Comprehensive and Simulated Modeling of a Centralized Transport Robot Control System

Murad Bashabsheh
Department of Robotics and Artificial Intelligence, Jadara University, Irbid, Jordan

***Abstract*—This work proposes a new simulation model for a centralized transport robot control system that was created with the AnyLogic environment and a special blend of agent-based and discrete-event approaches. The model attempts to do a comprehensive analysis of the centralized request distribution algorithm among robots, gauging the effectiveness of the transport system based on service arrival times. For in-depth testing, a transport robot model was developed using Arduino microcontrollers and NRF24L01 transceivers for communication. Item movement test sequences were created to be uniform in both full-scale and simulation testing. Good, though not perfect, agreement was found between the simulation and experimental results, underscoring the difficulty of obtaining high accuracy in real-time coordinate identification in the absence of sensors. This shortcoming notwithstanding, the novel simulation model provides an invaluable instrument for determining the viability and efficiency of transportation systems as well as analyzing decentralized control mechanisms prior to actual deployment. The novelty of this paper in that it builds a thorough simulation model for a centralized transport robot control system using an AnyLogic environment and a unique blend of discrete-event and agent-based approaches. This comprehensive technique is a novel contribution to the discipline since it enables a thorough evaluation of a centralized request distribution system.**

Keywords—Artificial intelligence; centralized control system; transport robots; automatic system; agent-based modeling; AnyLogic; Arduino microcontroller

I. INTRODUCTION

Robotic systems are crucial to the automation of transportation processes and warehouse logistics. These days, autonomous robots can choose orders without the need for human assistance, automatically take the necessary items from the shelf and arrange them in containers or on a pallet, and even arrange items on shelves. In these systems, transport robots are rather significant because they handle not just the loading and unloading of goods in warehouse complexes but also the logistics of transportation.

The automation and robotization of transportation processes are moving quickly, making it imperative to improve the effectiveness of the control systems for these kinds of objects. Robot mobility is essential for jobs like object transportation, object surveying, mapping, and search and rescue that require the machines to move across different types of terrain. When implementing centralized control proves to be challenging or unfeasible, autonomous mobile robots are deployed. In addition to mobile robots, artificial intelligence-based control systems, communications, and sensor technologies are also under development. However, even with great progress made in each of these fields, building fully autonomous robots that operate without human intervention remains a formidable task for the future.

In the process of designing control systems, natural solutions are frequently used. Such solutions are sought after by Bionics. People have observed that groups are more effective at solving issues than individuals when they study the behavior of animals that have a group lifestyle, such as ants, bees, and flocks of fish and birds. Therefore, similarities with nature are typically exploited while creating algorithms for controlling systems that comprise multiple robots.

Multiple intelligent robots that can send and receive messages as well as sense ambient factors make up multi-robotic systems. They collaborate to complete tasks while using either centralized or decentralized control. In applications requiring high dependability and accountability, a multi-robot system performs better than a single robot because it reduces the possibility of a single point of failure and increases operating efficiency. In search and rescue missions, planetary exploration, and warehouse and industrial complex maintenance all use real multi-robotic systems [1]. Multi-robotic systems come in six primary categories with different architectures [2]:

- Unaware systems;
- Aware and uncoordinated systems;
- Poorly coordinated systems;
- Highly coordinated centralized systems;
- Highly coordinated and weakly centralized systems;
- Highly coordinated and distributed systems.

For improving the effectiveness and coordination of transport robots in intralogistics activities, the centralized transport robot control system is a viable strategy. Better performance can be achieved by the system by centralizing decision-making, which optimizes task allocation and routing. But in order to properly utilize the system's potential, issues like scalability, possible single points of failure, and communication requirements need to be cleared up. In order to overcome these obstacles and improve resilience and adaptability, future research and development may include components of decentralized control. This system makes use of a centralized unit to manage crucial duties like dispatching, routing, and scheduling, making sure that tasks are distributed effectively and robots are working in unison [3, 4].

Decision making can be centralized or decentralized. Global information regarding the state of the entire system is preserved in a centralized multi-robot system. Every robot provides data to the system, which also keeps track of each one's location within the surroundings. Using the data that the robots provide, the control center may create a map. This system is either in a robot that serves as a master or in a stationary host. To accomplish a shared objective, the center coordinates the efforts of a group of robots. He oversees the entire process and assigns assignments to each team member.

Although this architecture is simple to create and operate, extraordinary circumstances and communication breakdowns can still affect it. For a small number of robots operating under well-defined and consistent settings, centralized control is generally an appropriate solution [5].

Transport control and autonomous logistics both make use of centralized robotic systems. One effective instance of utilizing centralized control over several robots is the hospital's transport system at Nemocnice Na Homolce (see Fig. 1) [6]. Sheets and dishes are moved around the building by mobile robots. They can even use elevators and go along routes indicated on the floor.

Fig. 1. Transport robots at the Nemocnice Na Homolce hospital.

