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Utilize Educational Robots to Design Logistic Systems

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Abstract: The use of educational robots is new in terms of their utilization for designing logistic systems. The current methodology for designing logistic systems is not directly oriented towards the use of educational robots. This indicates the need to develop a methodology is directly oriented toward the use of educational robots in logistic system design. The aim of this article is to highlight the possibilities of creating a new methodology for designing logistic systems applying using educational robots or small physical models in general. This article brings a new perspective on the possibilities of designing logistic systems. We consider educational robots, infinite conveyor belts, and so on, such as small physical models. From these elements, we can assemble a functional logistic system for study. This method is necessary solution for the accredited field of study industrial logistics.

Keywords: educational robots; physical models; logistic system; method; methodology

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1. Introduction

Understanding the significance and potential of educational robots, as well as developing methodologies in this field, is necessary for both education and practical application [1]. These innovative tools combine teaching with practical involvement and interactivity, allowing for the acquisition of knowledge and skills in various engaging ways. Developing methodologies for their utilization is crucial for effective education, considering pedagogical goals, user needs, and the specifics of the learning environment [2]. This methodology includes selecting suitable robots, setting objectives, and designing activities, with an emphasis on adaptability and flexibility. Integrating educational robots into teaching practices offers benefits such as improved engagement, development of critical thinking, and readiness for the digital future, highlighting the importance of a systematic approach to the development and implementation of methodologies. Given that available educational robots accurately mimic real industrial robots and related elements, the methodologies in question should not only serve for use in educational settings but also enable the creation of a logistic process consisting of robots and their components in real operations, using the algorithms provided by these methodologies [3].

Currently, there are studies specifically addressing how we can utilize existing knowledge from psychology, neuroscience, and education research, and apply them with validity and reliability in research on human robot interactions [4]. One study talks about how the interest in programming educational robots is aimed at determining the specific advantages and challenges that educational robots provide in the learning environment [5]. The effectiveness and utilization of robots are discussed in an article by Ján Semjon and Rastislav Demko, focusing on students' competencies in the field of robotic programming [6]. Such studies contribute to a better understanding of how humans can collaborate with robots. Educational robots undoubtedly provide a playful form of teaching and, also help develop computational thinking in students. Lan Hong [7] discusses this issue and the benefits of using educational robots in the article "The impact of educational robots on students' computational thinking: A meta-analysis of K-12" [7]. Implementing robots into the teaching process is an essential part of new teaching methods for students at various education levels. This issue has been analyzed by authors from the International University of Travnik in Travnik [8]. These scholarly articles demonstrate that working with robots is an essential part of the educational process.

Connecting the educational process with practical experience in educational robotics is essential for shaping qualified professionals in the robotics industry [9]. Educational robots allow individuals to gain practical experience in programming and controlling robots, which are key skills for industrial environments [10]. Without this type of education, workers will lack the necessary knowledge and abilities to create, maintain, and manage complex logistic systems using industrial robots. Integrating educational robots into the educational process is, therefore, critical for future professionals to successfully handle demanding tasks in the industry and contribute to the efficient functioning of logistic systems [11]. To properly tackle these tasks, it is essential to develop a methodology for creating logistic systems using educational robots, which can then be applied in real work situations. This methodology should encompass everything from the basics of robotics and programming to advanced techniques for controlling and optimizing logistic processes. Employees should have the opportunity to practically apply their knowledge and skills through projects and simulations to gain experience in solving real problems. This approach ensures that workers are prepared for the effective and successful utilization of educational robots in the creation and management of logistic systems in their professional careers [12].

The methodologies described in the following articles have significantly contributed to the more efficient utilization of small-scale physical models in building logistics systems. This is evidenced by several final theses of students who followed the described methodology and managed to create their own autonomous logistics system.

2. Methods and Methodologies

Scientific research can be characterized as a deliberate quest for knowledge, involving the study, acquisition of patterns, and organization of facts. The essential attributes include a defined goal, motivation to explore new information, a systematic approach, and results, as well as justification and verification of drawn conclusions and generalizations. It is important to distinguish between scientific and common knowledge, with scientific knowledge requiring the use of specific research methods. Therefore, continually seeking innovative approaches to studying unknown objects is crucial. Research methods represent the means of achieving goals in scientific practice, and the discipline dealing with these methods is referred to as "methodology" [13].

The success of any human endeavor depends not only on its object (the goal) and subject (the person executing it) but also on the way this endeavor is carried out, including the means and methods used. This concept forms the basis of the method. A properly chosen method could expedite and more accurately achieve the goal; it functions as a special navigation tool that helps the researcher avoid many errors and make the path smoother. There is often confusion between the terms "method" and "methodology". Methodology deals with the system of ways of knowing. For example, when conducting a sociological study, a combination of quantitative and qualitative methods can be used. These methods represent the methodology of research. The term "methodology" is closer in meaning to the process of research, its sequence, and its algorithm. Without quality techniques, even the correct method may not yield good results [14].

"Methodology", if understood as the way of carrying out the method, can be perceived as the study of the methods themselves. Examples of research methods include the following:

- Deduction, which consists of deriving a specific conclusion from a general judgment.
- Analogy, which allows drawing conclusions about the similarity of objects based on knowledge of their common characteristics.
- Modeling, which involves creating a model of the object of study for closer examination.

General scientific methodology represents the generalization of methods and principles of studying phenomena in various areas of science. The basic methods of scientific research are observation, experimentation, and modeling, with their characteristics varying depending on the specifics of the respective fields [14].

3. Methodology for Building a Logistic System Using Small-Scale Physical Models and Autonomous Components

The following sections focus on creating a procedure for constructing an autonomous logistic system using small-scale physical models. The basic approach of the methodology is derived from a model system, from which a unified procedure applicable to the creation of any autonomous logistic system utilizing small physical models, educational robots, and autonomous components has been developed.

In upcoming sections, we will aim to establish a model system and, subsequently, a formal schema for the model system. This means that based on the given model system, we will develop a formal schema. Then, from this schema, through generalization, we will develop a single schema. This common schema represents a universal methodology for building autonomous logistic systems using small physical models, educational robots, and autonomous components [15].

3.1. Methodology for Creating a Model System

The working model system is called the mining operation. The purpose of the "Mining Operation" model system is to demonstrate the possibilities of using autonomous elements in a mining environment. By creating this model system, we aim to demonstrate optimization opportunities, not only in mining operations but also in various industrial sectors where optimizations are necessary. In this case, we chose the mining operation to create the model system.

