Evaluating Collaboration among the Internet of Things through Agent based Modeling and Simulation Approach

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Approval

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Dedication

I dedicate this thesis to almighty ALLAH and my Supervisor Dr. Imran. Without help of Dr. Imran I would not be able to complete this thesis.

Thesis Acceptance Certificate

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List of Abbreviation

IOT	Internet Of Things
ABM	Agent Based Modeling
SWM	Solid Waste Management
GIS	Geographic Information System
IR	Infrared
RF	Radio Frequency
CIOT	Collaborative Internet of Things
DES	Discrete Event Simulation
RFID	Radio Frequency Identification
IERC	International Electronics Recycling Congress
ITU	International Telecommunication Union
MCU	Machine Control Unit
MPU	Memory Protection Unit
MQTT	Message Queue Telemetry Transport
GPS	Global Positioning System
MSW	Municipal Solid Waste
PAYT	Pay As You Throw
ROM	Read Only Memory
RAM	Random Access Memory

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Abstract

The "Internet of Things (IOT)" is a network of physical objects, devices, vehicles, buildings, and other things embedded with electronics, software, sensors and network connectivity. IOT allows objects to be sensed and controlled remotely across the existing network infrastructure, enhancing collaboration through direct integration of the physical world into computer based system. IOT collaborations technologies are increasingly deployed in real world. IOT based collaboration deals with the environment in which different agents are collaborates with each other via desired communication network to achieve the efficiency in real world. This thesis discusses the evaluation of agent based collaborative IOT technologies into real world to examine the feasibility, efficiency and flexibility among different integrated objects/things. We proposed a framework that works in anylogic to model the system and simulate it. In addition to it we use some GIS components and resource optimization algorithm such as Ruin & Recreate algorithm which combined work in anylogic to achieve the desired efficiency. For this purpose we take solid waste Management as a case study through the use of smart dumpsters and collaborative technologies. Determine all the agents, define different states of agent, collaborative environment and relationship between different agents and environments. Modeling the collaborative environment for the system into real world environment, run simulations on this environment and evaluate it by comparing the simulation results with actual real world and monitoring the efficiency and effectiveness of the system before the actual implementation of the system into real world.

Keywords: *Agent based modeling & Simulation, Vehicle Routing Optimization, Ruin & Recreate algorithm, Collaboration technologies, Internet of things, Smart Waste Management*

Chapter 1

Introduction

This chapter provides the opening and general information of the research to provide the complete idea of this thesis. It is also explain the problem statement that is under discussion with its proper solution statement.

1.1 Opening Perspective

IOT is a cutting edge technology and it is being rapidly adopted to solve problems and improve system efficiency. Using collaborative technologies with the help of ICT we can manage and provide better services and optimize the use of assets of smart cities including water supply, roads, traffic lights, sewerage and solid waste collection system.

Due to involvement of active entities, agent based modeling is suitable approach to evaluate the system. Agent based modeling simulation approach is a new trend and is now being rapidly adopted by many researchers in analyzing & solving complex problems of the real world. Using modeling and simulation that is based on agent based modeling will investigate the collaborative technologies (Smart dumpster) with different parameters to provide and manage all resources efficiently.

1.2 Challenge

Many processes in real world need to collaborate to complete their tasks. In different processes different active entities need to interact with each other. Indeed to make collaborative system automate, smart technology come into play. To upgrade existing manual systems into smart systems we need to investigate and check feasibility of smart system and how these smart systems can collaborate efficiently using smart technologies. To check feasibility of smart system and evaluate their correctness and efficiency, we propose a method which is simulation and modeling of smart systems, which investigate smart systems with different parameters and settings. To the best of our knowledge, currently there is no solid waste collection and disposal management system in Pakistan that used and take advantages of ICT (Information and communication technologies).

1.3 Problem Domain

Problem domain is an engineering term that refers to all information defining the problem and its constraints. It includes the goals which the problem area wishes to attain. The context within which the problem exists and all rules that define required essential function or other aspects of any solution product. It represents the environment in which a solution will have to operate [1] [2].

Presently, due to the rapid growing of computer technologies, IOT is playing a significance role to perform daily life activities in real world. Many systems have lot of process in real world that needs to collaborate with others process to complete the particular task. This requires lots of overhead in order to accomplish their process. Traditional systems due to lack of knowledge about related process use unnecessary resources and does not complete desired process on time. In real world many process dependent on other process which cannot be completed without timely communication. Wasteful use of the resources is the major problem in real world that increase cost drastically. In addition the traditional system is not feasible enough and provides no effectiveness, smartness with respect to efficiently use of resources. To convert current manual system into smart system collaborative IOT comes into play to make a real system smart and optimize its processes.

1.4 Problem Statement

Based on the above stated issue, the problem statement is as follows:

"Collaboration among the IOT aims to achieve efficiency and optimal performance of a system, by effectively and timely utilizing resources through proper communication and information sharing**.** An evaluation method is required to compare the traditional real world system with a proposed smart system that involves collaboration, with improved efficiency and optimal performance**.** A thorough assessment of the proposed system will yield detailed insights of how it improves efficiency and performance, and will contribute in effective design decisions for implementation".

1.5 Solution Domain

Solution domain is a term which refers to all information that defines the proposed solution of the problem. It comprises the concepts, methods, techniques, framework and processes that provide help in solving the problem under study [1].

Following sub-sections give a brief overview of layered approach used in this thesis:

Model Layer

It is typically referred to the creation of model. Model layer is used to model the different agents, its states, color and transitions according to the desired perform actions, show the behavior of the system and designed a complete model for the real world system.

Simulation Layer

Simulation is referred to the mathematical layer. All the mathematical steps are performed in this layer. In simulation layer the mathematical equations, programming and algorithms are write up to get the desired results and simulate the desired model.

GIS Components

GIS components are used to simulate the real world location of dumpsters and vehicles on the map providing by GIS in anylogic. The agents showing their states on map and these states are then further manipulated by system to perform desired actions.

Ruin & Recreate Algorithm

Ruin & Recreate algorithm is being used in Anylogic with GIS components to provide optimized route between source and destination. It aims to provide the best shortest path among different agents, by wrecking the current solution and recreating it by manipulating the paths and evaluating its cost functions.

Experiment Layer

In experiment layer compare the behavior of the model with different parameter values and analyze how certain parameter affect the behavior of the model. It is also used to estimate the influence of the processes in your model.

Visualization Layer

Visualization layer provides facilities to design business graphic component charts to efficiently present the output data obtained by performing simulation. All visual properties are configured at design time and show the simulated results in the form of charts.

In summary, these layers are used to perform simulation to evaluate collaboration among internet of things. We however believe that this framework is open-ended and it can incorporate any other collaborative IOT environment too.

1.6 Solution Statement

Consider a system in the real world with a problem that needs to be solved. In many cases, we can't simply afford to find the right solutions by experimenting with real objects Building, destroying or making changes may be too expensive, dangerous, or just impossible. Modeling & Simulation is the risk free world is used to find the right solution and to evaluate the feasibility, efficiency, performance of the system and also helps to make better decisions. By executing simulation multiple times with different parameters setting different results are produced that help us to compare its results with Traditional system results. We are not just limited to produce results from simulations but it also answers the resource availability and utilization problem. Simulation solves the problem of how resources in system can be utilized efficiently and effectively. Multiple methods are used to evaluate the system performance and its efficiency. In order to evaluate IOT based smart system needs an effective way for evaluation when system is nonexistent. We propose the use of Agent based Modeling approach in order to model the proposed Collaborative IOT based system and evaluate its efficiency and performance gain through simulation. Use Agent Based Modeling and Simulation to get deeper insight into system before actual deployment of Collaborative IOT infrastructure. Agent-based simulation is a very suitable tool to create models that mimic urban systems in general. Agent-based simulation, together with land-use transport interaction model and cellular automata are applied in planning support systems. Information gained through simulation help us to insight and eventually contributes in effective design decisions for implementations. We take solid waste management system as a proof of concept and show how Collaborative IOT helps in improving efficiency in real world.

1.7 Scope of the Thesis

In this section, the scope and boundaries of the thesis are outlined.

1.7.1 Correctness

In this thesis, the approach, methods, process and framework deal with the correctness issue of simulated real world processes on collaborative IOT environment. We evaluate the correctness of our contributions by visualizing the resources optimizing utilization of real world into collaborative IOT environment. The efficiency of the system is also monitored for correctness purpose. The other issues such as security and performance are currently beyond of the scope of this thesis and considered as future work.

1.7.2 Generalization

Currently the proposed approach is based on agent based model layer, simulation layer, Experimental layer and visualization layer and a simulated evaluated environment is designed as a demonstration of how our approach can be applied on to evaluate the collaboration among IOT . However the framework is presented in this thesis is open ended and may be generalized to evaluate any other collaborative IOT environment.

1.8 Summary of the Contributions

Previous researches provides important information related to Internet of Things , Agent Based Modeling and simulation technologies but no one can use collaborative IOT to address the efficiency and effectiveness of collaborative IOT environment. By evaluating collaborative IOT environment into real world we address the efficiency of IOT collaboration in real world and discussed its effect on resources.

The main contributions of this thesis are as follows:

1. The framework is developed to evaluate, compare and simulate the real world environment into a virtual environment.
2. Investigate the collaborative technologies using IOTs, in which resources are efficiently utilized to optimize the real world operations, such as waste management
3. Monitor the feasibility of the collaborative technologies and to improve the performance of the complex system.
4. Evaluate the efficiency of a futuristic system design before its implementation using agent based modeling and simulation.
5. Simulating Real World Solid Waste collection scenario to optimize resource utilization in Solid Waste Management.

1.9 Structure of the Thesis

This thesis is portioned into the following main parts to provide complete understanding and establish the proper structure of the thesis.

Chapter 1: Introduction

Chapter 1 provides the opening perspective, general and clear understanding about the research of this thesis as well as which parameters will motivate to accomplish the research. It also addresses the problem statement along with solution statement.

Chapter 2: Background and Related Work

Chapter 2 discusses the background knowledge and some work that is related to this thesis. It is also containing state of the art, characteristics of ABM and significance of using Agent based modeling and simulation approach.

Chapter 3: Literature Review

Chapter 3 helps in explaining the knowledge including substantive findings as well as theoretical and methodological contribution. It explains how the work is similar and varies from the others.

Chapter 4: Methodology

Chapter 4 focuses on the proposed framework for performing simulation to evaluate the collaboration among Internet of Things using Agent based modeling. It is also discusses the case study of solid waste management system and contain the diagram of proposed simulation results and discuss the simulation results in detail.

Chapter 5: Simulation and Results

Chapter 5 discusses the simulation of the designed framework and its results.

Chapter 6: Conclusion and Future Work

Chapter 6 reveals the conclusion and discusses the future work that will be carried out to support this work.

Chapter 2

Background and Related Work

This chapter provides the reader a clear understanding of general information about the research of this thesis. It also described the background, history and the basic definition of the problem under discussion.

2.1 Background

IOT is an extension to the computer networks (internet of computers) having traditional architecture (i.e. client server architecture). IOT (Internet of things) signifies a way in which real time interaction between different objects is made possible remotely which are acting as access points to internet services. "Smart" objects plays vital role in embedding and communicating other object [3]. IOT is used to develop smart cars, cities, phones, homes and much more which you want to make smart [4].

To make city's infrastructure smart, versatility and diversity of collaborative technologies play important and vital role. Several kind of smart objects are being used in collaborative technology which include sensors that report exact location of accidents and disasters to nearest hospital. Audio sensor can report the diameter of area where crime scene happens especially in active shooting to help police departments.

