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# Using Simulation to Model the Logistic Operations of a Company of the Cement Industry

*This paper presents a discrete-event simulation model to study the logistics operations involved in a plant of the cement industry, aligned with a real project developed in partnership between Cachapuz (a company that provides international weighing solutions) and the University of Minho. The purpose of this work consists in using simulation to model several activities, involving weighing, loading and unloading of raw materials, regardless of the type of industry, e.g. cement, tomato, cereals. Thus, this paper documents the work conducted to apply the developed simulation model in a case study of the cement industry. After validating the model, a set of simulation experiments were conducted, which allowed to estimate the maximum capacity of the plant and the impact in the performance of the plant, of the arrival of a cargo vessel. In this regard, it was found that in the case study in question, it is not possible to unload all the cargo from the vessel in a working day – around 3 working days would be required. Further conclusions and future work are discussed in the last section.*

**Keywords:** Logistic operations, supply chain, truck, cement industry, industry 4.0, simulation, Simio

## 1. INTRODUCTION

Supply chains are complex and dynamic networks, connecting different businesses and dealing with activities, e.g.: production, shipment and delivery [1,2]. Using tools to improve the performance of such supply chains is crucial for companies. Logistics plays an essential part in supply chain management to plan and coordinate the movement of products in a timely, safely and effectively way [3,4]. One of the key aspects of logistics is to manage raw materials receipt and schedule deliveries at the right time, place and quantities, otherwise, customer's orders cannot be met.

The need to improve industrial processes is, in fact, one of the main goals of Industry 4.0 and is emphasized by Kagermann et al. [5]. Such improvement may involve several methods, with the authors stressing the use of simulation to analyze the behaviour of complex systems such as supply chains, yet solutions in this regard are still scarce [6]. In the light of this, the project UH4SP (Unified Hub for Smart Plants) was developed at

Cachapuz, Portugal, owned by the Bianciai Group, in partnership with University of Minho. The company provides international weighing solutions and the project aims to integrate and provide information of all entities across the supply chain, through the development of an architecture with solutions oriented towards industry 4.0. The purpose for this solution is to be available to the company in question, but also to others that present similar activities, e.g.: entry of trucks to load; weighing incoming trucks; load trucks with material; and weighing outgoing trucks with materials.

There are several industries that may incorporate these activities, e.g., cement, cereals, tomato, etc. In this regard, the concrete contribution of simulation in the project concerned the visualization, of flows of entities (vehicles and ships) in and out of the plant, to perform these types of activities, through different types of routes (e.g., by sea, road, railway), with such visualization being aligned with the Industry 4.0 movement [7]. For this purpose, a case study was analyzed, consisting on a company of the cement industry, located in Maia, Oporto, Portugal. Thus, this factory was visited, and data was collected from it in order to produce a reliable simulation model. Thus, the purpose of this paper is to document the work conducted to develop such a simulation model, with a focus on analyzing local capacities,

Received: November 2018, Accepted: May 2019

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doi:10.5937/fmet1904683V

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FME Transactions (2019) 47, 683-690 683

as well as critical waiting times. To this end, the model was developed in Simio [8–10], an object-oriented Simulation tool, meaning that users can model the behaviour of physical objects comprising the real system. Simio is among the most used and popular simulation tools [8] and its modelling approach allows to model complex and detailed business processes, while also allowing the individual behaviour of every object to be modelled. The tool developed for this project allows to automatically create simulation models, through the use of the simulation software API, thus allowing effortless updates and application to different plants with similar logistics operations, regardless of the type of industry. This way, it is possible to apply this solution to different cement plants, while also complying with industry 4.0 standards. However, this paper does not cover this part of the project. In this regard, the concrete purpose of this paper is to present the results achieved with a simulation model instance.

The remaining of this document is organized as follows. Next section focuses on the literature surrounding this problematic. Section 3 addresses the problem at hand, whilst section 4 is related with gathering the required data, in order to model the system. In its turn, section 5 is concerned with the development of the Simulation model, leading to the discussion of the obtained results, in section 6. Conclusions and future work are discussed in the last section.

## 2. RELATED WORK

This section summarizes the literature related with the topic at hand, namely the development of technological solutions to improve the performance of supply chains of the cement industry, serving as benchmarking for the addressed case study. The products considered by these types of industries consists in bulky materials, with high transportation costs associated, which do not add value to the final product.

