



MODELING AND SIMULATION OF PIPELINE LOADING OPERATIONS ONTO BARGES: A CASE STUDY OF RESOURCE ALLOCATION USING DISCRETE EVENT SIMULATION

David Fernandes Cruz Moura (UNESA)

dfcmoura@gmail.com

Fabricio Cardoso de Vasconcellos (UNESA)

fabriciocardoso88@yahoo.com.br

Flavia Cristina da Silva Duarte (UNESA)

flaviacsduarte@hotmail.com

Henrique Alves Serpa (UNESA)

serpa007@hotmail.com

Marcelo Prado Sucena (UNESA)

marcelosucena@gmail.com

Storage port terminals are commonly used when a great quantity of steel pipes needs to be loaded onto barges to meet a specific demand. In this scenario, the allocation of cargo handling resources should be efficient to ensure that the loading of pipes occurs in the shortest possible time, thus reducing the total berthing time and the high port charges costs. Thus, the performance of the pipe loading operations is directly related to the yard productivity, which should ensure a continuous flow of pipes from the storage yard to the marshalling area. Therefore, this paper uses a discrete event simulation methodology in order to solve the problem of resource allocation of trucks, cranes and forklifts through modeling different allocation scenarios as to reduce total operations time followed by a verification of the need for investments in terminal. The following allocation scenarios were evaluated: scenario 1, maintaining the current system in the port terminal with the rental of one unit of mobile harbor crane equipment; scenario 2, rental of two units of mobile harbor crane equipment and scenario 3, rental of three units of mobile harbor crane equipment. This case study followed the steps of traditional discrete event simulation approach, such as: defining the object of study and the production system, the data collection and analysis, the formulation of the logical model, the implementation of the model in computation and validation in computation environment. A brief financial analysis is presented through the analysis of the scenarios proposed by the simulation model.

Keywords: Discrete event simulation, resource allocation, performance evaluation in port terminals.

1 Introduction

With the advent of information technology and data processing, terminal managers have gotten great help in the process of resource allocation to load pipelines from port terminals. According to Gambardella, Rizzolli and Zafallon (1998) simulation models have proven to be a reliable and convenient tool to support manager's decisions in daily operations. They provide a test bed to evaluate the validity of management policies and can be used to solve problems such as conflicts in resource allocation and management of the terminal.

In these cases, the managers decision making can derive from Decision Support Systems, where planning of resource allocation and technical management of the terminal, supported by techniques such as Operations Research and Artificial Intelligence, can be coupled with Simulation Models and tools analysis of statistical data. According to Heinrich (2010) specific literature cites several advantages of using simulation in production processes, among which may be mentioned: the verification of new configurations in the production process without the need to commit resources, the implementation of new operating procedures without interruption of the daily operations, identifying bottlenecks and process' deficiencies before construction or modification of the real system, the savings in investments as the simulation model represents less than 2% of total project cost and the possibility of using the simulation model repeatedly in different analyzes.

This study aims to propose a practical model using discrete event simulation in order to investigate the resource allocation issue such as trucks, reach stackers and cranes, as to reduce the total loading time of pipeline onto barges by checking different investment scenarios. The specific objectives are, as follows:

- i. Characterization of port logistics in Brazil's pipeline industry, highlighting the importance of pipeline construction to regional and national economic development;
- ii. Implement a methodology using Discrete Event Simulation to model the current scenario of loading pipeline onto barges, as well as developing alternative scenarios of investment in resources such as trucks, reach stackers and cranes;
- iii. Develop a brief economic analysis of the scenarios proposed by the simulation model.

The Port of São Sebastião is administered by Companhia Docas de São Sebastião, a company linked to the Department of Transportation of the State of São Paulo, Brazil. It is a federal delegation to the Government of São Paulo, and it is, therefore, a public port (Companhia Docas de São Sebastião, 2012). The Port of São Sebastião has a natural setting which makes it the third best port region of the world, attracting many investments in the area (Companhia Docas de São Sebastião, 2012). According to data provided by the newspaper Folha de São Paulo (2012), the Port of São Sebastião is undergoing a study of environmental viability for an expansion of its surroundings with estimated completion by 2035, which promises to extend operations capability up to three times, increase the number of berths from five to twenty unities and storage areas from four to six unities, as well as increasing the number of direct and indirect employment in 39%.

Recent data from the blog Fatos e Dados, in Petrobras (2012), communicate the discovery by Petrobras of a new accumulation of good quality oil north of the Lula field, the pre-salt Santos Basin. This discovery confirms the potential of the pre-salt region, outside the bounds of the first discoveries in the Santos Basin and highlights the importance of the surrounding areas, such as the state of São Sebastião for the pre-salt economy.