2.2 Significance of Agent Based Modeling and Simulation

Modeling and simulation

Agent based modeling is decentralized approach which consists of individual or group of objects that interact to share some information and then process that information to get result and draw conclusion. Modeling consists of two parameters modeler and agents.

Modeler represents major things and agents (which can be vehicle, city and products etc.) state their behavior, placed on shared network for simulation [5], [6], [7].

Simulation is a reproduction of operations of real world process or system to improve performance. The system itself called model and denote operation of system over time. Simulation can be used to verify operations. Simulation basically focuses on modeling and assessment of a real world process [8] .

Agent

Agents have the following characteristics [5]:

- Agent is an actor having some set of characteristics and protocols prevailing its behavior and help in making decisions based on experience
- Agent has limited scope through which it can be defined whether it is part of agent or not
- Agents are independently interacted with environment and other agents in certain limits
- Agents have learning ability and easily discriminate the behavior of other agents
- Agents are goal oriented and worked out with respect to the achievement of goals

2.3 Collaborations through Internet of Things

Collaborative IOT is now trending in real world due to its efficiency, management and effective use of resources. In CIOT collaboration is made possible between different agents by sharing information with each other's via shared communication mode. CIOT aims to achieve and maintain the highest degree of efficiency with timely and optimizing usage of resources.

2.3.1 CIOT in waste management

Waste management deals with all the activities and actions that are involved in proper manage and disposal of wastage. Waste management includes waste collection, transportation, handling and disposal of wastage with regular basics monitoring. Waste management prior intentions are to diminish the unsympathetic effects on human environment. In this scenario we deal with sub process of waste management that includes waste collection and transportation from its beginning to final destination. Waste is collected by smart dumpsters and treatment through proper transportation that engage collaborations among both activities.

CIOT is used to collect and appropriate transportation of waste with the context of resource optimization and achieve the efficiency of waste management. In CIOT waste management smart dumpsters collects the waste and share state with other agent (trucks, central office) by sharing information. Information embedded the state, position and location points. Agent Based modeling is implemented for collaborations between agents. Resource optimization aims to reduce the time, cost and working labor and maximize the efficiency that are needed for accurate waste management through collaborative IOT environment.

Collaborative IOT implement the real world environment into IOT based environment. CIOT is implemented through simulations. Simulation reproduces the real world implication of objects into dynamically executable environment to monitor and managed systematically. In real world objects interacts with environment and different agents to represent their working states. Simulations facilitates to simulate the states and behavior of objects/agents and interactions of agents among environment, agents /objects based on real world implication. Different types of simulations approaches are used to simulate the real world according to the scenario being implemented. Agent based modeling (ABM), system dynamics (SD) and discrete event simulations (DES) are commonly used for simulations.

To evaluate collaboration and efficiency of the system before implementing the actual system we use agent based modeling and simulation approach in anylogic. Anylogic provides different modes of modeling and simulations approaches that are used based on the specifications of the system.

2.4 Agent based Modeling

Agent based modeling is decentralized approach which consists of individuals and groups of objects/things that interact with each other via same network share information's among things then process the information to produces results and draw conclusions [5].

Agents is an actor having some properties and behave/act as same as human can but in limited scope. Agent can take decisions independent to the environment and others agents in described manners. Agents are goal oriented/design for the achievement of specific goal having learning ability and response to other objects based on experience and environment.

The reimbursement of using agent based modeling is to model the system with heterogeneous (such as people, companies, assets, objects, buildings and vehicles), self-directed and passive actors similar as human centered systems. The system is working through communication, takes decisions and share information across the agents. Agents based modeling is the best way to get deeper inside the system, monitor and control the system before take decision to actually designing/implementing the system into real world.

Following Figure explains the interactions and working behavior of Agent Based Modeling.

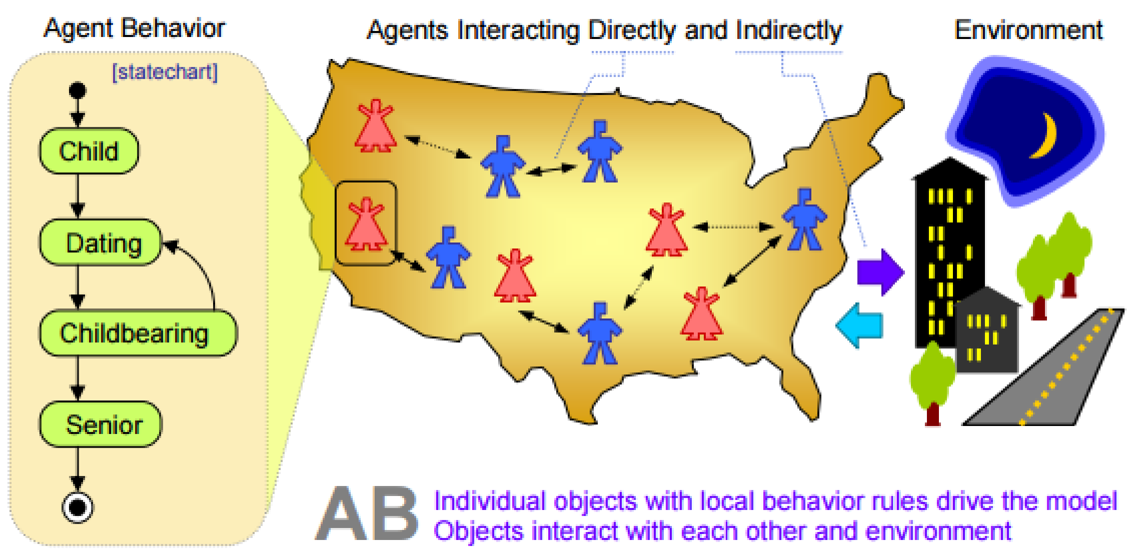


Figure 1: Interactions and working behavior of Agent Based Modeling [9]

2.5 State of the Art

Weingarten at el. discussed and presented the solution of simulators and identifies the generic simulator extension with the context of capability that is provided by real world application. Also developed the hybrid framework for simulation and execution of real world applications as smart as possible [10].

Brambilla at el. Proposed the hybrid framework used in large scale for simulation of IOT system. It provides loose coupling between simulation models and high modularity for reusability and extendable purposes [11].

Imran Mahmood proposed a framework to overcome the composability verification issue that holds in component based modeling and simulation. Also suggested the process to verify the composability of different kinds of system using component based modeling. The framework also provides methods, techniques and tools to verifying composability at different level of the system [12].

Over the few years with the augment in development of IOT Applications researchers have works to appraise the environment in which different objects are integrated to acts as smartly. Simulation and theoretical approaches used for the IOT. Theoretically accessed the system in descriptive manners is provided by theoretical approach. For simulation two types of simulations being used specialized and generic simulation. Specialized simulation is done through simulators that are provided by operating system. In this way entire device is simulated including hardware, application, communication, operating system. The number of devices is restricted in specialized simulation. On the other end generic approach requires simulation model of the application and can be used for the analysis of widely-scale, application-specific property without low level modeling overhead [13] [14].

Chapter 3

Literature Review

This chapter provides an overview of the subject under consideration. It will help in explaining how the work is similar and varies with previous researches.

This chapter reviews some key research that has already been performed in these fields. This research includes several different modeling approaches explored by the great researchers. There is some overlap between these topics. Therefore, there is a great opportunity in identifying some of leading issues across these fields and to deliver a methodology that will address the issues. Furthermore, this section concludes by discussing the limitations of the existing work.

Following Table represents the brief summary of the literature, details of the works are describe later.

Table 1: Literature Review

Ser No	Research Category	Related Work
1	An approach to Collaborative Internet of thing environment and technologies	a. Internet of things strategic research and innovation agenda [17] b. Consumer connectivity through consensus building [19] c. IOT global technologies and social trend [20]
2	Agent based modeling (ABM)	a. Agent based modeling and simulation of collaborative social networks [6] b. Agent based modeling of IOT network [34]

3	Framework for Modeling and Simulation	a. Verification framework for component based modeling and simulation [12] b. Simulation platform for large scale urban IOT environment [11] c. Model driven simulation approach [10] d. Agent based framework for self-sustainable system [35]
4	Internet of things leading strategies	a. From Internet of computer to Internet of things [3] b. Architecture approach towards the future of IOT [21] c. Success factors to Internet of things collaboration [22] d. Real time traffic management using IOT [23]
5	Tools and Technologies	a. Agent based modeling and simulation in anylogic [9] b. GIS component based product delivery [39] c. GIS as an integration technology [40]

3.1 CIOT in real world

Internet of things is a vital in making a city smart. IOT is not referred to a single technology. It provides an environment in which multiple things are connected and collaborates with each other's for proper communication. Multiple things like embedded sensors, RFID, GPS, and Wi-Fi are combined work to take decisions according to functionality and provide communication over the system. This sort of collaborative communication provides new services and ease in controlling different management activities. This takes many production opportunities in the field of IOT and increase to obscurity of IT [15].

3.1.1 IOT strategy and innovation paradigm

IOT provide solution over complex system by integrating software and hardware capabilities into single platform which referred to IT. These embedded capabilities are used to store, retrieve and process information by using communications technology such as electronic systems. There are basics three layers in which rapid combination of information and communication take place. These layers are data/cloud layer, communication network layer and devices layer [16]. IOT architecture contains application layer, network layer, device layer, service layer management and security capabilities as shown in the following Figure.

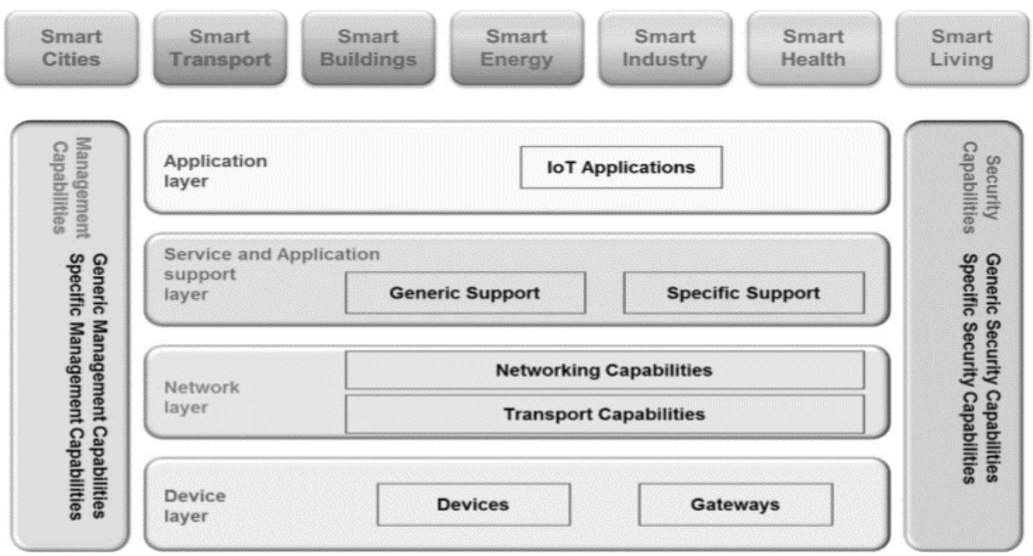


Figure 2: IOT Architecture with different working layers [17]

