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Towards integration of logistics processes from a cloud/fog-edge computing perspective

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***Abstract*—The emergence of the Internet of Things (IoT) and the cloud/fog-edge paradigm contributes for appearance of innovative designs for smart systems. The purpose of the doctoral research outlined in this article to design a method which will discover how IoT and the cloud/fog-edge computing can be utilized for advancing the reliability, transparency, and fault detection in processes within a smart transport and logistics system. The method is designed to contribute to the integrated use of different logistics modes in order to support decision-making and transparency for enterprises. The main focus is to detect how the envisioned system can ultimately provide an enhanced quality of service and integration of logistic shipments. The doctoral plan outlines five contributions that will lead towards integration of the logistics processes in a logistics setting. The first contribution is a taxonomy of functional and non-functional requirements that can be utilized for designing a new IoT platform for transport and logistics. The second contribution examines the cloud/fog-edge computing paradigm by considering existing IoT resource management techniques. The third contribution provides a holistic view of the structure and systems required for embedding the cloud/fog-edge paradigm in a specific demonstration. This conceptual blueprint aligns organizational needs for such system by using an enterprise architecture model. The fourth contribution combines previous results in a smart transport and logistics blueprint. The fifth contribution evaluates how a ML framework can be used to improve the alert detection, and quality of shipments based on the cloud/fog-edge paradigm.**

***Index Terms*—Internet of Things, cloud-fog-edge, logistics, smart system, enterprise architecture**

I. Introduction

Smart transportation systems are essential for effective management of mobility and shipment of logistic goods in smart cities. Still, there are many challenges occurring in such systems. For example, increased traffic congestion, shortage of real-time information and other discrepancies occur within today's transport networks [1]. Interesting in that regard is the integration of different transport modalities, which can be denoted by multimodal transport. According to [2], multi-modal transport is defined as a transport in which more than one type of a vehicle can transport goods from a particular source location to a final destination. A design of a system for transport and logistics operations needs to incorporate different technologies, to provide safety, availability, interoperability, ease of deployment, reliability and resilience.

In the past, companies had difficulties in monitoring and on time delivery of goods. Thereafter, they approached this particular problem by attaching sensing devices on the goods. More specifically, companies are continuously monitoring the condition of the goods in real-time by using sensor devices attached to pallets and gather data which is directly sent to the cloud. Nowadays, the main problem is about late delivery of goods which can also lead to failure events and diminishing quality of transported goods. This can be solved by gathering insights. Information can be generated and collected from direct and external sources, which can be accessed in real-time, transferred to a particular cloud data storage system to be processed, analyzed, and add values to a smart transport and logistics system (STLS). Processing such data in the cloud has noticeable advantages. However, when considering systems with huge amounts of data and large networks, a cloud computing solution can face certain limitations. Cloud computing servers are usually placed in physical locations far away from the Internet Of Things (IoT) devices. This can result in delays in data reporting and increase in latency in the application of corrective actions. This largely can occur due to absence of network or network delay between the edge and the cloud layer of their systems.

Additionally, IoT deployed in the cloud comes up with some more challenges regarding security and privacy [3] [4]. For instance, concerns can arise when the smart application's owner data are processed, sent, and saved to a network under the ownership of a third person. Security-related issues, such as data loss and data breach [5], should also be dealt properly with. Deciding to process IoT applications directly in the cloud does not represent an efficient solution for certain IoT applications and specifically not for time-sensitive applications. Furthermore, there is an increasing number of IoT platform providers that can help logistic companies to monitor and improve their business processes. Nevertheless, the number of scientific articles about the different IoT platforms, their services and how they can be compared is limited [6]. There is an additional problem about the lack of comparison frameworks for IoT platforms, which is analyzed in [6], since individuals or companies in industry 4.0 have issues when selecting a suitable IoT platform matching their business requirements.