This method focuses on analyzing individual elements of the model system and subsequently assigning a simulated element to a real one. The last part of this section focuses on the process of assembling such a model system in the "Logistic Innovation Robotics Laboratory" environment. In Figure 1, the diagram of the subject model system is depicted [15].

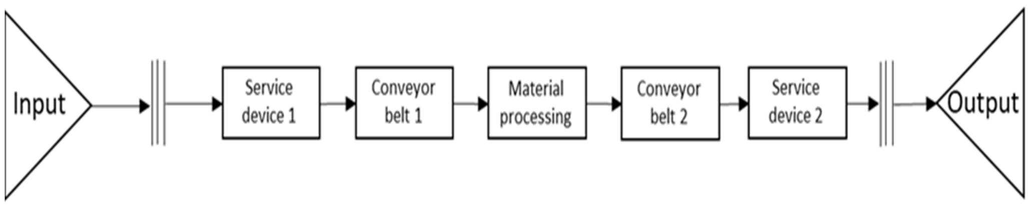


Figure 1. Scheme of the model system [15].

The scheme consists of several parts. The input part represents the material intake, which in the real world may represent the extraction of debris in a mine. In the laboratory environment, this debris is simulated using wooden balls. Bin 1, which in the real world is a heap or pile of debris, is a container filled with simulated material in the laboratory. Service device 1, which represents a robotic manipulator with a scoop in the laboratory, is an excavator used for collecting debris in actual operation.

Conveyor belt 1 is the same as in the real world, but its parameters may vary. Material processing in the laboratory simulates a break in activity. Conveyor belt 2 has the same definition as the first belt. Service device 2 is a robotic manipulator with a double pneumatic suction cup in the laboratory setting, while in the real world, it could be an excavator or digger designed for handling bricks. Bin 2 can be a pallet with material or a simulated set of wooden blocks, as seen in Figures 2 and 3. The output represents a pallet with bricks, which in the laboratory is depicted by wooden blocks [15].

3.2. Analysis of the Model System

The model system "Mining Operation" demonstrates the possibilities and functionalities of individual elements used in the model. These elements can be applied as examples for various areas of logistics, not just in mining operations. When creating a logistic model system, the elements are listed in Table 1.

Table 1. Utilized elements [15].

Element	Quantity/Parameters
Robotic arm	2×
Conveyor belt	2×
Programming unit	2×
Pneumatic device	1×
Excavator bucket	1×
Wooden balls	300 g
Wooden blocks	6 pcs
Container 1	10 × 10 × 8.5 cm
Container 2	6.5 × 16 × 10 cm
Plastic pallet	10 × 6 × 2 cm
Base	6.5 × 16 × 10 cm

The robotic arm WLKATA Mirobot functions similarly to a large crawler excavator, which is considered one of the most versatile construction machines. With additional attachments, it can perform various tasks such as loading, crane formation, rolling, and other construction mechanisms. These machines are suitable for small- and medium-scale operations. The conveyor belt used in the model systems may not have sufficient parameters to transport any materials but serves to move debris in various industrial sectors. It is often used in applications where the transfer of bulk materials is required [16].

The programming unit facilitates the connection of various devices, such as conveyor belts or pneumatic mechanisms, to the robotic arm. In the real world, for example, it would not be possible to connect a conveyor belt to a crawler excavator. Therefore, this external programming unit is not necessary in a real environment as it is part of the excavator or conveyor belt itself. Therefore, it is not necessary to compare it with the actual system in mines. In the laboratory environment, the excavator bucket is simulated by a replica of a real bucket attached to the arm of the crawler excavator. Like the pneumatic device, in a real operating mine system, the device listed in the attached table can be replaced. Other elements that require comparison with the real operating environment are wooden balls and a wooden block. These wooden balls can represent various types of stones or other minerals mined in the mine. In our simulated system, wooden blocks represent, bricks, blocks, or other products made of stones or other materials. Containers 1, 2, the plastic pallet, and the pedestal do not need to be compared with the real operating environment because their characteristics needs to be adapted to the specific operating environment and conveyor belt.

For a complete understanding of Figure 2, it is important to note that the model system "Mining Operation" is divided into two parts: Station 1 and Station 2 [17].

