Optimization of Bulk Liquid Storage in a Seaport Terminal

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A Windows-based computer program, consisting of input data and report interfaces and a mixed integer linear programming optimization model was developed to aid in the decision-making process regarding space allocation for bulk liquids at a Brazilian seaport terminals. The main results provide quantities of each type of bulk liquid to be stored into available tanks by time period as demanded by different clients.
Key words: mixed integer linear programming, bulk liquid storage.

Introduction

According to Codesp (2001), the Port of Santos has been leading Brazil's foreign trade seaport movements, of which 33% are accounted for the port. It has been considered the Latin America's biggest port, parallel to the most modern ports of the United States and Europe in what concerns cargo movement and proceedings. It has also performed the role of development agent for Brazil’s Southeastern region.

Within this context, several terminals are located, acting as Port Operators and providing handling services for bulk liquids in its facilities. Figure 1 shows a general view of those terminals, specialized in storing bulk liquids.

See Figure 1

One of these terminals (where this study was developed) is located at the Alemoa district, beside the Anchieta highway (which links Santos to São Paulo), and has a tank farm which adds up 72,000 CBM (approximately 453,000 brls) distributed in 86 tanks of several sizes. The tanks are built both in mild and stainless steel, occupying a total area of 60,000 sqm (over 23 square miles).

The terminal is linked to the Alemoa pier through 6 x 8" Ø pipelines boosted by an efficient pumping system. There are 3 berths, all able to receive ships up to 60,000 TDW. The truck loading area allows simultaneous operation of up to 20 vehicles per hour.

The terminal is also equipped with wastewater treatment and vapor emission control for all tanks. The terminal's facility is efficiently complemented by assets such as circulation areas, electronic truck scale, tank and pipeline manifold, shore tank to shore tank product transfer system, fire-fighting system, nitrogen purge and blanket for tanks and pipelines, as well as environmental protection systems including high-level alarm and closed circuit operations.

Most of its operations and administrative controls are computerized, offering quick feedback to the customers. However, the decision-making process regarding volume allocation for bulk liquids – even being considered very efficient - was still manual, depending on the experience from the engineers and operators of the terminal.

The movement of bulk liquids between the ships and the tanks demands high level of precision, safety and rapidity of the terminal, depending upon an efficient allocation planning. The tanks characteristics, such as their structure and coverage, their density to support a particular bulk liquid, compatibility with liquid previously stored, as well safety factors relating to inflammability risks in handling, transportation and storage operations, are some examples of binding constraints in such a decision process.

In view of that, a Windows-based computer program, consisting of input data and report interfaces and a mixed integer linear programming optimization model, was developed to aid in the decision-making process regarding volume allocation for bulk liquids at this specific Brazilian seaport terminal.

The mathematical model

A mixed integer linear programming was developed, taking into consideration different objective functions, all of them respecting a well defined set of constraints.

After a series of tests, taking into consideration different optimization approaches, the following seven objective functions were selected:

- objective function 1: minimization of unoccupied volume in the tanks to be used;
- objective function 2: minimization the number of tanks to be used;
- objective function 3: minimization of both previous objectives - unoccupied volume in the tanks to be used as well the number of tanks to be used;
- objective function 4: minimization of unoccupied volume in the tanks to be used, with the possibility of not splitting client requests into different tanks;
- objective function 5: minimization of unoccupied volume in the tanks to be used, but giving preference to the occupation of bigger tanks;
- objective function 6: minimization of unoccupied volume in the tanks to be used, but giving preference to the occupation of smaller tanks;
- objective function 7: minimization of unoccupied volume in the tanks to be used, but without splitting client requests into different tanks.

The following classes of constraints were considered in the optimization model:

- tank capacity by type of bulk liquid to be stored;
- uniqueness of each client request;
- tank structure and tank coverage characteristics;
- safety factors relating to inflammability risks;
- possibility of liquid transfers between tanks;
- compatibility with liquid previously stored in each tank of the terminal.

The main decision variables to be calculated are related to the proportion of the capacity of each tank to be allocated to each client request, by time period.

The mixed integer linear programming model, developed with GAMS language (Brooke et al., 1992), was incorporated into a Windows-based computer program, consisted of input data and report interfaces, written in Borland Delphi, version 5.0 (see examples of Windows in Appendix 1). The minimum hardware configuration needed to run the system could be approximated to a Pentium 233 MHz with 64 MB of RAM.