Costs in the cement industry depend essentially on the geographic location of the factory and other layout characteristics that may influence the logistics operations [11]. In fact, in this type of industries, companies tend to be located near the source of the raw materials, e.g., stone quarries. On the other side, the location of these raw materials' sources does not, per se, ensure the location of a factory, since there are other issues involved, such as: costs with raw material extraction, balance of required investment and costs with materials transportation. Regarding the later, Kamble et al. [12] suggested that 3 types of transportation are used in cement industries for both income and outcome of materials: roadways; railways and maritime transport. Thus, as an example, it may be more profitable to transport materials from Portugal to Manaus (Brazil) than to do it from another city in Brazil, via roadways. Thus, costs associated to transportation activities in the Supply chains of cement industries are relevant and must be properly assessed.

Srisurin and Singh [13] proposed a simulation model for the cement loading process of a plant located in Thailand. Their objective was to maximize the utilization factor of truck waiting time and machine idle

time. Although the approach was analogous to this case study, the main goal and some assumptions were different since the authors considered only the loading process of bulk cement. In another perspective, the utilization of Simio has great advantages regarding the animation of the logistic flows.

Vik et al. [14], [15] used Simio to simulate the logistics operations of a generic cement plant. The authors aimed to evaluate the proper layout of a factory and allowed users to automatically build the intended Simulation models, in order for the solution to be applicable to different cement plants. Unfortunately, respecting the characteristics of the industry, construct or remove facilities is not acceptable because, as it was said earlier, it required a large amount of monetary costs. In agreement with this assumption, the automatic generator and the simulation model in this study were developed to test scenarios for different demand quantities to evaluate the impact on the logistic operations.

Abogrean [16] focused their analysis on maintenance problems in a cement factory in Libya. For this purpose, the author developed a Simulation model in WITNESS, mixing discrete and continuous Simulation approaches, in order to model the Supply chain in question. In this case, the analysis focused on the system potential failure which can lead to long break periods. The author developed a generic simulation model where it is possible to acknowledge, for different demand scenarios, how much different parts for maintenance a plant should have for a generic machine. With the alteration of the parameters, the model allows the test of real machines. Additionally, it is conceivable to plan periods of maintenance and analyze which should be preventive or corrective.

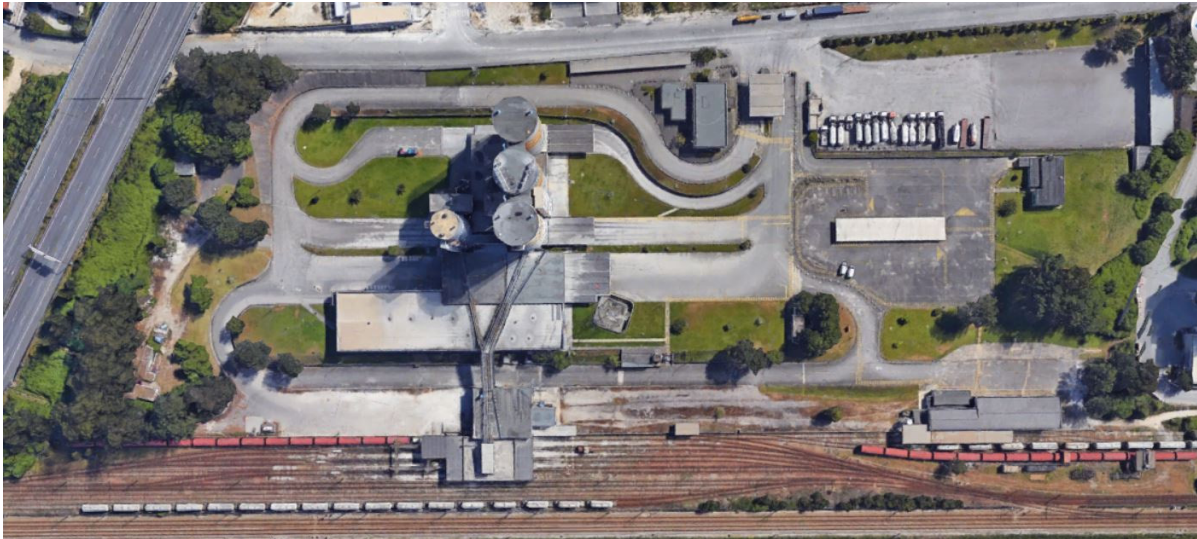
## 3. CASE STUDY

The factory analyzed to develop this study is located in Maia, Oporto, and is owned by InterCement. This plant is not responsible for the production of cement or clinker as final products, but is rather focused on distribution operations, also making use of weighing solutions for customers loading materials from this plant. Figure 1 shows the layout of this plant.