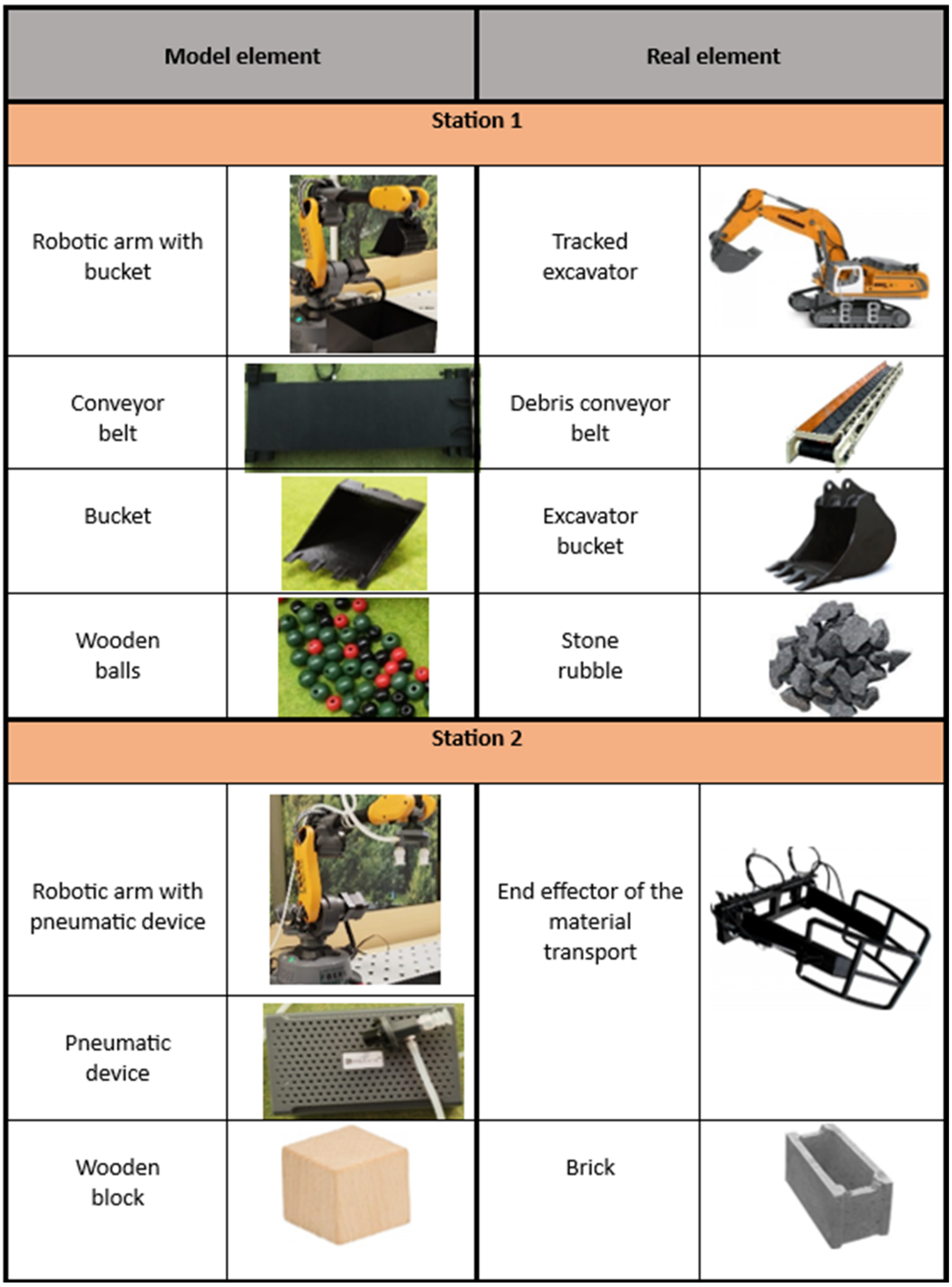


Figure 2. Comparison of real and modeled elements [18–23].

3.3. Assembly of the Model System

The model system was created in the environment of the "Logistics Innovation Robotics Laboratory" to demonstrate the versatility of industrial robots and their ability to replace traditional mechanisms used in mining operations. In creating this model system, certain adjustments had to be made due to the limitations of the laboratory environment and the technical parameters of the robotic arms, which did not allow programming and setting up simulated operations on a single computer. Therefore, the model system was divided into two parts, "Station 1" and "Station 2", as indicated in Table 1 and Figure 2. This divided model posed a problem for the simultaneous activation of both stations. However, software support provided by WLKATA Studio (Hackensack, NJ, USA) enabled the postponement of the activation of one of the stations, enabling synchronized activation of both stations at the same time. In this way, robotic arms and conveyor belts could perform their activities without further human intervention if properly timed [10].

Station 1 is tasked with extracting material from a fully loaded container using a robotic arm with a spoon at the end. Then, the robotic arm moves the material over the conveyor belt and empties it into another container. The conveyor belt subsequently transports the material to a processing device. The next step involves simulating material processing. After a certain period, Station 2 is automatically activated. The conveyor belt moves the processed material under the robotic arm. This robotic arm then activates its program and moves a pair of wooden blocks, representing the simulated material, onto a plastic pallet located on the base. The entire process of creating this model system can be divided into two phases [15].

1. Phase 1.

In the model system, there are two robotic arms, two conveyor belts, and materials designated for simulating real materials, containers, and other components. Therefore, it is important to place these components in laboratory conditions so that there are no conflicts between them, and they do not overlap or collide with each other. Another important aspect when assembling the model system is to ensure that it accurately reflects the real logistics system. It is crucial for this system to demonstrate various logistic operations and presents the easiest possibilities for optimizing these operations. The complete assembled model system "Mining Operation" is depicted in Figure 3 [24].

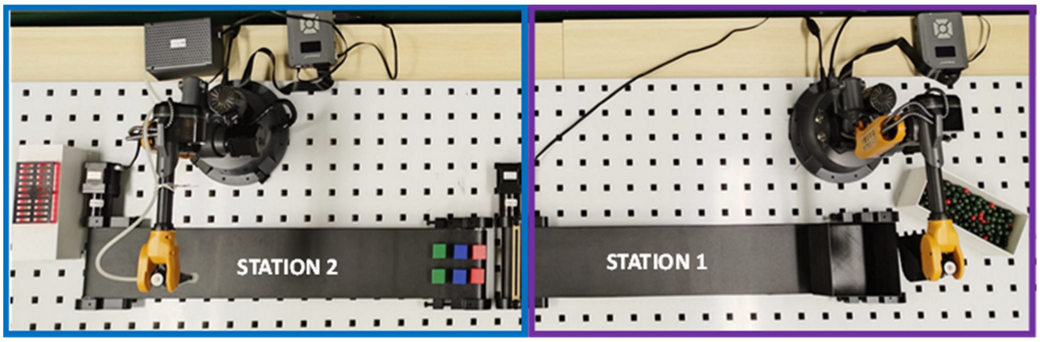
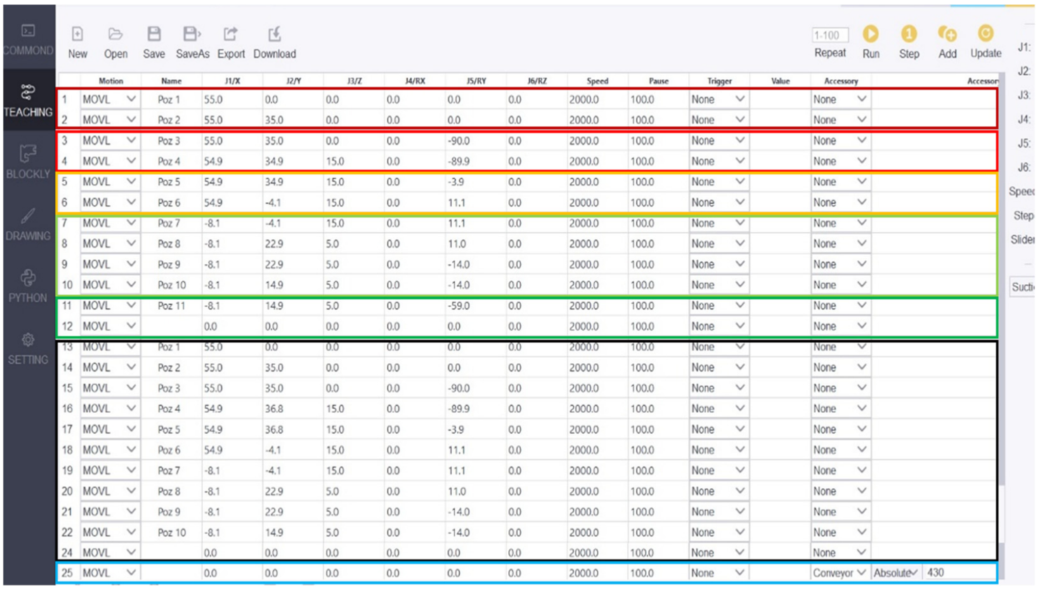


Figure 3. The assembled system [15].

