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ECONOMIC EVALUATION OF LOGISTICS INFRASTRUCTURE IN OIL INDUSTRY USING SIMULATION – JET FUEL SUPPLY CASE STUDY

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ABSTRACT

The main goal of this study was supporting economic evaluation by assessing which new projects will be necessary and when they should be operating in order to achieve the customer service level required under a scenario of fast growth in jet fuel demand at Guarulhos terminal. In order to achieve this objective, it was built a conceptual model, data were collected and computer based model was implemented. By comparing the system's performance under different terminal configurations, it's possible to choose the most economical solution that performs well in different scenarios. The analysis revealed that the current infrastructure allows achieving the customer service level required until 2018. In 2019, it will be necessary to provide a solution to increase the delivery flow rate by only spending a small fraction of the previously budgeted capital expenditure, while keeping system's performance.

1 INTRODUCTION

Oil and gas logistic infrastructure usually requires large capital expenditures and long term implementation. This supply chain deals with many products flowing in a continuous way, sharing resources like pipelines and storage tanks and involves stochastic variables such as flow rate, transit time and certification time. It results in a complex system. Designing an infrastructure to cope with market demand growth is a challenge that can be dealt with simulation techniques. Fioroni et al. (2013) and Cafaro et al. (2010) also applied simulation models on case studies about fuel supply chain.

This paper presents a simulation case study about jet fuel storage sizing at Guarulhos Terminal that supplies the two largest airports in Brazil, with jet fuel consumption of more than 200,000 cbm per month, which represents almost 40% of Brazilian market (Infraero, 2013). The main goal is supporting economic evaluation by assessing which new projects will be necessary and when they should be operating in order to achieve the customer service level required under a scenario of fast growth in jet fuel demand. By comparing the system's performance under different terminal configurations, it's possible to choose the most economical solution that performs well in different situations, considering capital expenditures constraints.

Guarulhos Terminal is located in São Paulo and stores gasoline, diesel and ethanol as well. It is supplied by multiproduct pipelines from where these products are pumped in batches. The terminal provides advanced storage and delivers automotive products to wholesales utilities nearby. Jet fuel is delivered by a short length pipeline to storage tanks in Guarulhos International Airport, which supply Guarulhos itself and other airports, like Congonhas, also in São Paulo.

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A simulation study comprises of different stages such as proposed by Harrel et al. (2013). These stages are further explained at the next section, devoted to methodology. Then, the problem and scope will be defined according to its goals and real system will be described. The following section translate the problem into a diagram that contains business rules and indicates which resources and entities should be represented and how they would be represented in a simulation model by using IDEF-SIM, a conceptual model technique proposed by Montevechi et al. (2010). Once finished conceptual modeling, the next section presents computational modeling and discusses simplifications adopted to represent a real continuous process into a discrete event simulation model. It is also necessary to develop pipeline scheduling algorithms that emulate real decision by logistics planners. Validation was done by comparing model's performance using historical input data against terminal historical performance. These results were also submitted to approval by operational team. Then, case study's results are presented.

2 METHODOLOGY

According to Balci (1990), the determination of a solution technique is an important step in the study of a given problem. According to Ingalls (2013), simulation is a suitable approach to consider the dynamics of a real system. In the case of investment decision in logistics infrastructure to service the aviation fuel market, discrete event simulation was considered the most appropriate tool for the study because the problem presents some variability in input data (such as the time of certification of tanks) and there is interdependence between the different products, since they share the same entrance pipeline at the terminal.

A simulation study is not only composed of a computational model. It should be based on the problem (Balci, 1990). According to Harrell et al. (2013) some steps should be considered: defining the problem and setting objectives, model planning and formulation, including data collection and model development, validation, testing, analysis and documentation of results.

In formulating the problem, a conceptual model was built using the IDEF-SIM technique. Then, significant time was spent in data collection and data analysis. The company has a database with a large volume of information, which, in a way, turns the information collection easier. However, it is necessary to process the collected data and analyze the information quality. During this stage, it was possible to make some inferences about real system's behavior.

To build the computational model, it was used ProModel@ (www.promodel.com), which is already used in simulation studies at the company. Three models were built with some logical differences and different goals.

The first model (considering 2012 historical data and process) was built to validate the process logic. As model input, the data obtained in the company database were replicated: scheduling entry was inserted into the model exactly as happened in reality. After validation of the processes within the computational model, a second model was constructed.