In this plant, there are 3 different communication routes that customers may take, in order to obtain the required materials from this plant: railways, highways; and by sea – the maritime port is located near the factory (roughly 21 km). Internally, the plant has its own railways shared with railways from an external public company. The railway system does not cause impact in this study, because it is fully automated and does not make any logistics constrains in the operations of the factory, yet they are represented in the model, since for other factories this may not be the case.

In contrast, roadways are responsible for two types of activities: (i) carry materials to customers from the factory; (ii) and transport materials from vessels to the factory. This implies a high number of logistic flows inside and outside the plant and origins problems in the traffic management of the trucks.

The second activity is very problematic because vessels face hard restrictions in the maritime ports such



**Figure 1: Cement plant, located in Maia, Oporto.**

as limits in docking time, high competition in the resources needed to unload materials, like cranes, or simply port operating hours.

In this sense, when a vessel arrives, the plant’s operating priority goes to the process of receiving trucks that are coming with the materials from the vessel to not exceed the stipulated deadlines as the retention cost of a ship are large.

Due to the size of the factory, when trucks arrive at the factory, but have to wait in the parking area to access it, this number of trucks is unknown to the factory. This originates situations in which trucks, after waiting for some time, decide to leave the parking area in order to go to another factory, or simply to do another task. Thus, this can culminate in the loss of customers.

Considering the mechanism of operation of the supply chain, five central objectives were defined:

1. Analysis of waiting queues and capacity constraints in the internal processes of the factory in the current scenario and in the proposed scenarios;
2. Parking occupation and time in park is unknown to the factory
3. Realization of experiences and simulations for different demand scenarios.

In a global vision, the purpose is to understand the best strategies to obtain the maximization of efficiency using the existing resources and to identify elements that disturb the flow of the operations in the factory.

**4. DATA GATHERING**

This section summarizes the data gathering that was conducted for this project. In this regard, it should be noted that the data gathering process was divided in the following two approaches:

- data gathered on the ground
- and data gathered in literature.

Data gathered on the ground concerned not only the plant of the case study, but also other similar plants located nearby, by conducting visits. The choice of applying these two approaches concerns two aspects. First, it was not possible to gather all data from the ground, due to the security and schedule reasons, since

the arriving of trucks is a rare and unpredictable event. On the other hand, using these two approaches to complement themselves was beneficial for the final intended solution, since it must be applicable to different factories of different industries. In this way, some input simulation data collected from the company’s information system were summarized.

**Table 1: Sample of input data (values in minutes)**

Operation type	Normal distribution (Mean, standard deviation)
Weighing of truck in entry for bagged material	(3, 0.5)
Weighing of truck in silo for bulk material	(3, 0.5)
Loading of truck with bagged material	(13, 5)
Loading of truck with bulk material	(9, 1)
Weighing of truck in exit for bagged material	(3, 0.5)
Weighing of truck in exit for bulk material	(3, 0.5)

In its turn, the visits conducted to the plants allowed to gather the following data:

- storage types: Materials can be stored in a warehouse or can be directly provided to silos;
- capacities of machines used to store material in bags, in the warehouse;
- processing times;
- number and capacities of silos;
- information of layouts, e.g., number of entrances, distances, circulation rules inside factories and others;
- type of truck: lorry trucks (to load bagged material) and cistern trucks;
- types of materials: materials were divided according to the type of truck used to carry them;
- capacities of trucks per material type;
- customers ‘order information, such as volumes involved.

To find the proper simulation data entered in the tool, after collecting the required data, distribution fitting approaches were used. In addition to these other types of data were gathered, albeit the most important are reported in this section. Furthermore, due to confidentiality issues data collected on the ground cannot be made public.