In smart logistics, enterprises regularly utilize data that emerges from various sources [7]. Also the data can come in various different forms e.g. near real-time, real-time and static data. Determining insights from the integration of data

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from various logistics processes can be a real challenge for many enterprises [7]. Additionally, this challenge happens to be frequently avoided in current literature [7]. Enterprise architecture can contribute in managing complex systems, which collect large amount of data such as big logistics enterprises. There is limited research focused on implementing the cloud/fog-edge computing concept in the enterprise architecture models for a particular application domain. However, some studies mention the embedding of IoT within enterprise architectures and suggest integration approaches. To deliver decision-making support for the complex business community, it is essential to recognize the emerging transformations of the IoT milieu and its related enterprise architectures, suggested in [8]. The architecture engineering and management of enterprise architecture is compound, which means that beside merging the IoT with it, other disciplines can be integrated as well such as: big data management systems, knowledge-based systems, semantic-based decision systems, collaboration, and mobility systems [8]. To summarise, an integrated transport and logistics plan (method) that will consider IoT throughout the logistics solution supported by other technological systems may contribute to improvement of transport and logistics.

The STLS system can support an integrated view of multiple transport modes (e.g., air, land, and sea) to provide efficiency and transparency for its users. The integration of certain collected information is mandatory in order to enable connections among users and different transport stakeholders. An advantage of integrating multiple transport modes can lead to a reduction of usage of vehicles for short trips. To overcome some of the limitations of the cloud, it is planned to design an innovative solution that will lead to appearance of an enterprise architecture model. It will be based on the cloud/fog-edge computing paradigm that can be applied in STLS. The new architectural concept would place the IoT access network and the cloud in a close proximity, and together with fog computing will enable support to real-time applications and reduction of latency. The purpose of this research work is to show how the cloud/fog-edge computing paradigm can be applied in a smart transport and logistics demonstration.

One of the goals of the newly created method is to design the STLS platform, that will enable efficient use of transport and logistics data. The main purpose of the designed STLS platform is to achieve integration of transport and logistics processes with a focus on improving the quality of service and shipment of goods by incorporating the cloud, fog, and edge paradigm. Enterprise architecture can be used as a framework for digital transformation of smart transport and logistics organizations. These organizations need to align the IT infrastructure with their specific business goals.

Consequently, the main artifact of this doctoral thesis is to design a method which will help enterprises to implement IoT and the cloud/fog-edge architecture for their logistics processes. It can be used as an input for developing a technical model for developing a future IoT platform. The method is composed of the following steps: research on requirements for IoT, research on resource management in cloud/fog-edge systems, development of an EA which encompasses the cloud/fog-edge computing concept, development of STLS EA for integrated logistics processes, and sensor data utilization. This type of a method can help companies /industry to incorporate the cloud/fog-edge computing paradigm to optimize processes.

This paper outlines the doctoral thesis plan as follows. Section I introduces the need for integration of smart logistics processes, while Section II describes the related work done for enterprise architecture modelling, and smart logistics system design. Section III introduces the research design consisted of the main research question and its sub-questions. Section IV represents the methodology, the five main research phases and its activities, which integrate the theoretical and engineering part of this research work. Section V draws the five most important steps of the research plan and its deliverables that are conducted in five phases. Furthermore, section VI introduces the five expected deliverables, one deliverable for each research phase. Finally, Section VII concludes this paper and provides recommendations for further research.

II. Background

A. Enterprise architecture modelling

Current literature on enterprise architecture (EA) and ArchiMate for STLSs conveys some reference architectures. The literature search was based on the method represented by Armitage and Keeble-Allen [9]. The search was particularly focused on literature that could connect IoT, smart multimodal transport systems with EA, and the cloud/fog-edge computing paradigm. The search queries' results showed that EA modeling with ArchiMate was not taken into consideration to solve the emerging problems when modeling and monitoring smart transport and logistics solutions.

ArchiMate is a modeling language that is used to define a notation for visualization of EAs [10]. The authors Zimmermann et al. in [11], [12], and [13], thoroughly explored the transformation of EA for the IoT, the progressive evolution of EAs, and architectural decision making for digital transformations. Their research was mainly focused on an exploration of the progress of decision-making processes, but not on how the architectures can be used in IoT or smart and logistics context. Consequently, there is a lack of a new method that will support researchers when modeling smart transport and logistics solutions.