2. Phase 2.

- Station 1.

The first phase of the second step is exclusively focused on "Station 1". As mentioned in the previous section, the main goal of this station is to take the material from the prepared container, move over the container located on the conveyor belt, and empty the material from the spoon into the container. This process is repeated twice by the robotic arm. Subsequently, the conveyor belt is activated and moves the container with the material along the belt, followed by a simulated material processing operation. The process of programming such a group of movements is demonstrated in the same way as in the previous simulated model. To achieve this, it is first necessary to display the program from the WLKATA Studio software interface, and then each line of the program is displayed using a photograph of the position of the robotic arm and other elements of the simulated "Mining Operation—Station 1" system. The color border of the line in Figure 4 corresponds to the color frame of the photograph showing the position of the manipulator [13].



	Motion	Name	J1/X	J2/Y	J3/Z	J4/RX	J5/RY	J6/RZ	Speed	Pause	Trigger	Value	Accessory	Accessory
1	MOVL	Poz 1	55.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
2	MOVL	Poz 2	55.0	35.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
3	MOVL	Poz 3	55.0	35.0	0.0	0.0	-90.0	0.0	2000.0	100.0	None		None	
4	MOVL	Poz 4	54.9	34.9	15.0	0.0	-89.9	0.0	2000.0	100.0	None		None	
5	MOVL	Poz 5	54.9	34.9	15.0	0.0	-3.9	0.0	2000.0	100.0	None		None	
6	MOVL	Poz 6	54.9	-4.1	15.0	0.0	11.1	0.0	2000.0	100.0	None		None	
7	MOVL	Poz 7	-8.1	-4.1	15.0	0.0	11.1	0.0	2000.0	100.0	None		None	
8	MOVL	Poz 8	-8.1	22.9	5.0	0.0	11.0	0.0	2000.0	100.0	None		None	
9	MOVL	Poz 9	-8.1	22.9	5.0	0.0	-14.0	0.0	2000.0	100.0	None		None	
10	MOVL	Poz 10	-8.1	14.9	5.0	0.0	-14.0	0.0	2000.0	100.0	None		None	
11	MOVL	Poz 11	-8.1	14.9	5.0	0.0	-59.0	0.0	2000.0	100.0	None		None	
12	MOVL		0.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
13	MOVL	Poz 1	55.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
14	MOVL	Poz 2	55.0	35.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
15	MOVL	Poz 3	55.0	35.0	0.0	0.0	-90.0	0.0	2000.0	100.0	None		None	
16	MOVL	Poz 4	54.9	36.8	15.0	0.0	-89.9	0.0	2000.0	100.0	None		None	
17	MOVL	Poz 5	54.9	36.8	15.0	0.0	-3.9	0.0	2000.0	100.0	None		None	
18	MOVL	Poz 6	54.9	-4.1	15.0	0.0	11.1	0.0	2000.0	100.0	None		None	
19	MOVL	Poz 7	-8.1	-4.1	15.0	0.0	11.1	0.0	2000.0	100.0	None		None	
20	MOVL	Poz 8	-8.1	22.9	5.0	0.0	11.0	0.0	2000.0	100.0	None		None	
21	MOVL	Poz 9	-8.1	22.9	5.0	0.0	-14.0	0.0	2000.0	100.0	None		None	
22	MOVL	Poz 10	-8.1	14.9	5.0	0.0	-14.0	0.0	2000.0	100.0	None		None	
24	MOVL		0.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		None	
25	MOVL		0.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		Conveyor	Absolute 430

Figure 4. Output from the software interface at Station 1 [own processing].

The first lines of the system program show the robotic arm positioned above "Container 1", ready to safely pick up material with the spoon. These lines ensure that the axes of the robotic arm are set so that the spoon does not meet the edge of the container or the floor on which the model system is located. These arm positions are displayed in Figure 5. This position allows the spoon of the robotic arm to be at the correct angle to pick up as much material as possible from the container in one move. Then, the spoon axis in the arm is inserted into the material.

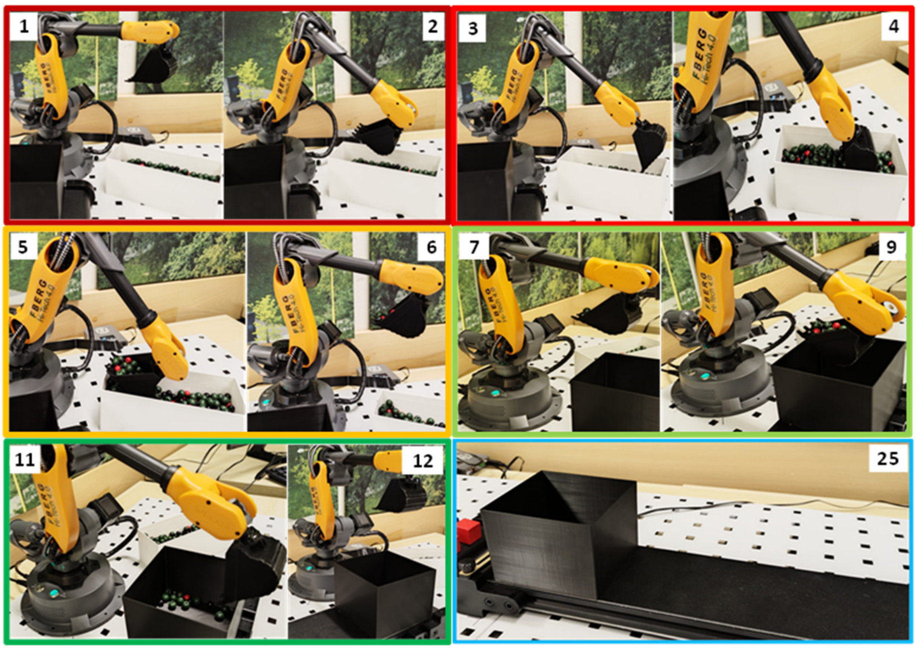


Figure 5. Positions of the manipulator and model elements in Station 1 [24].