The (IERC) International Electronics Recycling congress is effectively involved in studying to develop standards for next generation network which is preceding the work of International Telecommunications Union (ITU). According to IERC IOT is a dynamic global network infrastructure based on standards and communication protocols to provide self-configuring capabilities. It work in an environment where physical and virtual things are integrated into an information network by using smart views [18] [19]. Working abilities of IOT which refers to IERC as shown in in the following Figure:

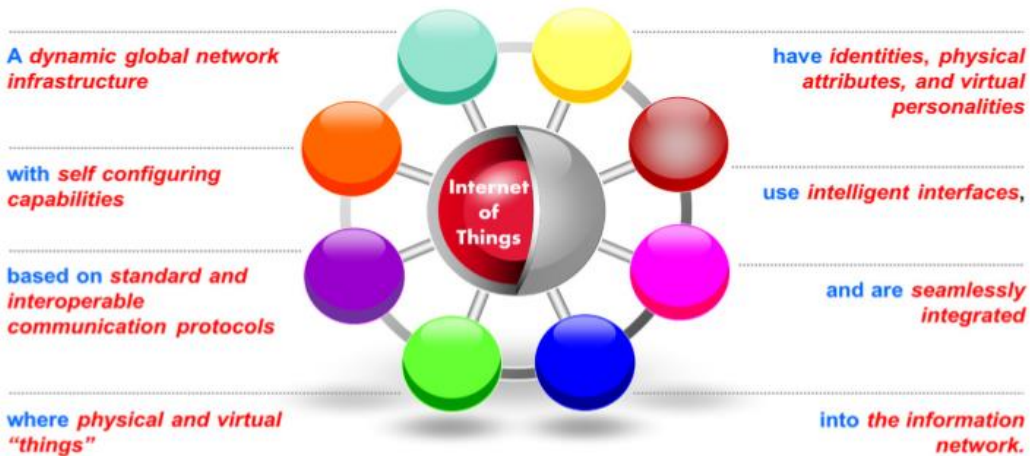


Figure 3: Capabilities of IOT according to IERC [17]

3.2 IOT Collaboration Assessment

IOT collaboration systems are developed to overlap the complex problems that we face in real world environment and provide ease to user or business decisions. To access the feasibility, efficiency and standardization of the system use two basic approaches:

- Evaluate through simulations
- Evaluate theoretically

Simulation has two types' specialized simulation and generic simulation. Specialized simulation provided through operating System includes entire device. In this way entire device is simulate including hardware, application, communication, operating system. The number of devices is restricted in specialized simulation. On the other hand generic simulation can be used to analyze the large-scale application-specifics without considering low level modeling [10].

Evaluation is categorized with respect to IOT essentials:

1. Technologies in IOT Environment
2. Internet of Things Infrastructure
3. Factors to IOT Collaboration

3.2.1 Technologies in IOT Environment

Technology exists as a root in IOT collaboration. The effectiveness, scalability, efficiency and accuracy are access through the technologies used to develop the IOT application. Different sort of technologies are converging to hold up and enable IOT applications. These technologies are summarized as [20]:

- Network Technology
- Embedded processing Technology
- Data and signal Technology

Network Technology

Network is an essential in IOT agent based collaboration. Network is referred to the topology and mode of according to which the working of the application is based. It provides the method as guidelines for the effective collaborations among agents. Network functionality, Management, scalability, composition and variability are the attributes that showing the efficiency of the network. The following challenges related to the different networks [17]:

- Complexity of the network of the future
- Growth of wireless network
- Mobile networks
- Expanding current network to future network
- Overlay networks
- Networks self-organized
- IOT and scalability
- Green networking

Embedded Processing Technology

Embedded processing is used for the environment in which software and algorithms embeds in hardware and works combined for the processing of information and other related activities. Security and complexity of software at hardware level is a major context in embedded processing. Technologies such as MCU, MPU, hybrid MCU/MPU, network processor widely used in embedded processing.

Data and Signal Technology

Physical devices or sensors that used for collecting, retrieving, manipulating, processing and transferring of the processed data in the form of signal through communication medium such as RFID, Wi-Fi, Cellular and GPS. Different types of devices used for sensing and data processing purpose based on the situation or business needs. Security of data, bandwidth of signal and accuracy in manipulating data is the key factors in IOT collaborative environment as shown in in the following Figure.

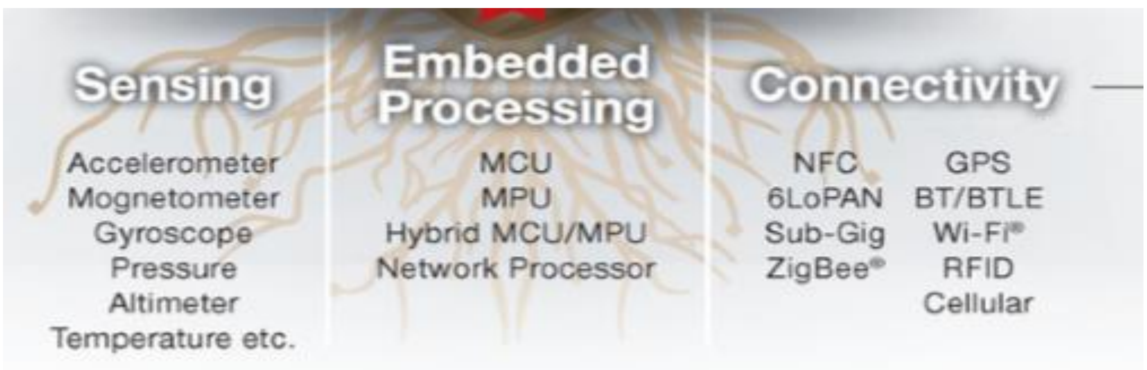


Figure 4: Different essentials on which the working efficiency of IOT is based [17]

3.2.2 Internet of Things infrastructure

IOT infrastructure exhibit the Architecture of internet of things collaborate agent to agent using standards and make decisions. The best thing related to IOT infrastructure is that it exists globally and vary in future as the requirements of the system being altered. It provides scalability to overcome the changing and to fulfill the future desires. The traditional approach that is used in IOT communication is RFID. It restricts the working of application to run and handle by just single client if the requirements tainted and system is used within the organization boundaries or handle by multiple clients then RFID not provides sufficient services in that conditions. Infrastructure is widely established to meet the future desires and effortless to extendable [21].

3.2.3 Success Factors to IOT Collaboration

Success of IOT based on the altering the traditional models focusing on the efforts. IOT represent the major growing of the opportunities for business. The Following factors leads to the success of IOT [22]:

- **Automation**

  Monitoring daily activities, retrieving data, connected devices automatically optimize the performance.
- **Real-time Visibility**

  Connected devices are continuously monitored and provide complete access.
- **Actionable Insight**

  Provide interfaces over complete authority to take decisions performance.
- **Customer Services**

  Customer oriented, meets all the desires of the customer by always-on, anywhere, any-time IOT services.
- **Global Scale**

  Provide opportunities to market to enlarge your business and take advantage of new revenue opportunities.

3.3 Resource Optimization using IOT

The main purpose of IOT is to achieve the efficiency of the complex system and to solve the problem of resource availability and usage by providing extendibility with the perspective of resources optimization.

Tanvi Tushar Thakur developed the system to manage the traffic flow density and congestion issues due to limited resource availability. IOT is used to optimize the resource and to prevent over traffic flow, density management and congestion problems by displaying/notifying traffic status early on website and also providing alternating paths to user [23].Yuri F. Gomes promote the application for personal healthcare based on IOT that interact with internet and try to resolve the traffic issue in e-healthcare by using MQTT (message Queue Telemetry Transport) protocol which is light weighted. The new way of direct communication tends towards the resource optimization by managing the heavy internet traffic problem [24].

Table 2: ABM and Simulation of real time IOT Application

Ser No	Related Work
1	Agent based model for solid waste management [26]
2	Solid waste management architecture using wireless sensor network [27]
3	Smart Solutions for Smart Cities: Using Wireless Sensor Network for Smart Dumpster Management [43]
4	Municipal solid waste recycle management based on IOT [28]
5	IOT based smart garbage system for efficient food waste management [31]
6	Agent based modeling of cholera diffusion [32]

3.4 Resource Optimization using IOT in SWM

Nikolaos V. Karadimas do his greatest to solve the problem of solid waste management in urban communities. He proposed the model for intelligent decision making system incorporated with GIS components into Agents based modeling and simulation. Execute the model and validated his results into real environment for the sake of decision making in actual implementation of the system [25]. Bi Guihong studies the complex solid waste management system and developed an agent based model using UML diagrams to simulate the household disposal, waste management and their effect on human under different Policies. Their experiments show that the approach is feasible for evaluating the complex solid waste management [26].

Sauro Longhi proposed architecture for solid waste to improve the managerial activities and reassign the optimization of resource. Web browser is used to remotely monitor the environment and server regains the measurements of garbage bins through data transfer nodes. Numbers of activities also have been designed to provide decision support system with the context of resource optimization in solid waste management [27]. The authors in [43], propose wireless networking technologies to optimize solid waste management with the help of smart dumpsters. Smart dumpster used waste level sensor to read the level of waste as being low, medium or high. Data collected through these sensors are send to municipal authority server. Data can be used to reduce the number of staff and truck for waste collection. Route optimization can be done to save fuel cost and minimize time. They also developed simulation model and perform simulation to optimize time and fuel. Chen Tao promote IOT technologies by analyze the complex SWM and propose the framework for information management based on IOT technology. Being Wuhan city as a case study to validate the feasibility of IOT based framework [28].

H.R. Schindler used IOT-based smart objects to decrease the amount of food waste. Their system is mainly based on three components which include server, router and battery-based smart objects namely smart garbage bins (SGBs). The smart objects share and communicate information via a wireless mesh networks while the router and server are responsible to collect and analyze the information. They also build web based services to improve performance and efficiency of system [29]. The authors in [30] developed and implemented an automated system of solid waste collection. Their system provided Allied Waste Services to City-Parish. They purposed a mechanism in which they place 96-gallon wheeled cart used as a waste collection can on the residents and it is resident's responsibility to place waste collection can in its correct place for pickup process. For pick up process they also used special vehicle which is noiseless and has robotic arm that is used to empty the can and place the waste collection can at its original position.

S. Park proposed a methodology to reduce the amount of trash entering the landfills by engaging RFID (radio frequency identification) with MSW (Municipal Solid Waste) by promoting incentive-based recycling programs and for waste management services he assist the growth of PAYT (Pay as You Throw) use-based billing [31].

3.5 Evaluate IOT through ABM and Simulation

Agent based Modeling and simulation is most preferred technique to simulate the behavior of the complex system where agents are decentralizes and vital in the execution of system.

Ellen-Wien Augustijn used Agent based modeling and simulation to develop a framework to investigate the cholera diffusion. Experiments were conducted in Kumasi, Ghana as a case study and use ABM model to simulate both environments of naturally occurring V. cholera and hyper infectious V. Cholera [32]. According to Samreen Laghari it is a hard task to test all the possible scenarios of complex system. Propose the use of agent based modeling approach to simulate the complex system and evaluate its complexity. Also solve the carbon footprint problem through that model [33].

Nicholas J. Kaminski examines the role of Agent based modeling using bottom up approach. IOT agent based model used to simulate the complex traffic road system and also inspect the performance of MAC protocol on which IOT communications are based [34]. Igor Tomicic interactions directed towards the development of system that is self-sustainable and entrenched the property of human sustainability. Use agents based modeling and simulation approach and develop a framework for developing and assessing the self-sustainable system because no system exists that helps in developing the sustainable system [35].

