System Roles in Developing Waste Collection Information Systems

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Abstract

Waste management is one of the systems where different sociotechnical aspects must be respected. The use of artificial intelligence and data analytics combined with new innovative technological solutions gives new opportunities in waste management. However, it is important to do not focus solely on these aspects in the cost of other issues such as different motivations regarding the waste management and legal aspects. This experience paper looks at the waste collection as one of the components of waste management and shows interplay of different systemic aspects in waste collection through the development of enterprise architecture model for waste management information system.

Keywords

Sociotechnical Systems, Waste Management, Waste Collection, Enterprise Architecture, Information Systems.

1 Introduction

Waste generation is inevitable in a modern society as Srika Rathi writes in his research article [1] published in 2007: "Economic development, urbanization and improved living standards in cities increase the quantity and complexity of generated solid waste. If accumulated, it leads to degradation of urban environment, stresses natural resources and leads to health problems."

Waste collection is a key phase of the full cycle of waste generation, reduction, movement, transformation, storage, and elimination [2]. It is also an important part of the waste management system in social, economic, environmental, and technical terms [3]. Although waste collection plays a central role in waste management, its importance is frequently underestimated [1], [4], with insufficient support provided by the involved stakeholders and academics, focusing on other parts of integrated solid waste management systems [3]. Pires at al., 2019, [3], display this with Google Scholar search results, which show that for key phrase "waste collection" there are about 157 000 results, while for "incineration" there are 375 000 and for "landfill" 639 000 results available. This demonstrates that researchers focus more on the later phases of waste management and pay far less attention on the waste collection phase. In the same research Pires et al. [3] explain further that in many cases waste collection managers are focused mainly on the technical resources, such as containers and transport vehicles, as they make up a large portion of costs. While these technical factors are important, in this paper we will also consider other factors with the goal to illustrate the interplay of different aspects in waste collection that must be respected when developing waste collection information systems.

Waste collection is a service that requires large investments and produces operational expenditures, environmental costs, and operational problems. Multiple studies [4], [5], [6], [7], have found that, because of the huge fuel consumption and human labor involved in operation, municipal solid waste

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collection is commonly the most polluting phase of municipal solid waste management. Combining different findings based on theoretical research and case studies, it is possible to see that it usually represents 50–75% of the costs associated with waste management. The main role of waste management and collection is to provide public health to citizens. However, waste has become a sought-after resource when it is qualitatively source and type separated [3].

To move towards its goal, this experience paper starts with the brief theoretical outline of different roles of a waste collection system in Section 2. Further, in Section 3, it illustrates the most researched role – the technical role of a waste management system. This illustration gives an insight in the complexity and variations available in this role. As the technical aspects are related with other aspects of sociotechnical systems, it can be assumed that other roles of the waste management system are not less complex. In Section 4, the information and communication technology (ICT) issues (also belonging to the technical role) are discussed in more detail. Section 5 presents a case study where enterprise architecture is constructed for a municipality waste management system and possibilities of reflecting all waste management system's roles in it are briefly discussed. The conclusion and directions of further research are presented in Section 6.

2 The Roles of Waste Collection System

After researching literature on the role and context of waste collection, a clear classification of the roles of waste collection systems can be put forward:

- Technical role,
- Environmental role,
- Social role,
- Economic role,
- Legal role.

Regarding technical role, different ways of collecting waste can have an effect on its properties and determine applicable treatment technologies. If waste is collected commingled it can be incinerated or stored in a landfill. On the other hand, if waste is separated by type granting higher quality, it can be recycled and become a valuable resource [3].

Because of the slow speed and long distances that collection vehicles must travel in order to collect waste, the process has an effect on greenhouse gas emission, congestion and air pollution, thus, playing an important environmental role. Achieving efficiency in waste collection process can have a positive impact on the environment [8], [3].

As mentioned before, waste collection is a highly visible service, so it is impacting the municipal identity. Therefore, its social role is to promote source separation to the waste producers with fitting communication, as their participation extent determines the rate of waste recycling [9]. Also, problems like odors, overflowing containers, occupation of public space and traffic can be associated with waste collection, negatively impacting the public image of waste management in a municipality. Therefore, it is important to minimize these factors.

Waste collection has a clear economic role being a cost intensive component of the waste collection system due to large investments and operational expenses [7]. As waste collection ought to be viewed as a public good, its availability, collection optimization, and cost integration in waste production should be appropriately addressed in practice [3].

The European Union has issued multiple policies and legal provisions regarding waste and handling of it over the last decades, advocating for source separated waste collection and stimulating studies comparing different types of waste management systems [10], [11] in [3]. The legal role of waste collection in each member country and municipality should comply with these policies.

The evolution of mentioned roles has been made possible by technological developments [3] that will be discussed in more detail further. However, this has not made waste collection an easier process to manage as all of the waste targets set by the European Union and local governments make it ever more complex, creating different waste streams requiring different technical solutions and management strategies. This adds complexity to the collection work that must be done, and the added complexity and set targets have an effect on the quantity and quality of the collection activities carried out [12], [13], [3].

The classification of roles can help in narrowing and specifying problems that need to be solved in order to set goals and practical projects and tasks that need to be carried out in order to improve waste collection process. As mentioned previously, the increasing waste production and limitations regarding legal, social, and environmental aspects are creating more pressure for improvements and technology can play a key role in achieving these improvements. To determine best possible applications, it is necessary to examine waste collection systems as sociotechnical systems.

Each role of the waste collection system presents a specific constituent system of a waste management system as a system of systems [14] that can have a high level of complexity. In the next section we will illustrate just one such role – the technical one.