Line 5 in the software interface shows the axes of the robotic arm after picking up the material with the spoon. In this phase, it is important to prevent movement of the sixth axis, which controls the spoon, in further programming of the robotic arm movement. This could cause uncontrolled pouring of material from the spoon to an inappropriate location. Line 6 shows the axes of the robotic arm in a position where the material is safely away from the container to prevent collision of the arm with the container during further movement. After filling the spoon with material, the next step is to move this material to the prepared “Container 2” on the conveyor belt. This step is carried out by line 7. If the axes of the robotic arm are precisely in the center of the container, the process proceeds to the next step in line 8, which involves pouring the material into the container.

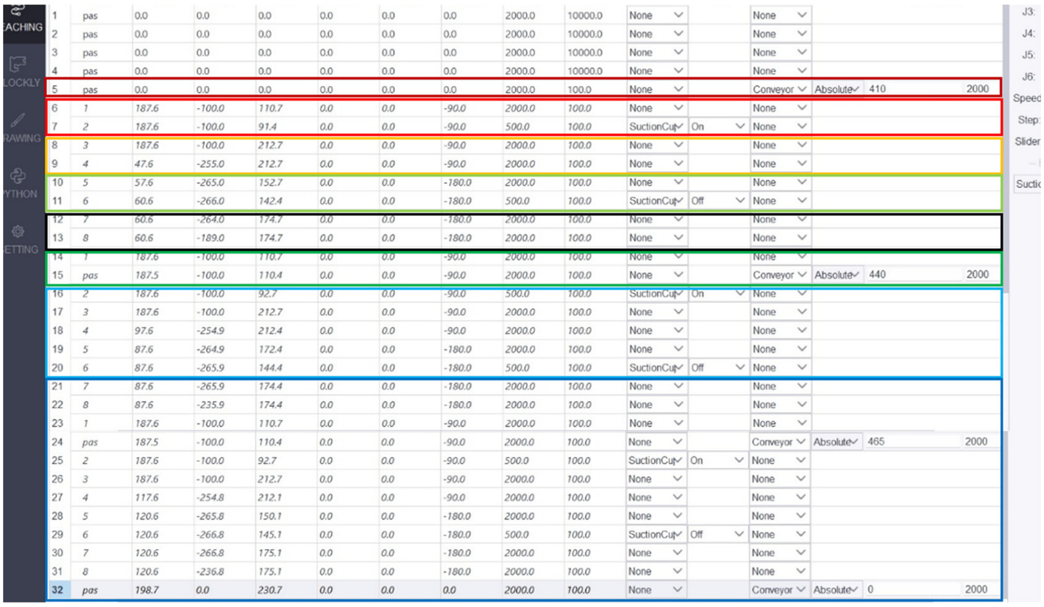
This process requires careful handling to prevent spilling the material outside the container and to avoid contact with the spoon at the edge of the container. To successfully execute this step, corrections represented by lines 9 and 10 are required. Figure 4 displays the positions of the robotic arm and the spoon from lines 7 and 8. Lines 9 and 10 serve for correction but are not relevant for demonstration through photography. Line 11 displays the axes of the robotic arm and the spoon after pouring the material into the prepared container. After this step, the robotic arm returns to its “zero” position, demonstrated by line 12. The “zero” position of the arm before learning further steps or repeating the process is not necessary; it primarily serves to prevent unwanted movements and damage to the arm. The WLKATA Studio software interface enables repeating the entire process multiple times.

However, during the creation of the model system, it was found that if it is necessary to repeat this process, for example, two times, it is not possible to set the conveyor belt to remain in the “zero” position during the first repetition and move in the desired direction during the second repetition. Therefore, it was decided that all lines of the first cycle would be copied, thus omitting the option to control the conveyor belt in the first cycle. Therefore, lines 13 to 24 are the same as lines 1 to 12. The line is used to move the material in the container along the conveyor belt to a position in the model system representing the container’s location so that the logistic operation makes sense. After this step, the simulated activity of material processing in the container follows. Line 25 closes the robotic arm cycle at “Station 1”. For the entire logistic system to be effective, it is necessary for the closing of the cycle at “Station 1” to be followed by the activation of the robotic arm, pneumatic device, and conveyor belt cycle at “Station 2” [24].

- Station 2.

The aim of this workstation is to transfer processed material, specifically wooden blocks, representing, for example, bricks, along the conveyor belt to the designated location. Then, the robotic arm will use the pneumatic device and a double silicone suction cup to transfer the material from the belt to the prepared plastic pallet on the stand. The double silicone suction cup can move two of such wooden blocks at once. The material, i.e., the wooden blocks, will be arranged in pairs on the conveyor belt, making it necessary to repeat this cycle three times.

To enable cooperation between “Station 1” and “Station 2” to create a unified logistic process, it is essential to delay the launch of “Station 2” until “Station 1” completes its cycle. The first step in assembling the system is to teach the robot and other elements of the model system a series of movements to be logically arranged. Later, the timing of launching “Station 1” will be adjusted so that “Station 2” starts only after the “Station 1” cycle ends. Individual movements are displayed in the software interface in Figure 6 from line 5 onwards. The first five lines in the software interface represent a time correction. The procedure is the same as in the previous workstation. First, it is necessary to display the program from the WLKATA Studio software interface, and then each line of the program will be displayed using a photograph of the position of the robotic arm and other 7elements of the simulated system at Station 2; see Figure 7. The color border of the line in Figure 6 corresponds to the color frame of the photograph, showing the manipulator’s position.