According to L. Atzori the survey focuses on integration and communication of collaborative technologies and intelligence of smart objects. Identification and tracking of smart objects, how collaborative technologies communicate using wired network, wireless sensor network and actual network and which protocol will be used on these networks. Contribution of Internet of thing in different discipline which includes telecommunication , social science , electronic , health care and much more. What major shall be faced by collaborative technologies are reported in detail [36]. I.Akyildiz discussed various framework and different aspects of RFID and its role in waste management system. This study investigates thoroughly the RFID tags from two points of views. First is which object they found in waste streams and second is at different stages of recycling they evaluate effectiveness and efficiency of different objects from very simple to complex objects [37].

According to I. Grigoryev Agent based modeling is relatively new technique as compared to discrete event modeling and system dynamics. To get deeper insight into system agent based modeling is used that traditional approach was not able to capture at all. Agent based models are widely used because of their benefits than other traditional methods and help researchers in solving and analyzing real world complex problems [38].

3.6 Thesis Position and Contribution

The literature review listed above discussed and provides quiet important information related to Internet of Things, Agent Based Modeling and simulation technologies but no one can use collaborative IOT to address the efficiency and effectiveness of collaborative IOT environment. By evaluating collaborative IOT environment into real world we address the efficiency of IOT collaboration in real world and discussed its effect on resources.

3.6.1 Contribution

The main contributions of this thesis are as follows:

1. The framework is developed to evaluate, compare and simulate the real world environment into automated environment.
2. Investigate the collaborative technologies using IOT which resources can be utilized efficiently and how much efficiently and effectively.
3. Monitor the feasibility of the collaborative technologies and to improve the performance of the complex system.
4. Evaluate an automated system using agent based modeling and simulation.
5. Simulating Real World Solid Waste collection scenario to optimize resource utilization in Solid Waste Management.

Chapter 4

Methodology

This chapter renders the core of the solution framework proposed in thesis. In this chapter, a collection of modeling techniques, algorithms, tools, methods are presented for simulations as a solution to problem in the evaluation collaboration among the IOT through agent based modeling and simulation approach.

4.1 ABM in Anylogic

Agent based modeling in anylogic provides different layers to model, simulate, experiment and visualized the desired parameter of the system.

4.1.1 Model Layer

In anylogic model layer provides facility to model the different attributes of real world system for simulation. Model layer is used to model the different agents, its states, color and transitions according to the desired perform actions, show the behavior of the system and designed a complete model for the real world system.

4.1.2 Simulation Layer

Simulation layer is used to perform all the simulation of the model that is designed in model layer. All the mathematical steps performed in this layer. In simulation layer the mathematical equations, programming and algorithms are writes to get the desired results and simulate the desired model.

4.1.3 Experimental Layer

In experiment layer all the set of configuration parameters are stored and run the different simulation tasks to measure its behavior. In this layer compare the behavior of the model with different parameter values and analyze how certain parameter affect the behavior of the model. It is also used to estimate the influence of the processes in your model.

4.1.4 Visualization Layer

Anylogic provides a facility to design business graphic component charts to efficiently present the output data obtained by performing simulation. All visual properties (color, scale, grid, legend) are configured at design time and show the simulated results in the form of charts (histogram and conventional chart).

4.2 Anylogic

Anylogic is a tool that is used for agent based modeling and simulations to support the study being carried. It can easily model the complex system. The anylogic provides multimode dynamic simulation and increase the flexibility of system by contacting other platforms (Excel, ERP). It provide dynamic platform for implementing Agent Based modeling, Discrete Event modeling and System Dynamics simulations. Anylogic increase the flexibility through multimode and distinctive capabilities. It simulates the agent working environment and produce results in the form of visuals shapes [7].

4.3 Implementation of Agent Based Modeling in Anylogic

Agent based simulation provide easier modeling by creating or removing the agents, interactions and relationships between the agents. Working of anylogic is based on object oriented has two powers implementing reality and manage change easily [9]. Following steps are used in anylogic for implementing agent based simulations.

1. Create new Model
2. Create a Population of Agents
3. Create State Chart of Agent
4. Create Variable of Agent
5. Edit State Entity and Exit Action
6. Add Statistics for Time Stack Chart
7. Add Time Stack Chart

Working flow of ABM simulation is represented in the following Figure.

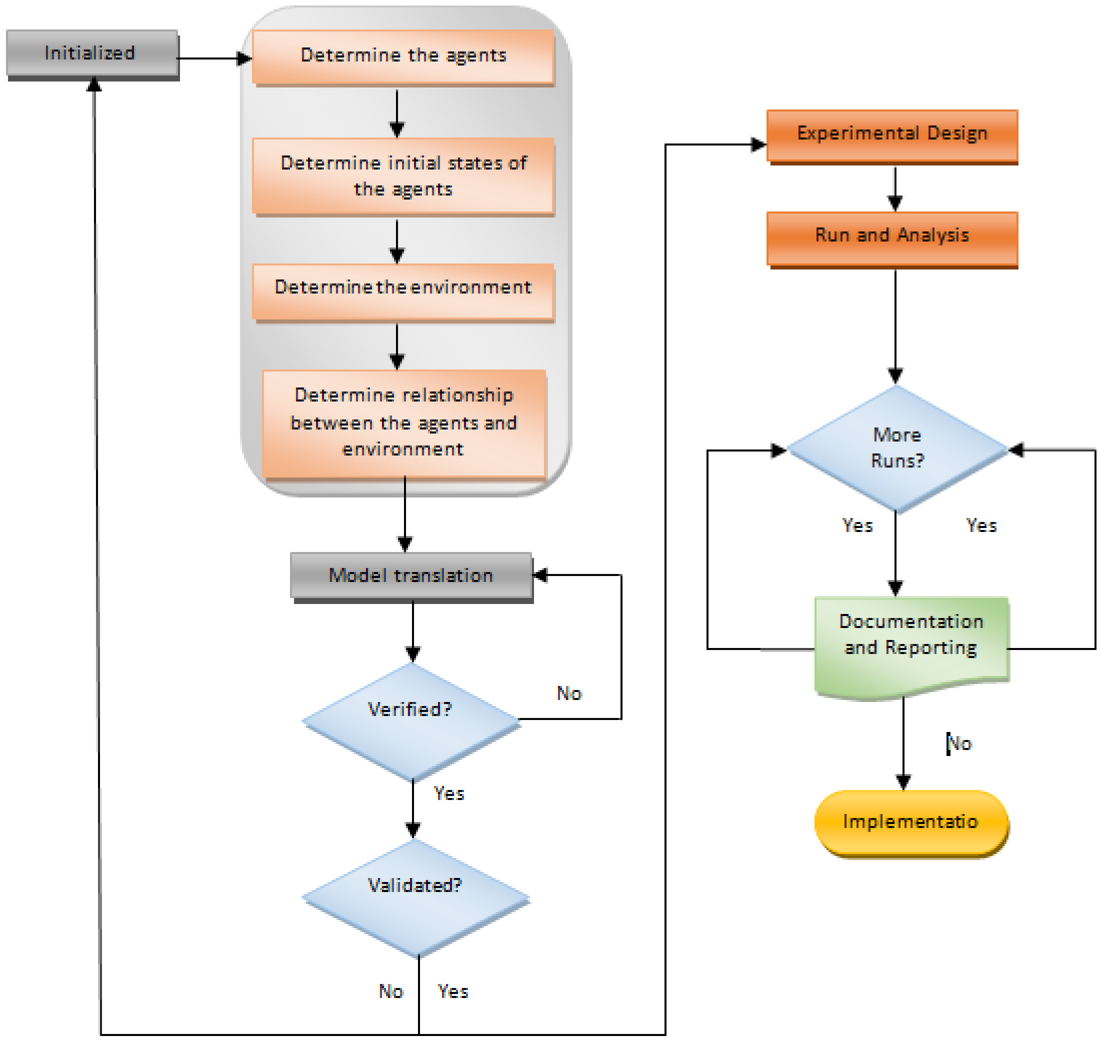


Figure 5: Working flow of Agent based modeling and simulations in anylogic [9]

In the first step data is collected and prepared a design related to data that is being processed. In the Model conceptualization layer determine all the Agents included in modeling, then determine and assign all the states of the Agents that are associated with each agent. After that determine the possible environment in which the Agents worked and also determine the appropriate relationship between the agents and environment considering all the factors respectively.

In the simulation steps Model is translated then verified and validated. In the continuous simulation is being run on the model and analyze the results of it. If more runs is required then go back to the design phase update the model and again run it. After that report and documentation is prepared and at the end simulation results are implemented.

4.3.1 Different type of Agents in Anylogic

Anylogic provides facility to create multiple types of agents based on the specifications of the model. Different type of agents exists in anylogic which are population of agents, a single agent and agent type only.

Population of Agent is used to create the number of agents that belong to same type and living in the same environment in current agent. Populations of agents are trucks, dumpsters, people and patient.

A single Agent is used to create a type of agent that will always exist within the current agent. Single agents are parking area, building, gas station and stores.

Agent type only is used to create type of the agent not for the creation of agent at this stage (such as Truck type, dumpster type).

4.3.2 Create Agents in Anylogic

Agents are created in anylogic by implementing the following steps. First of all select type of agent and assign its name then agent actions are selected that are executed when start, end and destroy the agent. In the next entity actions are described to select the role of the agents on state chart then movement parameters are assigned to mean the speed of the agent. After that environment of other agents is specified (which are GIS map, connection per agent, connection range, neighbor link, layout type and space type).

4.3.3 Agent working defined through State chart and Transitions

In anylogic state chart is used to point the state and transitions of the agents and describe the working model of the system. State chart display the states of agents with stack of time according to the transitions that are made in agents.

Agents representation of state and transition in Anylogic

There are different types of Agents used for agent based modeling and simulation in anylogic. Every agent has its own set of working and states with the perspective of goal achievement. Transitions switches the states of the agents when a particular action is take place or event is happened.

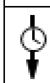
State chart

It is constructed to describe the events and time driven behavior. It has states and transitions.

State chart Elements

The following table shows the elements of state chart

Table 3: Statechart representative elements

	State chart entry point
	Sate
	Transition
	Initial state pointer
	Final state
	Timeout Transition

- **State chart entry point**

  It indicates the initial state of the state chart.

- **State**

  State represents the location of control with a particular set of reactions to conditions or events.

  - **State properties**

    State properties are as follow:

    - **Name**

Name of the state. It is used to identify the name of the state contained by the state chart.

- **Fill color**

  It's set the color for the state.

- **Entry action**

  In this property java code is written. It is used to be executed when the state chart enters state.

- **Transitions**

  It is used to switch from one state to another. When a specified condition is true then this transition triggered performing the specific action.

- **Timeout transitions**

  This transition is triggered after the specified time to switch from one state to another.

4.4 IOT Entities as Agents in our simulation

Agent based modeling is used to mapped the real world objects in anylogic. In real world, objects have some properties, decisions capabilities and their scope is defined for interacting with other objects. The real world objects behave as same as agents in modeling. Interaction is possible between agents by modeling the behavior, attributes, interaction and goals for every agents. In model Agents interact with other agents and complete their action by sharing information/message passing.

Smart dumpster (Skip-bins), control station and Truck (Skip-Lifter) are the agents. These are all decentralized but sharing information through message passing from one agent to other such as dumpsters to control station and control station to Trucks. The way of working model between decentralized dumpsters, vehicles and control station is agent based.

