SAKARYA UNIVERSITY JOURNAL OF COMPUTER AND INFORMATION SCIENCES
VOL. 5, NO. 3, DECEMBER 2022
DOI: 10.35377/saucis.05.03.1173791

Research Article

Simulation of Cargo Unloading Problem: A Case Study on Estimating the Optimal Number of Trucks and Cranes

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Received 11 September 2022; Revised 18 October 2022; Accepted 22 November 2022; Published online 31 December 2022

Abstract

Unloading and loading activities consume high operational expenses at cargo exchange terminals; for instance, the costs of these activities are approximately half of the total costs of the port. On the other hand, interest in modeling and simulation tools has increasingly grown to analyze operational and organizational systems. Where it is possible to build many systems and study their behavior, which saves a lot of effort, time, and cost by using some frameworks to implement modeling and simulation using the computer. In this paper, discrete events DEVS-Suite is used to implement a simulation of the cargo unloading problem, which represents a study to estimate the optimal number of trucks and cranes required in the process of unloading cargo according to some parameters; and the simulation duration is one month, which is equivalent to 43200 minutes. Based on the performance measures adopted in this study, the optimal number of trucks and cranes is 5 of three assumptions which are 3, 5, and 10, where the work will be in a permanent working condition, with high productivity and low cost.

Keywords: Modeling and Simulation, Model, System, DEVS-Suite, Cargo Problem

1. Introduction

In cargo exchange terminals, unloading and loading activities suffer from high operational costs; for example, loading and unloading operations account for nearly half of the total costs of the port [1]. As a result, there is a growing interest in increasing the efficiency of unloading and loading activities while reducing operational costs.

On the other hand, Researchers typically use simulation software to analyze the interoperability of different peripheral areas or to examine the operation of a sub-system in greater detail to save effort, costs, and time with a clear visualization of system implementation [2]. Many analysts, project managers, and those engaged in research and development must use modeling and simulation techniques [3]. In addition, Modeling and Simulation (M&S) systems have become widely used in a wide range of application areas as computing technology advances at a rapid pace, allowing for the production of much faster computers every day [4], it has the potential to improve modeling and simulation performance significantly.

Simulating a real-world process or system over time is referred to as simulation. Simulations require models; the model represents the major features or behaviors of the chosen system or process, while the simulation depicts the model's evolution across time. The relationship between modeling and simulation can be described as shown in Figure 1.

Simulation is utilized in a variety of situations, including technology simulation for performance tuning or optimization, complex manufacturing systems [5], safety engineering, education, training, testing, video games, networks, and human movement [6],[7],[8]. Simulation may be used to demonstrate the real-world consequences of certain situations and actions. Simulation is employed when the real system cannot be utilized because it is not accessible, unsafe, or inappropriate to use, or created but not yet built, or does not exist. In economics, simulation is utilized alongside scientific modeling of natural or human systems to obtain insight into how they work [9]. Furthermore, simulation modeling offers significant and distinctive capabilities for analyzing and designing service-oriented computing systems that must satisfy various and conflicting quality of service (QoS) standards [10].

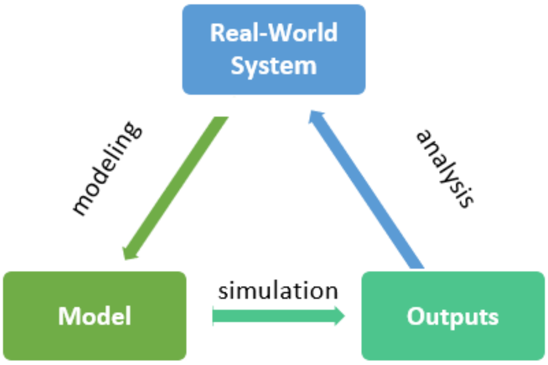

Figure 1 Relationship between modeling and simulation [17]

Several frameworks may be utilized to implement modeling and simulation concepts; in this study, the DEVS-Suite is used to implement the problem [16]. The DEVS-Suite simulator is one of the most commonly used modeling and simulation tools for parallel DEVS formalism [18]. DEVS describes a hierarchy structure for models using a few fundamental components. The coupling and decoupling ideas are supported by this framework, which is also very scalable [19]. The Discrete Event System Specification (DEVS) formalism allows a mathematical entity known as a system to be specified. A system has a time basis, inputs, states, and outputs, as well as functions that predict future states and outputs from current states and inputs [11],[12],[13],[20].