In centralized control systems for a group of robots, the follow-the-leader algorithm is frequently employed (see Fig. 2). The way fish or birds behave in schools serves as the basis for this algorithm. Robot slaves replicate the leader's movements and follow him. Through a communication network between them or through sensors, they get information about the leader's movements.

In the majority of implementations, the robot leader follows lines that represent pre-laid pathways. Despite the fact that every robot has sensors, only one leader has the computational capacity and navigational abilities to carry out a sophisticated plan. This indicates that while the leader robot follows the predetermined path, the follower robots stay at the appropriate distance and angle from the leader robot. To find out how far each robot is off from the ideal location, a coordinate transformation is first carried out for each robot. The goal of the slave robot control algorithm, which is based on this transformation, is to minimize the robot's current position inaccuracy.

Fig. 2. Following the leader strategy.

Theoretically justified, centralized architectures that manage the work of all robots from a single control point are practically unfeasible because of the control center's single point of failure and the difficulty of transmitting each robot's state to the center at the frequency required for real-time control. These strategies can be put into practice if the central controller is equipped with a monitoring system that enables it to keep an eye on every robot and send group messages to every robot under its supervision.

Decentralized management eliminates the need for a master or leader to supervise the entire process and possess complete knowledge of the system's status, unlike centralized systems. Rather, every robot functions as an independent entity that responds to the conditions in its surroundings. Naturally, the robot knows that other robots are around, and it's possible that they can communicate locally. Robot-environment interactions give birth to complex collective behavior. This design is scalable, incredibly resilient, and capable of operating well in challenging conditions. It is possible that a sizable group of uniform robots could work together to accomplish a shared objective [5].

For teams with many robots, decentralized control structures are the most popular method. These systems usually require the robots to respond only on the basis of situation-specific knowledge. Since no robot is in charge of another robot, this control scheme can withstand a lot of faults. However, because high-level goals need to be included into each robot's local control, achieving global consistency in these systems can be challenging. It can be challenging to redefine each robot's behavior if the goals alter [7].

Transport robots are essential to many different industries because they offer dependable and effective solutions for logistics and cargo handling. Nonetheless, these robots' control systems must be reliable and flexible enough to operate under changing conditions. Coordination of duties among several robots and performance optimization are two issues that traditional decentralized control mechanisms frequently encounter. In order to tackle these issues, how can the efficacy and efficiency of transport robots in a complicated environment be enhanced by a centralized control system?

This work aims to create and test a detailed simulation model of a transport robot control system that is centralized. We aim to give a comprehensive evaluation of a centralized request distribution mechanism by utilizing the AnyLogic environment and combining discrete-event and agent-based approaches. The purpose of the simulation model is to assess the effectiveness of the system in terms of service arrival times and to determine whether the control algorithm is workable in a variety of scenarios.

NRF24L01 transceiver module is used for the wireless communication between Arduino microcontrollers [8]. The method used NRF24L01 and Arduino tools as the communication network transceiver [9].

A nRF24L01 wireless transceiver module and an Arduino pro mini are used to create a flexible controller unit that may be utilized for a variety of applications. A dependable and affordable option for wireless communication between the transmitter and receiver units is the nRF24L01 wireless transceiver module [10].

This paper's main contributions are:

- The AnyLogic environment is utilized to model a centralized control system through a special combination of discrete-event and agent-based modeling techniques.
- Development of a transport robot model with Arduino microcontrollers and NRF24L01 transceivers for communication enables thorough testing in both virtual and actual environments.
- Comprehensive analysis of the simulation and experimental data, offering perceptions into the viability and efficiency of the suggested centralized control system and its capacity to influence the creation of decentralized control mechanisms via evaluation of performance.

By tackling these aspects, this work advances the field of transport robot control systems and provides a fresh viewpoint on how to maximize their effectiveness in logistical and industrial settings.

In the next section, we will briefly consider the features of modeling a centralized control system.

II. Literature Review

In recent decades, technology for handling materials has developed quickly. One major development is the transformation of autonomous mobile robots (AMR) from automated guided vehicles (AGV).

In the study [11], the authors introduced a thorough framework for intralogistics operations planning and controlling Autonomous Mobile Robots (AMRs). To assist managers in making decisions that will result in the best possible performance, a framework was created. In order to categorize and clarify how technology advancements in AMRs impact planning and control choices, the authors carried out a thorough assessment of the literature. They also suggested a research plan to address potential and future difficulties in the area of intralogistics' integration of AMR.

There is still a dearth of study on a wide range of additional intralogistics application areas because the majority of this field's studies have concentrated on manufacturing and storage. The circumstances in which decentralized control outperforms centralized control or is more profitable have not been thoroughly studied in many studies. When several decision variables are addressed at once, such as the quantity of vehicles, the locations of zoning and service points, or the simultaneous scheduling and path planning, it becomes easier to understand how various decisions interact and enables their evaluation to produce more balanced decisions.