According to O Estado de São Paulo (2011), the berthing delay of liner vessels in the Port of Santos, in the state of São Paulo, Brazil, can reach an average of five days, which mischaracterizes this service whose concept is agility on shipment (Gideon, 2011). The world average is approximately three days, which shows the need for investments in the Brazilian port structure (Ramiro, 2012).

The berthing average utilization rate in the Port of Santos in the cargo unloading and loading operations is approximately 18 hours per vessel. The optimal rate of berth usage to minimize delay and the occurrence of queues is 12 hours (Carlini, Ramos and Werneck, 2008). According to the experience of managers, the total pipeline loading time onto barges of 708 pipelines, 18 inches and 5.6 tons is approximately 18 hours, which generates queues at the berth area, loss of port calls and berthing costs. The total costs of delays at the Port of Santos are close to US\$ 95 million per year, or US\$ 73 per container, which represents 8% of freight costs of containers (Gideon, 2011). In this context, performance analyses and simulation tools are fundamental to investigate operations bottlenecks in port terminals because they provide alternative solutions and what-if scenarios of investments, without compromising resources.

Thus, due to the great importance of the supply chain pipeline logistics for the flow of products produced at the pre-salt cluster, port terminals play a crucial role for the cargo handling industry and need to operate at high levels of efficiency to minimize the vessels waiting times in the berthing area.

2 Loading Operations Characterization

The pipeline loading activities at the Port of São Sebastião, in the State of São Paulo Brazil, start at the storage yard, the area where all pipes are stored in their respective lots, according to pipe type. The resources that participate in this scenario are typically trucks, with total of 4 units available; reach stackers, total of 1 unit, shore crane, total of 1 unit and one storage yard, with the aim, according to the scope of works, to store up to 12,300 pipelines.

2.1 Pipe types

In this study, there are two major types of pipelines according to coating: plain and anode coating. Plain pipelines do not have any type of anode protection but only plain concrete coating; they differ by their physical characteristics such as inner and outer diameter. The pipelines with anode protection prevent corrosion converting all local anode (active) points of the metal surface in cathode (passive) points providing an electrical current (or free electrons) from a source alternative. This practice is also called sacrificial system because the galvanic anodes sacrifice themselves to protect the structural steel and pipe corrosion. Besides plain and anode coating, pipelines are ranked as pipe type A, B, C and D, as follows:

- i. Type A: 18 inches outer diameter, 0.75 inches inner diameter and 2 inches of concrete coating;
- ii. Type B: 18 inches outer diameter, 0.688 inches inner diameter and 2 inches of concrete coating;
- iii. Type C: 18 inches outer diameter, 0.688 inches inner diameter and 1.5 inches of concrete coating;
- iv. Type D: 18 inches outer diameter, 0.75 inches inner diameter and 1.5 inches of concrete coating.

Pipe types and coating play an important operation restriction and need to be considered in the planning of Barges Stowage Plan. In this study, the proportion of plain and anode pipelines in each loading of 708 pipelines follows a proportion of 93% of plain pipes and 7% of anode pipes. All pipes type B are loaded first, then pipes type C, followed by type D and finally pipes type A. Following a good working practice, the storage yard was divided into 25 storage lots, each with one type of product.

2.2 Shuttle Trucks

Shuttle trucks are responsible for pipeline transportation from the storage yard to the berthing area. Each truck can transport four pipes per trip and four trucks are available according to the scope of works. Empty trucks move from the berthing area to the storage area to be loaded again for the next trip.

2.3 Reach Stacker

Reach Stackers are responsible for lifting the pipes from the ground and loading on trucks. This equipment is a high-reach forklift container adapted with a spreader bar for the loading of four pipelines at one time. They perform the pipeline transportation at short distances in an agile way and have a loading capacity of 45 tons.

2.4 Port Scale

The Port of São Sebastião has a weighting road freight scale, brand Toledo, Model 820, Series 970 and 80 tons capacity located between the storage yards and the pier, which weights trucks and other vehicles intended to berths.

2.5 Mobile Harbor Crane

In the Port of São Sebastião pier is located a mobile harbor crane with 45 tons capacity responsible for lifting pipelines from the truck's bed and moving them to the barge surface. This equipment is a container crane adapted with a spreader bar for loading four pipelines at one time. Logical sequencing of pipeline loading activities from the storage yard to the berthing area is defined by Figure 1.