The case study in this paper is a simulation application of the problem of unloading goods that represents an investigation in determining the ideal number of trucks and cranes needed during the process of unloading products according to specific parameters. According to the performance metrics used in this study, the best number of trucks and cranes is 5 out of three assumptions of 3, 5, and 10, where the task will be in a steady state of work and good productivity.

2. Problem Description

This section contains a detailed description of the problem at hand, estimating the optimal number of trucks and cranes required for unloading goods shipments for a company. In this system, one container at a time can be handled by a cargo crane, and one container can typically be transported by a truck [14]. Trucks loaded with goods arrive randomly 24 hours a day, seven days a week, and are stored in the company's warehouses. To correctly complete the simulation process, a set of parameters is assumed. It is expected that these parameters are actual and obtained from a relevant company, but it is considered here for study [15]. They are as follows:

- The company has an equal number of truck and forklift drivers, referred to as C.
- The wages of each driver working for the company is 10 Turkish Liras per hour, in addition to a fixed salary of 20 Turkish Liras per day.
- The company adopts the principle of unloading the truck upon its arrival to avoid the significant fines imposed on it if it causes delays in the trucks.
- The unloading rate for each crane driver is fixed and equal to 7 tons per hour.
- The following cases were neglected:
    - The occurrence of malfunctions in the cranes owned by the company.
    - Absence or illness of any driver working for the company.
    - Filling the stores, as it was assumed that the company’s stores are enormous and cannot be filled.

3. System Description

3.1 System Analysis

To understand the system well and then analyze it accurately, it is necessary to refer to the following:

- System type: Queue system.
- Simulation type: Discrete Event
- Performance measures: Total unloading costs.
- System entities: Generate Truckload, Truck_Crane, Unloading management
- Events:
  - The arrival of a truck
  - Start unloading the truck
  - Finish unloading the truck
- Relationships:
  - The service time (truck unloading time) is directly proportional to the number of cargo trucks, assuming that the unloading rate of trucks is fixed.
- System goal:

  Determine the optimum number of truck drivers and cranes to obtain the lowest total unloading costs.

  The number of drivers should not be more than required because this causes additional costs to the company without any benefit. The number of drivers should not be less than the optimum number, which may cause delays in unloading the load, and consequently, the company may incur significant delay penalties.

3.2 Statistical distributions of the system

The statistical distributions of random system inputs can be described as follows:

- The times between the arrival of the trucks follow an exponential distribution.
- Truck load weights are random, follow a uniform distribution, and are close to each other.

So, suppose that:

- Average time between the arrival of trucks is 140 (adhere to the exponential distribution)
- Truckload weights between 20 and 40 (stick to the exponential distribution).

Since the unloading rate for all drivers is fixed and is seven tones, the service time (the time required to unload any truckload) is directly proportional to the weights of truck loads. It is random and follows the same uniform distribution, and is specified during a certain period that can be calculated as follows:

The smallest period of time = 20 / 7 = 2.85 Hour * 60 minutes = 171.4

The largest period of time = 40 / 7 = 5.7 Hour * 60 minutes = 342.8

4. Modeling Components of Cargo Unloading

This section shows the proposed scenario design for the problem described according to the system described in the previous section.

4.1 Cargo Coordinator model

This model is of multi-server coordinator type and is responsible for receiving trucks and distributing them to unloading stations, consisting of a truck and a crane for each truck with their drivers. This model is always active and represents a transit area only, so the truck arrival time does not affect its condition (See Figure 2).

