P L A N E T 4

Smart transport boxes

Build new products based on AI and IoT technologies.

The Challenge

Industry Sector:
Solution provider & integrator in manufacturing and logistics

Challenge classification:
Product servitization: create mutual value through a shift from selling product to selling service; Usability improvement through IoT technologies; Smart products; Reducing operational costs

Time for Project Completion:
6 months

Introduction of smart transportation boxes for provisioning and delivering of production tools to be maintained and recertified (part 1): Transportation boxes will know their location, condition (filling level, kind of tools inside, ...) and environmental surrounding environment (humidity, dust, temperature, ...) through sensors and localisation systems. Based on these data the box will decide when to be picked-up by the maintenance crew. This will be indicated by sending a message (SMS, eMail, ...) requesting a suitable pick-up date and time.

Main Requirements

N/A

Other Requirements

N/A

Key Performance Indicators

- Perform data analytics and take data-driven decisions;
- Create a realtime notification system;
- Track assets indoor or outdoor;
- Cut operational costs.

Other informations

The company expects to deploy 30 devices.

Need for device management operations (such as managing or updating the software remotely)?
Maybe

Strict deadlines in device operations for doing the tasks?
No

Research Phase

Taking into account the challenge description, its requirements and its information, elaborate at least 5 questions that can lead your research for a solution.

Research questions:

1. How to monitor the condition and surrounding environment of the transport boxes?
2. How to track the transport boxes?
3. How to make decisions based on data that comes from the monitoring of boxes?
4. How to inform the maintenance crew about the necessity of picking-up a box?
5. How to cut operational costs?

Given the questions and the main requirements of the challenge previously listed:

- *identify possible technologies using the Planet4 Taxonomy Explorer;*
- *identify and analyze the sources (papers, articles, etc.) of those technologies that best suit the challenge;*

Technologies identified in the taxonomy:

- Data Storage: Databases;
- Data Analytics: Data Visualization Tools and Platforms;
- Machine Learning: Deep Reinforcement Learning;
- Soft Computing: Optimization Techniques;
- Infrastructure as a Service (IaaS): Cloud Data Storage and Computing;
- Edge Computing;
- Fog Computing: Physical and Virtualization Layer (Network of virtual sensors and Things);
- Industrial IoT: Industrial Communication Protocols;
- Physical Devices and Controllers: Embedded Computing, Sensors (hardware);
- Signal Processing;
- Connectivity: Radio Communication Technologies, IoT Messaging Protocols (Message Queuing Telemetry Transport (MQTT)), Application Programming Interfaces and Programming Tools (Node-Red);
- Virtual Reality;
- 3D Printing Technologies.

Sources of those technologies that best suit the challenge:

[1] https://www.sciencedirect.com/science/article/pii/S027861251830428X
[2] https://journals.sagepub.com/doi/full/10.1177/16878140211040888

In light of the discoveries made:

- *report the answers for the questions above;*
- *compare 2-3 of the more common solutions identified in the sources (how would they change the approach to the solution? What are the possible benefits/issues in such a use of these technologies?);*
- *draw initial conclusions on which path you want to take in proposing a solution.*

Answers:

1. Sensors (hardware)
2. Short range wireless communication technologies for indoor box tracking (e.g., RFID/NFC) and cellular communication for outdoor box tracking (e.g., LTE/GSM/4G/5G, Wi-Fi, WLAN)
3. Data Analytics
4. Data Visualization Tools and Platforms
5. Optimization techniques (e.g., meta-heuristic approaches) for planning transport boxes flow routes

Comparison:

Equipping transport boxes with intelligence provides many opportunities for the company, including the ability to track boxes, monitor their contents and detect critical situations, such as damage to the shipping box. The possibilities mentioned above depend on the technology used. At this point, we consider two possibilities: (1) equipping the transport boxes with RFID tags and placing RFID readers in the appropriate places in the production hall or warehouse; (2) equipping transport boxes with RFID readers and additional sensors, as well as equipping transported items with RFID tags.

The first of the two possibilities considered is presented in Figure 1. RFID is a non-contact object identification technology that automates the object identification procedure. Thanks to RFID tags placed on transport boxes and RFID readers located e.g. in storage areas, in transport vehicles or at workplaces, the production control system can accurately track transport boxes in real time.