In research [12], a versatile framework for simulation and control designed for AGV-based autonomous transport systems. Two stages of simulation are typically used when creating apps such as these. The procedure is quite similar to other robotic systems, and the first stage is an initial test for the AGVs' navigation system. At this point, a simulation module is utilized in place of the actual robots in the modular control frameworks (ROS, Carmen, etc.) for simulation purposes.

To estimate the size of the fleet and assess routing and allocation strategies, the second simulation level is utilized. This simulation level is covered by the majority of the bibliography on the simulation of internal transport networks for various building types, including factories, warehouses, and medical facilities.

The manufacturing environment needs to be modular and dynamically reconfigurable. When it comes to traditional concepts like conveyor belts, the employment of mobile robots for transportation can potentially offer users considerable benefits. However, one drawback of this approach is its lack of flexibility, which is often caused by statically set road or rail networks.

In this research [13], the authors presented architecture for centralized fleet coordination for use cases related to intralogistics in highly automated manufacturing settings. The system's goal is to offer a workable method for centralized fleet management that permits prolonged operation hours, safe vehicle control, quick and adaptable response to shifting conditions, and optimal planning.

In order to improve simulation accuracy, future studies should concentrate on improving communication protocols between robots and the control system and integrating cutting-edge sensor technology. A more thorough evaluation of the system's resilience and scalability would also be possible by extending the model to incorporate a wider range of environmental circumstances and more intricate task sequences.

III. Centralized Cargo Transportation Management

A. Planning and Scheduling

A centralized management system operates under the supposition that the problem of group member placement is resolved in a single location. All of the computational power required for this is gathered in the control center. The control center creates goals for each robot and computes movement trajectories that account for their speeds and potential conflict scenarios based on the information that is currently available on the workspace setup. Robots can be modeled as agents that interpret control signals received through data transmission channels into commands for actuators, i.e., they unquestionably carry out all of the center's instructions.

Several parties participate in centralized cargo transportation:

- Loading of goods is carried out by the supplier;
- Transportation of goods is provided by transport companies;
- Unloading of goods is carried out by the consignee.

When moving huge amounts of commodities in comparatively tiny quantities, centralized transportation works well. Because of the concentration of control in this situation, loading and unloading may be scheduled more precisely.

B. Advantages and Disadvantages of Centralized Cargo Transportation

Centralized cargo transportation offers several advantages for businesses and organizations involved in the movement of goods:

- The efficiency of transport use increases by reducing downtime at loading and unloading points;
- The preparation of documentation for the release and acceptance of cargo is simplified;
- Settlements between cargo suppliers and transport companies are simplified;
- The number of personnel required to organize transportation is reduced;
- Driver productivity increases due to working on the same routes and transporting the same cargo;
- The duration of the cargo transportation process is reduced;
- Transportation costs are reduced.

Overall, centralized cargo transportation offers numerous advantages, including improved efficiency, cost savings, enhanced visibility, streamlined operations, better risk management, enhanced customer service, and scalability. By centralizing coordination and oversight of transportation activities, organizations can optimize supply chain operations, reduce costs, and gain a competitive edge in today's dynamic business environment.

While centralized transportation management offers various benefits, it also comes with certain disadvantages and challenges that organizations should consider:

- The reliability of transportation for some “unprofitable” consumers is reduced;
- It is necessary to change the order of marketing of organizations.

Overall, while centralized transportation management offers benefits such as efficiency, cost savings, and improved visibility, organizations should carefully weigh these advantages against the potential disadvantages and challenges, considering their unique business needs, operational context, and risk tolerance.

The simulation model developed in the AnyLogic environment is proposed in this research to examine a centralized control system for warehouse transport robots.

IV. Methodology

A. Anylogic Simulation Environment

The AnyLogic environment, which enables system dynamics, discrete-event, and agent-based modeling—all contemporary simulation modeling techniques—is used to construct the centralized control system model. Building agent-based models is made easier by AnyLogic's ability to give developers a single language to utilize when creating models. The Unified Modeling Language supports state diagrams for defining agent behavior, transition diagrams for describing algorithms, environmental objects for characterizing the agents' environment and gathering behavior statistics, and mechanisms for describing timed or random events that dictate the simulation's logic [14].

The model is constructed using a combination of discrete-event and agent-based methodologies within the AnyLogic environment. In the field of robotics and artificial intelligence, AnyLogic software is crucial because it provides a flexible framework for modeling, simulating, and optimizing complicated systems. It makes it possible to create intricate models of robotic systems, giving researchers and engineers the ability to model how robots would behave in various contexts. This feature is essential for virtual environment testing and validation of algorithms, control schemes, and system performance in general, before the system is physically implemented [15, 16].

For the purpose of simulating intelligent agents in AI applications, AnyLogic's agent-based modeling capabilities are essential. AnyLogic provides a framework to represent complex interactions and dynamics, whether modeling the behavior of smart sensors, autonomous robotics, or decision-making processes. It is crucial to optimize mobility and task execution in robotics. Robot movements can be optimized inside certain environments thanks to AnyLogic (see Fig. 3). Users can investigate different algorithms and settings to enhance task distribution, path planning, and overall system efficiency through simulations.