3 The Technical Role of a Waste Collection System

Pires, et al. [3], looking at waste collection from system perspective, determine that it consists of two elements − containers and vehicles. However, this composition does not include other two important components, which should be added. One of additions is sorting areas/locations, which are used for collecting waste of different types, which, in turn, is then transported to a landfill or re-cycling plant. And this highlights another needed addition − a disposal facility. These components are interdependent and, also, depend on the method in which the waste is treated after collection. The functionality and interaction of these components impact the quality and further treatment and the use of the collected waste. Moreover, the many elements it must interact with make it a complex system to manage. Deposition containers must be accessible and safe to use by both the waste generator and the collector. They must also blend in with the surrounding environment. The geographic placement of containers and collection routes must be well suited for the local traffic and infrastructure [3]. Pires et al. [3] also list three interaction aspects − city mobility, infrastructure, and citizens. A diagram of mentioned component interaction is displayed in Figure 1. Such diagram is well suited for representing systems interaction for the scope of this study.

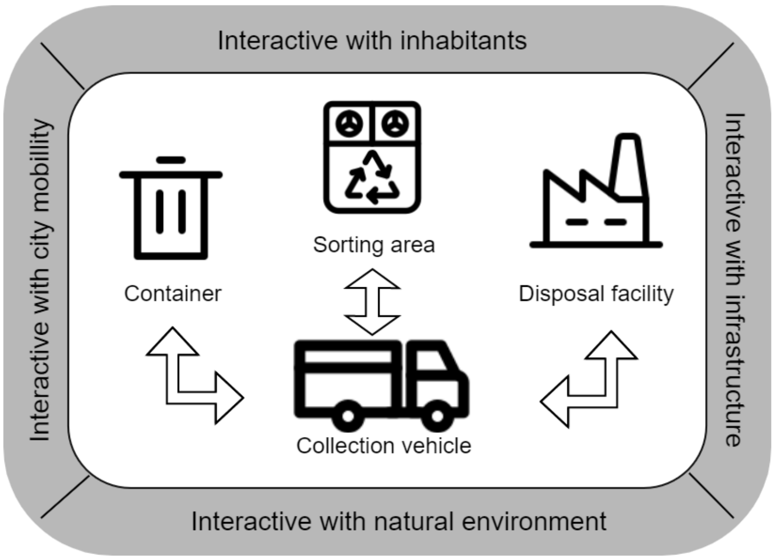

Figure 1: Waste collection systems interaction diagram

Further we will discuss three main components of the waste collection system from the point of view of its technical role. This will allow to see the level of complexity and possible variations in waste collection systems.

The first component illustrated is containers. Researchers Ana Pires, Graça Martinho, Susana Rodrigues, and Maria Isabel Gomes [3] in multiple studies provide an extensive overall classification of containers with up to five levels: emplacement, mobility, compaction, container access, and vehicle coupling. As other taxonomy methods found while researching literature are less detailed, mentioned classification is sufficient as the base for this study. The key factors to be distinguished are shown in a tree-diagram in Figure 2.

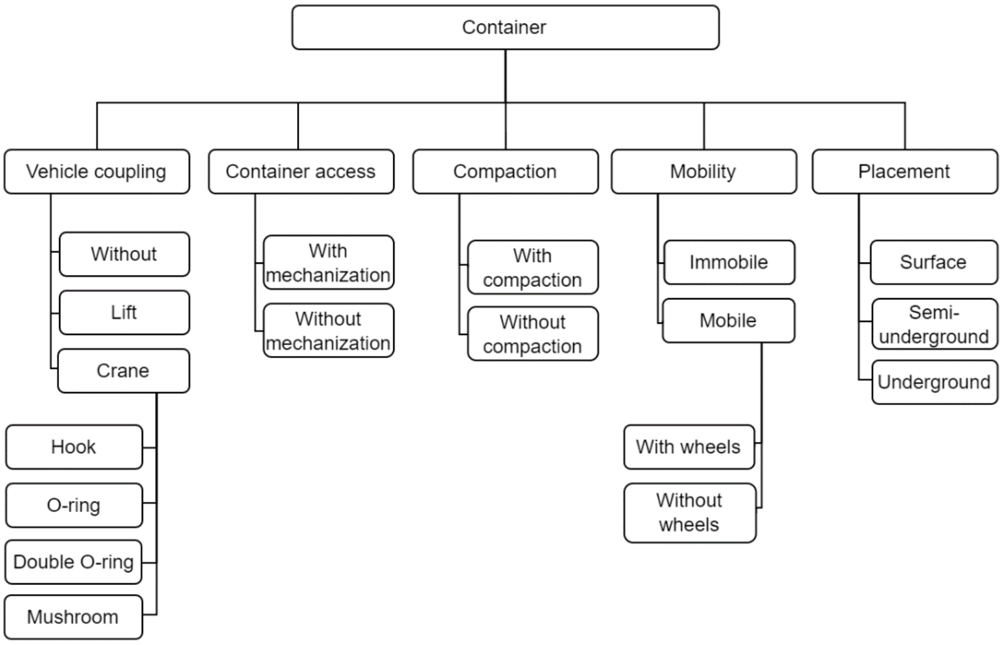

Figure 2: Aspects related to containers

The second component in waste collection is the collection vehicle. Similarly, as for containers, [3] provides a detailed taxonomy detailing the following sub-classes: body, body mechanization, lifting mechanization, and loading location. It aligns with classification proposed by Abdelazim M. Negm [15], focusing on container lifting and waste compaction factors. Since hydraulic packing devices are not used in the case study (Section 5), this level of detail regarding body mechanization can be reduced for the purposes of this study. This also applies for automated arm lifting mechanisms. The resulting classification diagram is displayed in Figure 3. As certain technological and mechanical solutions have become most common all over the world, the literature lists similar factors describing collection vehicles.