Application of the optimization system

The mathematical model was implemented in a specific seaport terminal, in Santos, Brazil. This terminal has 110 different tanks that can be rented for bulk liquid storage. To illustrate an application of the model, a case study was simulated with 12 tanks and 5 client requests, being the data utilized and the results obtained presented as follows.

- **Tank characteristics**

The volume capacities of the 12 tanks, as well their densities and construction material characteristics, are presented in Table 1.

See Table 1

- **Client requests**

The specifications of each of the five client requests considered, regarding type of bulk liquid, volume, density and construction material required, are presented in Table 2. Note that requests 4 and 5 are already stored at the terminal (in tanks 4 and 1, respectively), being subject to be transferred to some other tanks.

See Table 2

- **Results**

Five simulations were run, being simulations 1, 2 and 3 related to the case where the decision maker allocates the first three client requests – separately – to the 12 available tanks. The pertinent results for client requests 1, 2 and 3 are presented in Tables 3, 4 and 5, respectively.

Simulation 4 considers the first three client requests simultaneously, for the same available 12 tanks. It was also assumed that all the three client requests are expected for the same time period, which means that they cannot occupy the same volume in a certain tank within that time. Table 6 shows the obtaining results.

Finally, simulation 5 is an expansion of simulation 4, but treating all the five requests simultaneously, and considering the eventual transferences of requests 4 and 5. The corresponding results are presented in Table 7.

See Tables 3, 4, 5, 6 and 7

Discussion of the results

The simulations 1, 2 e 3 (Tables 3 to 5) confirm that the model could get an optimal solution, without violating any constraint. For instance:

- there were no conflicts between the sizes of the requests and the capacities of the selected tanks;

- from Table 5, the constraints related to tank structure and tank coverage characteristics were respected (only the Phosphoric Acid was allocated to tanks recovered with rubber – tanks 4, 8 and 12);
- only the requests 2 and 3 (Tables 4 and 5) had to be split into different tanks, once there was no single compatible tank that could store the whole request;
- in simulation 4, it was noticed that the optimal solutions were found for the simultaneous storage of the first three requests, exception made for the objective functions 4 and 7, which demanded no splitting requests (which was not possible due to the request 1, whose volume – 6650 m^3 of Ethyl Alcohol - would exceed the capacity of a single compatible tank);
- in simulation 5, it also can be noticed that the optimal solution respected all the constraints, including the possibility of liquid transfers between tanks (the Propionic Acid – 450 m^3 – which was originally stored in tank 4 - capacity of 2000 m^3 – was transferred to a smaller tank – tank 11, with a capacity of 800 m^3 – while the Toluene – 750 m^3 – originally in tank 1 – capacity of 2000 m^3 – was transferred to tank 6 – capacity of 800 m^3).

To compare the performance of the seven different objective functions in the five simulations, Table 8 shows the results obtained for a physical indicator, named “unoccupied volume”, which is the value related to the remaining unoccupied volume in the tanks that are actually used in the optimal solution.

See Table 8

It can be noticed that the objective functions 1 and 3 were the ones with the smallest values for “unoccupied volume” and, therefore, meaning the best results in terms of the actual occupation of the tanks. The consideration of not splitting client requests (objective functions 4 and 7); the reduction of the number of tanks to be used (objective function 2); the preference for bigger tanks (objective function 5) or to the smaller tanks (objective function 7) resulted in superior values of unoccupied volumes.

Concluding remarks

The computer program developed proved to be a useful tool for decisions regarding allocation of tanks for bulk liquid storage, at a specific Brazilian seaport terminal.

The possibility of choosing among seven different objective functions gave greater flexibility and confidence to the final user.

The use of mixed integer linear programming results together with the friendly interfaces that were developed, confirm the potential gains due to optimization associated with tank volume utilization and, consequently, greater profitability of seaport terminals.