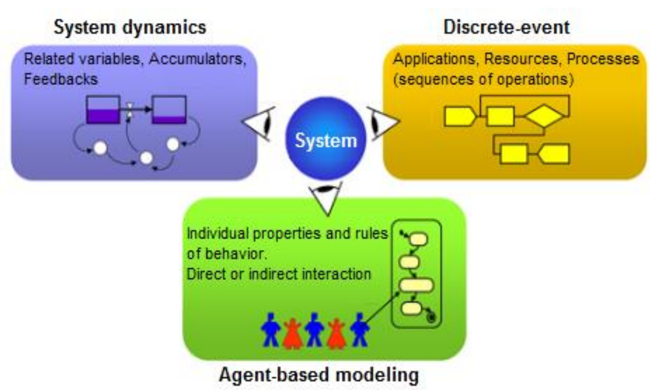

Fig. 3. AnyLogic supports three different simulation methodologies.

The term "AnyLogic" refers to the fact that it supports three popular simulation modeling methodologies, enabling users to mix and match various techniques inside a single model [17].

The executable simulation models that are created with AnyLogic are then run for analysis. Model development is done in the AnyLogic graphical editor with the help of a number of helpful features that make the process go more smoothly. After that, the built-in AnyLogic compiler is used to compile and run the model. Users can conduct a variety of experiments with the model, examine its behavior throughout the simulation, modify parameters, and view simulation results in multiple forms [18]. To specify the robotic duties, create the application interface, model, and simulate the system, AnyLogic was used. Discrete event, agent-based, and system dynamics simulation techniques were all used in the robotic system model simulation [19].

Graphical libraries combined with Java program code can be used to illustrate the model interface and its logic. The ability to develop hybrid models—combining an agent-based approach with a discrete or continuous description of the environment—is the primary benefit of AnyLogic, which led to the selection of this environment. State diagrams can also contain agents embedded in them. AnyLogic uses 2D and 3D animation libraries to give the modeling process visual representation [20].

B. Model of Transport Robot Based on Arduino Microcontroller

This work used mobile robots, the primary control system of which is a microcontroller, to do field research and a practical evaluation of the viability of centralized control algorithms. The Arduino Uno microcontroller from the Atmega 328p series, which is built into models with the NRF24L01 transceiver, was our choice for building the robot. Fig. 4 shows the experimental transport robots' look. Communication between the executive parts and the decision-making center is essential in a centralized control system.

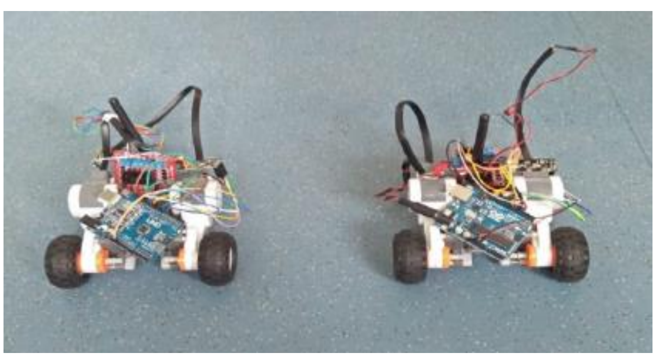

Fig. 4. Robots implemented on an Arduino Uno microcontroller with an NRF24L01 transceiver.

We make advantage of wireless technology enabled by the NRF24L01 transceiver to facilitate communication between the mobile robots and control center. The robot nearest to the next request receives data from the control center, and once it has finished its task, it sends a report and its updated position back to the center. The conditions of a practical experiment for a centralized control system are depicted in Fig. 5.

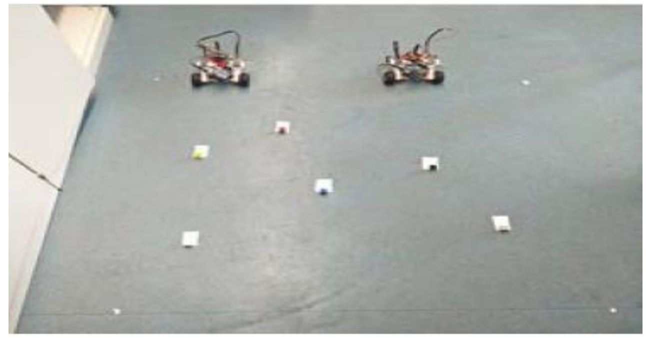

Fig. 5. Field experiment conditions for centralized control.

After positioning themselves, the two robots wait for a command from the control center via the NRF24L01 transceiver interface. It should be noted that robots are not capable of selecting a service object on their own. Requests are distributed across executors exclusively within the control center.

The coordinates of the initial position of the robots are given in Table I.