B. Smart Logistics System Design

According to [14], smart logistics represents a manner for integration into a resilient environment founded upon data and information. With this approach, the logistics companies can gather insights from the gathered information in order to become more intelligent and optimize time and costs. In [15], an alignment of the business-driven view with a data-driven view and a design of a solution that is technically manageable and useful are proposed. However, a holistic approach for the logistics domain and a new definition for a situation-aware information system with a particular business context are missing. An EA approach might be suitable to fill that gap [15]. A new design of a situation-aware smart logistics enterprise architecture (SSLEA) was proposed to employ an IoT infrastructure to govern the detection and handling of exceptions during the completion of transportation processes [15]. Furthermore, a few reference architectures for smart transport and logistics systems and IoT based logistics solutions were found: [16], [17], [18], [19], [20], and [21].

C. Research Challenges

Due to the appearance of a large amount of data, which is generated by IoT devices during the whole supply chain process, data privacy, data security, and resource management, are seen as challenges [22]. Additional technical challenges are data acquisition and transportation modeling.

1) Data Acquisition

Several data sources can be used for data acquisition such as: consortium, Open Data, and users' demands [23].

- Open data is needed in order to examine the effect of weather changes and transport traffic onto the logistics processes. However, one of the biggest issues Open Data is facing is regarding data quality. Many datasets can not be used, and that can cause a burden to the processing.
- User-tailored or crowdsourced methods are some of the methods to predict user's demands [23]. The idea behind this statement is that each request of a particular individual can be satisfied with appropriate mobility solutions. The real challenge is to respond to the distributed users' requests with corresponding solutions.

2) Transportation Modeling

It is important to create models for transportation, but that can be challenging due to its dynamic nature. A well-made estimation model can be used to estimate travel demands, provide offers of suitable reference to logistics planners and policymakers to organize the applicable resources [23]. Accurate predictions can be made based on machine learning (ML) algorithms which can aggregate and analyze real-time data, historical data, weather conditions, and events. For instance, *linear or logistic regression* can be used for making predictions on the collected event data. Which ML prediction technique will be used depends on the type of variable that will be considered: linear for continous variables and logistic for categorical variables.

3) Data Privacy

During the execution of logistics processes, personal information and enterprise information is transferred over the internet. In [22], have been depicted the challenges to IoT deployment on maintaining privacy according to the data collection policy and data anonymization. Data anonymization can be ensured by cryptographic protection and protection of data relations. In [22], a logistics information privacy protection scheme with position and attribute-based access control for mobile devices is proposed.

4) Data Security

In [22], reasons why there are certain security issues of using IoT systems are discussed. An IoT system represents a dynamic system, which does not have defined parameters and is heterogeneously concerning the communication medium, protocols, and devices. Additionally, human interaction is not scalable in IoT devices and therefore it is difficult for security analysts to handle security activities. An extension or revisiting of existing security solutions is needed.

5) Resource Management

With the expansion of the IoT technologies in smart logistics, there has to be management of large variety of data formats, data protocols and sensing resources in the operation processes. This raises the topic on resource management and provisioning of devices in an efficient manner. Resource management is a challenge for smart logistics operations, and an interesting research topic for researchers. In [22], a resource management model has been examined, in which fog is used to manage resources, complete data filtering, perform preprocessing and deal with security measures. The proposed model deals with the issue on resource prediction, resource estimation, pricing for new IoT customers and advanced reservation.

III. Research Design

This section consecutively explains the scope of the research, and research questions. The concept of this research design is partly inspired by [24].

A. Research Questions

The main research question that this doctoral research project will intend to answer is: ***How can we design a method that will incorporate IoT and the cloud/fog-edge computing paradigm to contribute for integration, reliability and higher transparency of logistics processes?***

Sub-questions emerged from the main research question intend to support the main goal:

- *RQ 1:How can a novel taxonomy of IoT functional and non-functional requirements be used as a foundation for a comparative analysis when selecting an IoT platform for logistics?*
- *RQ 2:What are the existing resource management techniques that can be used in a cloud/fog-edge computing paradigm and how can they contribute for managing of sensing resources in operation processes?*
- *RQ 3:How can a design of an architectural overview support the management of services in a specific transport industry based on a cloud/fog-edge architectural paradigm?*
- *RQ 4:Which integration strategies can be used for a smart transport and logistics system to improve the quality of shipment processes via air, land and sea?*
- *RQ 5:How can we utilize ML and process mining techniques for a smart logistics system involving the cloud-*

fog-edge computing paradigm?