## 5. MODEL DEVELOPMENT

The first step in the development of the model was to perform a requirements survey, among involved stakeholders of the project, i.e., members of the company and the university. Consequently, it was defined that the development of the model would focus on the study of the logistics flows and on impacts on the performance of the company, rather than focusing on the detailed modelling of processes and operations, such as producing raw materials. With this in mind, the following assumptions of the model can be considered:

- The quantity of materials in the factory is infinite since it is always available. It is true that the lack of raw material can cause delays which, in its turn, affects the logistics flows. Yet, the authors decided not to consider this in the model, since the observations on the ground and conversations with members of the company allowed to verify that material disruption is a very unlikely event, because: (i) source of raw materials in these types of companies is located near the company and (ii) companies of these type deal with few different types of products, easing the management and storing of the materials.
- Individual characteristics of trucks such as size and acceleration profiles were not considered;
- A truck cannot carry more than one product, which ensure that it will load or unload only in one location inside the factory;

At this point, it was possible to divide the model into four important elements: (i) roads and paths; (ii) infrastructures; (iii) vehicles; (iv) and elements outside around the factory.

Regarding roads and paths, one of the options that Simio provides is the possibility to import new textures for the models. The great advantage of this solution is the construction of links between objects, supported with a texture similar to the real-life objects. The representation of paths in Simio is made using multiples "Path" and "TransferNode" objects.

In the infrastructures, the most import elements to represent in a cement factory are entrance and exit gates, silos and warehouses. The behaviour of the entrance object differs depending on the type of truck that is processed. Thus, the following different types of trucks were considered:

1. Trucks for bulk-loading – Currently, the rule applied in the entrance of trucks of this type is FIFO (First in, first out). However, they are not obliged to stop in the gate entrance since they are weighed in the scale located in the silo to record the truck tare weight. So, in the simulation model, these types of trucks are not processed in the server (Simio object) responsible for representing the entrance gate, but

they must pass there to enter in the factory because there is no other way to enter the plant;

2. Trucks for loading bagged material – In a similar way to the previous type of truck, the rule of entrance in this case is also FIFO. Nevertheless, these must be weighted at the entrance. Thus, in this case, the property "input buffer" of the server responsible for modelling this situation, is set to 0, ensuring that, in case of traffic congestion, the queue is made in the path before the entrance gate.

In the simulation model instance used for this case study, there are 4 silos used to supply bulk material to the trucks. Regarding the capacity of silos, only 1 truck can retrieve material from 1 silo. In its turn, the warehouse, which stores bagged material, has the capacity of 4 trucks at the same time.

To represent the routes, since each type of truck makes a fixed route for each type of operation, the concept of "Routing by sequence" present in Simio, was used. This concept allows the modeler to define tables that define a sequence of nodes on the model, which entities must visit.

Lastly, other 3D objects, such as railways, bridges and others, are used to confer a more realistic look to the model, making it more appealing and familiar to the end-user. Figure 2 shows a 3D view over the developed simulation model.

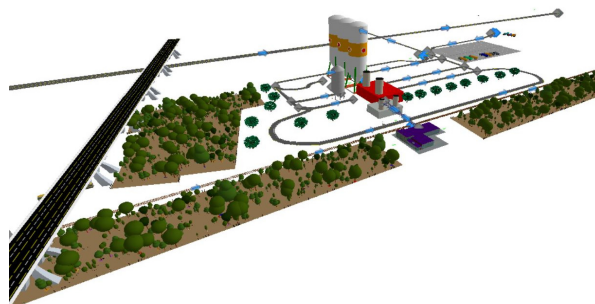


Figure 2: 3D view of the developed simulation model

## 6. SIMULATION EXPERIMENTS

With the purpose of evaluating the system and the effects caused by the flow of vehicles, some metrics were considered, namely:

- Average waiting time of entities in park
- Average time of entities in the system
- Average number of trucks in path to warehouse
- Average number of trucks in path to Silos

The following subsections of this section focuses on conducting simulation experiments, using the developed simulation model and analyzing the obtained results. In this regard, next section focuses on running a scenario equivalent to the current scenario in the analyzed plant. In its turn, second subsection focuses on assessing the maximum capacity of the plant and the last subsection focuses on the impact to the plant of the arrival of a cargo vessel.

### 2.1 Model Validation

This subsection concerns with running and analyzing the corresponding results of the conducted experiment,

equivalent to the current scenario of the plant. For this experiment, the following trucks' arriving rate table, shown in Table 2, was used. The obtained results can be consulted in Table 3.