TABLE I. INITIAL POSITIONS OF ROBOTS

Robot number (ID)	Initial position		Status
	X	***Y***	
1	3	0	T.
2	8	0	T.

Status determines the state of the robot. If he is ready to perform the next task, then his status will be .T. (True) and .F. (False) otherwise.

The coordinates of six requests that need to be fulfilled by robots are displayed in Table II. Every minute, applications are received for services.

TABLE II. COORDINATES OF APPLICATIONS

Application number	Application coordinates	
	X	***Y***
1	3	4
2	5	5
3	2	7
4	6	2
5	8	3
6	9	8

The robot that is free and nearest to the next request is identified by the control center, which then gives it the necessary command. The simplest Manhattan metric is applied to identify which robot is closest:

$$D = \left| x_i - x_j \right| + \left| y_i - y_j \right| \qquad (1)$$

where: D - Distance between the position of the robot and the application; x_i, y_i - Coordinates of the current position of the robot; x_j, y_j - Application coordinates.

The Manhattan metric reflects the features of the robot motion control system.

Robots can only move in orthogonal directions, or along the coordinate axes, which allows for relatively high positioning accuracy because they lack sensors [21].

C. Agent Model in Anylogic

Since most logistics systems use centralized control, the development of agent-based transport system models has not yet gained much traction. The current state of affairs is drastically shifting. First off, one of the most often used approaches is now agent-based modeling. Secondly, transport units are starting to have the ability to function as decision makers on their own, actively contributing to the completion of group tasks. Because they can take part in the planning and control of transportation, agents are active subjects. Agent technologies function in the transportation industry as components or subsystems. The work's model aims to investigate more than just centralized management techniques. Robots can only move in orthogonal directions, or along the coordinate axes, which allows for relatively high positioning accuracy because they lack sensors. It must be able to evaluate efficiency and decentralized strategies, which is why an agent-based approach was chosen for its implementation.

The agents in the model are of two types: sources of service requests and robots that fulfill requests by transporting things between locations.

The materials processing library's flowcharts were used in the creation of the model to illustrate the process logic, which involves choosing the robot that is closest to a request and moving the product from its current place to its destination. The production line and automated guided vehicle transportation features in this collection are helpful for simulating the movement of items in warehouses and factories. Library elements were also employed to tackle the issue of automatic transport unit routing since they simplify model construction and do not restrict control logic.

The flowchart (see Fig. 6) provides a formal representation of a process for a centralized control system by means of materials processing library items [22].

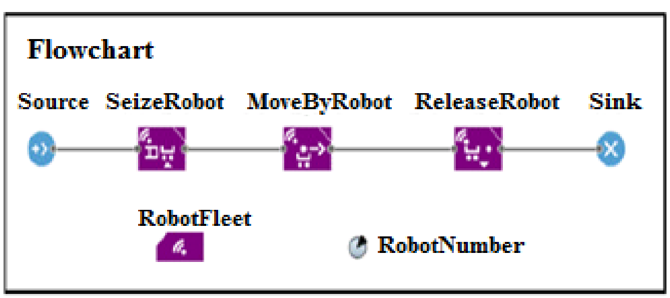

Fig. 6. Transportation process diagram.

The goal of the model is to investigate the efficacy of centralized control algorithms for executive elements, or transport robots, and then validate the outcomes through large-scale experimentation.

The source of applications is the Source element, which randomly generates a flow using the data presented in Table II. The distribution of applications among executors and the transmission of commands to robots occur in the SeizeRobot block. The MoveByRobot block is responsible for moving the cargo in the model, and the ReleaseRobot block is responsible for unloading at the destination point and generating a signal about the completion of the request.

The two processes that make up the working logic of the transport system under consideration are picking the available robot that is closest to the present request and moving some conditional cargo from one place to another. The application has the geographic coordinates.

The robots have to stand at their home location in the initial state (see Fig. 5). Every individual is given a distinct unique identification - ID (see Table I). A random number generator is used to establish the order in which orders appear in the model. The frequency at which applications arrive is selected to allow for the possibility of scenarios in which an application must wait for an executor to be assigned to it. In every application, a weight that is not heavier than the robot can support is moved. The methodology does not address the challenge of including small associated cargo inside packages. The robots are not going to come back to base after they have delivered the payload. At the unloading point, they are awaiting an order to handle the following request. The model can be run, and a 2D or 3D view of the results will be presented.

In a centralized control system, implementing the specified system operating logic is rather easy. Implementing even tactics with dynamic performer redefinition is made possible by the presence of stable channels of information interaction between the performers and the center.