In the second model (considering 2013 historical data and process), some rules and data have been updated. Furthermore, the main feature added was a scheduling algorithm, which simulates the planner's decision. With these changes, the model can be used not only for making long-term analysis of infrastructure investments, but also used in most operational decisions, such as lot sizing scheduling.

Finally, it was built a third model, in which we considered the business rules and logic of the second one. Demand entered into the model was informed by commercial forecast area. This model aims to make the analysis of investment projects in infrastructure by 2020. Moreover, as already mentioned, the model can be used as support for test batch scheduling in the short term.

According to Sargent (2013), the validation of a computational model is an important step in a simulation study. The author defines validation as proof that a computational model has accuracy consistent with the intended application. All models were verified and validated by different areas of the company involved in this project: the short-term planning area, terminal operation, commercial, and logistics studies area.

Additionally, Sargent (2013) presents some procedures for validating a model. In this study, the conceptual model was validated with the stakeholders and the computational model was validated by observing the system's behavior (through the model animation) and by comparing the results' model against those from the real system, for the years 2012 and 2013, such as volume of jet fuel and diesel delivered, customer service level, tanks turnover ratio and pipelines utilization.

It was designed experiments to run in the third model, considering different scenarios of demand forecast (from 2014 to 2020); increasing in pipelines pump rate; tanks in maintenance, unavailable for operation; reduction of certification time, that can be obtained with the purchase of equipment for the terminal laboratory.

With these experiments, it was possible to evaluate the terminal ability to cope with regional market growth and define the projects that are necessary to ensure fuel delivery.

3 PROBLEM

This case study is about supplying Guarulhos International Airport through Guarulhos Terminal. Guarulhos Airport is the largest one in the country by many criteria, including: number of flights, passengers and, mainly, by jet fuel consumption. Three wholesale companies operate at Guarulhos. Together, they have storage tanks that have a total operational capacity of 32,000 cbm (not considered at the model). They supply the airport itself, but also supply Congonhas airport, the second largest airport by the aforementioned criteria. The total jet fuel's consumption at these airports amounts over 200,000 cbm per month. Figure 1 shows the jet fuel supply logistics to Guarulhos Airport and the simulation model scope.