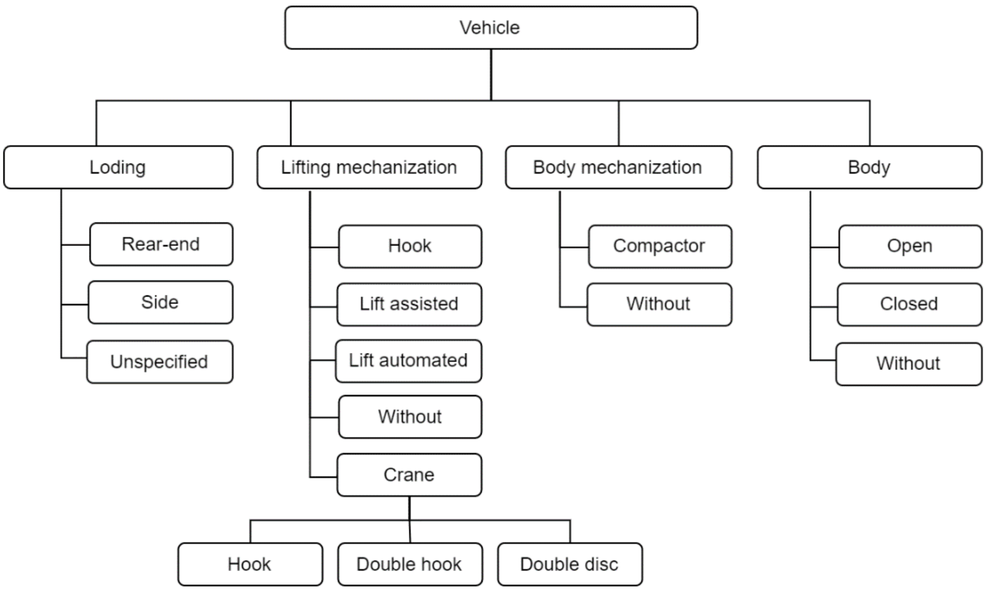

Figure 3: Aspects related to collection vehicles

The third component to be discussed here is a collection method. The collection method describes interaction process of a container and a collection vehicle and is a vital part of a waste collection system. It can be manual, semi-automated, assisted or fully automated. In case of a manual collection method, the waste container is moved to the collection vehicle and discharged in it completely by human labour. This is a highly labour-intensive method. Semi-automated system requires human involvement in operating the crane, whether it is by manually hooking the crane to the container or operating the crane with a controlling device. In an assisted collection method mechanical and manual involvement is present. The waste container is manually brought to the collection vehicle by the collection staff, and afterwards the container is lifted and discharged by a lifting device built into the collection vehicle. A fully automated collection method, as it implies, does not require any human manual labour. In this case a discharging mechanism is operated by the staff from the collection vehicle without performing any manual labour. The alignment of container vehicle coupling and vehicle lifting mechanization sub-classes is displayed in Figure 4, showing different collection methods.

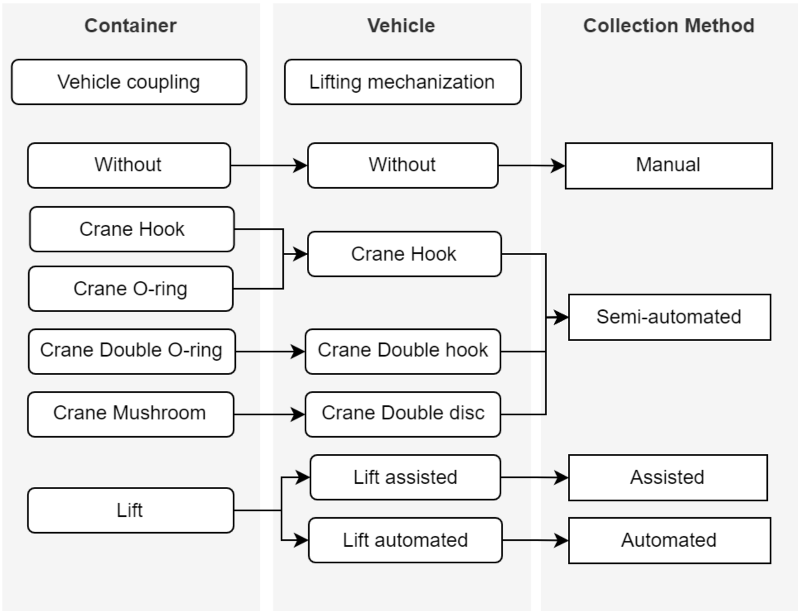

Figure 4: Variety of waste collection methods

The differences in the fulfillment of the technical role of the waste collection systems require appropriate flexibility of the ICT solutions used in waste collection. In the next section the state of the art in such solutions is discussed.

4 ICT Solutions for Waste Collection

In this section an overview of current ICT solutions related to waste collection is provided, some of key technologies impacting operations are highlighted, as well as common practices seen already are mentioned. If we are to look at waste collection from a broader scientific point of view, it can be viewed and analyzed from the perspective of environmental informatics, as this interdisciplinary science very well covers the process. Hilty at al. [16] provide the following definition of environmental informatics: "Environmental informatics is the science of information applied to environmental science. As such, it provides the information processing and communication infrastructure to the interdisciplinary field of environmental sciences aiming at data, information and knowledge integration, the application of computational intelligence to environmental data as well as the identification of environmental impacts of information technology." In environmental informatics research, synergy between environmental sciences, electronic engineering, and computer sciences is ever increasing. Although the discipline far exceeds the scope of waste collection or even waste management, it can provide a detailed outlook on ICT developments, use, and classification related to waste collection systems, as it is occupied with data collection, data analysis, data evaluation and other ICT related topics. This can provide the means to identify the ICT tools for improvements in waste collection systems such as data collection using sensors, data transmission via networking solutions, data analysis applying analytical methods and data science developments, data visualization for better decision making, and other ICT and system engineering approaches [17].

The field of environmental informatics has been developing since 1980s. Lu et al. [18] list various data-based tools for decision makers, such as spatial-data-based decision support systems and software leveraging environmental impact data. Pillmann et al. [19] also highlight that accumulation of research has led to increased environmental awareness and political responses. Environmental informatics is becoming more important for waste management including waste collection phase due to the increasing need for complex ICT solutions and applications [18] in order to address the increasing complexity with various streams and achieve set collection targets. Applying informatics methods and ICT can help solve these problems by providing appropriate data and tools for decision-making on various levels [17]. According to Chang et al. [17] applicable methods and tools include: "database systems (DBS), geographical information systems (GIS), global positioning systems (GPS), decision support systems (DSS), expert systems (ES), integrated environmental information systems (IEIS), and management science/operational research (MS/OR)". These methods and tools are being applied for strategic planning, optimization, management, and operational control (Figure 5).