The SeizeRobot unit in the model regulates how the product is loaded. The loading process is completed by transport robots that travel to the request's source. Five seconds are needed to load. Due to the lack of suitable sensors, the positioning accuracy of robots in full-scale tests is unknown; however, this does not lessen the amount of information included in the experiments designed to evaluate the performance of the control algorithm. The MoveByRobot block provides the robot's movement from the loading point to the unloading point in the model. Robot agents automatically find the quickest path through the network and avoid running into other robots. When it was impossible to stay off the tracks, the conveyors would halt and then resume their motion at random intervals. Complex robot activity that is typically managed remotely by an operator or automated system is simulated by this delay. Our designed robot models have a more straightforward movement mechanism: they move first along the X axis and then along the Y axis from the beginning position to the finish point [23, 24].

The ReleaseRobot block allows you to implement two options for releasing robots. In the first case, after the unloading process, the robot must return to the base location and only there will it become ready to execute the next request. In the second option, the robot remains at the unloading point until the next request arrives. The model implements the second control option, since it is more accurately implemented in full-scale experiments. Accordingly, the robot is released (assigned the .T. status) immediately after the cargo is delivered to the final point.

The simulation results are represented in two dimensions in Fig. 7. A group of robots transports items; they are each assigned a base, or beginning location. One of the model's parameters is the number of robots. This parameter has a maximum value of four. The cargo location or request coordinates are displayed in the red rectangle. The robots follow the lines of an orthogonal grid that is provided. The locations of the robots' bases are indicated by gray rectangles outside the mobility area.

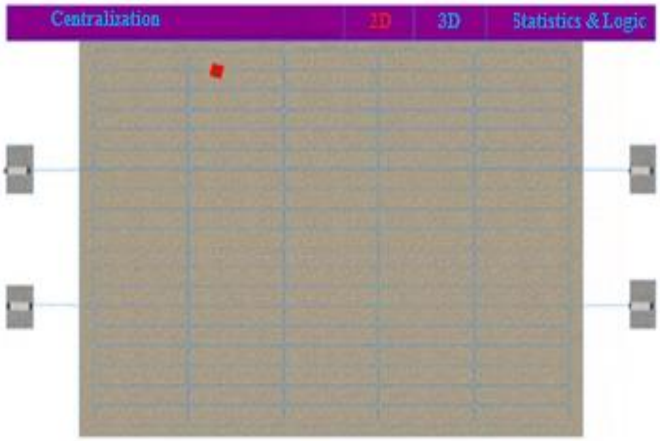

Fig. 7. 2D representation of simulation results.

The simulation results are represented in three dimensions in Fig. 8. While the fourth robot waits for the application to arrive, the other three robots—one stands at the base, the other two approach the application, and the third serves the application.

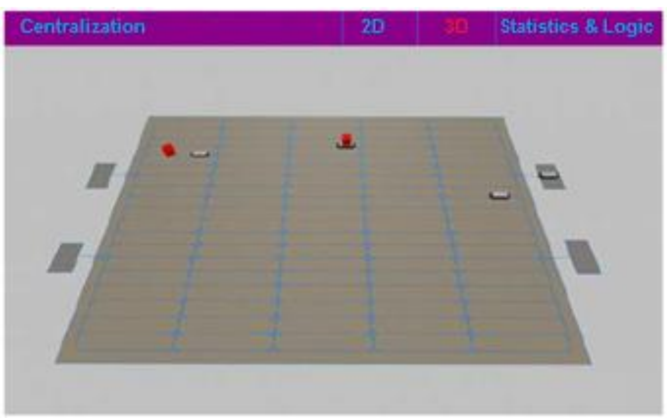

Fig. 8. 3D presentation of modeling results.

One of the main criteria for the effectiveness of service systems is waiting time. This is the interval in a simulated transport system between the time a request appears and its service begins. The results' analysis is made easier for the user by the built model's ability to display the data as histograms.

V. Experimental Results

By using AnyLogic to conduct experiments and analyze the results, you can gain valuable insights into the potential benefits and challenges of implementing centralized cargo transportation management in a distribution network. These insights can inform decision-making, support optimization efforts, and drive improvements in supply chain efficiency and performance.

The frequency of applications was selected with the robots' speed in mind. In trials, requests come up at random times. You can accomplish this by using the AnyLogic function with a mathematical expectation of one minute and a normal distribution. The robot can only operate autonomously for an hour during the simulation, which is equivalent to the robot's battery life when fully charged. There could be 60 recurring requests during the simulation; Table II lists their positions.

Fig. 9 shows the simulation results for one of the experiments.

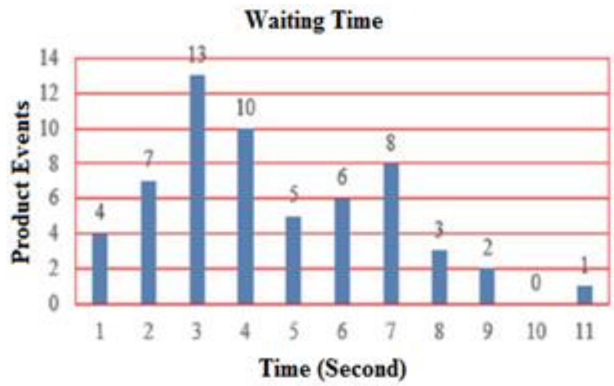

Fig. 9. Simulation results.