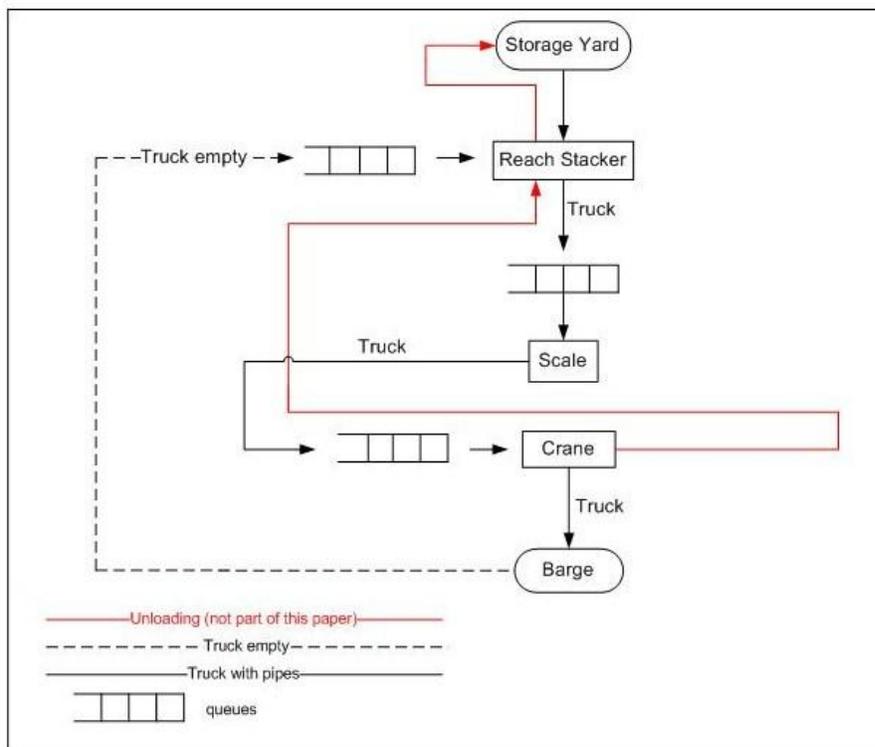


Figure 1: A schematic representation of pipe flow from the storage yard to the barge

3 Simulation Architecture

Simulation is a decision support tool to design and analyze the performance of complex systems. It is the process of building a representative model of a real system and conducting experiments with this model in order to better understand their behavior and assess the impact of alternative strategies of operation

(ANDERSSON, OLSSON, 1998; SHANNON, 1998, 2002 Ingalls apud HEINRICH, 2010). The common steps of a simulation project are described in Figure 2.

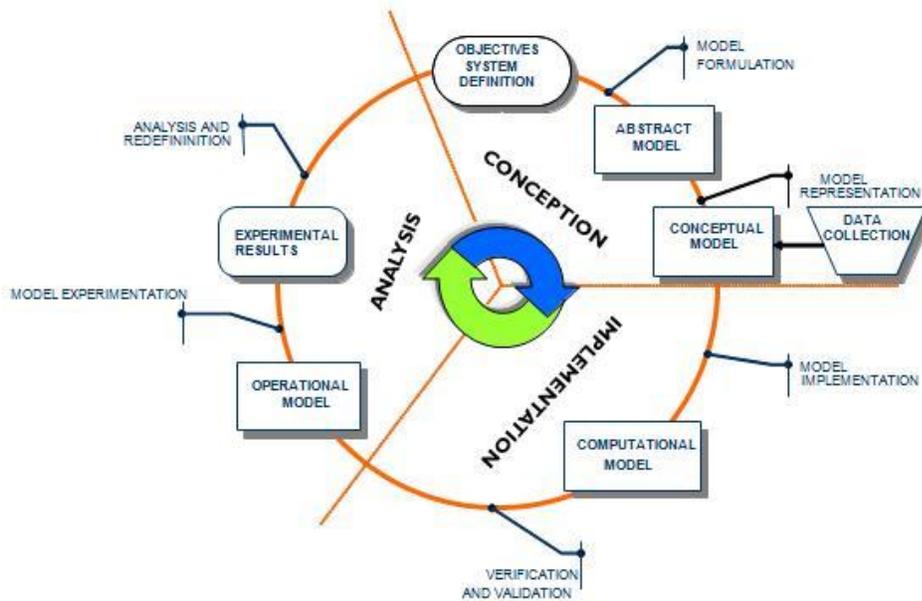


Figure 2: Simulation Project Steps. Source: Chwif and Medina (2006).