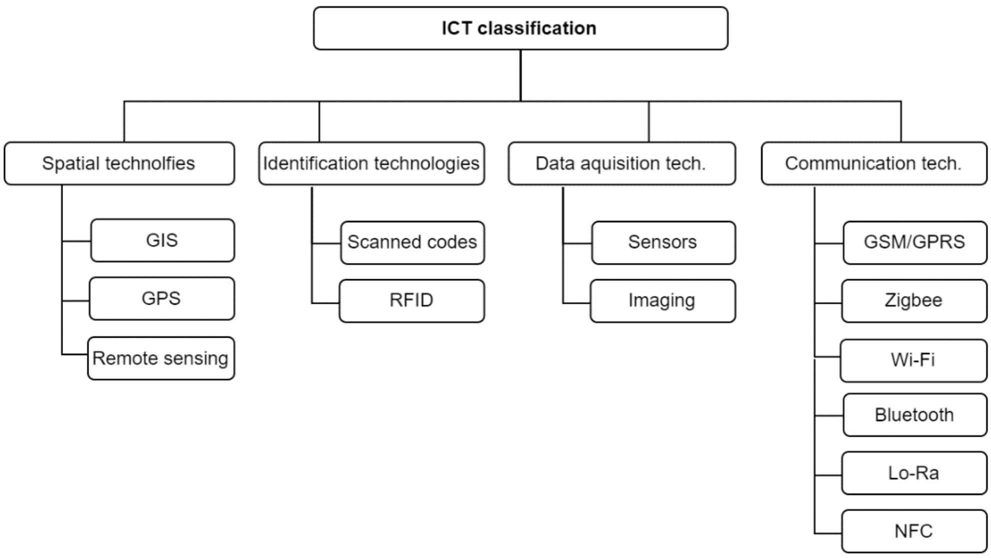

Figure 5: Spectrum of aspects in ICT solutions for waste collection

Possible benefits regarding environmental and financial factors are also highlighted by previously described roles of waste collection systems. Deep integration of waste collection into surrounding environment and large resources spent on operations provide plenty of room for efficiency gains and improvements. Also, there is high potential for significant cost saving and financial impacts due to the huge proportion of costs (up to 75% of total waste management operational expenditure) associated with waste collection process. ICTs have automated many elements of waste management like data collection, communication, data storage, and analysis [20]. Hannan et al. [20] provide classification of ICT application in waste management: "spatial technologies, identification technologies, data acquisition technologies, and data communication technologies" reused in Figure 5. For the scope of this study, relevant communication technologies such as Lo-Ra and NFC should be added to Hannan's et al. classification. Lo-Ra is a low range, low power consumption technology, and such a network is currently being built out in the city of the case study, and NFC is a near-field-communication method that was widely adopted in last decade. NFC is used for identification and access purposes, for example, when limiting access to containers or disposal areas with accounting of disposed waste. Further details of the case study are discussed in the next section.

5 The Model behind the Waste Collection Information Systems: A Case Study

The case study was done in the city with about 1 million citizens, namely, Riga in Latvia. In this study one of the authors was personally involved in the design of information system's elements. Also, interviews were made referring to the roles and components of waste collection discussed in the previous sections. The results of the case study are reflected in ArchiMate 3.1 [21] models which will be briefly discussed further in this section.

As the Motivation area of the ArchiMate language can provide a high-level insight in creating other models, it is the first to be described. The model is displayed in Figure 6, and as it can be seen in the model, different elements are very much related to each other.