1	pas	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	10000.0	None		None			
2	pas	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	10000.0	None		None			
3	pas	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	10000.0	None		None			
4	pas	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	10000.0	None		None			
5	pas	0.0	0.0	0.0	0.0	0.0	0.0	2000.0	100.0	None		Conveyor	Absolute	410	2000
6	1	187.6	-100.0	110.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
7	2	187.6	-100.0	91.4	0.0	0.0	-90.0	500.0	100.0	SuctionCup	On	None			
8	3	187.6	-100.0	212.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
9	4	47.6	-255.0	212.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
10	5	57.6	-265.0	152.7	0.0	0.0	-180.0	2000.0	100.0	None		None			
11	6	60.6	-266.0	142.4	0.0	0.0	-180.0	500.0	100.0	SuctionCup	Off	None			
12	7	60.6	-264.0	174.7	0.0	0.0	-180.0	2000.0	100.0	None		None			
13	8	60.6	-189.0	174.7	0.0	0.0	-180.0	2000.0	100.0	None		None			
14	1	187.6	-100.0	110.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
15	pas	187.5	-100.0	110.4	0.0	0.0	-90.0	2000.0	100.0	None		Conveyor	Absolute	440	2000
16	2	187.6	-100.0	92.7	0.0	0.0	-90.0	500.0	100.0	SuctionCup	On	None			
17	3	187.6	-100.0	212.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
18	4	97.6	-254.9	212.4	0.0	0.0	-90.0	2000.0	100.0	None		None			
19	5	87.6	-264.9	172.4	0.0	0.0	-180.0	2000.0	100.0	None		None			
20	6	87.6	-265.9	144.4	0.0	0.0	-180.0	500.0	100.0	SuctionCup	Off	None			
21	7	87.6	-265.9	174.4	0.0	0.0	-180.0	2000.0	100.0	None		None			
22	8	87.6	-235.9	174.4	0.0	0.0	-180.0	2000.0	100.0	None		None			
23	1	187.6	-100.0	110.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
24	pas	187.5	-100.0	110.4	0.0	0.0	-90.0	2000.0	100.0	None		Conveyor	Absolute	465	2000
25	2	187.6	-100.0	92.7	0.0	0.0	-90.0	500.0	100.0	SuctionCup	On	None			
26	3	187.6	-100.0	212.7	0.0	0.0	-90.0	2000.0	100.0	None		None			
27	4	117.6	-254.8	212.1	0.0	0.0	-90.0	2000.0	100.0	None		None			
28	5	120.6	-265.8	150.1	0.0	0.0	-180.0	2000.0	100.0	None		None			
29	6	120.6	-266.8	145.1	0.0	0.0	-180.0	500.0	100.0	SuctionCup	Off	None			
30	7	120.6	-266.8	175.1	0.0	0.0	-180.0	2000.0	100.0	None		None			
31	8	120.6	-236.8	175.1	0.0	0.0	-180.0	2000.0	100.0	None		None			
32	pas	198.7	0.0	230.7	0.0	0.0	0.0	2000.0	100.0	None		Conveyor	Absolute	0	2000

Figure 6. Output from the software interface at Station 2 [own processing].

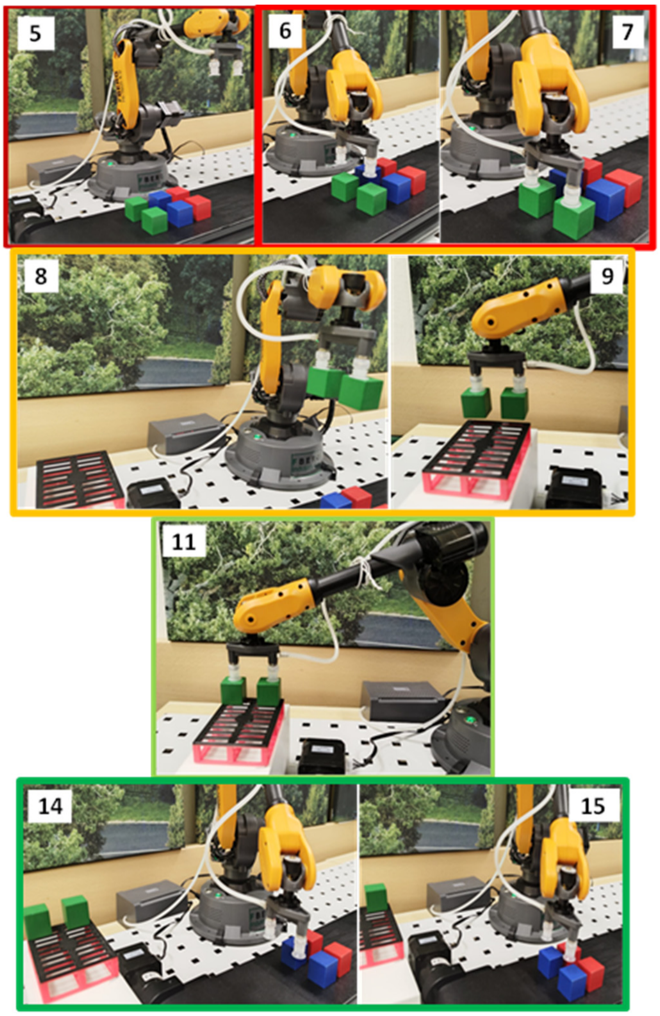


Figure 7. Positions of the manipulator and model elements at Station 1 [24].

This section describes the movement of the conveyor belt, which is designated within the model system as the position from which the robotic arm, using the pneumatic device, will pick up wooden blocks from the conveyor belt. This position changes minimally during the cycle to allow for picking up all three groups of wooden blocks.

The robotic arm moves over the pair of blocks to be picked up from the conveyor belt. In this position, the robotic arm receives a command to activate the pneumatic device, approach the material, and grasp the pair of blocks using the double silicone suction cup. This procedure ensures the transfer of the pair of blocks to a safe position to prevent them from falling or colliding with the stand with the plastic pallet. Then, the robotic arm moves over the plastic pallet and prepares for the careful placement of the pair of blocks in the designated location. Line 10 serves to correct the sixth axis of the robotic arm to ensure that the blocks are placed on the pallet perpendicular to its edges. This step is crucial to prevent the blocks from falling or damaging the arm. Line 11 then serves to precisely place the blocks on the pallet and deactivate the pneumatic device. Line 10 is not depicted in the photograph. Lines 12 and 13 are used to correct the robotic arm so that it does not overload or injure itself when moving back to the original position or collide with the stand or conveyor belt.

These movements are like those in lines 9, 10, and 11 but in the opposite direction. They do not need to be shown again in the photographs. The movement in line 14 mirrors the movement of the robotic arm in line 6. Then, the conveyor belt moves to a position where the robotic arm does not need to make any further movement. This movement is depicted in line 15. Lines 16, 17, 18, and 20 are the same as lines 7, 8, 9, and 10, except for line 19, which corrects one of the axes of the robotic arm. This series of movements is repeated to pick up the third and final group of material from the conveyor belt and transfer it to the pallet with the plastic pallet. Line 32 is used to move the robotic arm and conveyor belt to the starting position. Figure 8 shows the positioning of the blocks after completing the cycle at "Station 2".

Figure 8. The position of the simulated material after the model's work is completed [24].

3.4. Evaluation of the Creation of the Model System

In the subject system, we demonstrated extensive possibilities of using the robotic arm and its components in creating a model of an autonomous logistics system. The main intention was to present basic manipulations with the robotic arm and its components. In this model system, as well as in real operations, it is crucial to think ahead. Incorrect settings or inappropriate conditions can lead to discrepancies between expected and actual outcomes. It is important to consider that improper movements may damage equipment, handling materials, or even the robotic arm itself, leading to financial losses and health risks. Therefore, it is necessary to create, optimize, and verify such model systems in laboratory conditions and present them as models. The main goal of creating such models is to minimize the differences between theory and practice.