The simulation study starts by understanding the problem; the objectives need to be clear, as well as the specific questions that should be answered by the simulation model (SHANNON, 1998; BANKS, 1999; LAW, 2003; CARSON, 2005 apud HEINRICH, 2010).

The data collection phase consists in collecting the relevant information on the structure and operating procedures of the system, determining system parameters, summary data and establishing algorithms in the design of the conceptual model (LAW 2003 apud HEINRICH, 2010).

The conceptual model is developed by modeling the system to the specific objectives of the simulation study through the translation of this system into theories and assumptions based on systems theory and verification of model fit for the intended purpose (SARGENT, 2007 apud HEINRICH, 2010).

In the implementation step, the conceptual model should be programmed and verified within the software of choice. The main advantage of using commercial software is the reduction in project time development (Banks, 1999; LAW, 2003 apud HEINRICH, 2010).

Validation of the results is the process of verifying the representativeness of the simulation model with the system studied, considering the particular objectives of the study (Banks, 1999; LAW, 2003 apud HEINRICH, 2010). Different configurations of the model parameters should be tested to check the consistency of the results generated. It is advisable the reproduction of various sequences of simulations, as many as necessary (Banks, 1999; LAW, 2003 apud HEINRICH, 2010).

3.1 Conceptual model

In the present case study, firstly it was necessary to draw the current operations scenario at the port terminal by means of the Activity Cycle Diagram (ACD), as described in Figure 3. Such representation as described in Guedes (2001) was chosen for its simple design, easy understanding and rapid analysis of its logical components. The system is graphically represented by a set of interconnected elements, namely:

- i. Entities: Elements which retain their identity over time, such as trucks, reach stackers and cranes;

- ii. Activities: Member of active cooperation between classes of entities;
- iii. Queues: Idle states, in which entities await for events.

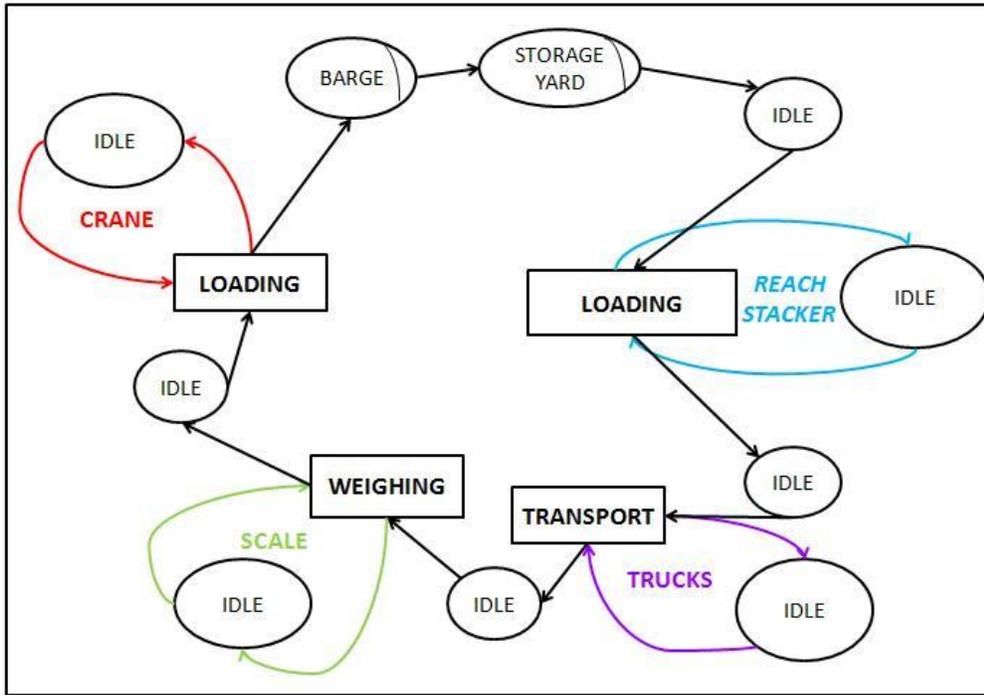


Figure 3: Activity Cycle Diagram of loading pipes on barges. Source: Authors.

For this study, the entities were defined by pipes, reach stackers, trucks, cranes and the port scale used to weight loaded trucks and other vehicles moving to the pier area.

From the ACD analysis, data needs to be collected from five activities:

- i. Reach Stacker loading time intervals;
- ii. The sum of truck traveling times from yard to pier and return;
- iii. Truck weighing time intervals;
- iv. Crane loading time intervals.