Since the model's instructions are created at random, running it again will yield slightly different results, but the distribution's general characteristics will remain largely unchanged. The sequence of request generation is recorded in a file for subsequent reproduction in a full-scale experiment.

The full-scale experiment findings for the same order generation sequence used in the simulation are displayed in Fig. 10. It is important to highlight that we did not aim to guarantee good repeatability of the experimental outcomes. Without location sensors, robots cannot accomplish this.

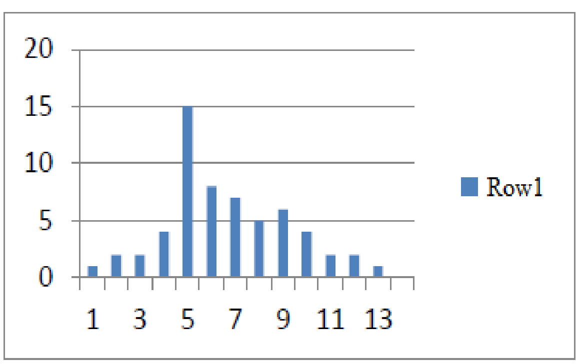

Fig. 10. Results of a full-scale experiment.

Though the generated histograms vary, overall, it can be said that the model makes it possible to assess the features of the service system accurately enough to compare various approaches.

VI. Conclusions

This study used the AnyLogic framework to effectively design and evaluates a unique simulation model for a centralized transport robot control system. The simulation offered a thorough study of the centralized request distribution mechanism by combining discrete-event and agent-based modeling techniques. Although there were some differences because of the difficulties in identifying coordinates in real-time without sensors, the results showed a strong correlation between the simulation and the experimental data.

Future research could concentrate on integrating cutting-edge sensor technologies and improving the communication protocols between robots and the control system in order to increase the simulation's accuracy. Furthermore, broadening the scope of the model to incorporate diverse environmental scenarios and intricate task sequences may offer a more thorough evaluation of the system's resilience and scalability.

Overall, this innovative simulation model is a useful resource for assessing the viability and effectiveness of centralized transportation networks. In addition, it establishes a foundation for investigating decentralized control systems, providing important insights ahead of actual implementation in practical applications. This paper makes a substantial contribution to the field by combining discrete-event and agent-based methods in a novel way, opening the door to more sophisticated and precise simulations in autonomous transport systems.

An accurate enough predictive feature of service quality can be obtained for a comparison investigation of the efficacy of different tactics using the model of a centralized control system for a transport robotic system established in the AnyLogic system. The number of robots and their description of their movement area can be easily changed with the help of the shown model.

The goal of future study will be to model decentralized control. The primary model code in this instance won't alter. With the knowledge that transport robots may communicate with one another using WiFi communication modules and Arduino microcontrollers, altering the SeizeRobot block's working logic is all that is required. Wireless network topology optimization techniques can be used to guarantee the stability of communication networks among mobile devices.

References

[1] M. Wahde, “Introduction to autonomous robots. Lecture Notes from the course Autonomous Agents, Chalmers university of technology,” 2012.

[2] L. E. Parker, D. Rus, G.S. Sukhatme, “Multiple Mobile Robot Systems”, Springer handbook of robotics, pp. 1335-1384, 2016.

[3] G. Fragapane, D. Ivanov, M. Peron, F., Sgarbossa & J. O. Strandhagen . Increasing flexibility and productivity in Industry 4.0 production networks with autonomous mobile robots and smart intralogistics. Annals of operations research, 308(1), pp. 125–143 2022. doi.org/10.1007/s10479-020-03526-7.

[4] M. Jiang, & G. Q. Huang, Intralogistics synchronization in robotic forward-reserve warehouses for e-commerce last-mile delivery. Transportation Research Part E: Logistics and Transportation Review, 158, p. 102619, 2022, doi.org/10.1016/j.tre.2022.102619.

[5] Xu Ke, “Integrating centralized and decentralized approaches for multi-robot coordination,” Rutgers The State University of New Jersey, School of Graduate Studies, Vol. 107, 2010.

[6] Z. Yan, N. Jouandeau and A. Ali-Chérif, "Multi-robot heuristic goods transportation," 2012 6th IEEE International Conference Intelligent Systems, Sofia, Bulgaria, pp. 409-414, Sept 6-8, 2012, doi.org/10.1109/IS.2012.6335251.

[7] H. Zheng, et al. “A Primer For Agent-Based Simulation And Modeling In Transportation Applications,” U.S. Department of Transportation, Federal Highway Authority (FHWA), Vol. 75, 2013.

[8] A. Rehman, T. Saba, M. Kashif, SM. Fati, SA. Bahaj, H.A. Chaudhry, “Revisit of Internet of Things Technologies for Monitoring and Control Strategies in Smart Agriculture. Agronomy,” 12(1):127, 2022, https://doi.org/10.3390/agronomy12010127.