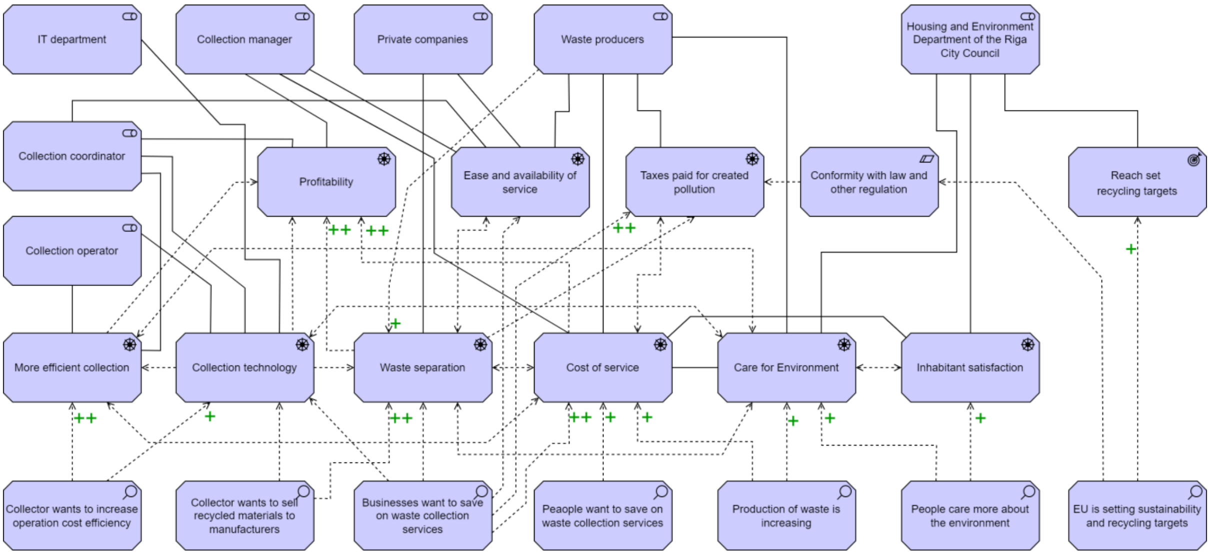

Figure 6: Motivation for waste collection

The top interrelated elements are 'Collection technology', 'Waste separation', 'Cost of service', 'More efficient collection' and 'Care for Environment'. All of these key elements are Driver types. This very well aligns width ArchiMate definition of Driver element: "A driver represents an external or internal condition that motivates an organization to define its goals and implement the changes necessary to achieve them." All of these key elements also align with findings in literature discussed in previous sections, such as waste collection making up to 70% of waste management expenses, technology being an important factor in operations, waste separation being one of the key methods for increased efficiency, and cutting costs and lowering environmental impact of the waste collection operations. Combining the fact that 'Collection technology' is the most interrelated element and evaluation of technological solutions used in waste collection in the city, the potential for technology to have strong impact can be seen. The city's strong move towards waste separation is backed by 'Waste separation' element being the one of the most interrelated elements with 10 relationships. Cost of service is a factor that is affecting Riga's waste producers in a direct way, so the element corresponding to it, being top interrelated driver, shows the potential in decreasing costs. The move towards separation is also associated with increasing re-sale of recyclable waste of different materials like glass, paper, and textile to manufacturers to be re-used in producing goods. Additional revenue that this practice provides is financial incentives for waste collection service providers to motivate waste producers to practice waste production with the focus on quality of separated waste, hence the strong impact of 'Cost of service' and 'Waste separation' elements on 'Profitability' element. Regarding this, waste collection service providers are continuously advertising good waste separation practices and reporting increasing quality of separated waste.

Analyzing the elements obtained in the model, it is clear that the motivation area of the waste collection enterprise architecture concerns all roles of the waste collection system that were listed in Section 2.

The business layer of waste collection enterprise architecture provides more details into the waste collection process and waste collection service provider interactions with other involved stakeholders. For this purpose, two business layer models are developed. The first model, displayed in Figure 7, is focused mainly on active elements of the Business Layer of ArchiMate 3.1 framework. It shows stakeholders involved in waste collection, their means of interaction, contracting, change requests, and feedback, as well as reporting of contracts and containers in service, and highlights main business functions and products.

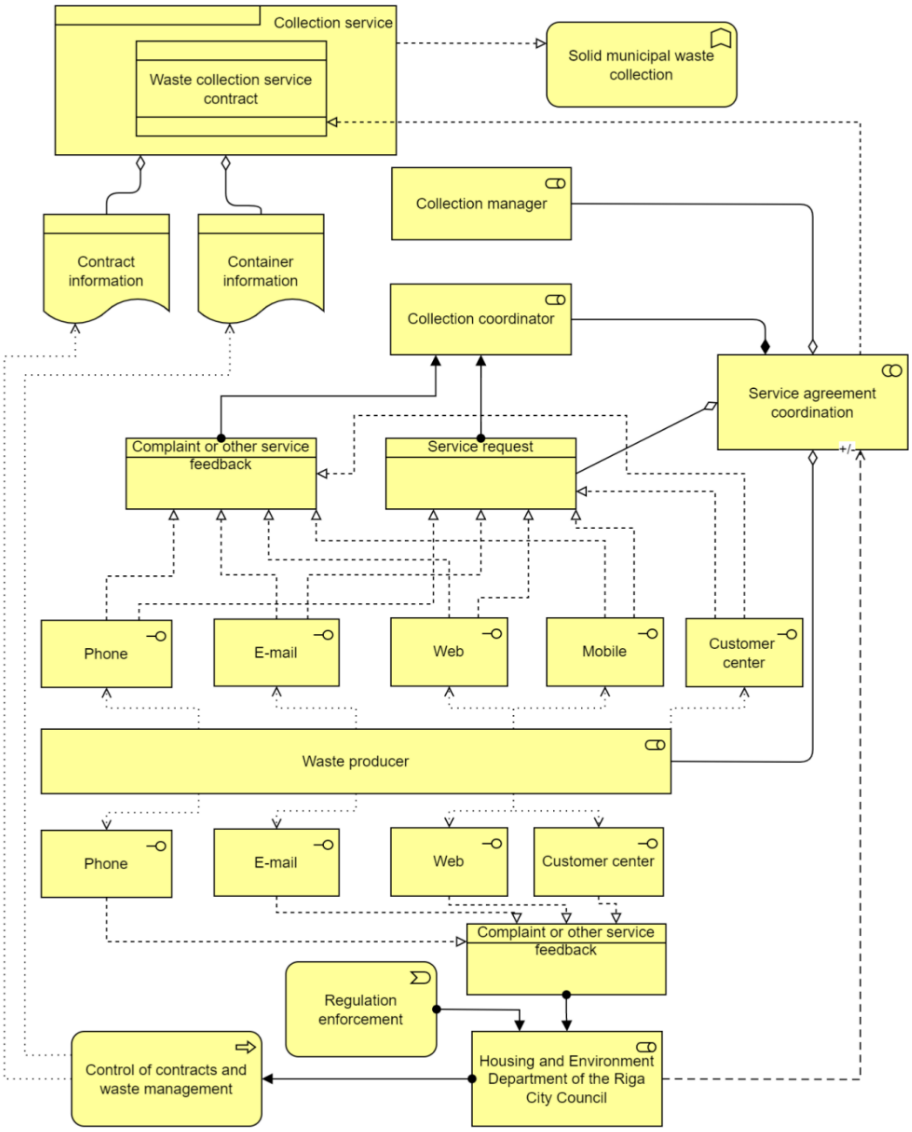

Figure 7: Business layer for waste collection

The main product is the waste collection service which is detailed by 'Waste collection service contract'. A service contract is reached by stakeholder 'Waste producer', 'Collection operator' and 'Collection manager' cooperating upon a 'Service request' made by the 'Waste producer'. This contract then details collection service to be provided, which is represented by business function of 'Solid municipal waste collection'. This is the main element describing waste collection process and is displayed in Figure 8. Waste collection service providers must report information about contracts and containers in the service to the Housing and Environment Department of the Riga City Council. This department has proved information that currently there is no system integration in place, as software is still in development, so necessary information is exchanged in file format through regular means of communication once a month. The files are shown as representation elements ‘Contract information’ and ‘Container information’ in the model and are accessed to perform ‘Control of contracts and waste management’ business function assigned to Housing and Environment Department of the Riga City Council. Another business object element ‘Complaint and other service feedback’ represents feedback provided by the waste producer through various interfaces both to municipality and service provider. An often case of such feedback is overflowing waste containers that need to be emptied or missed collection events.