After data treatment and outliers removal from the database, it is necessary to know the probability distribution functions that describe each activity so that the data can be inserted into the simulator. The data was first placed in histograms, which allows the adjustment of the probability distribution which best describes the dispersion of the data. Therefore, with the use of a curve fitting software like *Stat Fit*, a tool from the *Simul8 Corporation*, the theoretical probability distributions are identified by fitting of statistic tests such as Kolmogorov, Smirnov, Chi-square and Anderson Darling. Numerical expressions of the functions are given and the results for each activity is implemented into the software *Simul8*.

3.2 Conceptual Model Implementation

Based on data collected with the managers of the terminal, loading time mean in the real scenario is 18 hours for each load out of 708 pipelines on barges.

The model architecture was built with the storage yard representing the system's input, providing a continuous flow of plain and anode pipes type A, B, C and D. Three main operational restrictions were established: the plain/anode proportion, resources operating four pipes at the same time and logical sequence of pipes B/C/D/A.

A logical restriction is set up dividing the pipes following the barge stowage plan, where 93% are plain pipes and 7% are anode pipes.

As all resources (trucks, reach stackers, cranes and port scale) can attend four pipes at a time, this restriction was considered at all *Work Entry Points* in the simulator.

The pipe type restriction was programmed following an IF/ELSE logic where a clock and a counter were established to count the number of pipes flowing by the counter until each type number is reached. For example, if the type B is 4.047 pipes, type C is 7.730 pipes, type D is 490 pipes and type A is 46 pipes, if the counter registers less or equal to 4,047, pipes type B are loaded on the barge. If the counter shows less or equal to 11,777 (number of types B plus C) types C pipes are loaded. Otherwise, if the counter shows 12,267, the sum of pipes type B, C and D, then type A pipes are being loaded on the barge.

Another restriction was imposed to make sure that a shuttle truck is only available for transport after it reaches the mobile harbor crane, therefore the reach stacker can only load the next truck when the equipment has returned from the berthing area.

After conceptual model construction and implementation in Simul8 software, the results were calculated on the percentage of resource utilization and the average time in queue. The simulator interface can be seen in Figure 4.

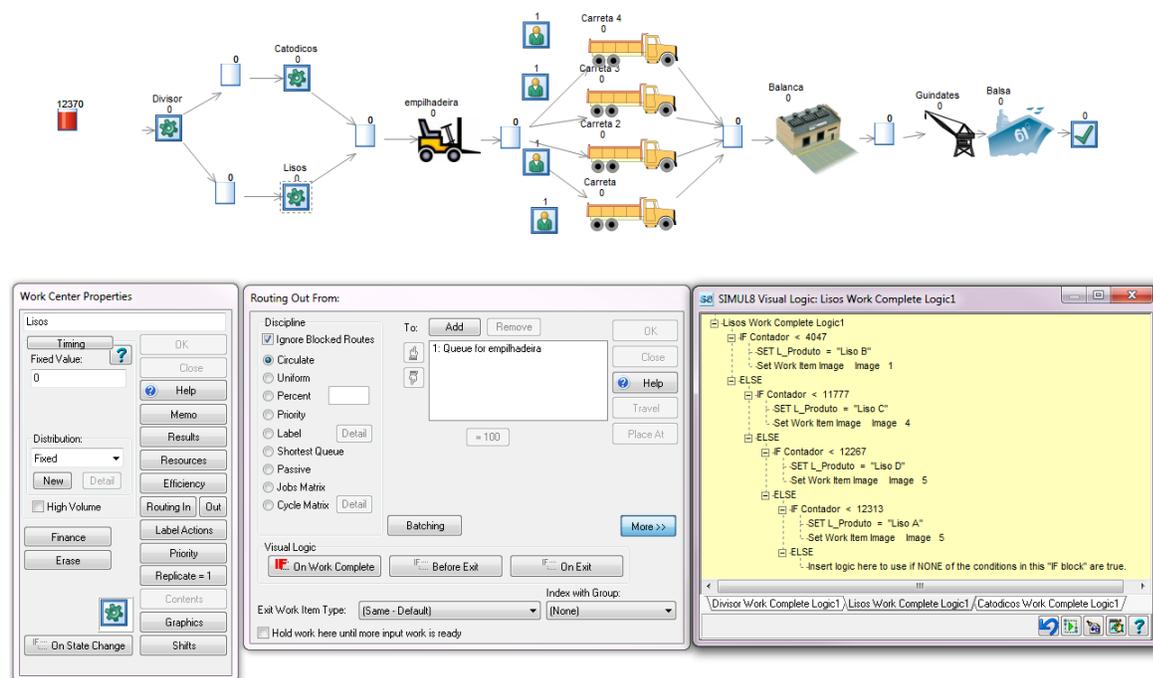


Figure 4: Computational model construction in Simul8. Source: Authors.