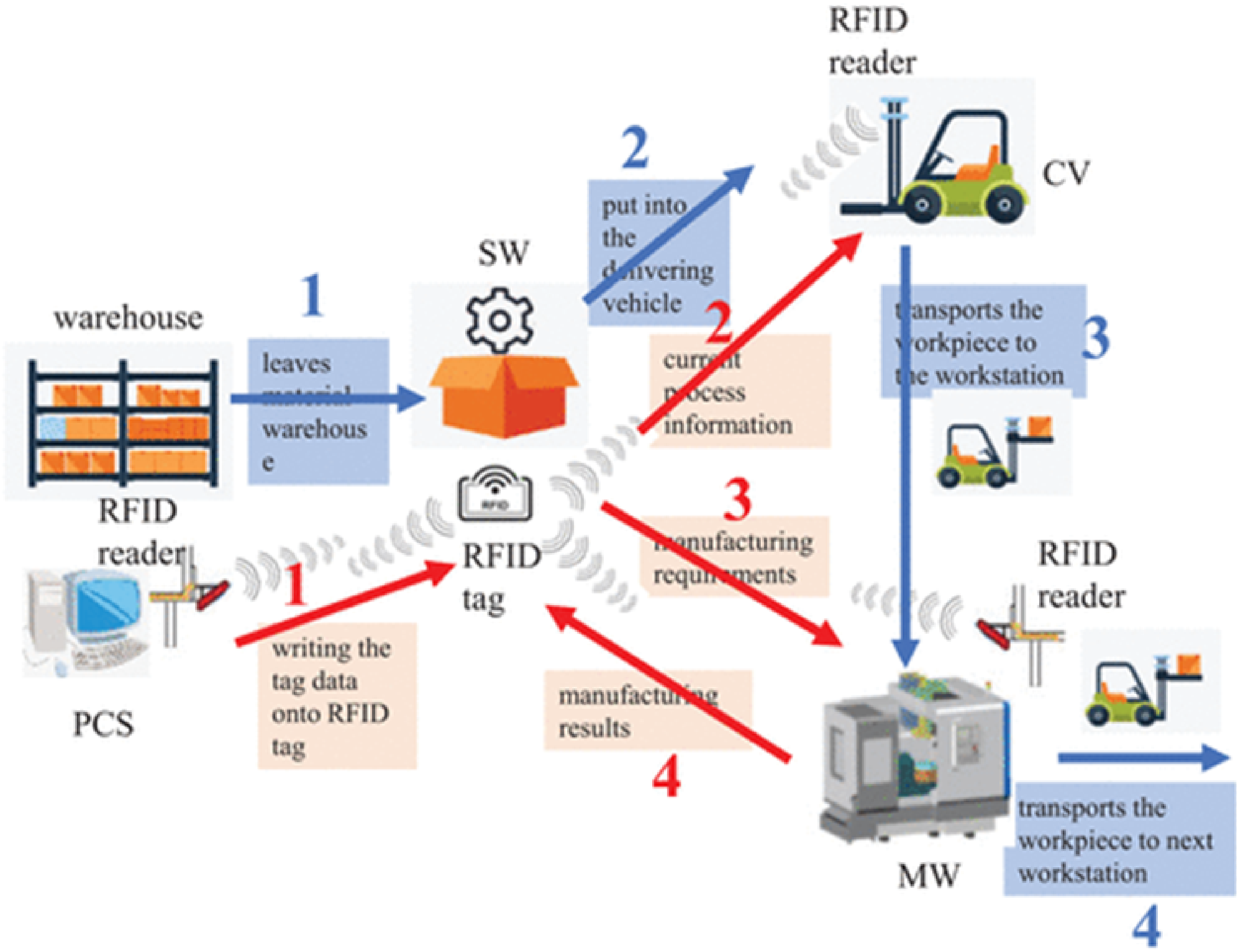


Figure 1. The communication between process level cyber-physical production systems. Source: [2]

A set of RFID tags and antennas enables communication between the transport box, the production control system of the transport vehicle, workstations and the warehouse. When the transport box leaves the warehouse, the production control system writes the relevant data on the RFID tag about where the transport box should go. The transport box is then placed in the transport vehicle. The vehicle, thanks to the RFID reader, can read information about the destination place of the transport box. When the vehicle transports the box to a suitable place (e.g. to a workstation), the machine or a person working at this station can read information about the contents of the transport box from the data stored on the RFID tag. This information is e.g. production requirements. After finishing work in the workstation, the workstation can save the results of work on the RFID tag. In the next steps, the transport box can be transported to the next places in accordance with the guidelines of the production control system.