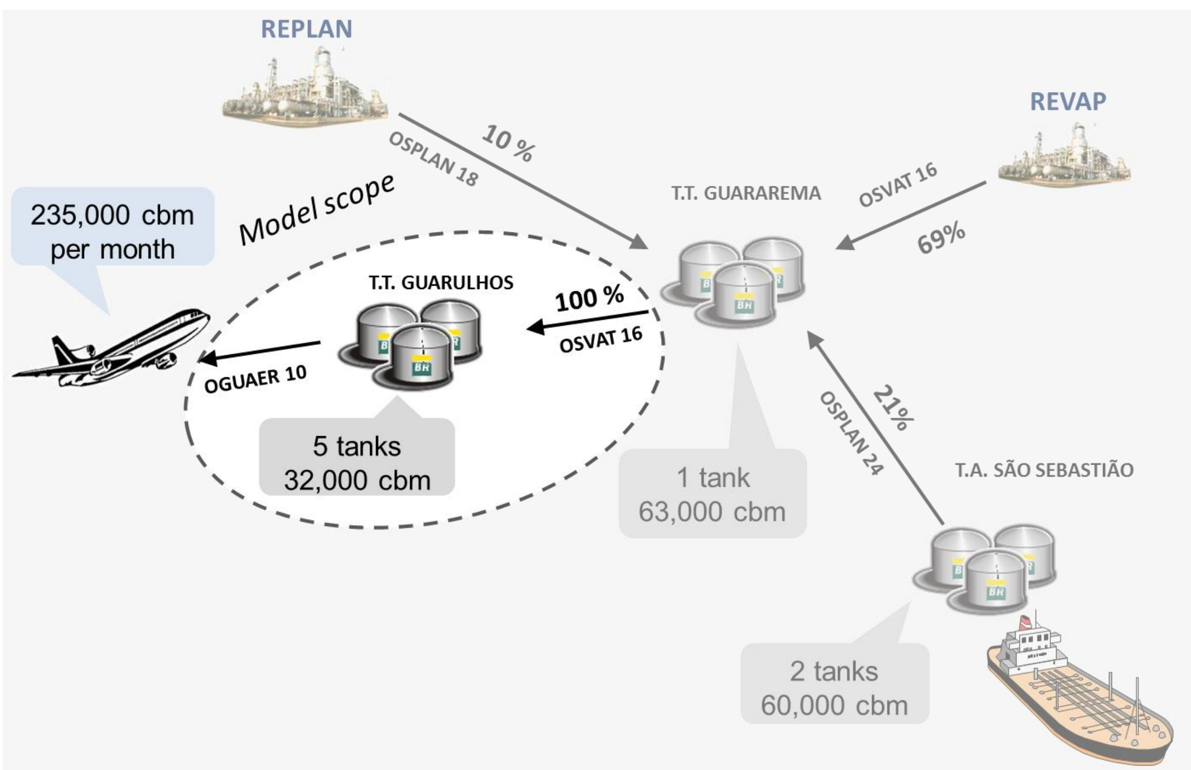

Figure 1: The jet fuel supply logistics to Guarulhos Airport.

Considering the objective of assessing the required investments at Guarulhos Terminal, the model scope (according to figure 1) included a detailed representation of its operations. This terminal receives jet fuel and two grades of diesel by pipeline, stores and sends it by pipeline to wholesale facilities. For the sake of the model simplicity, the supply chain upstream and downstream were discarded, since there`s a strong dependence among products operations originated at or destined to other refineries and terminals, which would soar the number of entities. Downstream operations were not considered because historical input data and business rules by different wholesalers were not available.

Guarulhos facilities at the airport are supplied by a pipeline that pumps product from Guarulhos Terminal at a 480 cbm/h rate (average flow rate). This pipeline has a 10 in. diameter and could pump at a higher rate provided there were investments to upgrade pumping system as a whole, what means exchange valves, filters and pumps.

Guarulhos Terminal operates gasoline, ethanol and two grades of diesel as well, whose supply is dependent on jet fuel`s operation. There are 5 tanks to store jet fuel, 4 tanks to low sulfur diesel and 2 tanks to high sulfur diesel. These tanks are supplied by a multiproduct pipeline, called OSVAT 16, which operates with low sulfur and high sulfur diesel, beyond jet fuel. OSVAT 16 has 16 in. diameter and a 650 cbm/h pumping rate (average flow rate). This rate could also be increased by upgrading pumping system. This pipeline scheduling is done by considering the availability of products at origin facilities (REPLAN, Guararema, São Sebastião or REVAP), availability of space at destination tanks at Guarulhos, pipeline transit time, pipeline inventory and the order of batches. The simulation model developed to this case study includes a scheduling pipeline algorithm that will be further explained at the computational model section.

Considering jet fuel's demand expected growth, it was suggested the building of an additional tank with 15,000 cbm of capacity. As demand increased, storage turnover ratio was increasing at a fast pace, when compared to other products and terminals, and there was concerns whether Guarulhos Terminal was able to maintain customer service level to such important airports. Although turnover ratio was high, logistics planners were not sure if it was close to the upper limit. Moreover, there was a clue about the terminal's bottleneck, but there were no consensus about how it moved through supply chain and which projects should be deployed to cope with increasing demand. Besides, no one could identify the effects of interdependence among operations of different fuels in the future.

So it was developed a simulation model to assess if it was necessary to:

- Build new storage tanks to jet fuel;
- Upgrade inbound and/or outbound pumping system in order to increase pumping rate;
- Identify and evaluate improvements at the process, trying to reduce downtime at tank cycle time;
- Assess the impact of buying new equipment for product certification analysis at the terminal's operational performance;
- Evaluate effects of interdependence of operations among different grades and fuels.

4 CONCEPTUAL MODELING

According to Robinson (2013), the process of abstracting a model from part of the real world it represents ('the real system') is known as conceptual modeling; in other words, choosing what should be and what shouldn't be included in the model. According to the same author, a conceptual model includes the objectives, inputs, outputs, content, assumptions and simplifications of the model. In this work, the conceptual model was built using IDEF-SIM. According to Montevechi et al. (2010), the IDEF-SIM technique has been developed with focus on simulation and its main characteristic is the suitability of its application logic with the one used in discrete event simulation, which will make the stage of computational modeling easier. Figure 2 presents the simulation conceptual model used in this application.