**Table 2: Arrival rates of truck entities**

Hours intervals	Trucks for bagged material	Cistern trucks
9-10	2	4
10-11	2	4
11-12	2	4
12-13	2	4
13-14	2	4
14-15	2	4
15-16	2	4
16-17	2	3

**Table 3: Results obtained for the first set of experiments**

KPI	Truck type	Value (mm:ss)
Average waiting time of entities in park	Lorry truck	00:24
	Cistern truck	00:21
Average time of entities in the system	Lorry truck	25:36
	Cistern truck	19:32
Number in queue to plant	Lorry truck	0
Number in queue to silos	Cistern truck	0

As the results indicate, the factory is relatively underutilized, since no queues are formed and therefore, trucks do not suffer waiting times. These records match the data collected from the plant. It should be stressed that, in order to achieve such results, the involvement of stakeholders was very important, as well as field observations and interviews that were conducted.

## 2.2 Maximum Capacity Assessment

For this scenario, the maximum storage capacity was used to assess the number of trucks required to load the materials. The results were inserted in the simulation

model and can be consulted in Table 4. Table 5 shows the obtained results for this simulation experiment.

**Table 4: Truck's arrival rates used to assess the maximum capacity of the plant**

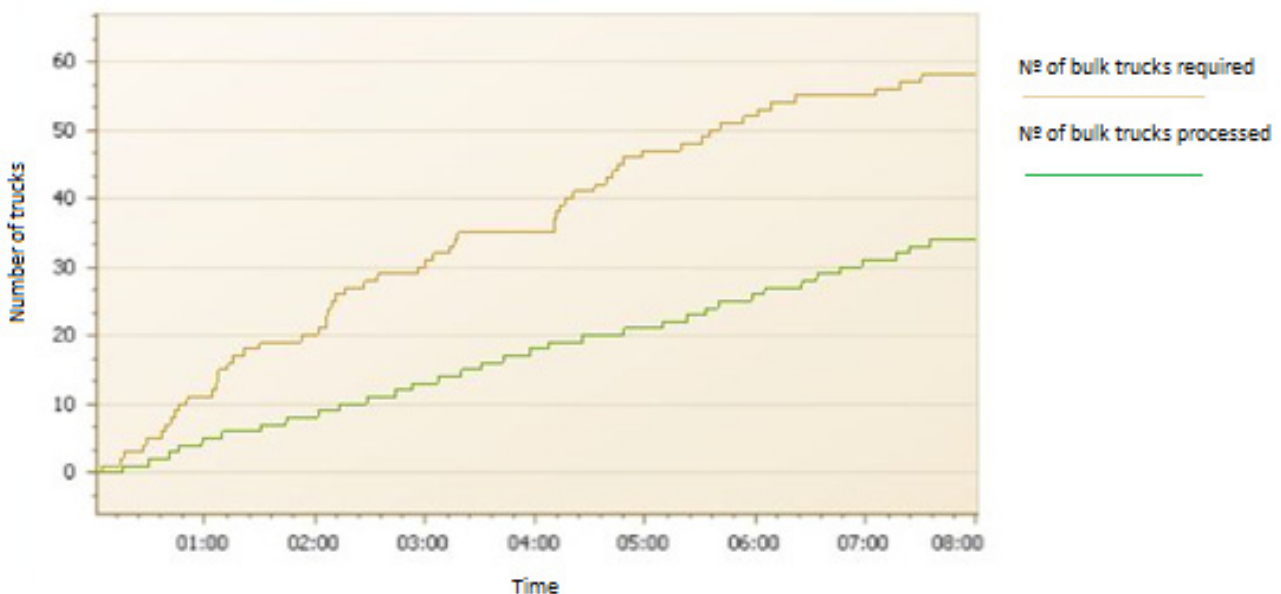
Hours intervals	Trucks for bagged material	Cistern trucks
9-10	7	7
10-11	7	6
11-12	7	6
12-13	7	6
13-14	7	6
14-15	6	6
15-16	6	6
16-17	5	4

**Table 5: Results obtained for the second set of experiments**

KPI	Truck type	Value (mm:ss)
Average waiting time of entities in park	Lorry truck	48:39
	Cistern truck	00:53
Average time of entities in the system	Lorry truck	122:00
	Cistern truck	14:55
Number in queue to plant	Lorry truck	13
Number in queue to silos	Cistern truck	1

By checking these values, it can be seen that the problem, in peak flow periods, is in the warehouse's processing capacity when compared to the demand level of bagged material. Compared with the previous model, the average time of the bulk trucks in the system rose approximately to 1h30m. Lastly, to assess the maximum capacity of the plant, the graph depicted in Figure 3 can be anal analyzed.