4.2 Cargo Coordinator model

This model is an atomic model that represents the process of unloading the truckload of each truck using a crane, as it takes time (uniform distribution between (171.4 and 342.8)) as mentioned earlier. This model also has two states: passive and busy. Passive implies that this station can accept a truck to unload its cargo if its sequence is in the queue, while busy means that the station is currently unloading a previous cargo. After completing the unloading process, a notification of the completion of the unloading process will be returned to the transducer model.

4.3 Experimental Frame

The model's experimental frame is a coupled model. Consisting of two basic models: Generator and Transducer.

4.4 Generator Truckload model

This is an atomic model responsible for generating truckloads to observe their behavior within the proposed model. Also, the input ports in this model are (in, start, stop) through the port (in), so it is possible to inject input data for testing this model. As for the output, there is one output port (out) (See Figure 2).

4.5 Transducer model

This model is an atomic model responsible for measuring performance indices such as “turnaround time” and “throughput” for the truckloads processed by an unloading station model during a specified period (See Figure 2). Also, the input ports in this model are (ariv, solved, in) so that the “ariv” port for receiving a copy of the truckload generated by Generate Truckload model, solved for receiving the truckload processed number, In addition, (TA, Thru, out) are the outports, with "TA" standing for "turnaround time" and "Thru" for "throughput.”

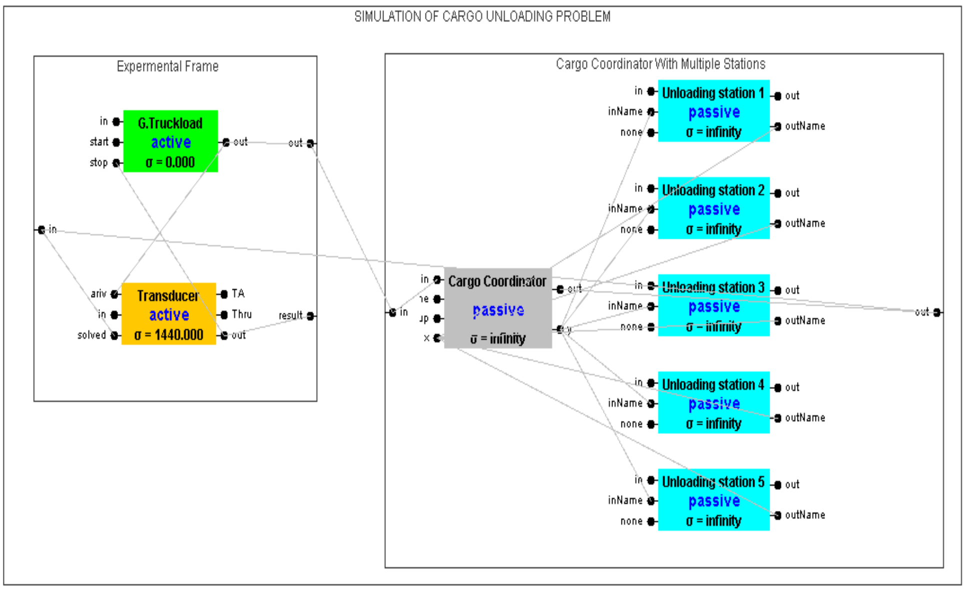

Figure 2 Simulation model of cargo unloading problem with five unloading stations

5. Simulation Experiments

In this section, the parameters of the built model will be placed with the parameters of the proposed system as follows:

- The state of Generate Truckload and Transducer models are always active.
- Sigma value of Generate Truckload model equals exponential distribution of (140) between each generating process.
- Sigma value of the Transducer model equals one month in minutes, which means (30*24*60=43,200) minutes, representing the total simulation time. Thus, this time will decrease after each step by processing time value.
- The sigma value of the Cargo Coordinator model is always infinity, and its state value can take these values:
    - passive: in one of the two cases:
        - First case: On the initial run of the simulator (See Figure 3).
        - Second case: sending the truckload on “y” outport to all (Unloading station) models.
            - send_y: when the generated truckload by (Generate truckload) model is received by “in” inport and sent to “y” outport.
            - send_out: When the truckload that has been processed is sent from outport “outName” of one of the (unloading station) models to “x” inport.
- The sigma value of each (unloading station) model is (infinity) when start running the simulation; after that, it will be taken (uniform distribution between (171.4 and 342. 8)), and then it decreases gradually.
- On the other hand, the state will take “passive or busy.”

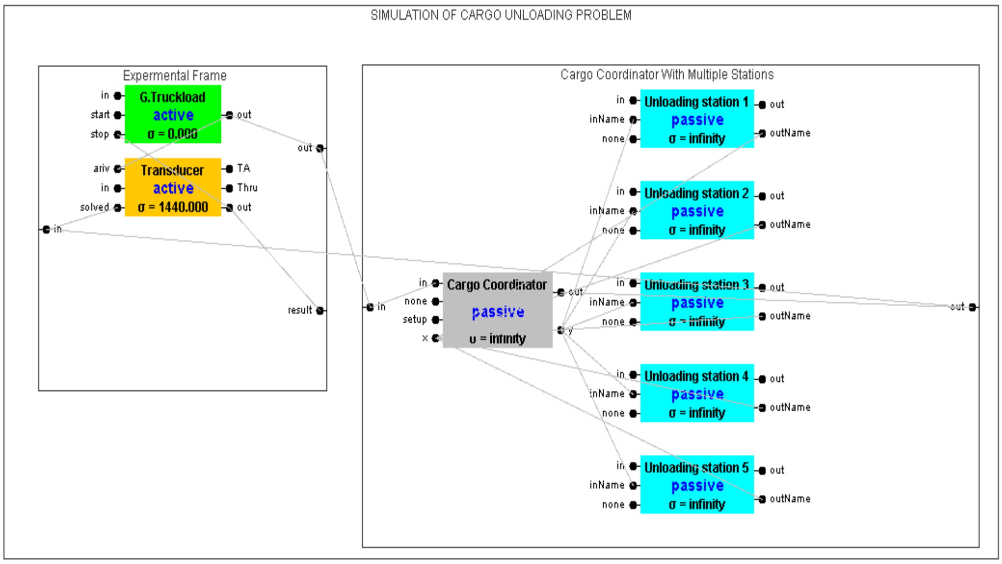

Figure 3 The initial run of the simulation

According to the previous parameters, the steps of the simulation will be as follows:

<u>Step 1:</u> Create a truckload by the (Generate Truckload) model, and send it to the (Cargo Coordinator) model (See Figure 4).

<u>Step 2:</u> Send the truckload to ALL (Unloading station) models for processing by one of them if its state is passive and its order equivalent to the next order in the queue, and change its state to "busy" also, decrease its sigma value by truckload processing time. (repeat this step until complete processing truckload) (See Figure 5).

<u>Step 3:</u> send the processed truckload information by the (unloading station) model to the (Cargo Coordinator) model (See Figure 6).

<u>Step 4:</u> send the processed truckload information from the (Cargo Coordinator) model to the (Transducer) model for computing some performance measures (See Figure 7).