Two main agents are participating in Simulation which are smart dumpsters and Trucks

4.4.1 Smart dumpster

Smart dumpsters are used for the purpose of wastage collector. Dumpster include ultrasonic sensor to continuously monitor the state of the dumpsters. When signal is sensed by sensors transition happened in dumpster and changes its state. There are different states of dumpsters in anylogic that shows the processing of the system.

4.4.2 Truck

Trucks are used for the purpose of proper disposal of wastage collected by smart dumpsters. Trucks transport the filled dumpsters or collected wastage to place where it can be treated for next processing. Trucks have different states of representation in anylogic according to their transitions or working conditions.

4.4.3 GIS Components in Anylogic

We are using GIS components to simulate the real world location of dumpsters and vehicles on the map providing by GIS in **Figure 6** Anylogic. The agents showing their states on map and these states are then furthers manipulated by system to implement desirable actions.

Two main GIS components are used in simulation to defined map and their location for agents on map

Which are following:

1 GIS map

2 GIS point

GIS map

Anylogic provides the facility to use routes for agents on GIS map. If you want the agent is travelling through specified routes, the Route is selected in term of initial and final position and anylogic then download the accessible routes from an online service providing by GIS online map services.

Map for agents in GIS showing the location of agents by providing map that shows the particular routes between different agents having starting and ending position of the agents.

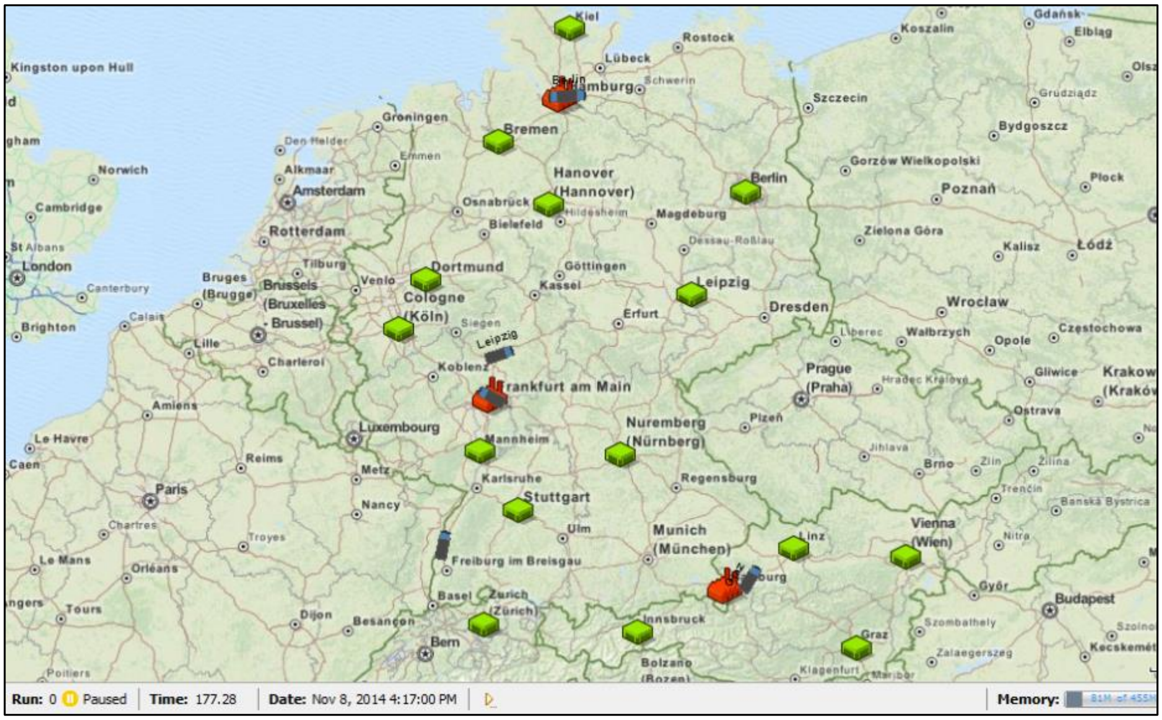


Figure 6: Anylogic integrated GIS components showing Agents position on map [39]

GIS point

GIS point basically works on spatial data and tells us about the co-ordinates and location of objects/dumpsters. GIS capture, store, analyze, manipulate data and produces exact points and road map for the object [40].

GIS point in Anylogic are used to point agents on map by using latitude and longitude. These GIS points are further passed to agents to move form one source to other source.

Geographic Information System components work together in Anylogic to represent the states of the smart dumpsters and trucks in the form of points/road map providing by online GIS map services.

We are using GIS map to define routes between Trucks and dumpsters. Trucks are following optimized routes to save resources. To optimize routes we are using Ruin & Recreate Algorithm.

4.4.4 Vehicle routing problem

An algorithm used to find shortest path among nodes in graph. For example if we want to go to multiple cities having multiple different routes, we may want optimal path to save our resources. Basically this algorithm solves our problem efficiently by providing optimal solution/path.

Multiple Truck problem

For multiple trucks and multiple sectors, waste management problem is transformed into an extended form of Traveling Sales Man problem (TSP) called Capacitated Vehicle routing problem (CVRP). VRPTW used (Vehicle Routing Problem with Time Windows), a timed variant of solving CVRP.

Formally, a CVRPTW is defined as a graph:

Let $\mathcal{G} = \{\mathcal{V}, \mathcal{E}\}$ be an undirected graph, where $\mathcal{V}$ is the set of vertices and $\mathcal{E}$ the set of edges.

- The vertices $v_i \in \mathcal{V} \mid i \in \{0, \dots, n\}$ represent a set of $n - 1$ dumpster sites and a depot site ($n = 0$), each site having a demand d_i
- The edges $e_{ij} \in \mathcal{E} \mid (i, j) \in \mathcal{V}, i \neq j$ is associated with a cost c_{ij}
- A fleet of $\mathcal{M}_k \mid k \in \{0, \dots, m\}$ vehicles, located in a depot v_0, each having a capacity d_k

The CVRPTW consist of finding vehicle tours at minimum cost such that each dumpster is served exactly once by a single vehicle $\mathcal{M}_k$while each tour starts at the depot v_0, serves the dumpster without exceeding the vehicle's capacity d_k and finally ends at the same depot v_0.

A CVRPTW is a graph where dumpsters are nodes (with longitude & latitude) that are connected with edges (with cost = travel distance and travel time). We need to find a path that serves all the dumpsters with minimum total cost involved. Since each truck has only 5 dumpster capacity and they all are parked at the depot and we have time constraint, there exists a tradeoff between using multiple vehicles at a time for quicker deliveries, or using same vehicles multiple times for minimizing vehicle usage.

Algorithm I: Capacitated Vehicle Routing with Time Window

Input: Trips:Array, Depot:Location, Landfill:Location, FleetSize:Integer

Output: Optimum Solution

```
Initialize Vehicle Routing Problem  VRP
    VRP ← RoutingCostMethod = GeoCosts ▻ calculates GIS road distances
    VRP ← FleetSize = FINITE    ▻ Specifies that the fleet has finite size

    ▻ Add a fleet of vehicles
    VehicleType ← "Truck" [Capacity = 5]  ▻ define new vehicle type with fixed capacity
    for i = 1 to FleetSize  do
        V ← Vehicle (VehicleType)
        V ← StartLocation (Depot)
        V ← EndLocation (Depot)
        VRP ← Add Vehicle (V)
    end for

    ▻ Extract jobs from messages received by CDA
    for each Trip ∊ Trips do
        for each Message ∊ Trip do
            Shipment S ← Shipment (Message.ID)
            S ← Pickup Location = (Message.long, Message.lat)
            S ← Cluster = (Message.Sector)
            S ← Delivery Location = Landfill
            S ← Required Capacity = 1 unit
            VRP ← AddJob(S)
        end for
    end for

    ▻ VRP optimization algorithm
    Initialize Vehicle Routing Algorithm ▻ Configure Ruin & Recreate parameters
    Optimum Solution ← Ruin & Recreate(VRP, 100) ▻ Ruin & Recreate Approach
Return Optimum Solution
```

Algorithm I takes the following inputs: (i) an array list of 'Trips', which contains a sector wise collection of dumpsters with locations, requesting pickup; the location of the depot (CDA), location of the landfill and the size of the trucks available for service. The algorithm outputs an optimum solution, which is generated after a finite number of iterations, and is applied in the further process of the simulation. In line1, the algorithm initializes a vehicle routing problem object and configures cost calculation method. Line 3 specifies that the size of the fleet is limited and will be considered as constraint. Line 5-12 initialize vehicles of fixed capacity (i.e., 5 dumpsters), their source and destination locations. Lines 15-24 are responsible for creating jobs of type 'shipment' by extracting 'Trips' array list. Lines 28-29 are concerned with the main execution of the algorithm by calling a subroutine.

Pseudo code of Ruin & Recreate algorithm

The steps on which Ruin & Recreate algorithm working is based for finding the optimizing path are described in the form of pseudo code. This provide clear understanding to reader related to its working.

```
S^0 ← Generate initial solution(VRP)   ▻ Randomly construct an initial solution
S^• ← Improve(S^0)   ▻ Solution through local search using Greedy Search (first improvement)
    While (i < Max Iterations)
        Ruin Mode ← Choose a Ruin Strategy {Random, Radial}   ▻ Select ruin strategy
        S ← Choose Ruin Candidate (S^•, Ruin Mode)
        S^~ ← Ruin (S)
        Recreate Mode ← Choose an insertion strategy {Greedy, Regret}   ▻ Select strategy
        S^* ← Recreate (S^~, Recreate Mode)
        If S^* is better than S^• then
            S^• ← S^*   ▻ Accept if a better solution is achieved
        end if
        i = i + 1   ▻ Next iteration
    end While
Return S^•
```

The solution in Ruin & Recreate is achieved by greedily finding route from source to destination. There exists multiple routes form source to destination during iterations. The route finding are based on minimum cost objective function using either greedy insertion or regret insertion technique. A greedy insertion approach simply inserts a dumpster with cheapest possible route in repeated fashion using local neighborhood search. Regret insertion is based on a theory that suggests people anticipate regret if they make a wrong choice, and take this anticipation into consideration when making decisions. The regret heuristic incorporates a kind of look-ahead information when selecting the request to insert. When the solution is recreated it is compared with the initially improved solution. If it is better it will be replaced otherwise the initial solution will persist. When all the iterations are exhausted we achieve an optimum solution.

Ruin & Recreate Algorithm used for resource optimization

Ruin & Recreate Algorithm is being used in Anylogic incorporate GIS components to provide optimized route between source and destination. In Anylogic, GIS takes coordinates of starting and ending point and draw optimized route on map. Agents follow this optimized route to save resources in desirable system.

Figure 7: Resource Optimization with Ruin & Recreate and GIS

In **Figure 7** Trucks need to go to different dumpsters located at different locations and having different routes. We want an optimal solution to save our resources. So we have to implements Ruin & Recreate algorithm to find best path to a particular given dumpster. Anylogic using GIS components provide shortest/optimized path between Trucks and Smart Dumpsters through Ruin & Recreate algorithm. It provides better usage of resources such as (time, fuel) in effective mode to achieve the highest degree of efficiency.

Chapter 5

Simulation and Results

The simulation of the designed framework and its results are discussed in this chapter.

5.1 Solid Waste Management

We take solid waste management as a case study to support and evaluate our subject area. In our case study dumpster are equipped with sensor that report valuable information in order to make decision making related to route planning , sufficient number of staff and truck for particular area and also we can save labor cost , fuel as well as time. In the above mentioned scenario active objects (smart objects) need to communicate with each other to manage and use resources at best level.