The developed model system is complex and demanding to assemble and program, but it demonstrates the possibilities of creating a nearly fully functional logistic system in the "Logistics Innovation Robotics Laboratory" environment. Its objective is to showcase the versatility of the WLKATA Mirobot educational kit and the possibilities of collaborating between different parts of the logistic system. This model serves as the basis for the subsequent development of a methodology for building autonomous logistic systems, including the general steps necessary for assembling such systems. These fundamental elements will be diligently illustrated in the creation of a formal scheme [24].

4. Creation of a Formal Scheme

Thanks to the model system, an algorithm for building autonomous logistic systems focused on educational robots was developed. Next, a formalized scheme-algorithm of activities will be created. Each of the activities in this algorithm will be similarly described. Based on a detailed description and analysis of individual steps, we will create a unified generalized formalized scheme, which will be part of the conclusion of this article (Figure 9).

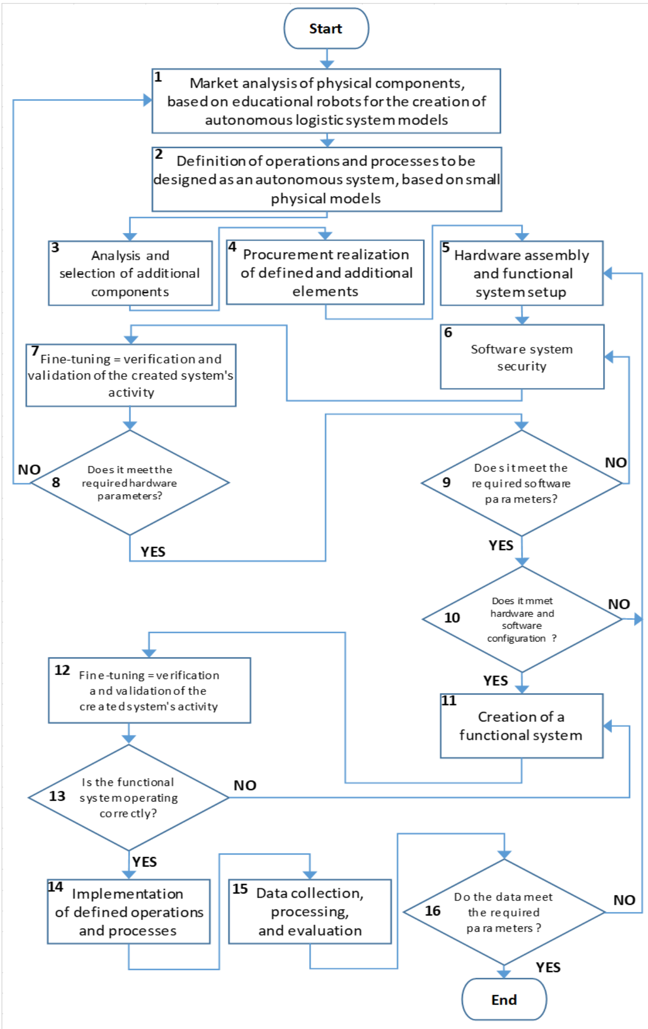


Figure 9. Formalized scheme of the model system [24].

1. The first phase of this work deals with studying the market of physical components based on educational robots used to create models of autonomous logistic systems. During this analysis, available physical models suitable for use in the development of these logistic systems are examined.

2. The next step is to define the operations and processes that represent the autonomous system based on small physical models. After the analysis, it is necessary to specify the operations and processes to be included in the model system and represent their activities in the environment of the "Logistics Innovation Robotics Laboratory".
3. The next step involves analyzing and selecting additional components needed to create the "Mining Operation" model. These components include wooden balls, a spoon, wooden blocks, and containers that will represent various elements in the system. This process involves analyzing and selecting suitable additional components for the model system.
4. This phase involves activities aimed at purchasing and securing individual systems and components of the model system.
5. Gradual hardware assembly of individual components.
6. This segment ensures the installation of software to work with hardware according to defined criteria. Specifically, this concerns setting up sensors for the vehicle to follow a defined route marked by a black tape on the mat.
7. This block is used to fine-tune the assembled system and verify its functionality up to this point.
8. If not, the algorithm returns to block no. 1, where physical elements of the market based on educational robots for creating models of autonomous logistic systems are analyzed. This means that the hardware does not meet the requirements for creating models of autonomous systems in a laboratory environment. The selection of another type of hardware must be considered. If the system operates according to the specified criteria, the algorithm proceeds to block no. 9.
9. The second decision block is used to verify the correctness of the system software operation. If the software of the model system is not functioning properly, it is necessary to return to step no. 6, which involves securing the system software. This is done because the software was installed incorrectly, or another software solution needs to be considered. If the software operates according to the required criteria, the algorithm proceeds to block no. 10.
10. Block no. 10 represents a situation where both the hardware and software components of the model system are operating in accordance with the required criteria. If both hardware and software components are functioning correctly, the algorithm proceeds to block no. 11—functional system creation. If this setup does not work properly, it is necessary to return to block no. 5.
11. This block involves tasks to be performed to logically arrange the individual stations of the model system.
12. This block is used to fine-tune the assembled system and verify its functionality up to this point.
13. The fourth block for system verification is used to verify its operation. If the system does not meet the specified criteria in terms of both hardware and software components, the decision block returns to block no. 11, which concerns the creation of a functional system, and the entire process needs to be repeated and the system corrected. If the functional system is correctly operational, the algorithm proceeds to block no. 14.
14. This block contains a series of activities performed after verifying the functionality of the system. It includes teaching the model system to perform defined operations designed as autonomous systems.
15. This block is used to process the information provided by the research with the designed system.
16. The last decision block is responsible for checking if the data meets the specified criteria. If the data do not meet the required parameters, the algorithm returns to decision block no. 5, which concerns hardware assembly and the assembly of a functional system. If there are inconsistencies between the output and required data,

the cause may be improper hardware assembly. If the data meet the required criteria, the algorithm proceeds further, thus reaching the END of the formalized scheme.

5. Results and Discussion

Educational robots, specifically designed for teaching and training, offer significant advantages in modeling logistics operations in mining environments compared to large industrial robots and computer simulations [25]. These educational robots are smaller, more flexible, and more cost-effective, allowing for practical use and testing of logistics operations in real conditions [26]. Unlike large industrial robots, which can be too expensive and complex for educational purposes, educational robots are easier to install and maintain. Their presence in classrooms and training centers enables students and workers to actively engage in learning, leading to a better understanding of logistics processes and technical challenges in mining environments [27].