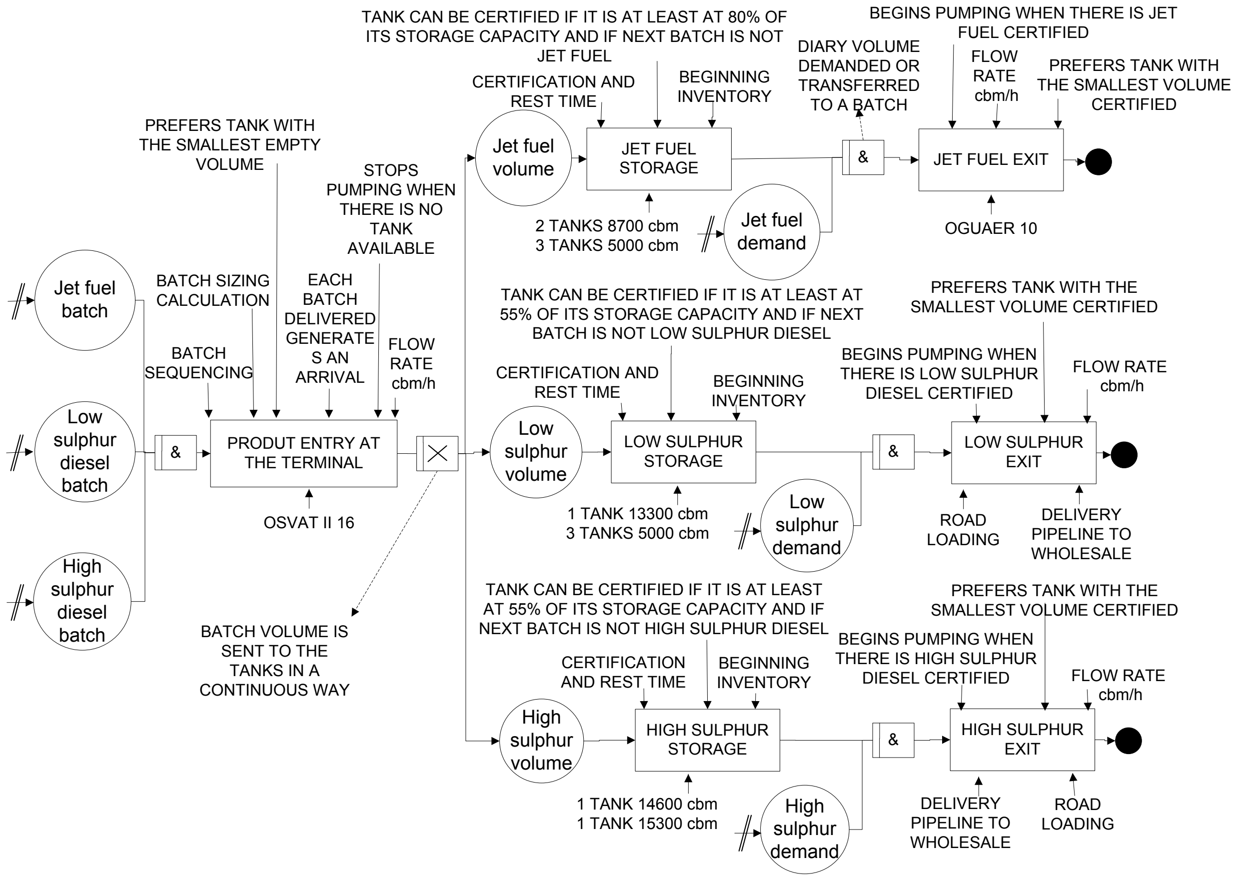

Figure 2: Simulation conceptual model.

The conceptual model can be described as follows. The model trigger is marked by two simultaneous events: product batches (low sulfur diesel, high sulfur diesel and jet fuel) arrive in the input pipeline and the daily demands for these products arrive in the output pipelines (these demands pull the logistic system). Each product batch that leaves the input pipeline generates a new arrival in the input pipeline. The product batch volume is calculated by the simulation model at the time of its arrival in the input pipeline (the batch size is a function of the destination tank empty space and the market consumption rate). In the input pipeline, batches must respect a scheduling rule to avoid product quality loss (batches of low sulfur diesel must be between two batches of high sulfur diesel) and the input pipeline pump rate, which is a stochastic variable. When a product batch reaches the input pipeline's end the model checks if there is any available tank to receive the volume. If there are several tanks, the priority is the tank which has the smallest empty space. If there are no available tanks, the input pipeline pumping is stopped until there is some available tank. A tank is available to receive product when its status is empty, filling or certified (only for high sulfur diesel). On the other hand, it is not available when it is full or emptying. In the tanks, the product follows a processing cycle (figure 3): filling (red line), tank draining (green line), certifying operation of the product's quality (yellow line), delays because it's waiting the order of emptying (purple line), and emptying (blue line). The tank storage capacities were considered as the volume that can be moved, excluding the ballast volume. Certification times from each tank are also stochastic variables.