The second option is to create an intelligent transport box. The intelligent transport box would not only be equipped with an RFID tag as in the first option. In addition, it would contain a number of embedded sensors (e.g. accelerometer, gyroscope, magnetometer, altimeter, temperature and humidity sensors) that enable monitoring of the conditions under which the transport box operates. Moreover, the transport box can also be equipped with an RFID reader, thanks to which it will be possible to monitor the contents of the box in real time. However, monitoring the contents of the box would involve RFID tagging for all items that can be transported in the box. The second option is definitely more expensive, but it gives the company much more opportunities to monitor, control and optimize the flow of transport boxes.

Conclusions:

Nowadays, there is a growing tendency to integrate physical and digital worlds with each other and with the required real-time connections between the digital model and the physical machines, products and processes contained within it. This entails the need for continuous availability of information about products, tracking their flow in the production process, and improving operational control through dynamic decision making. Taking this into account and looking at the requirements formulated by the company, the second option should be chosen, i.e. the development of intelligent transport boxes.

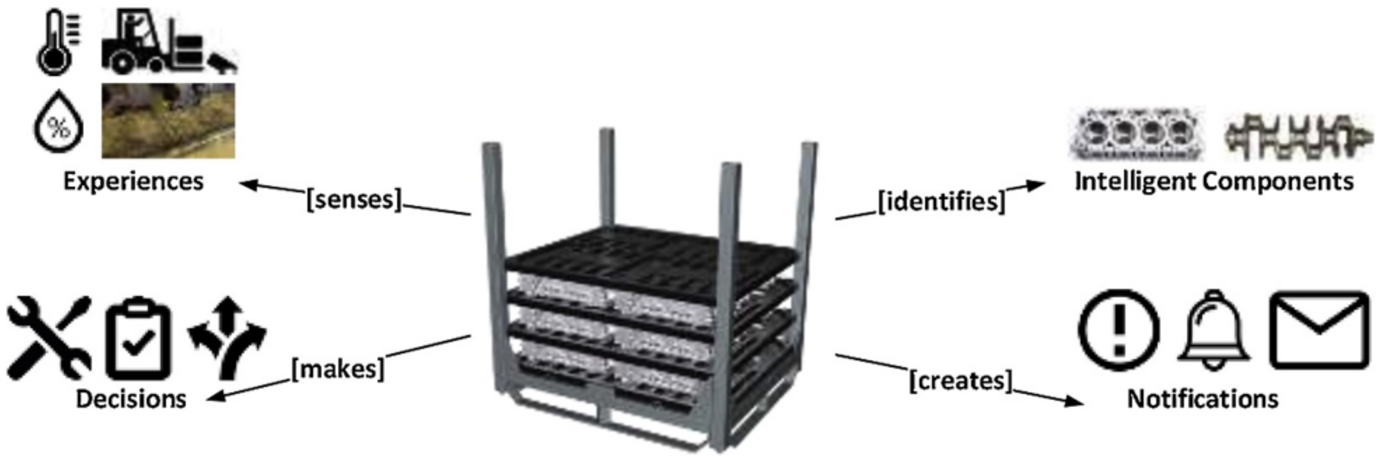


Figure 2. An intelligent container overview. Source: [1]

Figure 2 shows selected functions of the intelligent transport box: sensing experiences (e.g. ambient temperature, humidity, dirt, poor transport operations—drops, shocks); identifying and communicating with intelligent items (products) that will be transported in the box and with machines or transporter vehicles; making decisions based on data from sensors, e.g. about the need to transport the box, checking the condition of the box or repairing it; the possibility of publishing notifications, e.g. warnings about improper transport of the box. In addition, the intelligent transport box can manage information, notifications and decisions on behalf of the items it contains, and after unloading items, it can be associated with another set of items.

Proposed Solution

Making use of the technologies identified after the analysis of the sources, describe a possible solution to the challenge. Also, do not forget the constraints (time, number of devices to produce/connect, etc.): the solution must be applicable to the real context of the company that commissioned the challenge.