Example

Manual solid waste management system is working on daily basis. Every day a truck with 3 persons goes out for checking the each dumpster weather it is full or not. If the dumpsters are full then handle it by the person and empty it. This requires lots of persons, wastage of fuel and time. So manual solid waste management system includes wasteful usage of resources and has no efficiency.

5.1.1 Manual System, Risk Increment

Improper solid waste management in most Pakistani cities is increasing risk to health of public. A ground is provided for mosquitoes and flies by that waste, causing malaria and cholera. Open static water and open dumping grounds, near population and no proper management for that waste, is becoming more and more dangerous in these days. Estimation is that Pakistan is generating 54,888 tons of solid waste each day [41].

To handle this large amount of solid waste, manual system may fail because only Karachi is generating 6450 tons solid waste per day. We cannot manually handle it in proper way due to insufficient resources and management. We see dumpsters full of waste in cities but it is hard to check each dumpster manually so when dumpsters are full, management do not know that trash is coming out of dumpster.

5.1.2 Manual System, Acquire more Resources

Manual system is working on people based monitoring and management. It requires more time, effort, labor, fuel, working and management headache to complete daily base tasks. Working labor is divided according to areas and these labors go through all the garbage collecting dumpsters in given area to check its state and clean it. This increase time to check each dumpster in given area and also increase other resources fuel, trucks and working labor. Manual system creates complexity, not efficient and demand for more resources in waste management.

5.2 IOT in SWM

As it is discussed that what actually IOT is and what IOT based things and applications can do.

IOT working is based on following things [42]

- 8051 microcontroller
- IR sensor
- RF module
- Intel Galileo Gen2

5.2.1 8051 Microcontroller

The purpose of this controller is to read and process data received from sensor. Data is wirelessly transmitted to the central system (Intel Galileo microcontroller) via RF transmitter. Specifications of microcontroller are

- 128 bytes RAM
- 4096 bytes ROM
- 1 serial port
- 2 timers

- 4 I/O ports

This is 8-bit microcontroller consists of one chip designed to control applications.

5.2.2 IR Sensor

In **Figure 8** IR stands for Infrared. Sensor use infrared rays to check level of waste in dustbin/ dumpster. Levels specified are empty, quarter filled, half, partially filled and empty full.

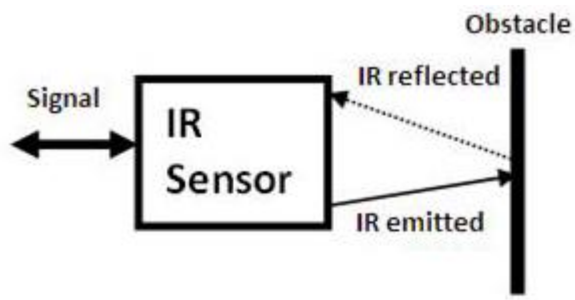


Figure 8: Efforts includes In IR sensor for measuring dumpster states [42]

We'll use this on the upper level of the dumpster to check proper reflection of light with obstacles.

5.2.3 RF Module

This module consists of transmitter and receiver modules. Transmitter module takes serial inputs and transmits these signals through RF. The system allows one way communication between two nodes that are transmission and reception.

5.2.4 Intel Galileo Gen2

Intel Galileo boards are open source and open hardware, in other words all of the source code and hardware schematics are available online, which you can download, use and modify.

If we want to get an overview of working of these elements, that is shown in **Figure 9.**

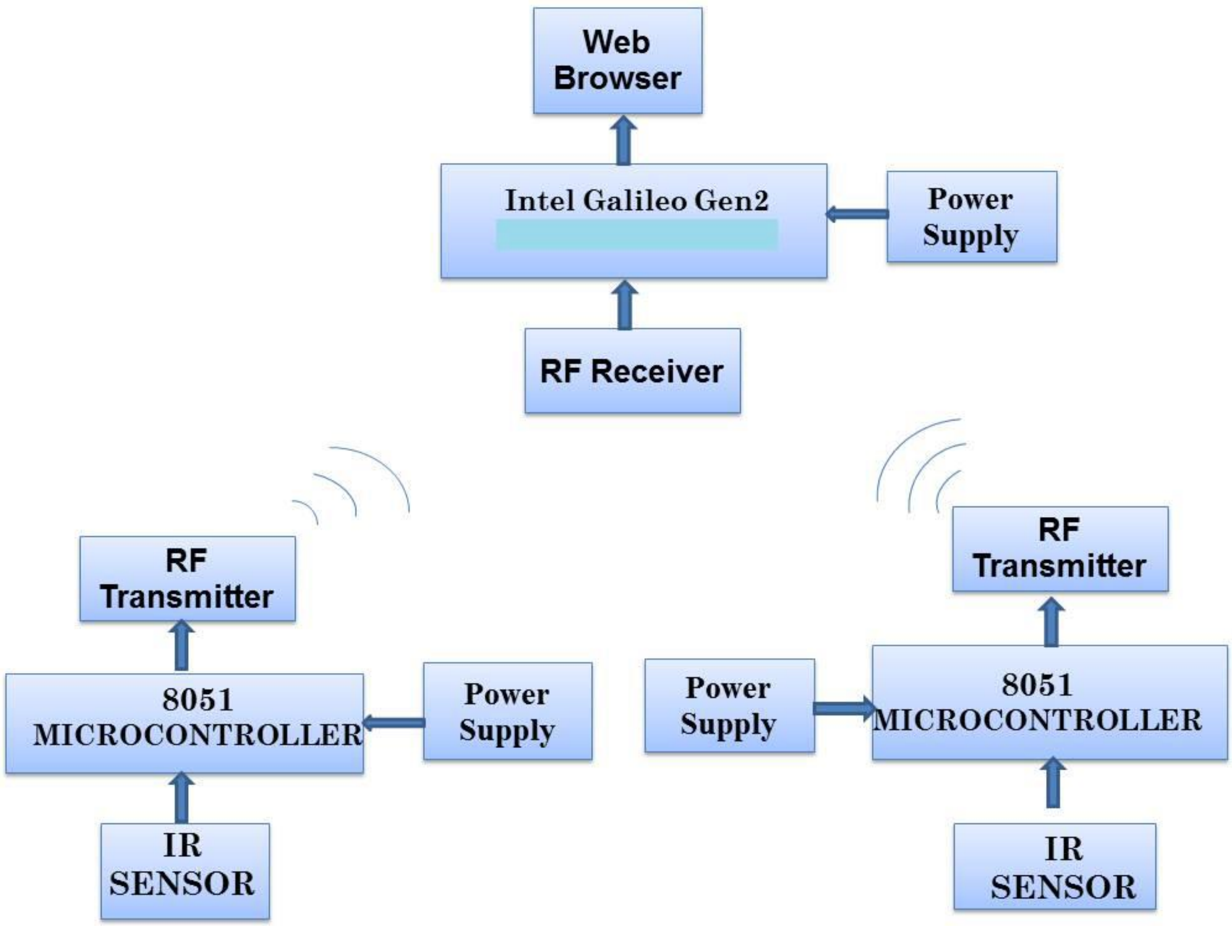


Figure 9: Inner working flow of IOT based components or things [42]

5.3 Evaluating CIOT in SWM

We are going to evaluate that what are the parameters that are making IOT based solid waste management more effective.

5.3.1 Outcome Evaluation

IOT based solid waste management is more effective because of real time notifications and data passing. All data is collected and organized by main Control Station. In manual system, it may not be so easy.

5.3.2 Effect on cost

If you do the process manually then it will be more costly. As in manual system members have to check each dumpster in each route. This may waste lot of petrol if most of dumpsters are empty and visit is useless. Data collected from sensors will help us to save cost by avoiding useless visits.

5.3.3 Effect on Human Resources

As in manual system, more persons needs to complete a task. For example if there are 10 routes to visit that needs 5 groups. Each group consists of 2 members and responsible to check each dumpster in specified routes. Some visits may go waste because of no information if dumpsters are empty or full. IOT based system give us data about optimized routes and number of dumpsters that are full. This useful information can help us to manage human resources by allocating jobs effectively. It may decrease 30-40% need of workers (i.e. 6-7 people can perform task of 10 people).

5.3.4 Effect on Time

As all of technology invented to ease human and save a lot of time. Manually checking for each route and each dumpster in all routes required lot of time. IOT based system tells us which route has maximum filled dumpster and need a visit. So there is no useless visit and time saved to perform other task

5.4 Simulation visualization

Simulation visualization describes representation of agents when simulation is in running mode.

Agent's location is defined on GIS map by using GIS points. Lorry icon (2d graphic) is used to represent Truck (Skip-Lifter) agent. Circles with different colors are used to represent Smart Dumpster agent as showed in **Figure 10**.

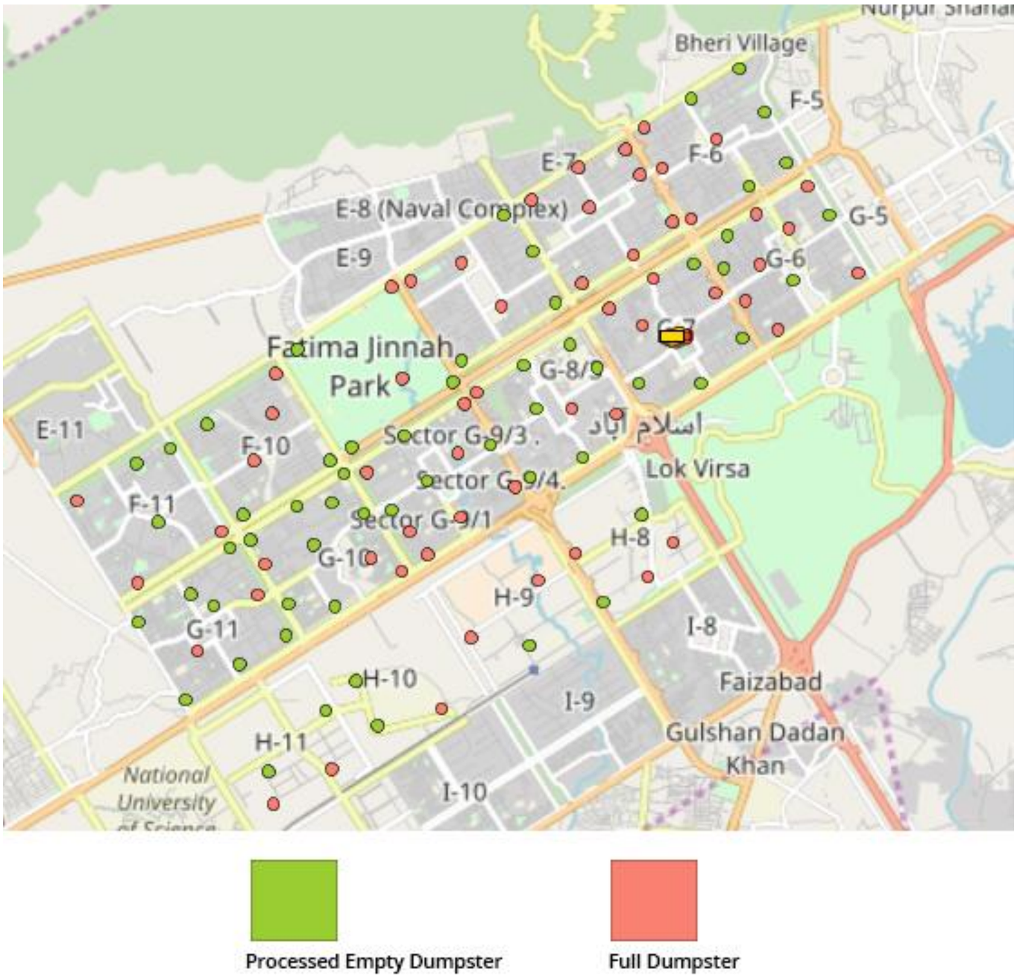


Figure 10: Different states of agents on GIS map

Pink Color is used to represent Full Smart Dumpster

Yellow Green is used to represent Processed Empty Smart Dumpster.