Large industrial robots are designed for mass production and complex operating conditions, which may not be suitable for educational purposes. Their complexity and high costs limit accessibility and experimentation opportunities [28]. When used in mining environments, these robots are efficient and durable, but they offer limited opportunities for study and training due to their high level of automation and reduced need for human intervention [29]. Computer simulations of industrial robots provide a virtual environment for analyzing and optimizing logistics operations without the need for the physical deployment of robots. While simulations are useful tools for theoretical study and planning, they cannot fully replace practical experience. Simulations do not allow for direct interaction with real materials and conditions, which is crucial for solving practical problems in mining environments [30].

Overall, educational robots are ideal tools for modeling logistics operations in mining environments from a teaching and training perspective. They offer practical and affordable solutions that enable active and hands-on learning, surpassing the capabilities of large industrial robots and computer simulations in the context of education and training (Table 2).

Table 2. Financial affordability of selected types of modeling [27–30].

Modeling in real conditions		
Robotic arm	2 pcs	EUR 100,000–150,000
Conveyor belt	2 pcs	EUR 10,000–100,000
Other necessary costs	-	up to EUR 500,000
Total costs	-	EUR 610,000–750,000
Modeling using educational robots		
WLKATA Mirobot KIT	2 pcs	EUR 3520
Conveyor belt for WLKATA	2 pcs	EUR 860
Other necessary costs	-	EUR 400
Total costs	-	EUR 4780
Modeling using computer simulation		
Visual components premium	One-year license	EUR 20,000
Total costs	-	EUR 20,000

Figure 10 illustrates a universal algorithm that can be used to create a model of an autonomous logistic system, utilizing physical models focused on educational robots in activities such as loading, transporting, unloading, conveying, and similar tasks.

The following algorithm is designed to be clear and explicit in guiding potential users on how to achieve the desired outcome. Each step of the algorithm can lead anyone interested in using small-scale physical models, particularly in educational robots for logistic systems, to the goal of creating a functional logistics system based on these models.

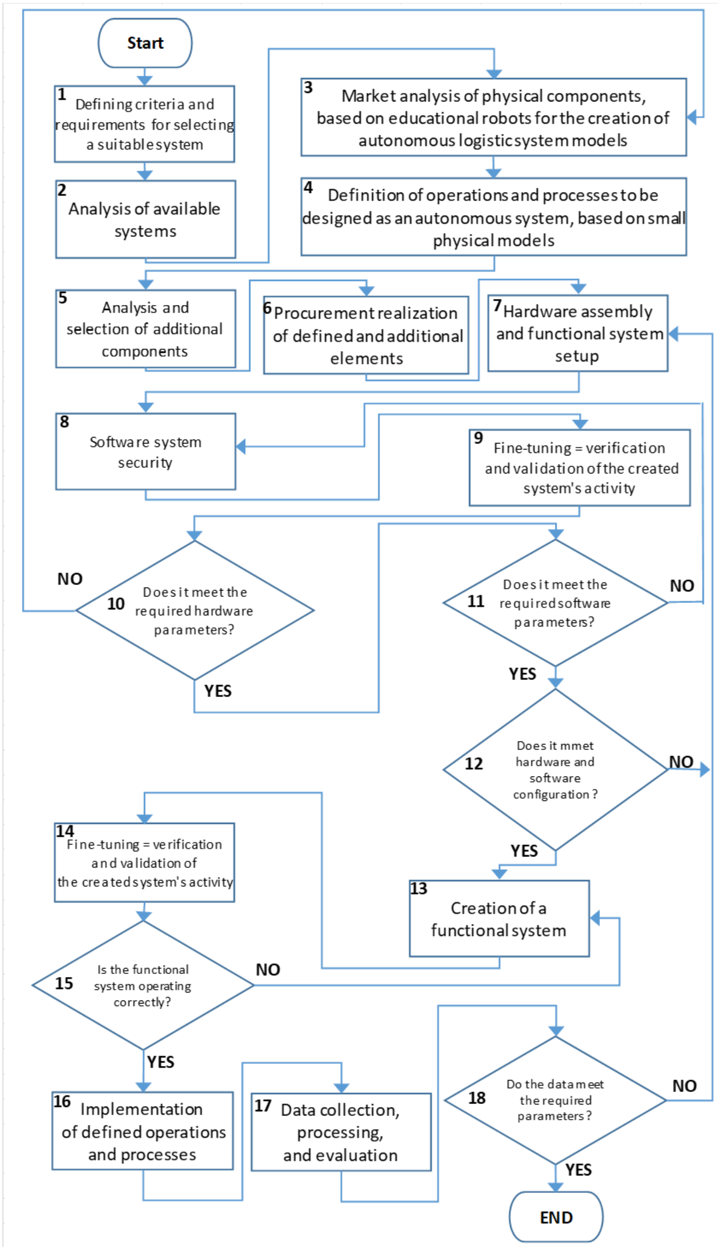


Figure 10. Generalized formalized scheme.

6. Conclusions

These research findings indicate that the use of educational robots is practical in terms of visual and physical (tangible) designs. It is relatively quick to design a functional logistic system, and it can be assembled from available elements. It is possible to identify risks that may not be immediately detectable in a virtual environment. The economic dimension of this form of designing logistic systems is highly efficient and comparable to designing in CAD systems. The added value of this method of designing logistic systems lies in the tangibility of the real model, which is not possible in CAD systems. It can be anticipated that this segment will continue to develop significantly over time, due to the sophistication of educational robots, the cost of this segment, and the possibilities of their use for designing various practical systems. This appealing environment typically leads to attracting qualified individuals to work, increases their interest in the field, and encourages further education in industrial and logistics management. These factors form the basis for increased participation of individuals in the field of logistics and for their continuous education in this area.

The general applicability of this methodology is evident in various fields where small physical models are utilized, particularly in educational and practical applications of logistic systems. The main advantage of a physical model compared to a computer model is its tangibility and ability to identify risks and shortcomings that might be overlooked in a virtual environment. Additionally, it allows for faster prototyping and a more intuitive understanding of system functionality. On the other hand, physical models can be more costly to produce and may require physical space for storage and manipulation. However, with advances in technology and simulations, computer models are continually improving in accuracy and efficiency, making them increasingly attractive for certain applications.

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