Solution Summary

Brief description of the solution (1-2 paragraph + 1 image)

Based on the review of the sources, we propose to implement the solutions shown in Figure 3. Figure 3 shows reference architecture, which consists of six layers. Authors of [1] describes these layers as follows:

1. "the asset layer represents the unique real-world assets which are intelligent containers (Returnable Transit Item, RTI) and intelligent items,
2. the integration layer, representing the service bus and how differing technologies can integrate the real world into the cyber-physical system (CPS),
3. the service implementation layer, describing the individual service implementations that provide well defined services, i.e. data capture, data filtering and data analytics,
4. the service abstraction layer describes fundamental business service, i.e. scheduling, RTI locating and monitoring, that orchestrates service implementations from the layer below,
5. the business process layer orchestrates a number of service abstractions to define a particular business function, i.e. dynamic RTI control or quality control monitoring and finally,
6. the application layer describes the interaction of business processes to define an application, i.e. intelligent manufacturing."

The implementation of the intelligent transport boxes assumes that the items transported in the boxes will be equipped with RFID tags (intelligent products). Each intelligent product and intelligent container must be uniquely addressable with its own data model. CPS can listen for notifications (i.e. location updates, bad handling events), and proactively initiating commands (i.e. move to repair). CPS can offer services with relevant rules developed on the business process layer. An example would be identifying a wrong shipment. By analyzing the data sent by the intelligent container, thanks to feature recognition techniques, information about unwanted hits on the transport container can be extracted along with the strength of the impact. Knowing the type of the transported item (e.g. glass products sensitive to impacts) thanks to RFID tags, it can predict whether the items transported in the container have been damaged.