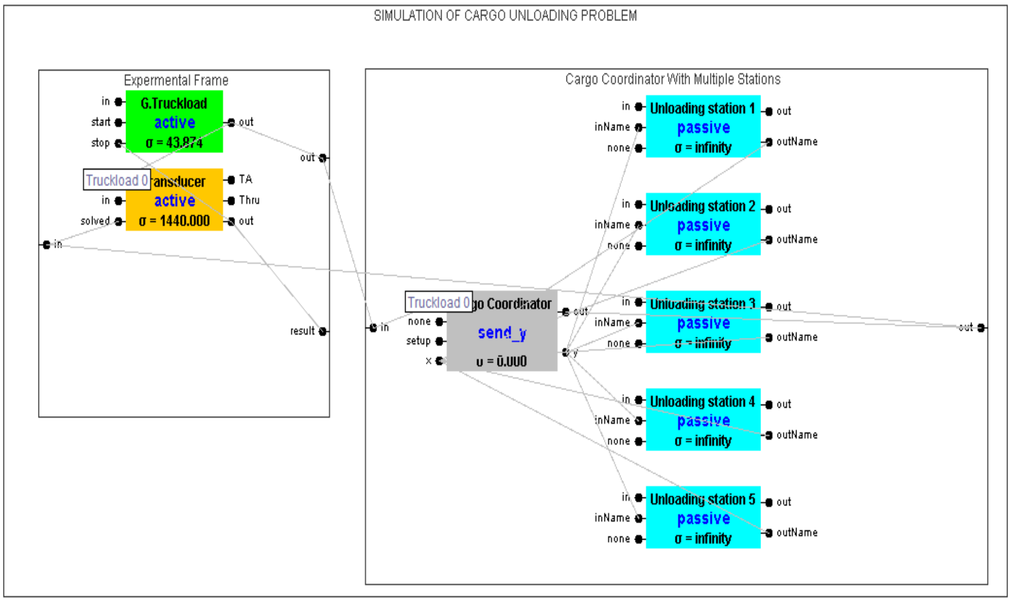

Figure 4 Step 1: Creating a truckload

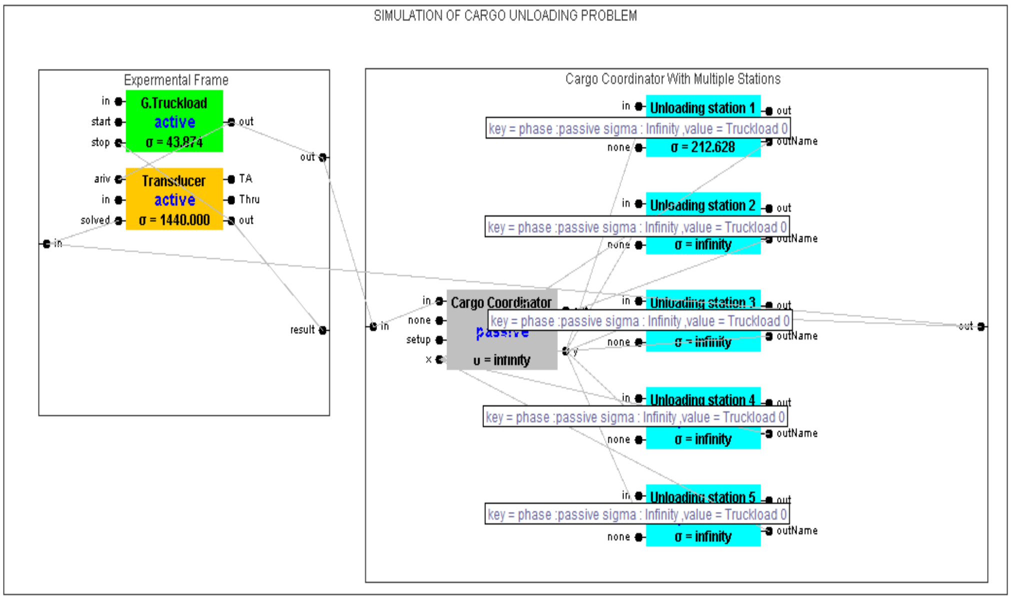

Figure 5 Step 2: Send the truckload to ALL (Unloading station) models

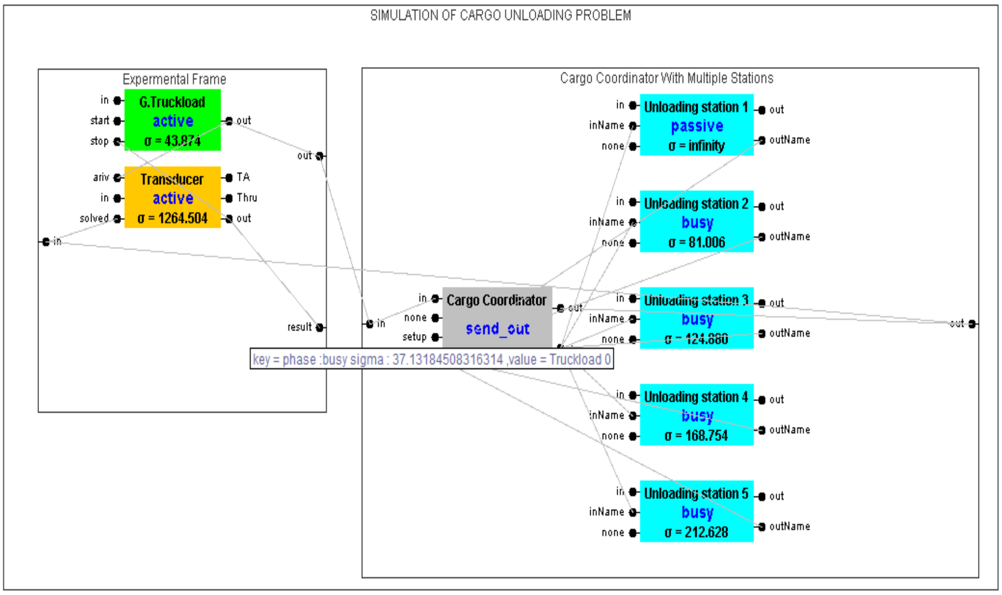