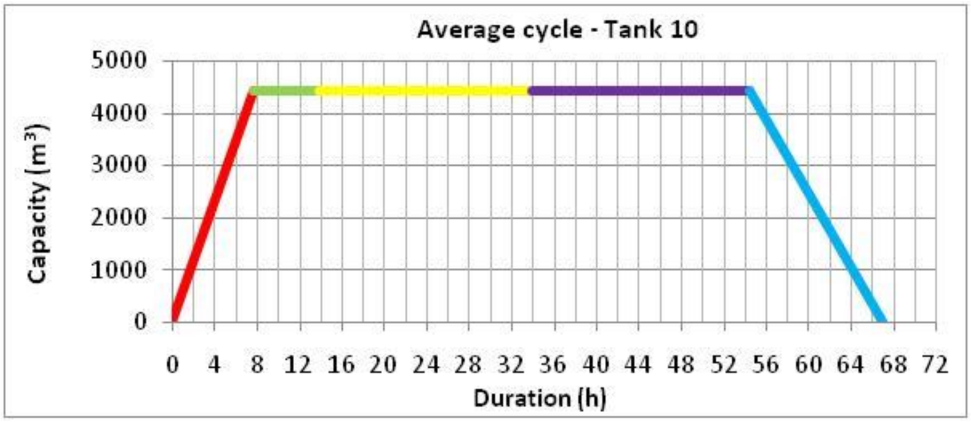

Figure 3: Jet fuel processing cycle times.

After an available tank is chosen to be filled, the product volume contained in a product batch is transferred continuously to a tank. The inventory level in every storage tank is modeled as a continuous variable. After the batch transfer, the model checks whether the tank is filled with more than 80% of its storage capacity (diesel is 55%). If the next product batch contains the same product, then continues filling up to operational capacity. Otherwise the tank starts the certification process, even without completing the tank capacity. Only tanks with certified product can send to the client. The emptying priority is the tank that has the lowest certified product volume. The output pump rate is another stochastic variable. The model ends when each market demand meets the corresponding certified product volume.

The primary simulation model's performance indicator is fill rate, which is the ratio between certified product delivered and demand, as percentage. If there is not enough certificated product to fill a day's demand, next day the difference between last day's demand and volume delivered will be attended with delay. Other important indicators are pumping stops frequency due to tanks unavailability, average inventory, lots size, utilization ratio of pipelines and tankage turnover ratio.

The scope of this model does not contain the infrastructure of the client terminal, assuming that the client is capable of receiving the daily demand, requested by him. Likewise, the model assumes that there is product available to form the batch at the origin terminal. Another simplification is that product loss by interface between batches is not considered.

Conceptual model's validation was performed by engineers and programmers. As the knowledge about the real system being simulated increased, the conceptual model was modified during the development work.

The conceptual model addressed the gathering of input data. The database now has the record of the volume of each batch that entered the terminal in the last year and its duration. Thus, the mean flow rate of each batch were calculated and adjusted to a probability distribution. The same procedure was performed to output flow rates for each product and time to rest and certification for each tank (Figure 3). In total, there were 16 probabilistic variables (associated with each feature of the conceptual model). Other data collected were: the prediction of daily demand for each product for 2014, operational capabilities and initial inventory for each tank.

Collection and analysis of input data enabled the project team to question the functioning of some operations. For example, Figure 3 shows that after the product to be certified there is a delay before the product is shipped to the customer. Part of this time delay is intrinsic to the process, since there are five jet fuel tanks and a single pipeline for input and another for output. However, part of this waiting time is caused by failure of pumping to the client due to its lack of storage space.

When analyzing histograms of the volume of certified products in each cycle to each tanks of aviation fuel and their respective operating volumes, it was verified that there are many cycles where the tank is not completely filled before the start of the certification process. This information was useful to establish the minimum volume of jet fuel in a tank before it can be certified.

With the conceptual model and input data collection was possible to construct the computational model. Moreover, this conceptual model allowed the organization operational knowledge about the real system while performing an audit of existing processes.