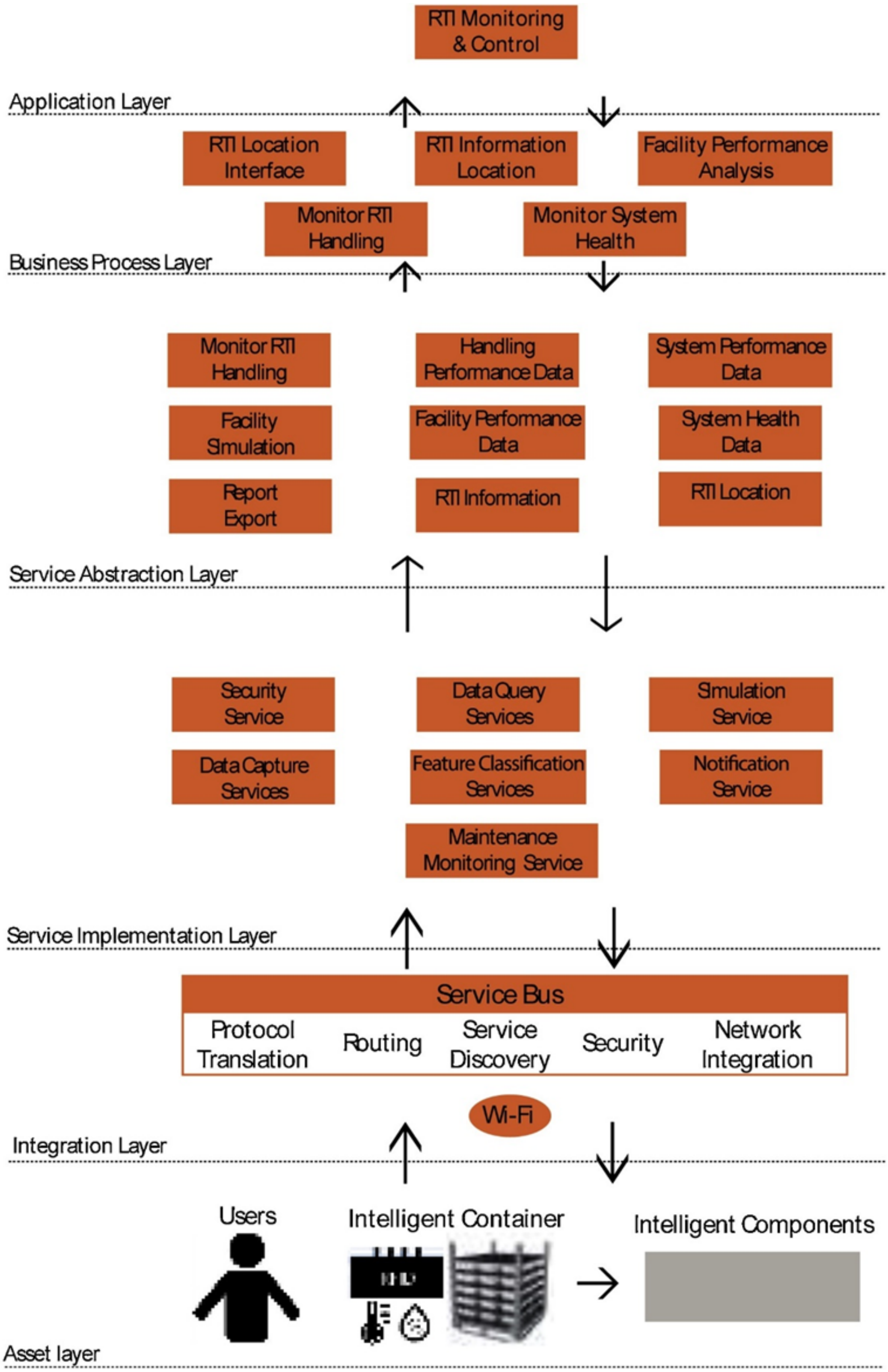


Figure 3. Reference architecture with an intelligent container and intelligent components. Source: [1]

Solution Description

Describe the solution and its details

Authors of [1] points out four fundamental requirements that are necessary to achieve RTI intelligence:

1. "data processing, the hardware must have embedded processing capability that is able to sample connected sensors, perform data manipulation (i.e. filtering, feature extraction and pattern recognition and to compute the resultant information via rules representing decision making criteria, i.e. classifying what represents an RTI collisions or drop,
2. data storage for sensor data, RFID interrogator data and the intelligent container's information model. This storage additionally acts as a buffer between the local device (RTI) and the cyber-physical monitoring system providing a level of resilience to communication errors or lack of a communication channel (i.e. no wireless signal),
3. wireless communication, to provide real-time data dissemination, controls and RTI notifications, the intelligent RTI requires a wireless communication link. The wireless link also represents the bridge between the asset layer and integration layer of the reference architecture,
4. a power source is required to support all of the data collection, processing, storing and communication activities, such as battery cells or fuel cells."

Operation of the presented solution is based on the *publish and subscribe* model, an example of which is shown in Figure 4. Authors of [1] describes this example as follows:

"When an intelligent container comes online, each entity, i.e. the intelligent container or CPS services, subscribes to one or many topics, denoted 1, 2 and 3 in Fig. 4. A topic is a name or reference for the type of information that an entity wishes to receive or publish data about. In this example, the reporting of an intelligent RTI collision (1 and 2) and for the sending of events (3). In the event that an RTI identifies a collision, it is responsible for publishing those data to the service bus on the collision topic, denoted 4. Once the published data have been received on the service bus, it simultaneously re-publishes the same information to all entities subscribed to that topic, in this case, the notification service (5) and the quality control service (7). At this point, both services undertake their role within the CPS, with the notification service compiling an email of the event to stakeholders (6) and the quality control service determining that the RTI requires it to be quarantined, due to potential damage to components in the collision. This quarantine command is then re-published onto the service bus (8) and then onto the intelligent container, which had previously subscribed to its respective command topic (9)."