Figure 6 Step 3: send the processed truckload information to (Cargo Coordinator) model

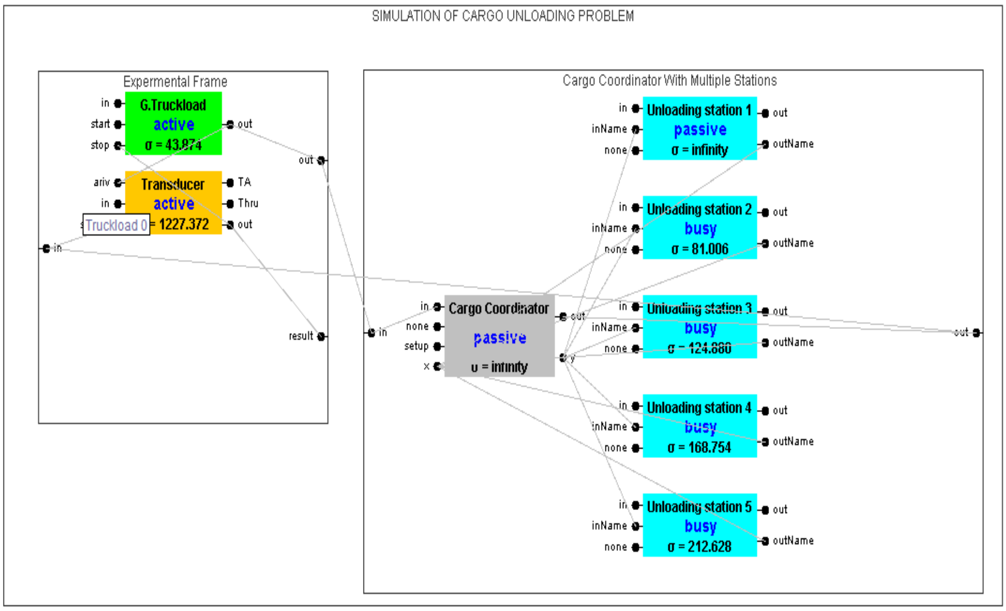

Figure 7 Step 4: send the processed truckload information from (Cargo Coordinator) model to (Transducer)