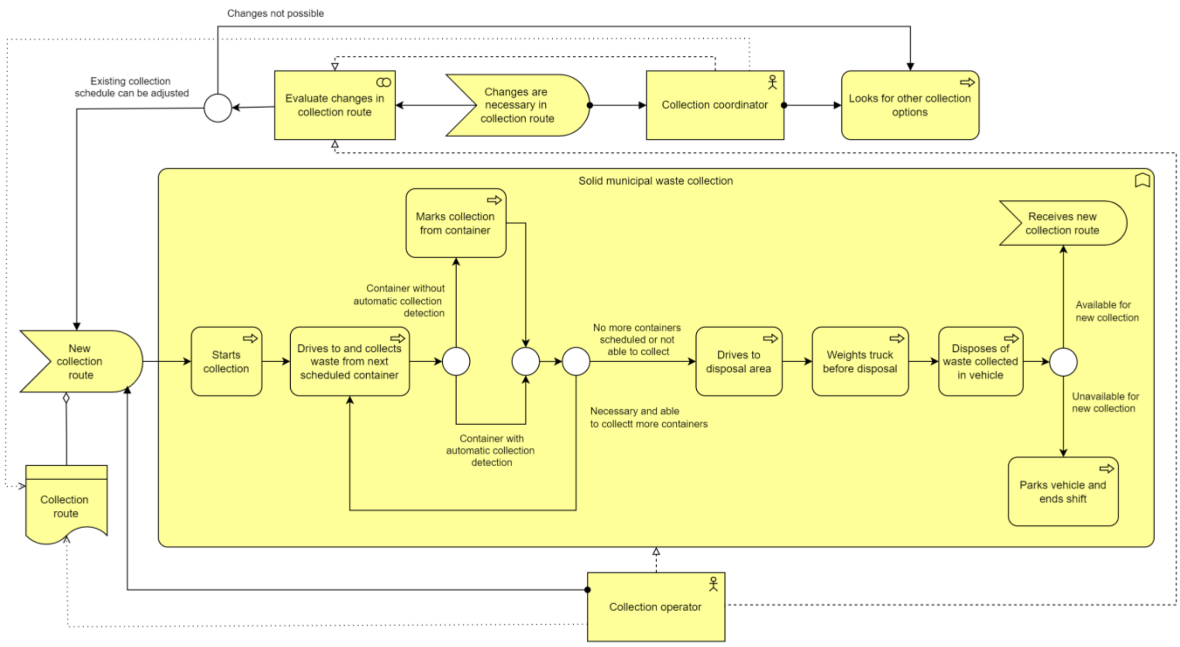

Figure 8: Solid waste collection

The models shown on the business layer of the enterprise architecture concern (partly) technical, social, and legal roles of the waste collection system.

Technical (including software) details are further explored on an application layer of the waste collection architecture in Figure 9. On it, the key application components and collaborations and data objects are shown. The central element of the model is ‘Application Component Waste management system’. It has multiple modules. As this component is a web application, it also has a ‘Web user interface’ for user interaction. In reference to Business Layer function elements, two application functions ‘Create collection route’ and ‘Update collection route’ detail access data object ‘Collection Route’ used to execute application functions, to support business functions. Data object ‘Collection Route’ is associated with other data objects – ‘Containers’, ‘Vehicle’, ‘Driver’, and in automated collection detection in return gets associated with ‘Collection event’ objects. Collection event data objects are created with application function ‘Automatic collection event report’ that is triggered by accessing/scanning RFID code from RFID tag installed in a container. The waste management system receives and saves collection event data after the RFID reader application detects such event and transmits it. Similar collaborations with other integrated applications are shown in the model with the collaboration and linked elements. Earlier described customer mobile app and web portal in use by the waste service providers are identified by application objects ‘Customer web portal’ and ‘Customer mobile application’. They are integrated with waste management system and expose graphical user interfaces to waste producers for receiving and providing information, and support customer service business activities.

The application layer elements basically represent technical role of the waste collection system while via relationships to business and motivational systems they may be related to the social role of the waste collection system as well.