IV. Methodology

This doctoral research project (Figure 1) comprises a theoretical and an engineering section. The empirical part (phases I and II) is focused on development of a theory about IoT, requirements (functional and non-functional), and investigation of existing techniques about resource management in the cloud, fog and edge computing paradigm. The engineering section (phases III, IV and V) is about designing, developing, and validating the STLS platform in the functional context of logistics companies from the Dutch industry. The design of the STLS platform will respond to the taxonomy of requirements elaborated in the theoretical part of this research project. The Design Science Methodology from [25] will be used to develop the STLS platform in a systematic manner.

A. Research phase 1: Taxonomy

The research phase 1 is conducted in order to respond to research question 1. The phase is divided into three main activities, in order to discover the advantages of IoT platforms. Initially, a literature review about IoT, various services offered by popular IoT platforms, and requirements for IoT is conducted. Additionally, the thorough literature study is focused on five IoT platforms: Azure, AWS, SaS, ThingWorx, and Kaa IoT, which evaluates the performance of the created taxonomy. Secondly, a new taxonomy of functional and non-functional requirements for an IoT platform is developed. The taxonomy of functional and non-functional requirements for an IoT platform was a thorough research, where together with the second author of [6], were explored features that are already present in some of the biggest IoT platforms based on available online documentation. Inspired by this research, we created a more advanced framework of features that are present in some of the platforms.

Thirdly, by using the new set of functional requirements, a toolbox of multiple statistical techniques is provided. The toolbox was used as a basis for comparing the reviewed IoT platforms. Initially, it was checked whether these platforms are supporting the features of the framework, and then based on their supporting values(weights), various techniques were used to compare the platforms. The results (see [6]) can be used to assist companies in choosing a suitable IoT platform and to inspire IoT designers when creating a new IoT platform. Exploring and comparing various IoT platforms can help in identifying the advantages and disadvantages of current IoT platforms. Thereafter, researching about some of the best IoT platforms can help in developing an improved design models for a new smart transport and logistics platforms which will encompass IoT.

B. Research phase 2: Resource management techniques and evaluation framework

In order to answer research question 2, four research activities were conducted [26]. First, the concepts of Cloud, Fog, and Edge Computing are defined into details, and the differences between the layers are clarified through a concise literature review study. Second, the resource management techniques are classified into six classes: discovery, offloading, load balancing, placement, quality-of-service, and energy management. Third, an evaluation framework for the researched techniques is created, which consists of algorithm name, deployment method, classification type, resource management criteria, additional classification and environment mode. Lastly, the analyzed algorithms are visualized per type of solution paradigm: cloud-fog, fog-edge, fog-based or cloud-based. Additionally, the intention of the gathered knowledge from this research phase is to be applied in the deliverables 3, 4, and 5.

C. Research phase 3: Architecture model

This research phase consists of three main research activities to answer research question 3. The first one refers to collecting literature about EA modelling, taxonomy of cloud/fog-edge computing, and smart system solutions. In the second activity, in order to distinguish the contribution of the application of the cloud/fog-edge computing paradigm, an EA is developed that can be used in a smart airport demonstration study [27]. This activity is focused on development of an EA model by using ArchiMate, which was done through following the Design Science Research Methodology (DSRM) by Hevner [28]. Finally, the last activity is focused on validation and evaluation of the EA model. To validate the proposed EA for ALMS, a prototype that introduces some functionalities to its users is developed. The goal of the prototype is to support the efficient alert generation process to optimize the maintenance services for ALMS. The prototype does not cover all the aspects that are modelled in the architecture, but only the maintenance component from the application layer. In order to evaluate the architecture and prototype implementation, a group of experts was asked for opinions. The experts discussed the EA model, and then completed the provided survey. The development of this EA model is of importance for the later research phase dedicated to the development of STLS, which would integrate the shipment processes within air, land, and sea transport.

D. Research phase 4: Integration strategy

The fourth research phase will be merging the logistics processes in air, land and sea transport. This research aims to provide enterprise architecture modelling support for smart logistics service providers. Such a model should function as a common language for enterprise architects and process engineers. This will contribute to implementation of smart logistics principles at logistics providers such that business and IT alignment is achieved, effectively increasing visibility and transparency across the integrated enterprise. For this research, ArchiMate is the enterprise architecture language of choice. Deliverables 2 and 3 were created to be used as inputs and will become components of the integrated enterprise architecture model for STLS, which will be merging the logistics processes in air, land and sea transport.