5.1 The metrics used in the simulation

It is assumed that this goal is achieved by finding the optimal number of trucks and cranes required to unload cargo. All stations must be in use to ensure that there are no idle drivers so that if drivers stop working, there is a loss when paid work wages and salaries for them without work. Accordingly, to find the value of this measure by simulation, it is assumed that the optimal number of trucks and cranes required is (10), then running the simulation for a month and extracting the available calculations (turnaround time, throughput), then repeating the same scenario if the number is (5) and finally compare the results obtained from the simulation of the three models.

6. Results And Discussion

This section contains simulation results for three models according to the number of unloading stations, with charts showing each model's throughput.

6.1 Simulation results of a model with ten (unloading stations)

Table 1 Simulation results with ten unloading stations

Metric	Value
The total truckload arrived	986
The total truckload solved	986
Average turnaround time (TA)	212.6279416460899
Throughput	0.02270396289958388
Iteration	3946
Time	43428.5417202682

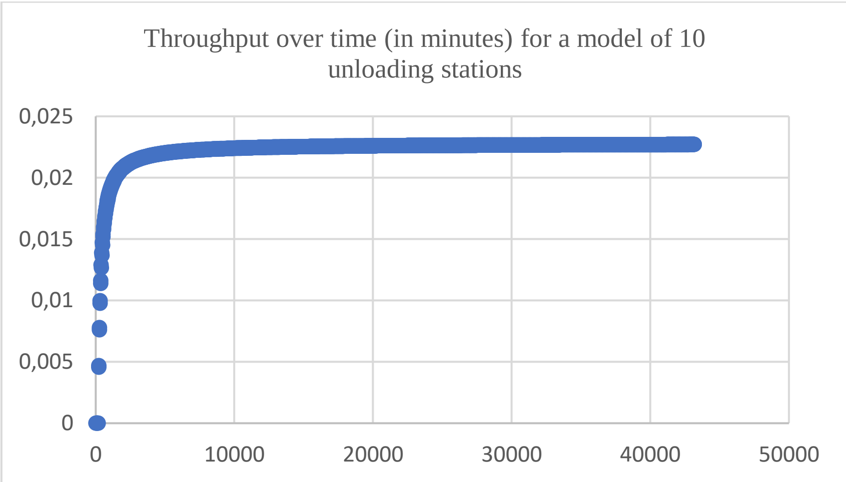

Figure 8 Throughput over time (in minutes) for a model of 10 unloading stations

As shown in Figure 8. We can see that the result gives high throughput on the 0.015 clocks even if it's good throughput, but in this case, we have wasted the workers. We will get at least four workers as idle workers. Results are summarized in Table 1.

6.2 Simulation results of a model with five (unloading stations)

Table 2 Simulation results with five unloading stations

Metric	Value
The total truckload arrived	986
The total truckload solved	986
Average turnaround time (TA)	212.6279416460899
Throughput	0.02270396289958388
Iteration	3946
Time	43428.5417202682