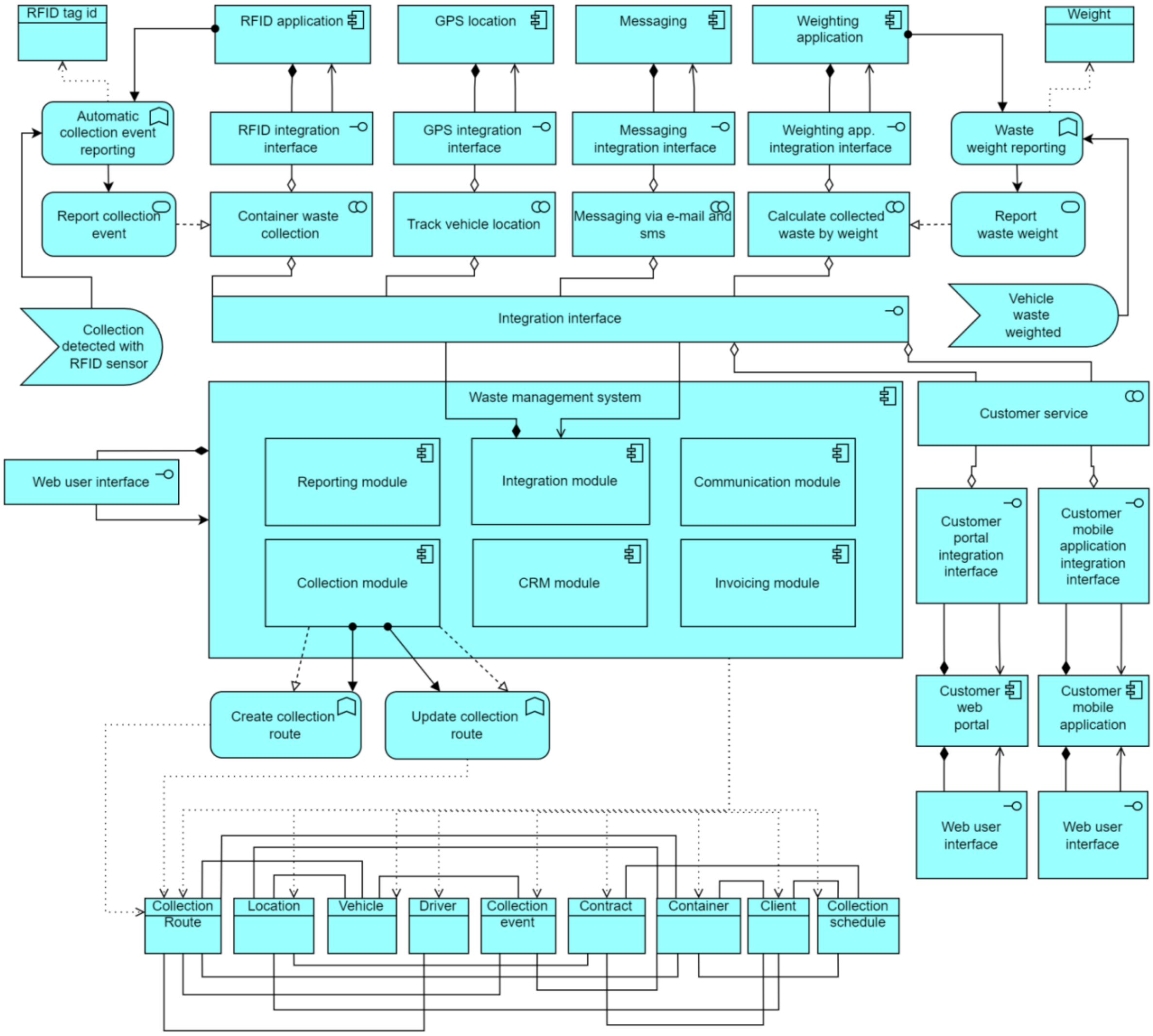

Figure 9: Application layer for waste collection

Last layers of the waste collection domain including its information system is the Technological and Physical Layers available in Figure 10. This model displays key technological components used to run the application detailed in Application Layer model. Also, it incorporates other key physical resources involved in the collection process. The movement of waste is displayed by material elements that, using equipment elements Container and Vehicle, are moved to Landfill facility. By using technological layer components 'RFID tag' and 'RFID reader' device, Application layer's 'Collection schedule' data object can be created. RFID tag reader connectivity is enabled through the 'Mobile network' and data communicated through Internet to Waste management information system run on System server 'Web server' software component. Other vehicle mounted technological component (Tablet and GPS device) networking is also provided via the Mobile network. In addition, GPS device is using GPS satellite network for GPS location tracking. The tablet is used by the vehicle driver to interact with Waste management system Web user interface detailed in Application Layer model. Additionally, devices like 'Mobile', "Tablet' and 'PC' are used to interact with the same web user interface. The 'Customer mobile application' is used only on mobile devices, including tablets.

Technology and physical layers basically concern the technical role of a waste collection system, while their elements may be connected to the other roles via Motivation elements.

The enterprise architecture model represented in this section shows the usefulness of conceptual schemes displayed in Figures 2–5 when trying to establish enterprise architecture that is the basis for waste collection information system's design, development, and maintenance. If all architecture artifacts are considered, we can find references to all five waste collection roles identified in Section 2.

However, we can see that these representations cannot give full information on how each of these roles are accomplished in detail (except of the technical role). This requires further research where, probably, such systems as waste management can be analyzed from systems of systems [14] perspective by defining several interacting systems, namely: the technical system, the environmental system, the social system, the economic system, and the legal system. Respecting that each of these systems have their "native" modeling approaches, another research question is how to find a common representation mechanism for being able to analyze them all as constituent systems of one system of systems.

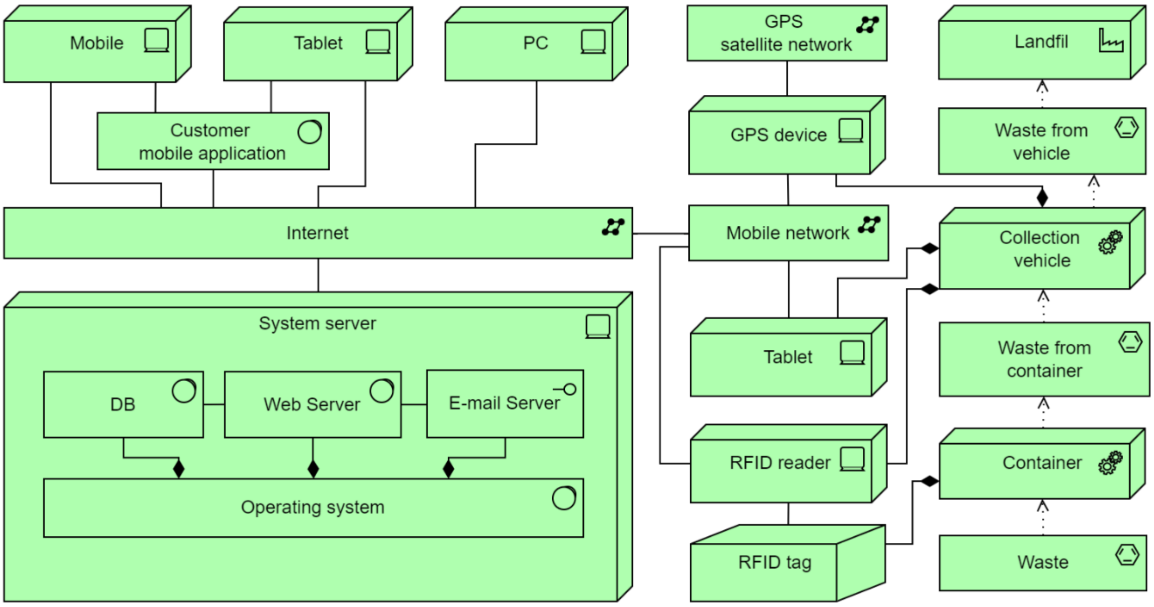

Figure 10: Technology and physical layers

6 Conclusion

This experience report pondered over the sociotechnical aspects of the development of a waste collection information system. ArchiMate language was chosen to represent the waste collection domain including its information system. The attention was paid to different roles of a waste management system that were discovered in the literature, such as the technical role, the environmental role, the social role, the economic role, and the legal role. To illustrate the complexity and variability of the technical role it was analyzed in detail. The results of analysis were applied in the case study that examined waste collection system in one city with about 1 million inhabitants. The resulting enterprise architecture gave an opportunity to refer to all identified roles of a waste management system, however, such roles as the environmental and economic ones were mainly available as the motivation elements of the developed architecture.