As verified through the simulation model proposed, it was observed the presence of truck queues awaiting for the crane work. The average time in queue is 13.6 minutes with resource utilization of 99.9%. Table with results can be seen in item 3.3.

3.3 Conceptual Model Validation

This case study model was validated running 100 replications of the conceptual model, the results can be seen in Table 1. Despite the distributions of the input parameters are the same, as the software generates

random numbers, each replication will present a different output and the average result is obtained constructing the confidence interval of 95%.

Table 1: Validation of the conceptual model

Simulation	Performance	95%	Mean	95%
Anode A	Pipe number	1.44	2.12	2.80
Anode B	Pipe number	277.18	263.80	290.42
Anode C	Pipe number	538.81	547.48	556.15
Anode D	Pipe number	32.58	35.08	37.58
Plain A	Pipe number	18.47	21.32	24.17
Plain B	Pipe number	3,749.58	3,756.20	3,762.82
Plain C	Pipe number	7,175,85	7,184.52	7,193.19
Plain D	Pipe number	449.01	451.56	454.11
Crane	Utilization (%)	99.97	99.97	99.97
Crane Queue	Time (minutes)	13.59	13.60	13.60
Scale	Utilization (%)	16.50	16.53	16.56
Scale Queue	Time (minutes)	0.00	0.00	0.00
Truck	Utilization (%)	13.06	13.07	13.07
Truck	Idle (%)	86.93	86.93	86.94
Truck Queue	Time (minutes)	23.48	23.48	23.49
Reach Stacker	Utilization (%)	28.30	28.32	28.33
Reach Stacker	Idle (%)	71.67	71.68	71.70
Total Loading time	Time (minutes)	18,072.89	18,075.87	18,078.58

Source: Authors

By the simulation model, the mean time for loading all pipes stored at the yard equals 18,075.87 minutes or 301.25 hours. Provided that each barge has the capacity of 708 pipes the loading time estimated by the simulation model is 17.32 hours.

$$time = \frac{708 * 301,25}{12313}$$

$$time = 17,32 \text{ hours}$$

According to managers experience, the load out assumes an average of 18 hours for each barge with 708 pipes capacity which shows that the computational model can successfully describe the real scenario at the port terminal.

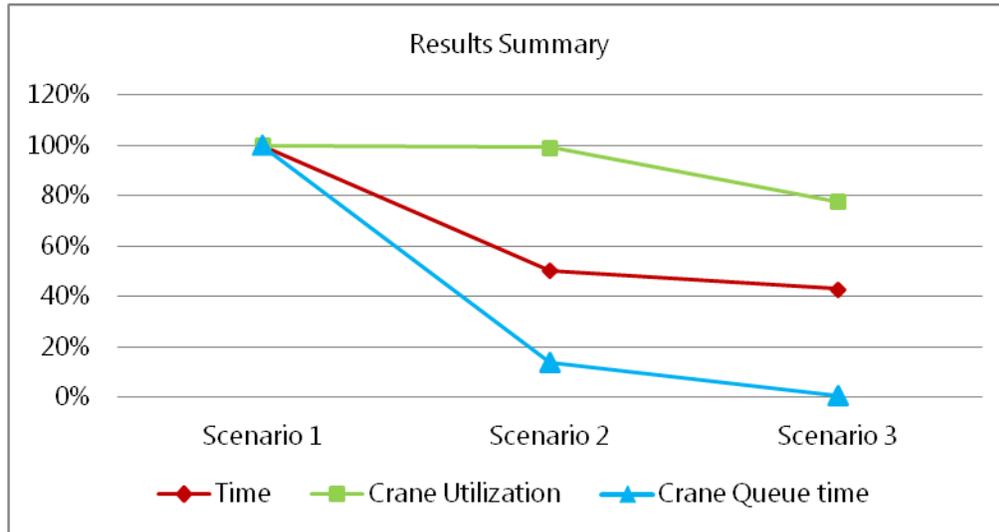
In addition, the confidence interval of 95% constructed after 100 replications of the model demonstrates that the number of pipes loaded is between 12,242 and 12.321. In the real scenario the total number of pipes at the storage yard is 12.313, therefore the model is validated.