5 COMPUTATIONAL MODEL

The computational model was built in ProModel, approved and widely used software in the company. The models built in this project work with approximately 40 control variables; 30 subroutines logical; 10 arrays of input and output data and 1300 lines of programmed logic. Throughout the study, the models were built in several versions with increasing complexity and detail.

The conceptual model developed by the IDEF-SIM was the basis for the computational model construction. This methodology has accelerated the construction in software and assisted the validation process.

Some variables were used as displays in the simulation screen, along with the ProModel's animation, in order to assist verification and validation process of computational model, as can be observed in figure 4. Also, some software's functions helped in model's validation.

Figure 4: Computational model performance indicators.

The horizon planning in the model is one year, parameterized according to the year studied (2012 to 2020). The demand for each product varies with the year studied. The definition of simulation year and other input data can be changed through a MS Excel worksheet, which interfaces with the model (Figure 5). Some changeable data are: certification time; pipeline pump rate; activation and maintenance of tanks.

The model's scope considers only the intra-logistics at Guarulhos terminal: input pipeline, tanks and output pipelines. The Guararema terminal's tanks (that send products to Guarulhos) and the client tanks were not considered in this model. Thus, it is considered that there will always be available products to supply Guarulhos terminal and the customer will always have free tanks to store product.

In the simulation model, the products are initially considered discretely in batches. This is how the products enter the pipeline. However, the transfer of liquids has a continuous characteristic which must be represented. As in previous works (Limoeiro et al., 2008 and Limoeiro et al., 2010), a technique called pseudo-continuous simulation was used. In this approach, a series of hourly discrete events associated with the flow rate emulate the continuous transfer of liquids. These continuous transfers are still associated with discrete events, such as tanks become empty or a batch arrives. It is necessary to let these different operations communicate.

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SIMULATION MODELLING OF LOGISTICS INFRASTRUCTURE - JET FUEL SUPPLY IN GUARULHOS TERMINAL

TANKS

TANK	CAP. (M3)	ACTIVATE?
6º TANK	15.000	YES
7º TANK	15.000	NO

TANKS IN MAINTENANCE

JET FUEL	MAINTENANCE?
TANK 10	NO
TANK 11	NO
TANK 12	NO
TANK 13	NO
TANK 14	NO
HIGH SULFUR DIESEL	**MAINTENANCE?**
TANK 02	YES
TANK 16	NÃO
LOW SULFUR DIESEL	**MAINTENANCE?**
TANK 03	NO
TANK 04	YES
TANK 05	NO
TANK 06	NO

CERTIFICATION TIME

TANK	PRODUCT	TIME (H)
T10	JET FUEL	26, 8.94, 9., 61.8)
T11	JET FUEL	, 1.91, 11., 39.5)
T12	JET FUEL	5(4.43, 2.9, 3.93)
T13	JET FUEL	, 1.74, 10., 32.1)
T14	JET FUEL	32, 1.33, 9., 26.3)
6º Tanque	JET FUEL	T(15,21,23)
7º Tanque	JET FUEL	T(15,21,23)
T3	LS DIESEL	T(10,17,19)
T4	LS DIESEL	5(1.9, 4.71, 8.82)
T5	LS DIESEL	U(8.91, 5.91)
T6	LS DIESEL	5))-1.))**(1./1.64)
T2	HS DIESEL	5(2.1, 7.08, 28.7)
T16	HS DIESEL	5(2.1, 7.08, 28.7)

PIPELINE PUMP RATE

PIPELINE	PUMP RATE (M3/H)
INPUT	U(680,50)
OUTPUT JET FUEL	T(330,380,440)
OUTPUT LS DIESEL	U(350,50)
OUTPUT HS DIESEL 1	U(500,50)
OUTPUT HS DIESEL 2	T(420,530,650)

Year of Simulation	2020

ANNUAL DEMAND

YEAR	LS DIESEL	HS DIESEL	JET FUEL
2015	1778,79	2195,30	5944,20
2016	1868,38	2033,36	6387,88
2017	1827,68	1117,85	6318,40
2018	2416,04	1074,56	6671,60
2019	2583,73	958,87	7043,34
2020	2765,53	884,84	7295,18
2021	2859,15	836,92	7591,04
2022	3008,27	790,56	7798,94
2023	3115,64	727,45	7952,01
2024	3243,23	672,12	8179,57
2025	3369,89	615,33	8272,71
2026	3501,26	558,28	8464,21
2027	3615,82	508,39	8510,31
2028	3733,53	440,27	8641,35
2029	3838,64	392,73	8729,58