As the graph shows, the maximum supply capacity of bagged material is not the 50 000 bags, which is a value provided by managers of the plant, but rather is approximately 30 000, as the simulation results indicate. This value is based on the number of bulk trucks processed in the warehouse area – roughly 30.



**Figure 3: Number of entered versus number of processed cistern trucks**

### 2.3 Considering the arrival of a cargo vessel

Alike the previous scenario, the experiment run for the one concerned by this subsection also considers the maximum flow of the plant, obtained by the simulation results. Furthermore, note that in this scenario the same incoming flow of trucks of the previous scenario was used (see Table 4).

**Table 6: Results obtained for the third set of experiments**

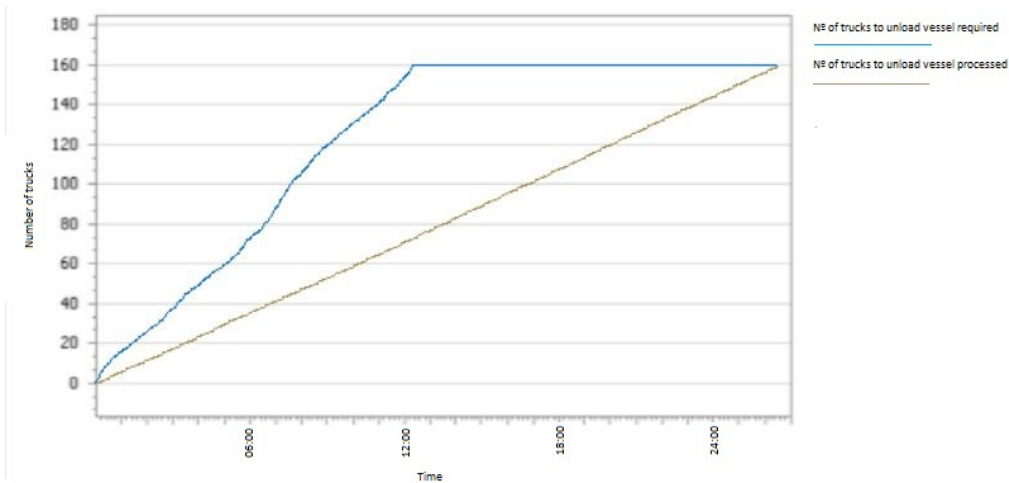
KPI	Truck type	Value (mm:ss)
Average waiting time of entities in park	Lorry truck	08:34
	Cistern truck	00:20
	Unloading trucks	87:43
Average time of entities in the system	Lorry truck	12:46
	Cistern truck	15:14
	Unloading trucks	176:52
Number in queue to plant	Lorry truck	13
Number in queue to silos	Cistern truck	1
Number in queue to warehouse	Unloading trucks	1

Under normal conditions, the factory does not perform any type of preparation to respond to the considerable increase in flow of trucks required to unload the raw materials from the cargo vessel. Essentially, accor-

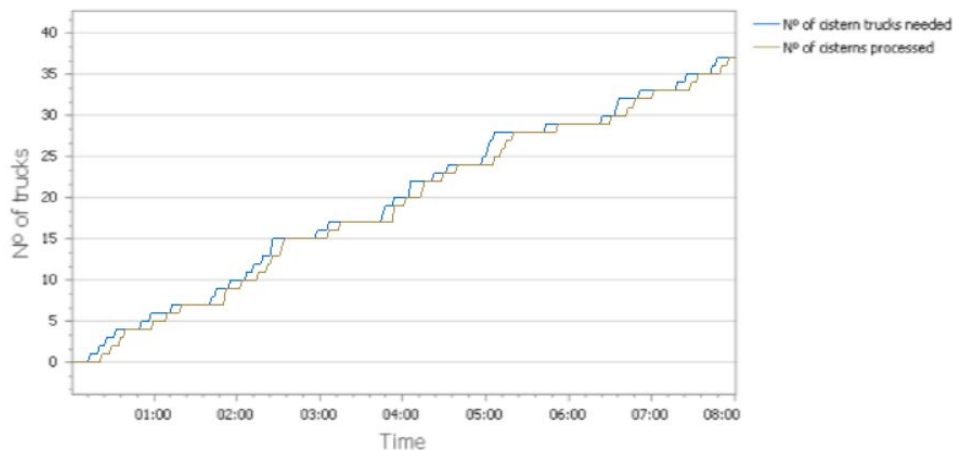
ding to the information gathered, in these periods, the plant allocates all its capacity to process trucks coming from the vessel. This is due to the high costs involved in docking these vessels. Thus, when they arrive, they must be rapidly dispatched. The obtained results can be seen in Table 6.