4 What-if Scenarios

According to the computational results it is possible to access different what-if scenarios of investments in the port terminal as well as suggest improvements on resource allocation in order to reduce total operations time. According to Table 1 the major bottleneck in the pipeline loading operations at the Port of São Sebastião is the mobile harbor crane, as queues of trucks are formed at the berthing area causing

other resources like trucks, reach stackers and port scale to be frequently idle. Therefore, proposed improvements should focus on minimize queue formation at the berthing area. This study suggests three scenarios of resource allocation: Scenario 1 represents the real system maintenance with one crane; scenario 2 represents the leasing of two cranes and scenario 3, the use of three cranes at the port terminal. After setting the software parameters to achieve the goals proposed, a number of simulation runs were performed and the results summary can be found in Graph 1.

Graph 1: Operational results in the different suggested scenarios



Source: Authors

At the end of replications, the following results for Scenario 2 demonstrate that the total loading time dropped to 9,094.25 minutes, or 152 hours, a reduction of 50% compared to Scenario 1. The crane queue decreased to 1.87 minutes, a reduction of 86% compared to Scenario 1. Full usage of both cranes is seen (99% each) indicating that this scenario becomes a very interesting solution to queue formation at the berthing area.

Scenario 3 displays the following results: total loading time dropped to 7,756.46 minutes, or 129 hours, a reduction of 57.3% compared to Scenario 1. The crane queue decreased to 0.08 minutes, a reduction of 99% compared to Scenario 1. According to the simulation, the three cranes operate at 78% indicating that resources are idle 22% of the time.

The curve expression contained in Graph 2 describes the behavior of the mathematical function "Loading time" versus "Number of cranes". The following mathematical expression demonstrates that from approximately 4 cranes, the y axis will not show any variance; therefore the total loading time will remain constant.

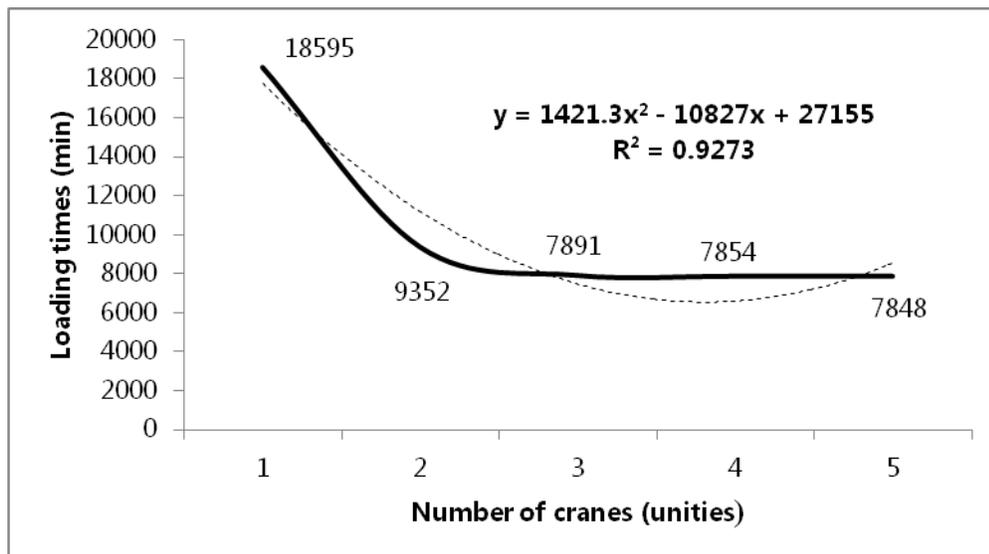
$$f(x) = 1421x^2 - 10827x + 27155$$

$$\frac{\partial y}{\partial x} = 2842x - 10827$$

$$\frac{\partial y}{\partial x} = 0$$

$$x = 3,8$$

Graph 2: Loading times x Number of cranes



Source: Authors

5 Economic Analyses

The operating costs for each equipment, in periods of six hours, were obtained through market research and listed in Table 2. All rates obtained for each equipment already include the appropriate depreciation costs, manpower, maintenance, fuel and spare parts. In each economic scenario, equipment rates were calculated by the number of equipment available and the number of leasing periods (each period with 6 hours). Were listed in the table only variable costs of operation.