5.5 Working of simulation

Every IOT entity is an agent which plays vital role in model. In simulation, SD (skip-bins), Truck (skip-lifter), Parking Area and Dumping Yard are agents which communicate via message passing. Before simulation start, skip-lifters are located in parking area.

GIS map is used to define location of parking area as shown in **Figure 11**.

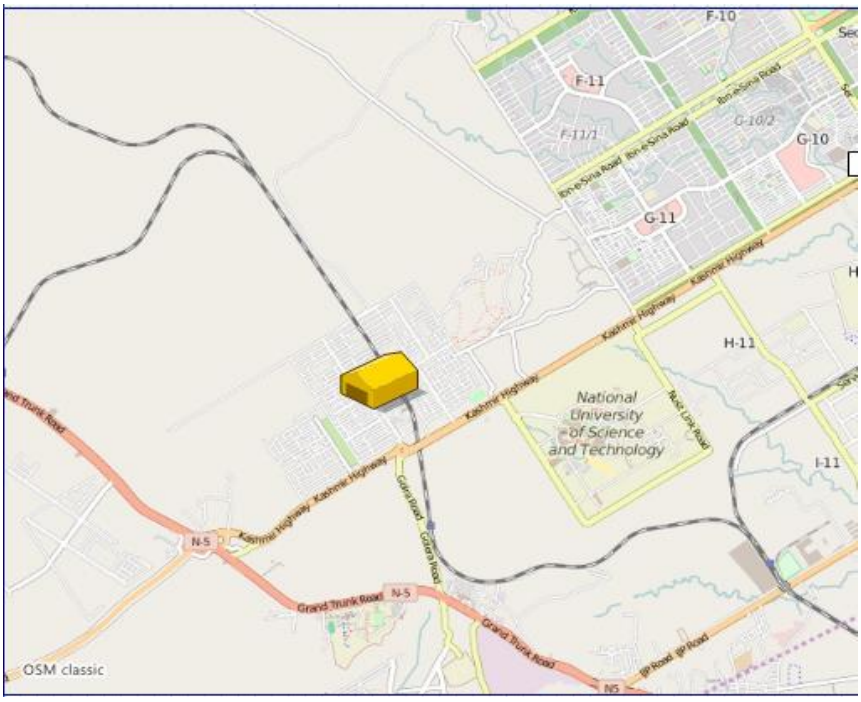


Figure 11: Parking Area on GIS Map

Truck (Skip-lifter) are parked in parking area. Truck (Skip-lifter), SD (skip-bins) and Dumping Yard locations are also defined on GIS map.

As we stated before each skip-lifter is responsible for particular area. After simulation start, list of full skip-bins are assigned to skip-lifter. In this way skip lifter knows in advance how many skip-bins are full. Skip-lifter goes on daily basis from Parking Area to assigned area at specified time and only visits full skip-bins to save its resources and avoid useless visits. After visiting each full skip-bins, skip-lifter goes to dumping yard to dump its trash and after that goes back to Parking Area.

5.5.1 Internal Working of Simulation

Internal working of simulation describes steps that each agent will follow throughout simulation. As our simulation based on agent based modeling and in agent based modeling each agent is intelligent and able to take decision and can communicate with other agents. Each agent has to perform certain steps to complete its working. Working of agents is defined by states and transitions and together transitions and state becomes state chart. Throughout simulation different agents are in different states and their next state is decided by transitions. Some agents need to communicate with each other to know other agents state before executing next state of itself and agent communicate with each other via message passing. After executing last state, agent is no longer able to perform further steps. Let's discuss each agent state chart one by one.

5.5.2 Truck (Skip-Lifter) State Chart

In real world scenario Truck goes daily from parking area on specific time to collect trash form assigned area. Likewise when simulation starts, Truck waits for specified time to start its journey to collect trash from specified area. As show in Truck state chart, Truck follow different state until complete its last state and come back to parking area.

Figure 12 explains the Truck (Skip-Lifter) State Chart in which each agent execution starts from state chart entry point.

Idle State: Truck first state is idle in which truck wait for specified time.

Moving State: After specific time Truck moves form idle sate to moving state in which Truck (agent) find shortest path form parking area to nearest Smart Dumpster, which status is full. After finding shortest path to full Smart Dumpster, Truck moves from parking area to Smart dumpster location.

Processing Dumpster state: After reaching at Smart dumpster location it processes the Smart Dumpster. During processing Truck (skip-lifter) replaced empty Skip-bins with full skip-bins. It takes average 8-10 minutes for processing. After processing skip-bins Truck find another full Smart Dumpster with shortest path and move to smart dumpster location then process it and repeat same process until 5 full dumpsters are processed. After processing 5 full dumpster, Truck agent goes to dumping yard to empty the skip-bins and repeat same process until all full dumpster of allocated sector are processed. After processing last full dumpster, Truck agent find shortest path from dumping yard to parking area and move to parking area at the end of state chart.

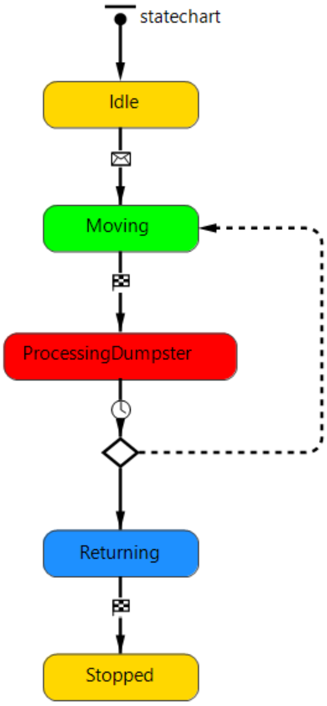


Figure 12: Truck (Skip-Lifter) State Chart

5.5.3 Smart Dumpster (Skip-Bins) State Chart

Smart dumpster in real world scenario takes average 1 to 2 days for filling and able to send its status to control station either full or empty. Smart dumpster must send its location with status before Truck-agent leave from parking area. If some smart dumpster are full after leaving parking area then Truck agent are able to tackle this type of case. As stated before each agent execution start from state chart entry point.

Smart Dumpster agent needs to communicate with Truck agent to complete its state chart execution. **Figure 13** explain the Smart Dumpster State chart in which each agent execution starts from state chart entry point.

Empty State: On start of simulation, Smart dumpster agent is in Empty state in which agent wait for specified time to change its status from empty to full.

Full State: Initially a Smart dumpster is in the EMPTY state. After a random time period uniformly distributed between 8 – 24 hours, the dumpster will transit to FULL state. It can only return back to EMPTY state when a truck unloads it. When a truck – agent arrives and empties the dumpster by sending a message: “Emptied”, the Dumpster agent goes back to EMPTY state. It is equivalent to the municipal staff resetting the dumpster’s state when it is emptied.

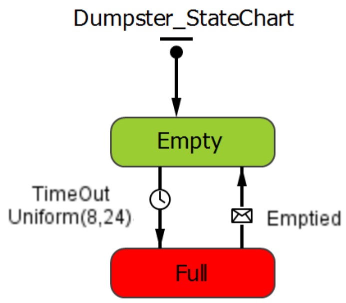


Figure 13: Smart Dumpster State chart

5.6 Agent used in Model

Multiple type of agents are used in simulation. Two Main type of agents are:

1) **Truck (Skip Lifter)** as shown in **Figure 14**

Figure 14: Truck (Skip Lifter)

2) **Smart Dumpster (Skip)** as shown in **Figure 15**

Figure 15: Smart dumpsters (Skip bins)

5.6.1 Truck (Skip Lifter)

Skip lifter now a day is desirable equipment for waste collection and disposal and it is normally used for transportation of SD from collecting area to dumping yard. Skip lifter designed in a particular way that can lift SD of different sizes and can carry trash up to 10 tons easily. Skip lifter has the ability to load SD automatically as show in the following figure.

Figure 16: Truck used for automatically loading Smart dumpsters

Three persons are assign to each truck one of them is Driver and others 2 are helper that helps to load SD. Helpers have smart phone to receive status of SD to facilitate drive either they are going to emptying SD or not, More trucks could be assigned to particular area based on work load. If there are special events then more trucks will be assigned to particular area to save community from different diseases otherwise trash will be out form SD and will disturb community environment. Truck goes on daily basis on specific time to assigned area to empty SD. Trucks takes average 10 minutes to load SD on Skip lifter. Trash loaded SD is replaced with empty SD for filling with trash. After loading SD trucks goes to dumping yard to dump trash and then go back to parking area.

5.6.2 Smart Dumpster (Skip-bins)

Skip-bins are waste container designed in a way to load and unload onto Skip lifter instead of dumping Truck of Garbage to dumping yard. Skip-bins are replaced with an empty skip-bins. Skip-bins are available in different sizes and different shapes from small to large sizes, open to close and semi closed shapes. In waste management closed skip-bins are used to prevent trash coming out of skip-bins and to make sure waste volume does not exceed maximum limit of skip-bins. To put heavy skip-bins onto and off a skip-lifter each skip-bin has lugs at the end of skip-bins which allow skip lifter to load and unload skip-bins. Smart dumpster are able to send its status to skip-lifter helpers via control station. Smart dumpster sends it status either full or empty. Helpers on skip-lifter have smart phone with application installed on their phone. With the help of application helper on skip-lifter can check smart dumpster status on their phone in real time.

5.7 Comparison of Traditional and Smart Dumpster in Simulation

In **Figure 17** comparison explains total distance difference between Traditional (Scenario 1) and Smart Dumpster (Scenario 2) in simulation with the help of Bar Chart. When truck visits more dumpster then utilization of resources increases. Trucks utilize more fuel to cover more distance to visit each dumpster in specified area. In scenario 1 truck covered 601 KM distance to visit all Traditional Dumpster while it covered only 410 KM in Smart Dumpster (Scenario 2).

