloud services instead of third party IoT platforms to ensure scalability of the system.

Lesson 3: Interoperability is key: IoT devices and platforms need to be able to communicate with each other seamlessly. It is important to ensure that devices and platforms are interoperable and can work together. Data in our case A was delivered by using JSON, standard communication protocol. It is very likely that case B shall be using the JSON or the MQTT protocol. We observed in case A that data transmission from sensors was conducted every 6th hour (the goal was to transmit data on hourly basis). In case B, we put data transmission frequency clearly to Invitation for tender document.

Lesson 4: Maintenance is important: IoT devices need to be maintained and updated regularly to ensure they are functioning properly and securely. Battery life is impacted by cold weather. Offers from IoT providers could have clearlier statements on battery life and maintenance of IoT devices. Most of the providers are offering their own platform instead of implementing IoT in customer's premises.

Lesson 5: Data management is critical: IoT devices generate large amounts of data. It is important to have proper data management and analytics tools in place to make sense of this data. Third party IoT platform was responsible for receiving data from Digita LoraWAN network. Data was further stored in AWS MySQL database. The application server of Alfa application has access only to database server that increases security of data management.

Lesson 6: User experience is important: IoT solutions should be designed with the end user in mind. The user interface should be intuitive and easy to use. In the mobile application Alfa, visualization of container worked well. We aimed at listening users carefully to address their needs. The online form related to QR codes might need further improvement and clarification.

According to our observations, there are other factors that might also have effects on IoT system implementations in Finland: First, if sensors are placed outdoors, there is significant temperature variation (in extreme cases +35 C - -40 C) between summer and winter seasons in Finland. Second, a large part of forestry operations are performed in remote forest destinations, often without official street addresses. This might cause challenges in producing reliable location data.

Third, there is only one public LoraWAN network provider Digita in Finland. This should be taken into account while software engineers build LoraWAN-based systems in Finland. Creating contracts may take time and thus should not be ignored while planning IoT project schedules. Fourth, Finland is a sparsely populated country. Long distances mean a lot of traveling and eliminating unnecessary traveling creates a good business case for IoT implementation projects. Finding a profitable and viable business case for IoT is often a challenging task.

Fifth, IoT technology also has societal impacts on people living in rural areas of Finland. Through IoT based monitoring [15], one can monitor elderly people, detect potential accidents and incidents both outdoors and indoors or locate injured forestry workers or trigger alerts.

Finally, despite the high level of digitalization, the lack of skilled workforce is a challenge for many cities. This means unavailability of software engineering talents that are able to design cloud-based IoT systems and take care of advanced privacy and security requirements.

V. CONCLUSION

This study aimed at answering the research problem: How quality aspects should be taken into account while designing and implementing IoT-based software systems for forestry inventory management? The main contribution of this paper is to present lessons learnt from two experiments with different monitoring targets: liquid level monitoring and continuous mass monitoring of oil canister pallets. Both IoT experiments were performed in facilities of the second largest forest harvesting company in Finland.

There were three research questions in the study. Regarding the first research question, we observed various IoT monitoring needs in the forest machine operator, such as various types and sizes of containers (fuel containers, water containers, oil containers, fungicide containers, diesel exhaust fluid containers,

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marking colour containers). However, in addition to liquids there are several tangible supplies that company orders on frequent basis, such as grease tubes, oil filters, oil canister pallets, chain blades and chains. These tangible supplies need another type of monitoring system that we aimed at to design in the second IoT case.

Concerning the second research question, how quality attributes are visible in building IoT solutions, we highlighted activities that were specific to IoT-based digital transformation, such as selecting right sensor and data network solution, performing data conversion, defining data storage mechanism for IoT data, as well as installing the sensor modules. All of these require work efforts.

Finally, related to the third research question, we studied how IoT monitoring shall support forest operations. First of all, IoT-based monitoring allows proactive approach on ordering both liquids and supplies. The monitoring system enables sending alerts on low inventory levels, as well as showing visualization as graphs or tables based on the ingested IoT data. In the future, this data can be used and analyzed to optimize the ordering process based on consumption patterns.

The following limitations are related to this study: There are certain limitations related to the case study research method. First, case study does not allow the generalization of results to other organisations but we can use our results to extend the theory related to planning, designing and building realtime IoT-based systems. Second, Case B is still ongoing and we have no detailed information how the selected IoT provided has done the actual implementation in AWS cloud. However, the prototype is close to delivery to the customer site. Third, more staff from user side could have been interviewed to receive more feedback on improved liquids ordering process. Further research could focus on ICT quality aspects in cloud-based Internet of Things projects, for example, in Amazon Web Services projects or Azure IoT implementations.

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