[9] A. B. Bakri, R. Adnan and F. A. Ruslan, "Wireless Hand Gesture Controlled Robotic Arm Via NRF24L01 Transceiver," 2019 IEEE 9th Symposium on Computer Applications & Industrial Electronics (ISCAIE), Malaysia, 2019, pp. 16-22, doi: 10.1109/ISCAIE.2019.8743772.

[10] H. K. Pandey, S. Negi, L. Kothari, A. Jaiswal, S. Thapliyal and M. Singh, “Development of a Versatile Wireless Control System Using nRF24L01 Transceiver and Arduino Unit,” 2023 International Conference on Computational Intelligence for Information, Security and Communication Applications (CIISCA), Bengaluru, India, pp. 103-108, 2023, doi: 10.1109/CIISCA59740.2023.00030.

[11] G. Fragapane, R. De Koster, F. Sgarbossa, & J.O. Strandhagen, “Planning and control of autonomous mobile robots for intralogistics”,: Literature review and research agenda. European Journal of Operational Research, 294(2), pp.405-426 2021, https://doi.org/10.1016/j.ejor.2021.01.019.

[12] J. López, E. Zalama, & J. Gómez-García-Bermejo, “A simulation and control framework for AGV based transport systems”, Simulation Modelling Practice and Theory, 116, p. 102430. Apr 2022, https://doi.org/10.1016/j.simpat.2021.102430.

[13] M. Berndt, D. Krummacker, C. Fischer & H.D. Schotten, “Centralized robotic fleet coordination and control”, In Mobile Communication-Technologies and Applications; 25th ITG-Symposium, Osnabrueck, Germany, pp. 1-8, November 2021.

[14] X. Sun, H. Yu, W.D. Solvang, “Measuring the Effectiveness of AI-Enabled Chatbots in Customer Service Using AnyLogic Simulation”, In International Workshop of Advanced Manufacturing and Automation, Singapore: Springer Nature Singapore, pp. 266-274, October 2022 https://doi.org/10.1007/978-981-19-9338-1_33.

[15] A. A. Lyubchenko, E. Y. Kopytov, A. A. Bogdanov, and V. A. Maystrenko, “Discrete-event Simulation of Operation and Maintenance of Telecommunication Equipment Using AnyLogic-based Multi-state Models,” Journal of Physics: Conference Series, vol. 1441, no. 1, p. 012046, Jan. 2020, doi: 10.1088/1742-6596/1441/1/012046.

[16] V.M. Antonova, N.A. Grechishkina, and N.A. Kuznetsov, “Analysis of the Modeling Results for Passenger Traffic at an Underground Station Using AnyLogic,” Journal of Communications Technology and Electronics, vol. 65, no. 6, pp. 712–715, Jun. 2020, https://doi.org/10.1134/S1064226920060029.

[17] Y.G. Karpov, “Simulation modeling systems,” Introduction to modeling with AnyLogic 5, St. Petersburg, 2005.

[18] M. Bashabsheh, “Mathematical model of the spread of COVID-19 using any logic system,” AIP Conference Proceedings, Vol. 2930, No. 1, 2023, doi: 10.1063/5.0175416.

[19] Y. Liu and Y. Song, “Research on simulation and optimization of road traffic flow based on Anylogic,” E3S Web of Conferences, vol. 360, p. 01070, 2022, doi: 10.1051/e3sconf/202236001070.

[20] C. Niu, W. Wang, H. Guo, and K. Li, “Emergency Evacuation Simulation Study Based on Improved YOLOv5s and Anylogic,” Applied Sciences, vol. 13, no. 9, p. 5812, May 2023, doi: 10.3390/app13095812.

[21] J.J. Meyer, L.V. Moergestel, E. Puik, D. Telgen, M. Kuijl, B. Alblas, J. Koelewijn, “A Simulation Model for Transport in a Grid-based Manufacturing System," INTELLI: The Third International Conference on Intelligent Systems and Applications, pp.1-7, 2014.

[22] S. Lupin, H. H. Linn and K. Nay Zaw Linn, "Data Structure and Simulation of the Centralized Control System for Transport Robots," 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Saint Petersburg and Moscow, Russia, pp. 1880-1883, 2019, doi: 10.1109/EIConRus.2019.8656853.

[23] I. Mas and C. Kitts, “Centralized and Decentralized Multi-robot Control Methods using the Cluster Space Control Framework,” In Proceedings of the 2010 IEEE/ASME International Conference on Advanced Intelligent Mechatronics, Canada, July 6-9, pp.115-122, July 2010, doi: 10.1109/AIM.2010.5695768.

[24] S.A. Lupin, Aj Min Tajk, D.A. Fedjashin, “Optimizacija topologii besprovodnyh setej - reshenie dlja napravlennyh antenn”, International Journal of Open Information Technologies, 7, p.p. 32-38, 2018.