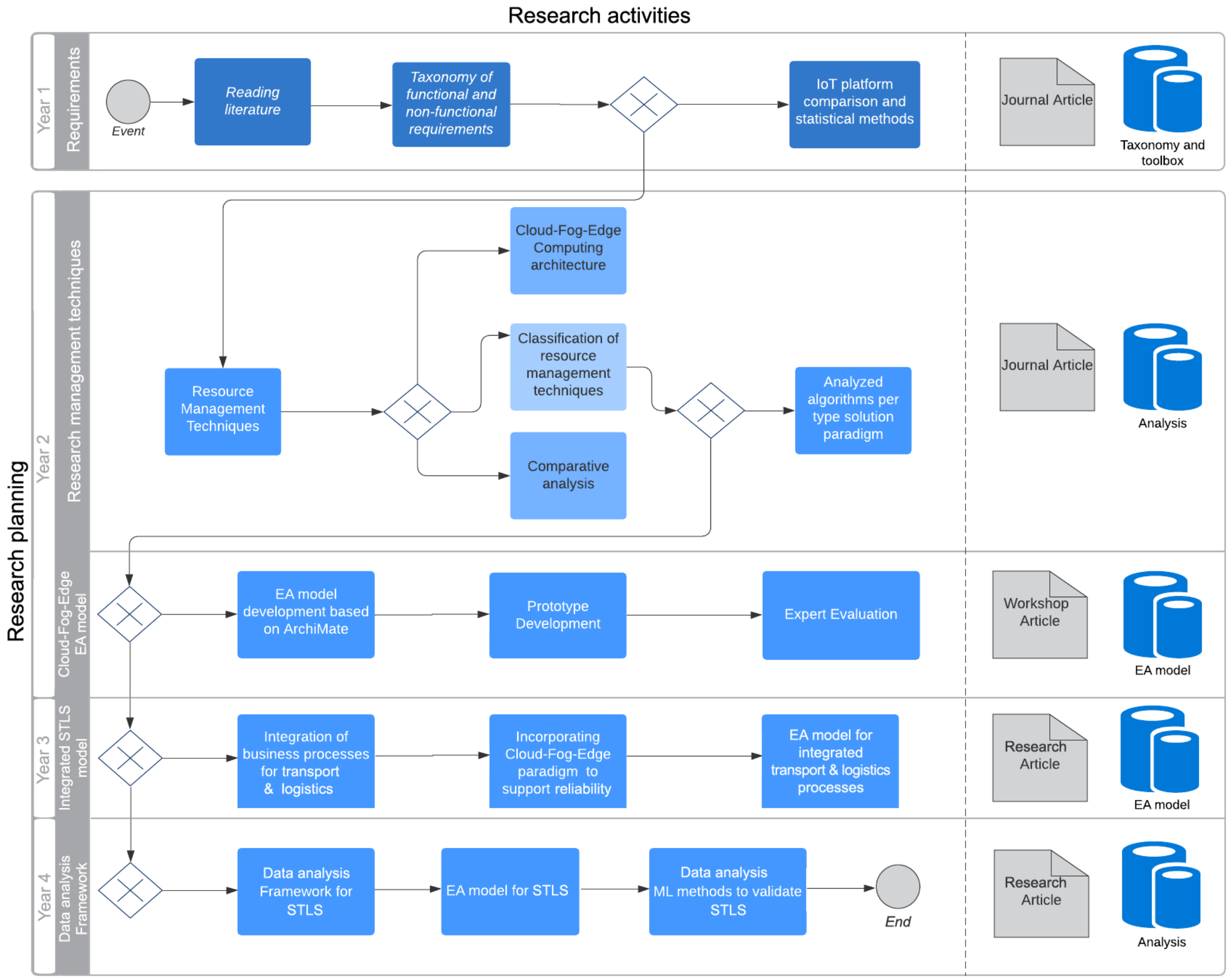

Fig. 1. Conceptual model of the research

E. Research phase 5: Data analysis framework

The last research phase refers to development of a framework for ML analysis and other analytical techniques in order to improve the quality of shipment in logistics (STLS). This phase focuses on exploring about utilizing data analysis techniques e.g. ML and process mining (PM) discipline. PM can be used to reconstruct, analyze and improve business processes by using event data from IT systems. While looking at the process discovery, users are able to investigate the actual process, and then decompose the process data in order to identify certain insights and sources of gaps.