The results confirm the inferences regarding elongated work periods when receiving material from ships. Comparing the average waiting time of the entities in the park (time spent on the path to the factory entrance), it can be concluded that the inclusion of the new entity caused a negative effect on the average waiting time of the in that path for trucks lorries, although, the average number of trucks waiting in path to warehouse remains unchanged. This suggests that the problem resides in the entrance circuit of the factory. On the other hand, to analyze if a working day is enough to unload all the content from the vessel, the graph depicted in Figure 4 can be analyzed.

As can be seen, a working day is not enough to unload the cargo vessel, since after 8 hours of simulation, there was still content that had to be unloaded from the vessel. In fact, the below graph suggests that more than 3 work days (roughly 26 hours) are required to completely remove all the cargo from the vessel. Conversely, all trucks trying to access the silos of the plant could do it, as the graph depicted in Figure 5 illustrates.



**Figure 4: Number of entered versus number of processed trucks to unload vessel**



**Figure 5: Number of entered versus number of processed trucks to access silos**

## 7. CONCLUSIONS

This paper presented the work conducted on the scope of a project developed in partnership between the University of Minho and Cachapuz, a company owned by the Bianciai Group. The overall scope of the project is to integrate and provide information of the supply chain, through the development of an architecture aligned with industry 4.0, whilst the concrete purpose of simulation is to model the logistic operations of a cement plant, but also from other companies of similar types of industries. The main activities include: entry of trucks to load, weighing of incoming trucks, load trucks with material, and weighing outgoing trucks with materials. Thus, several industries may incorporate these activities, e.g., cement, cereals, tomato.

This way, simulation allows the visualization, of flows of entities (vehicles and cargo vessels) in and out of the plant, through different types of routes (e.g., by sea, road, railway), focusing on the previously identified activities, applied on a selected case study of the cement industry. Although not covered in this paper, the models can also be automatically created.

After presenting the case study and the data gathering process conducted, the model was validated, in order to conduct a set of experiments, which allowed to assess the maximum capacity of the plant and the impact in its performance of the arrival of a cargo vessel. In this regard, it was possible to verify that at least 3 working days (around 26 hours) are required to retrieve the all the cargo from vessels, while still aiming to maintain constant workflow and logistic operations within the plant. It is interesting to note that, without this simulation model, the plant's managers did not now what would be the required time to retrieve all the cargo from vessels. Hence, with the proposed artifact, the plant's managers may now apply the tool to plants with similar activities, visualize its logistic flows to detect unusual patterns and even test alternative scenarios, allowing a proactive approach rather than a reactive one. With the proposed work, the authors also hope to contribute to the literature of industrial cases of simulation in Industry 4.0 contexts, as some of the reviewed studies suggested that those studies are scarce.

As future work, the main goal is to publish the work related with the automatic generation of simulation models, in order to apply this solution to different plants of similar industries. In fact, this work is already ongoing.

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**КОРИШЋЕЊЕ СИМУЛАЦИЈЕ ЗА  
МОДЕЛИРАЊЕ ЛОГИСТИЧКИХ ОПЕРАЦИЈА  
ЈЕДНОГ ПРЕДУЗЕЋА У ЦЕМЕНТНОЈ  
ИНДУСТРИЈИ**

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Жозе А. Оливейра, М. Самеиро Карваљо, Мануел  
К. Фигуеро**

Овај рад представља симулациони модел на основу дискретних догађаја за проучавање логистичких операција постројења цементне индустрије, усклађено са стварним пројектом развијеним у партнерству између „*Cachapuz*“ (компаније која пружа међународна решења за решења мерења) и

Универзитета Мињо. Сврха овог рада је коришћење симулације за моделирање неколико активности, укључујући мерење, утовар и истовар сировина, без обзира на врсту индустрије, нпр. цемент, парадајз, житарице.

Овим радом се документују примене развијеног симулационог модела у студији случаја цементне индустрије. Након валидације модела, спроведен је скуп симулационих експеримената који су омогућили процену максималног капацитета постројења и утицаја на перформансе постројења, доласка теретног брода. С тим у вези, утврђено је да у предметној студији случаја није могуће истоварити сав терет са пловила у радном дану - потребно је око 3 радна дана. Даљи закључци и будући рад разматрају се у последњем делу рада.