MONTHLY DEMAND

MONTH	LS DIESEL	HS DIESEL	JET FUEL
January	138,19	156,46	572,69
February	147,07	154,18	511,04
March	144,86	260,43	550,70
April	141,36	246,90	520,22
May	148,36	251,76	542,09
June	152,36	251,20	521,29
July	157,52	252,34	562,45
August	163,75	254,87	537,16
September	156,96	237,35	531,99
October	161,22	236,87	545,68
November	152,43	217,60	551,83
December	138,89	192,62	573,98

Figure 5: Excel worksheet of computational model input data.

When the products exit the pipeline, they are transferred to tanks continuously. To this end, the entity stores the attribute of the batch volume, which is used for pumping and filling the selected tank. When emptying the tanks, the product is continuously removed from the tank and then the product is processed in a batch (discrete logic) to be delivered to the customer.

From the year 2013, the computational model calculates the input lot size, considering the tank available volume and how long the batch will take to cross pipeline, according to the lots already scheduled. The sequence of batches at input pipeline is: jet fuel; high sulfur diesel; low sulfur diesel and high sulfur diesel. When a batch is transferred to the tanks, another lot of the same product is ordered at the beginning of pipeline. At this time, the volume to be moved is calculated according to the formula:

$$\text{lot sizing} = \text{available tank capacity} + \left(\frac{\text{daily demand}}{24\text{ hours}} \text{ x } \frac{\text{total volume of the pipeline}}{\text{input pump rate}}\right)$$

The volume is calculated using the available capacity in tanks and volume to be delivered until next batch being processed (considering the daily demand of the product and the time for the next batch to be processed).

After going through the pipeline, the model must define in which tank the product will be allocated. For jet fuel and low sulfur diesel, model checks between empty or filling tanks, which have less available capacity to stock this product. For high sulfur diesel, this logic is a bit more complex because, if necessary, the batch may be allocated to a tank with product already certified and with free space. If computational model does not find an available tank, the input pipeline stops.

A similar logic decides from which tank product will be taken to meet the demand. Among certified product tanks, it will be chosen the one that has a smaller volume. These rules allow filling and emptying tanks more quickly, which increases turnover ratio. Another implemented logic that is adopted to increase turnover ratio is to certify tanks that are not totally full. If tank has 80% of its capacity with product, it can be certified.

In figure 6 computational model's animation is presented. Ten replications for each scenario were run. One replication spent about five minutes to run for one year horizon.

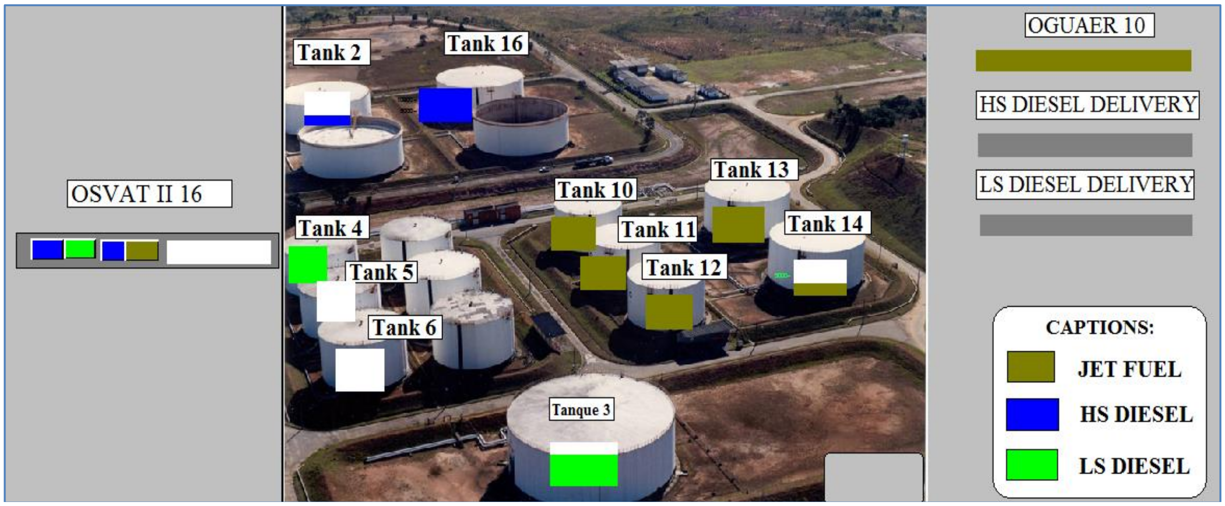

Figure 6: ProModel model animation.