Table 2: Brief economic analyses of proposed simulation scenarios

Equipment	Rates	Scenario 1	Scenario 2	Scenario 3
Trucks (unities)		4	4	4
Cranes (unities)		1	2	3
Total loading time (h)		302	152	129
Cranes rental (US\$)	2,700	135,900.00	136,800.00	174,150.00
Reach Stacker rental (US\$)	2,700	135,900.00	68,400.00	58,050.00
Barge berthing tax (US\$)	249.50	12,551.87	6,317.00	5,361.56
Tug berthing tax (US\$)	53.00	2,668.67	1,343.17	1,139.93
Storage yard rental (US\$)	753.50	37,919.87	19,085.50	16,197.56
Manpower (US\$)	13,840.50	696,634.47	350,623.97	297,569.03
Trucks rental (US\$)	490.00	98,653.33	49,653.33	42,140.00
Total (US\$)		1,120,228.23	632,223.48	594,608.08

Source: Authors

6 Conclusion

This study aimed to investigate the resource allocation issue such as trucks, cranes and reach stackers at the Port of São Sebastião, located in the city of São Paulo, Brazil in order to propose a reduction in total loading time of pipelines on barges. Firstly the study briefly characterized the port logistics scenario in Brazil's pipeline industry, following by the presentation of the simulation model, validation and suggested what-if scenarios to enhance productivity and suggest improvements in resource allocation. Finally a brief economic analysis of the suggested scenarios proposed by the simulation model was carried out. Scenario 1 represented the real system maintenance; scenario 2 represented the leasing of two cranes and scenario 3, the leasing of three cranes.

With the results for each scenario, it was concluded that scenario 3 consists of a reduction in total operations time by 57% compared to the real scenario and a cost reduction of about 47%. Scenario 3, despite the better performance according to the objectives of this work, represents a difficulty in the management of the terminal, as it might reduce the space available for the safe movement of equipments, people and products. Scenario 2, therefore, constitutes the best option, as it showed a 50% reduction in the total loading time and cost reduction of approximately 44%.

We conclude that performance evaluation by means of a discrete event simulation methodology allowed the assessment of alternative investment scenarios, constituting itself as a fundamental tool for the characterization of a port terminal of pipeline loading, diagnosing problems and identifying possible improvement opportunities.

7 References

CARLINI, Nelson; RAMOS, Danilo; WERNECK, Roberto (2008). Porto 24 horas Acessos. Developed by CMA CGM Brasil. Viewed in 30 de 08 de 2012. Available at: www.logisticainternacional.com.br/pdf/porto_24horas_acessos_290508.pdf.

CHWIF, L., MEDINA, A.C. Modelagem e Simulação de Eventos Discretos: Teoria e Aplicações, 2. 11T. São Paulo: Bravarte, 2006 12 p.

COMPANHIA DOCAS DE SÃO SEBASTIÃO (2012). O Porto. Material Institucional. São Paulo, 2012. Viewed in 01 de 11 de 2012. Available at: www.portodesaosebastiao.com.br/pt-br/material-institucional.asp.

FOLHA DE SÃO PAULO (2012). Viewed in 30 de 08 de 2012. Available at: www1.folha.uol.com.br/cotidiano/1143364-ampliacao-do-porto-de-sao-sebastiao-preocupa-o-litoral-norte-de-sp.shtml.

GAMBARDELLA, L. M.; RIZZOLI, A. E.; ZAFFALON, M (1998). Simulation and Planning of an Intermodal Container Terminal. IDSIA – Istituto Dalle Molle di Studi sull'Intelligenza Artificiale. Switzerland. Viewed in 28 de 07 de 2012. Available at: www.idsia.ch/idsiareport/IDSIA-41-98.ps.gz.

GIDEON, Elias (2011). Congestionamento nos portos eleva custos. O Estado de São Paulo. Viewed in 30 de 10 de 2012. Available at: www.estadao.com.br/noticias/impresso,congestionamento-nos-portos-eleva-custos,680584,0.htm.

GUEDES, E. P (2011). Uma metodologia de análise de frota aérea com o uso de simulação em um sistema de informações geográficas – Estudo de Caso: Carga Aérea no Brasil. Thesis (Doctorate in Transport Engineering) – COPPE, Universidade Federal do Rio de Janeiro, Rio de Janeiro.

HEINRICH, Daniele (2010). Simulação da Produção de Madeira Serrada. Thesis (Master in Administration) – Escola de Administração, Universidade Federal do Rio Grande do Sul, Porto Alegre.

PETROBRAS (2012). Nova descoberta no Pré-Sal da Bacia de Santos. Blog Fatos e Dados. Viewed in 28 de 07 de 2012. Available at: www.fatosedados.blogspot.com.br/2012/04/12/nova-descoberta-no-pre-sal-da-bacia-de-santos.

RAMIRO, Silvana (2012). Sistema Portuário Brasileiro é um dos mais lentos do mundo. Jornal da Globo. Viewed in 28 de 07 de 2012. Available at: www.g1.globo.com/jornal-da-globo/noticia/2012/08/sistema-portuario-brasileiro-e-um-dos-mais-lentos-do-mundo.html.