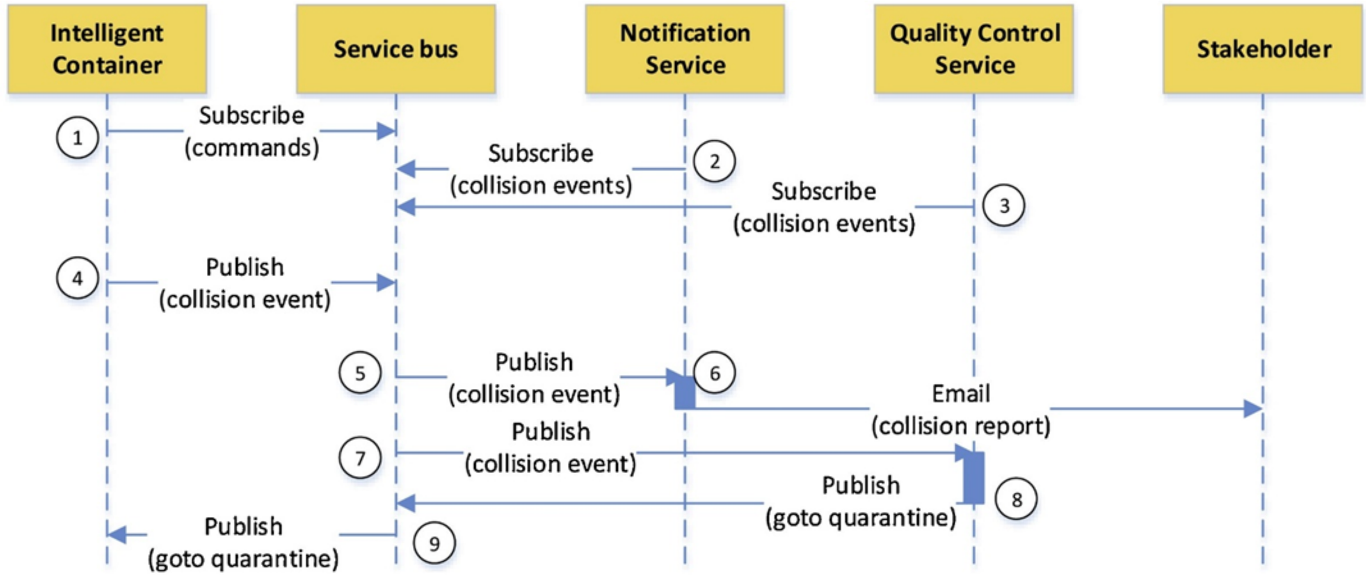


Figure 4. Example usage of the publish and subscribe service bus. Source: [1]

For the implementation of a *publish and subscribe* service bus the Message Queuing Telemetry Transport (MQTT V3.1.1) technology is utilized. Authors of [1] describes MQTT as follows:

"The MQTT standard defines a one to many publish and subscribe messaging service that is payload agnostic. The standard also implements quality of service distribution techniques for traffic management, "at most once" – a single message delivery attempt is made but not guaranteed to succeed based on traffic and network conditions, "at least once" – a message is guaranteed to arrive, but duplicates may occur and "exactly once" – a payload is guaranteed to be delivered exactly once. […]

To implement the MQTT standard an MQTT broker is required (e.g. Mosquitto MQTT broker). An MQTT broker is the software implementation of the MQTT standard with respect to server-side operations, i.e. allows and maintains TCP/IP connections with devices, applies security protocols and is responsible for the republishing of messages and handling subscriptions."

To develop supporting intelligent container services, a software package *Node-Red* is needed. Authors of [1] define Node.Red as follows: "*Node-Red* is a flow based programming tool designed for developing applications within the internet of things domain. *Node-Red* provides a web browser based development environment with Node.JS and JavaScript foundations. The platform is a flow based programming environment, built around modern internet technologies such as MQTT, Hyper Text Transport Protocol (HTTP), Websockets, JavaScript Object Notation (JSON) and eXtensible Markup Language (XML). A software developer can drag and drop *nodes* representing software functionality and place interconnects representing the flow of data. Within *Node-Red*, programming is not limited to existing nodes and flow based design, JavaScript function blocks can also be developed. The advantages of utilising *Node-Red* for this research is that it supports technologies such as MQTT and provides tools for rapid development, prototyping and integration of software functionality."

Implementation Plan

Describe the solution implementation plan considering among other things: gantt chart with milestones, high-level cost analysis, possible difficulties (at least 3 major issues or difficulties) and additional opportunities (at least 2 extra benefits).

1. Development of the system hardware and software platform architecture: selection of sensors and RFID components, built-in modules for reading data from sensors and communication with the supervisory system, network communication structure, server layer, software.

Milestone 1: Hardware and software architecture

2. Implementation of the hardware-software platform architecture: development of Graphical User Interface, thanks to which the user will be able to monitor the flow of transport boxes and will receive event messages. The GUIs reside within the Node-Red environment.

Milestone 2: Hardware and software architecture

3. Equipping the transport boxes with a set of sensors and embedded controllers: accelerometer, gyroscope, magnetometer (compass), temperature, humidity and altimeter (pressure) sensors.