The results obtained led to the hypothesis that for deeper analysis of all sociotechnical roles of the waste collection system – the model of system of systems showing how these roles are performed could be developed, which is the matter of further research.

This study is limited to only one case study and only one sociotechnical system. While this system has a rich variety of constituents of different types, still more studies are needed to see whether five identified roles are sufficient for describing all relevant aspects of a larger range of sociotechnical systems. One more limitation of the case study is that during it the strategy layer of enterprise architecture was not constructed and the relationships between the layers were not identified. The presence of strategy layer and relationships between the layers would show more of the economical role, however even then, likely, it would not be possible to see this role of the waste management system, as well as most of other roles, in their full performance just from the enterprise architecture representations obtained in the case study (without innovative groupings of architecture elements) because the possible representations of the roles discussed in this paper differ from the common views of enterprise architecture.

References

[1] S. Rathi, Optimization model for integrated municipal solid waste management in Mumbai, India. © 2007 Cambridge University Press (2007). doi:10.1017/S1355770X0600341X.

[2] J. Bautista, J. Pereira, Modeling the problem of locating collection areas for urban waste management an application to the metropolitan area of Barcelona. Omega 34, 617–629, 2006. doi:10.1016/j.omega.2005.01.013.

[3] A. Pires, G. Martinho, S. Rodrigues, M.I. Gomes, Sustainable Solid Waste Collection and Management. Springer International Publishing, 2019, doi:10.1007/978-3-319-93200-2.

[4] B. Bilitewski, C. Oros, T.H. Christensen, Mechanical Biological Treatment, in: T.H. Christensen (Ed.), Solid Waste Technology & Management. John Wiley & Sons Ltd, pp. 628–638, 2010. doi:10.1002/9780470666883.ch40.

[5] G. Tchobanoglous, H. Theisen, S.A. Vigil, Integrated Solid Waste Management: Engineering Principle and Management Issue. McGraw Hill Inc., New York, 1993.

[6] J. Ferrer, E.Alba, BIN-CT: Urban waste collection based on predicting the container fill level. Biosystems, volume 186, p. 103962, Dec. 2019, doi:10.1016/j.biosystems.2019.04.006.

[7] M. Faccio, A. Persona, G. Zanin, Waste collection multi objective model with real time traceability data. Waste Manag. 31(12), 2391–2405, 2011. doi:10.1016/j.wasman.2011.07.005.

[8] O.M. Johansson, The effect of dynamic scheduling and routing in a solid waste management system. Waste Manag. 26(8), 875–885, 2006. doi:10.1016/j.wasman.2005.09.004.

[9] J. Tanskanen, M. Melanen, Modelling separation strategies of municipal solid waste in Finland. Waste Manag Res, 17(2), 80–92, 1999. doi:10.1177/0734242X9901700204.

[10] A. Iriarte, X. Gabarrell, J. Rieradevall, LCA of selective waste collection systems in dense urban areas. Waste Manag. 29(2), 903–914, 2009. doi:10.1016/j.wasman.2008.06.002.

[11] A. Gallardo, M.D. Bovea, F.J. Colomer, M. Prades, Analysis of collection systems for sorted househould waste in Spain. Waste Manag. 32(9), 1623–1633, 2012. doi:10.1016/j.wasman.2012.04.006.

[12] M. K. Pieber, Waste collection from urban households in Europe and Australia. Waste Manag World, July-August 2004, pp. 111–124, 2004.

[13] T. Kogler, Waste collection – a report with support from ISWA Working Group on Collection and Transportation Technology. Report for the International Solid Waste Association, 2007.

[14] ISO/IEC/IEEE 21839:2019, Systems and software engineering – System of systems (SoS) considerations in life cycle stages of a system. URL: https://www.iso.org/standard/71955.html.

[15] A. M. Negm, N. Shareef (Eds.), Waste Management in MENA Regions. Springer, 2020. doi:10.1007/978-3-030-18350-9.

[16] L. M. Hilty, B. Page, F. J. Radermacher, W. F. Riekert, Environmental Informatics as a new discipline of applied computer science. N. M. Avouris, B. Page (Eds.), Environmental Informatics, EUROCOURSES, Springer, volume 6. pp. 1–11, 1995. doi:10.1007/978-94-017-1443-3_1.

[17] N. B. Chang, A. Pires, Sustainable solid waste management, a systems engineering approach. Wiley-IEEE Press, IEEE Press series on systems science and engineering, 2015. doi:10.1002/9781119035848.

[18] J. W. Lu, N. B. Chang, L. Liao, Environmental informatics for solid and hazardous waste management: advances, challenges, and perspectives. Critical Reviews in Environmental Science and Technology, 43(15), 1557–1656, 2013. doi:10.1080/10643389.2012.671097.

[19] W. Pillmann, W. Geiger, K. Voigt, Survey of environmental informatics in Europe. Environmental Modelling and Software, 21(11), 1519–1527, 2006. doi:10.1016/j.envsoft.2006.05.008.

[20] M A. Hannan, M. A. Al Mamun, A. Hussain, H. Basri, A review on technologies and their usage in solid waste monitoring and management systems: issues and challenges. Waste Manag. 43, 509–523, 2015. doi:10.1016/j.wasman.2015.05.033.

[21] ArchiMate Specification. URL: https://pubs.opengroup.org/architecture/archimate3-doc/.