6 RESULTS

First of all, the model with historical input data (2013) generated outputs similar to the historical terminal performance, especially if measured by customer service level. These results were approved by operational team experts. Therefore, the model was accepted and considered valid.

As there was already a basic project of a new tank for jet fuel storage at Guarulhos terminal, it was necessary to re-evaluate when the tank should be operational, considering an updated demand forecast and a reduced budget. Then, it was tested if the tank under evaluation was necessary in the horizon planning under these new assumptions. Table 1 displays the results from scenarios ran under current configuration, according to conceptual model.

The customer service level was fully achieved for all products from 2014 to 2020, without building any new storage tank for jet fuel. However, it also can be observed, in Table 1, that the delivery pipeline utilization is steadily increasing, exceeding 85% in 2019. For practical purposes, 85% is the operational limit for pipeline utilization considered at the company, since there are failures and other unpredictable events that can interrupt operation. Furthermore, it's necessary to rebuild inventory when these failures happen.

As previously mentioned at section 3, there are solutions to increase the delivery pipeline flow rate that demands low capital expenditures, such as exchanging current filters and valves. These solutions can increase flow rate from 480 cbm/h to 560 cbm/h (average flow rate). New scenarios were run for 2019 and 2020 considering 560 cbm/h flow rate. Under these conditions, the customer service level was achieved and the delivery pipeline utilization was under 70%. Additionally, for robustness purposes, it was checked if the same performance was achieved even if a storage tank for jet fuel was in maintenance for the entire year. Even at such a drawback scenario, the infrastructure kept the required customer service level.

Table 1. Results from scenarios considering current configuration of tanks and pipelines.

Key performance indicator		2014	2015	2016	2017	2018	2019	2020
Average inventory (m^3)	Low sulfur diesel	22780	22989	22897	23155	20402	20402	20445
	High sulfur diesel	16931	14890	15990	19088	19809	20780	21275
	Jet fuel	25045	26068	25795	26174	26000	23206	23114
Pipeline utilization	Entrance	78%	71%	73%	65%	72%	75%	77%
	Delivery - jet fuel	82%	75%	80%	79%	83%	88%	92%
Turnover ration (monthly high)	Low sulfur diesel	2,4	2,4	2,5	2,7	3,3	3,6	3,8
	High sulfur diesel	3,6	2,8	2,8	1,4	1,4	1,2	1,1
	Jet fuel	7,4	6,8	7,2	7,2	7,6	8,0	8,3
Entrance pipeline interruption	Number of stops	21	10	11	4	3	5	0
	Total time per year	63	14	11	2	3	4	0

It can also be observed at table 1 that the turnover ratio for high sulfur diesel is declining according to its declining demand, while average inventory is increasing by more than 25%. It makes possible to change storage tank allocation to distribute better storage capacity among products.

It was also verified the number of stops at the entrance pipeline due to lack of space in the destination tanks. Despite there were some interruptions, especially at experiments of early years, considering it's checked every hour, there were not many interruptions and they didn't last too long. So, it means that they can be avoided by operational team by relaxing any business rule considered as an assumption at the computational model or by taking some corrective actions.

7 CONCLUSION

The simulation study itself helps learning about the real system behavior. While developing the conceptual model and collecting data it was already possible to identify opportunities to improve the current infrastructure utilization, by achieving higher performance with limited budget. Besides, the conceptual model helped on process documentation.

After implementing the computer based model and running scenarios it was concluded that the new storage tank for jet fuel won't be necessary until 2020. By only spending a small fraction of the previously budgeted capital expenditure (CAPEX), with improvement in the current delivery pumping system, the customer service level can be achieved under the limits of pipeline utilization adopted by the company. Therefore, the use of simulation provided a CAPEX reduction while keeping system's performance. Furthermore, the model animation helps people comprehend systems behavior under future conditions and the effects of simulated scenarios.

Future works will be focused on risk analysis using this model under higher demand scenarios, on combining optimization with simulation to improve tank allocation, on replicating the same analysis to other similar terminals and on modeling the client terminal.

ACKNOWLEDGMENTS

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