For this purpose, there are three main research activities that will be conducted. The first one is focused on collection of literature about ML and PM and how it can support the industry by using event data from various IT systems. Additionally, one of the aims can be finding scientific articles that could combine ML and PM methods, which already support logistics processes. In the second activity, a machine learning or process mining framework embedded into an EA model can be developed, in order to respond to a quality of shipment case study will be created. A possible integration of process mining with ML and artificial intelligence will be examined, in order to achieve highly smart and fully automated insights into the business processes of a quality of shipment case study.

In the final third research activity, an attempt to determine which particular analytical methods can best detect failures within data gathered from logistics systems can be done. That can be completed in order to validate the created EA model from the previous step. ML techniques for prediction can be used in order to determine the QoS level upon delivery of goods, and this can be done by using logistic regression, which is a classification algorithm for categorical variables. In other words, it is used for prediction of a probability of a class label as a function of independent variables.

V. Research Planning

The steps to be completed during this doctoral research project are visualized in Figure 1. In the first step, the aim is to conduct state-of-the-art literature review about IoT, to develop a novel taxonomy for functional and non-functional requirements and to deliver a toolbox of statistical methods. The second step comprises state of the art study about cloud-fog-edge paradigm and resource management techniques. In the written survey about this matter, a classification of resource management techniques and an evaluation framework for the selected techniques are provided. In the third step, the following elements are considered: development of an EA model by using ArchiMate, validation of the model by using a prototype and an evaluation done by a group of experts. The fourth step is focused on integration of the operation processes within multiple models of transport (air, land, sea) and involving the cloud/fog-edge paradigm in the integrated EA model for STLS. The fifth and last step is dedicated to creating a new analytical framework for STLS, modeling an EA model for STLS and then providing a validation/evaluation with regard to selected ML or PM methods applied to event data provided by the industry.

VI. Research deliverables

In the following section there is a short presentation on the deliverables that are mentioned in the previous Section V. There is one deliverable per research phase, e.g. Deliverable 1 is an output of Research phase 1. More insights of the research activities and the link to the deliverables are shown in Figure 1.

A. *Deliverable 1: Taxonomy of functional, non-functional requirements, and a toolbox of statistical methods for IoT platform comparison*

B. *Deliverable 2: An evaluation framework and classification of resource management techniques used in a cloud/fog-edge computing paradigm*

C. *Deliverable 3: EA model for an efficient management of services in transport based on cloud/fog-edge computing*

D. *Deliverable 4: An integration enterprise architecture model for cloud/fog-edge computing paradigm in STLS*

E. *Deliverable 5: Machine Learning/Process Mining Framework to provide data-driven insights in a logistics system (STLS) based on a cloud/fog-edge paradigm*

The ultimate goal in the end, is to see how the available data can contribute for providing insights, and validating the case study in transport and logistics.

VII. Conclusion

Logistics service providers are required to deliver innovative smart solutions that will help them to discover many insights about the operational and logistics processes. With the introduction and development of the IoT and the cloud/fog-edge concept, there can be only additional motivations for logistics organizations to enhance their activities by using advanced decision support tools. The main question in this research is to the discover how IoT and the cloud/fog-edge computing paradigm can be used to support and integrate the business processes for improving the reliability within the transport and logistics. The solution should attempt to detect and minimize the failures within the collected event data during shipping goods from multiple IT systems. The research phases are designed to create a method to support enterprises in implementing IoT and the cloud/fog-edge computing architecture introduced in this article. Additionally, five research deliverables are proposed. The integration of all research phases is presented in an overview (Figure 1). The goal is that this research methodology will support the logistics service providers to use the suggested IoT architectures, and algorithms. Furthermore, it will be investigated how data analytics can help in detecting failures while goods are being shipped and, in the end, in which manner the reliability, reduction of waste of goods, QoS, and sustainability can be achieved.

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