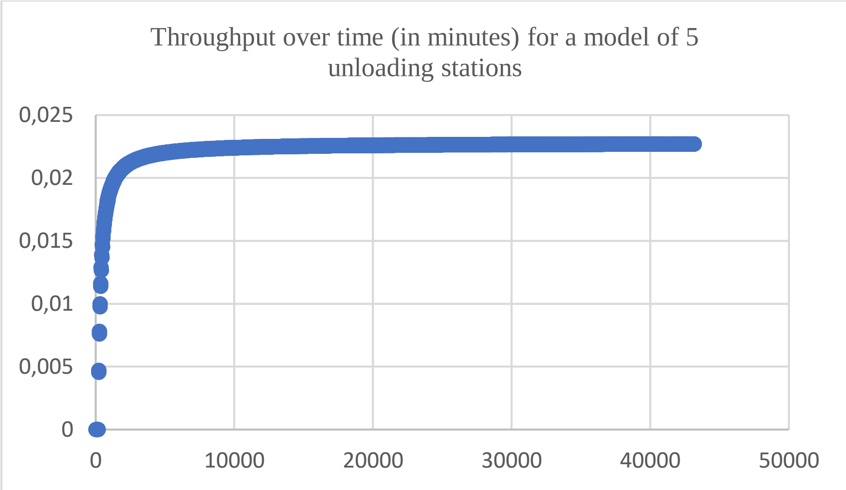

Figure 9 Throughput over time (in minutes) for a model of 5 unloading stations

Figure 9 shows that the time is very close to the ten unloadings because our simulation depends on the milliseconds. When we put the real-time, it is possible to recognize the real difference. Compared to the previous simulation, this case (5 unloadings) is better and closer to the optimum condition of the project because we always have one standby unloaders to cover the difference between each two unloading of a total of 5 cars. The results of this case are summarized in Table 2.

6.3 Simulation results of a model with three (unloading stations)

Table 3 Simulation results with three unloading stations

Metric	Value
The total truckload arrived	986
The total truckload solved	986
Average turnaround time (TA)	212.62794164609028
Throughput	0.013631588272366794
Iteration	2764
Time	43428.5417202682

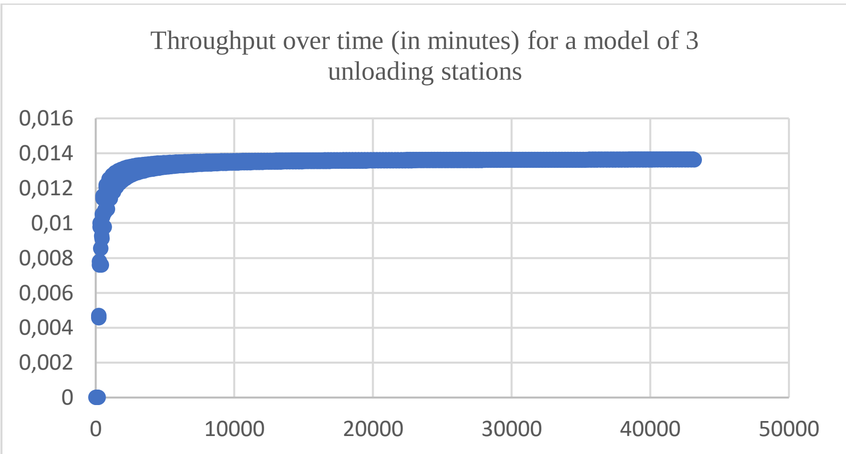

Figure 10 Throughput over time (in minutes) for a model of 3 unloading stations

Figure 10 shows that the throughput it's more intense in the clock 0.01 than the Figures 8. and 9. This is because the simulation iteration was less than the simulation iteration for the cases 10 and 5 unloadings, which means the longest simulation time shows us more accurate results than the shorter simulation time. Table 3 gives a summary of the results in this case.

7. Conclusion

According to the charts and tables above, if ten trucks and cranes are assigned to each truck with its driver, about half of the trucks would be idle, which will result in a loss of pay for five drivers who have no or very little work. Additionally, if three trucks and cranes exist, productivity will be reduced. Therefore, based on the simulation metric that was proposed, the model with five unloading stations will be in a state of permanent work and high productivity, which means that it is the optimal number of trucks and cranes according to the parameters specified in this study is (5) trucks and cranes for each truck with their drivers.

The contribution of this study is the possibility of building an application based on a DEVS-suite simulator to simulate the process of unloading cargo so that this application was used to calculate the optimal number of cranes and trucks required for the operation of unloading cargo by applying multiple scenarios and finding what achieves the goal, which is here a permanent state of work and high productivity without loss of wages.

In future work, the ideal number and type of trucks will be investigated in case there are various truck sizes (big, medium, and small) with a fixed crane size.

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