Milestone 3: All transport boxes are equipped with sensors

4. Equipping the transport boxes with a RFID tag and RFID antenna.

Milestone 4: All transport boxes are equipped with RFID

5. Organizing a workplace where transported items will be equipped with RFID tags.

Milestone 5: Workstation for tagging items

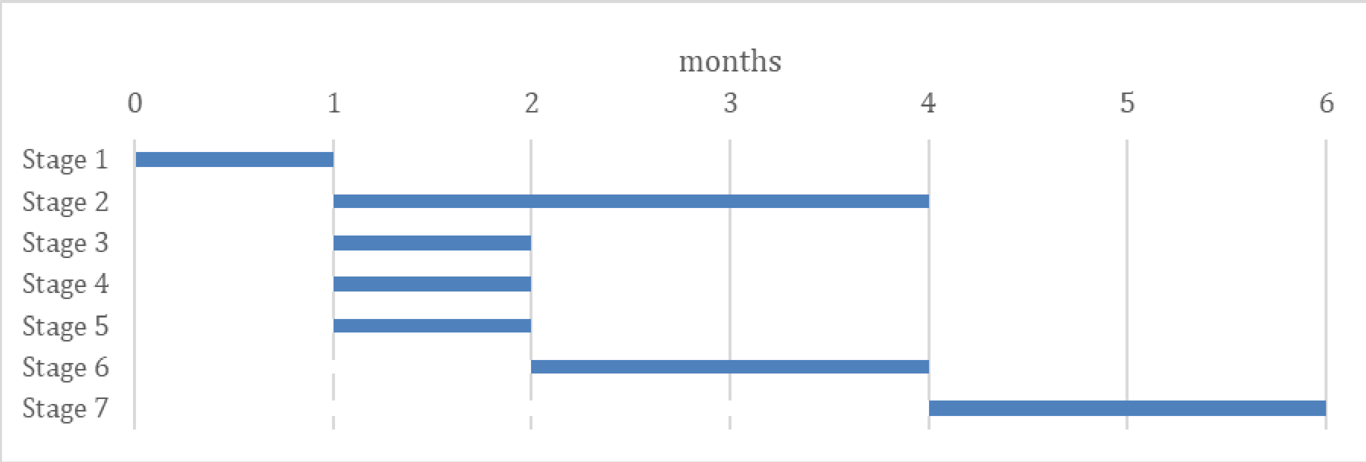
6. Launching the hardware and software platform.

Milestone 6: Hardware and software platform implemented in the company

7. Testing data transmission between transport boxes and the developed system.

Milestone 7: Successful completion of the tests.

Gantt chart:



High-level cost analysis:

Implementation of the stage 1 – labor costs (3 employees x 1 month)	6300 €
Implementation of the stage 2 – labor costs (6 employees x 3 months)	37800 €
Implementation of the stage 3 – labor costs (2 employees x 1 month)	4200 €
Implementation of the stage 4 – labor costs (2 employees x 1 month)	4200 €
Implementation of the stage 5 – labor costs (2 employees x 1 month)	4200 €
Implementation of the stage 6 – labor costs (4 employees x 2 months)	16800 €
Implementation of the stage 7 – labor costs (3 employees x 2 months)	12600 €
RFID	100000 €
Embedded devices and sensors	65000 €
Server	30000 €
Network layer	20000 €
Software	105000 €
TOTAL	406100 €

Additional opportunities:

- full detailed history of monitoring of the transport boxes (events, routes),
- calculation of measures regarding the transport boxes (e.g. collision rates),
- defining any events about which the maintenance crew will be automatically informed (e.g. exceeding the maximum temperature at which the transport box can operate, exceeding the tilt angle, which may indicate the transport box overturning),
- automatic decision making about the need to inspect the transport box, e.g. in the case of collision detection,
- intelligent containers can reduce the load on CPS by taking over services such as feature determination, data capture and handling performance data, which can reduce the computational needs of a CPS software implementation,
- greater integration of product, processes and operators within the manufacturing domain.

Possible difficulties:

- Difficulties with the correct operation of the RFID system due to possible disturbances in the production environment.
- Problem with communication between the company's staff and IT specialists.
- Unavailability of personnel and/or workstations related to the necessity to carry out the production process.