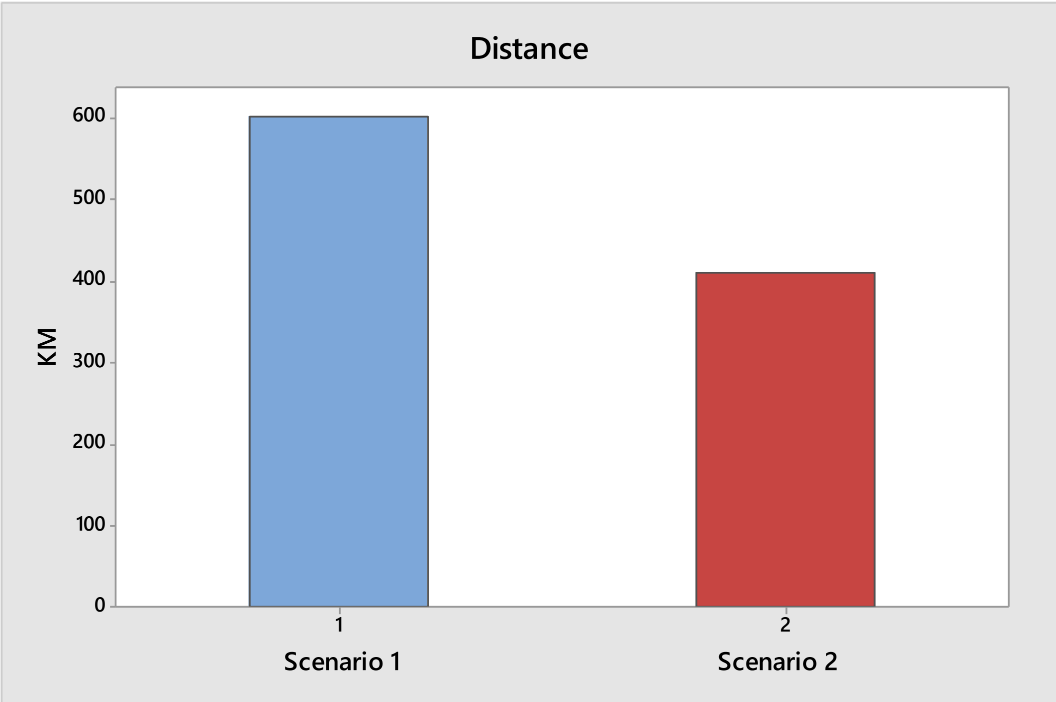


Figure 17: Distance comparison in Smart Dumpster and Traditional Dumpster

In **Figure 18** comparison explains total time difference between Traditional (Scenario 1) and Smart Dumpster (Scenario 2) in simulation with the help of Bar Chart. When truck visits more dumpster then take more time to visit each dumpster in specified area. In scenario 1 truck takes 2.93 HOURS to visit all Traditional Dumpster while it takes only 2.3 HOURS in Smart Dumpster (Scenario 2).

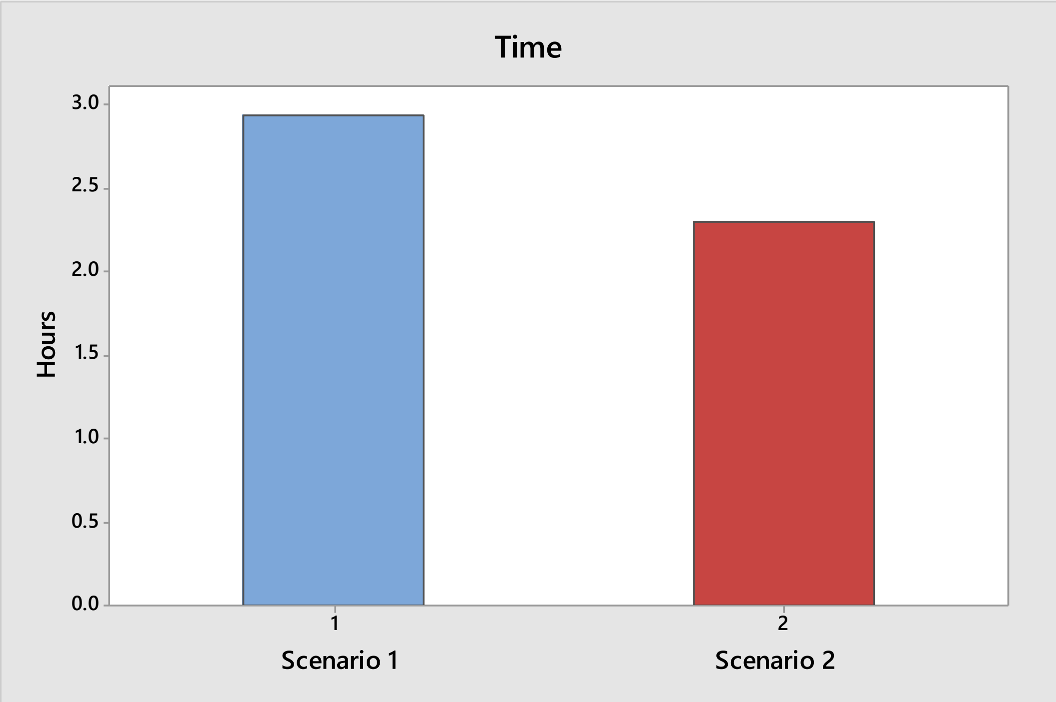


Figure 18: Time comparison in Smart Dumpster and Traditional Dumpster

5.7.1 Traditional dumpster

Traditional dumpsters are used in community as a waste container in which people dump their trash. In simple dumpster scenario, dumpster is dumb and not able to communicate with any entity. Truck visits each simple dumpster either it is full or not which increase utilization of resources in way of fuel, time and labor work. Y-axis shows distance covered by each truck and X-axis shows trucks with an average value of 28.6 in **Figure 19**.

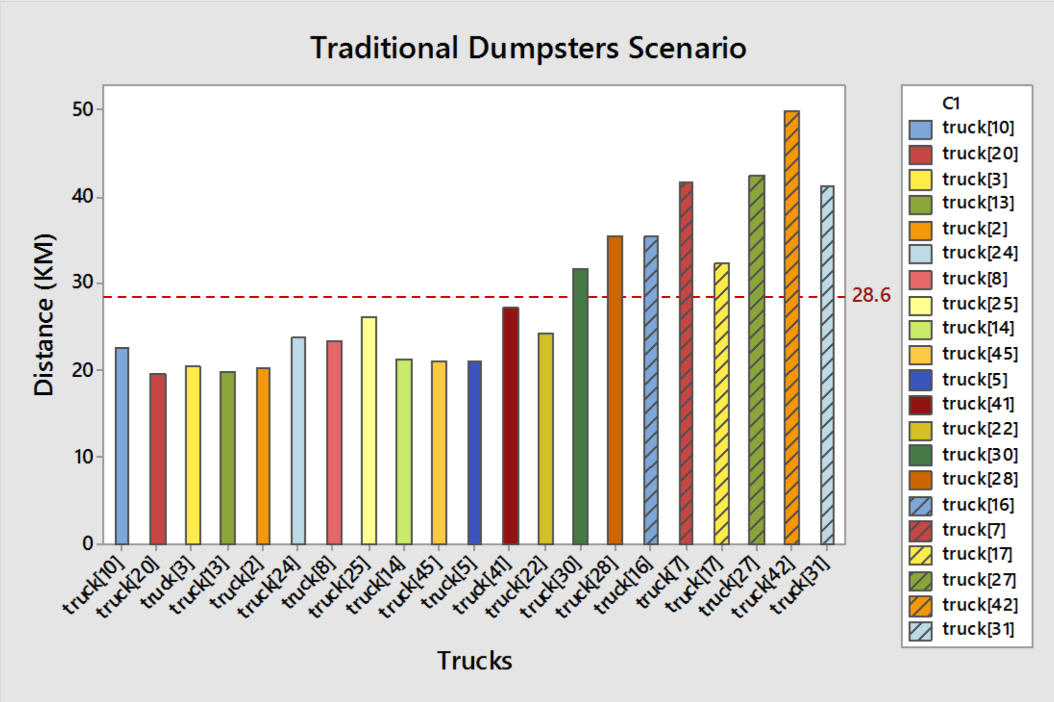


Figure 19: Distance covered by each Truck in Traditional dumpsters

5.7.2 Smart Dumpster

Smart Dumpsters are intelligent entities. Each smart dumpster has an ultraviolet sensor that sense filling level of dumpster and after sensing level of trash in dumpster send its status to control station for further information analysis. Smart dumpster are able to take decision and communicate with other entities of system in real time. In smart dumpster scenario, Smart dumpsters send its status on specific time and in real time to Trucks via control station. Trucks visits only those dumpsters which status is full to avoid useless visits and use resources efficiently and effectively. Y-axis shows distance covered by each truck and X-axis shows trucks with an average value of 23.7 in **Figure 20**.

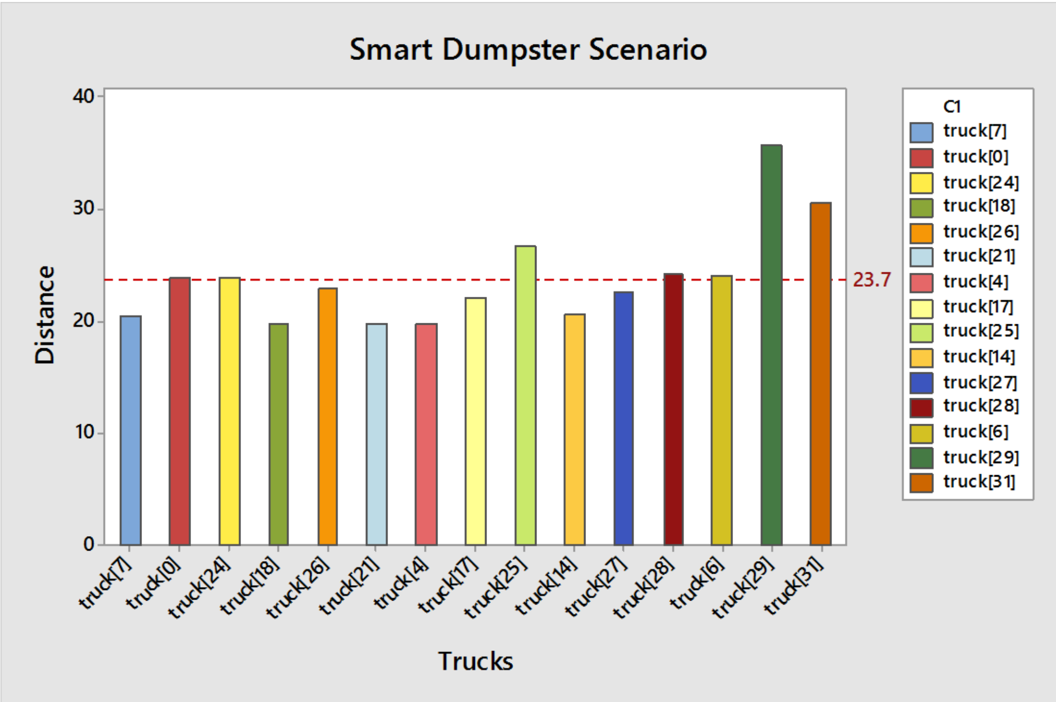


Figure 20: Distance covered by each Truck in Smart dumpsters

Chapter 6

Conclusion and Future Work

This chapter provides the Conclusion and Future work of the thesis.

In this research we have developed the environment in Anylogic that works on different layers in Anylogic to evaluate the collaboration among internet of things. GIS components and Ruin & Recreate algorithm work together in Anylogic to optimize the resource utilization by finding optimal path and achieve the desired efficiency in IOT based collaborative system. The approach is being used based on Agent based modeling and simulation.

IOT is a cutting edge and widely adoptable technology. IOT environment works across different entities. In IOT all entities is considered an agent and agent have some properties and actions as in real world such as (Trucks and dumpsters) to perform certain task so ABM is used to model the real world system into IOT based collaborative environment.

To evaluate the collaboration among Internet of Things we take solid waste management as a case study to support our research. By using Agent based modeling in Anylogic we define different agents and assign a transition state to each agent. When transition is happen agent change its state with respect to transition. Simulation is used to draw and compare the results of real world system and IOT based sold waste management collaborative system.

Results derived through Simulation conclude that Internet of Things in collaborative technologies are more efficient and effective as compared to real world collaborative system.

Future work of collaboration among internet of things is to enhance the security through modeling and simulation which results in reduced the effect of external factors and increase the efficiency of internet of things collaborative environment. Develop the effective security steps, implement those steps in collaborative IOT environment and evaluate the environment using agent based modeling and simulation approach.

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