References

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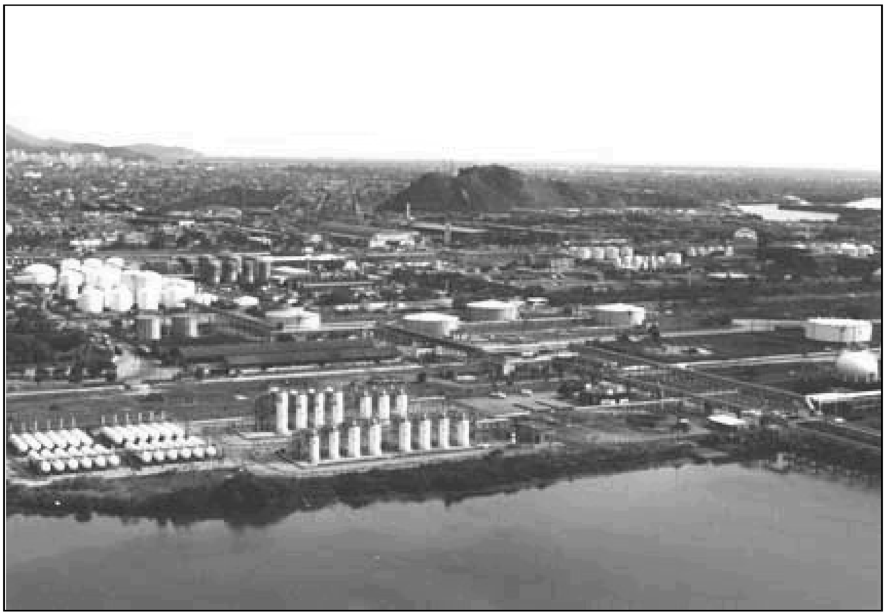

Figure 1 – General view of Port of Santos, with detail of the terminals specialized in storing bulk liquids (Source: Codesp, 2001)

Table 1 – Main characteristics of the tanks considered in the case study.

Tank	Capacity (m^3)	Construction material	Density (g/l)
1	2000	Carbon Steel	1.0
2	1800	Carbon Steel	1.0
3	2000	Inox Steel	1.0
4	2000	Carbon Steel recovered with rubber	2.0
5	1000	Carbon Steel	1.0
6	800	Carbon Steel	1.0
7	1000	Inox Steel	1.0
8	1000	Carbon Steel recovered with rubber	2.0
9	500	Carbon Steel	1.0
10	400	Carbon Steel	1.0
11	800	Inox Steel	1.0
12	500	Carbon Steel recovered with rubber	2.0

Table 2 – Client request specifications.

Request	Bulk liquid	Volume (m^3)	Density (g/l)	Construction material required
1	Ethyl Alcohol (Etal)	6650	0.8076	Carbon Steel, Inox Steel
2	Phosphoric Acid (PhoA)	1300	1.5841	Inox Steel, Carbon Steel recovered with rubber
3	Acetic Anhydride (AcA)	1650	1.0800	Inox Steel
4	Propionic Acid (ProA)*	450	0.9923	Inox Steel
5	Toluene (Tol)**	750	0.8658	Carbon Steel

* It is already stored in tank 4; subject to transference to another tank.
** It is already stored in tank 1; subject to transference to another tank.

Table 3 – Proportion of the tanks to be allocated to request no. 1 (simulation 1).

Tanks	Objective function						
	1	2	3	4	5	6	7
1	100%	100%	100%	-	100%		-
2	100%	100%		-	100%	100%	-
3		93%	98%	-	100%	18%	-
4				-			-
5				-	85%	100%	-
6	100%			-		100%	-
7	100%	100%	100%	-		100%	-
8				-			-
9	90%		100%	-		100%	-
10	100%		100%	-		100%	-
11			100%	-		100%	-
12				-			-

Table 4 – Proportion of the tanks to be allocated to request no. 2 (simulation 2).

Tanks	Objective function						
	1	2	3	4	5	6	7
1							
2							
3		83%		83%	83%		83%
4							
5							
6							
7	91%		93%		91%	93%	
8							
9							
10							
11	93%		90%		93%	90%	
12							

Table 5 – Proportion of the tanks to be allocated to request no. 3 (simulation 3).

Tanks	Objective function						
	1	2	3	4	5	6	7
1							
2							
3							
4		65%		65%	65%		65%
5							
6							
7						31%	
8	81%		81%				
9							
10							
11	62%		62%			62%	
12						100%	

Table 6 – Proportion of the tanks to be allocated to requests no. 1, 2 and 3 (simul. 4).

Tanks	Objective function						
	1	2	3	4	5	6	7
1	Etal 98%	Etal 93%	Etal 100%	-	Etal 100%	Etal 17%	-
2		Etal 100%		-	Etal 100%	Etal 100%	-
3	Etal 100%	Etal 100%	Etal 100%	-	Etal 100%	AcA 83%	-
4		PhoA 65%		-	PhoA 65%		-
5	Etal 100%	Etal 100%	Etal 100%	-	Etal 85%	Etal 100%	-
6	Etal 100%		Etal 100%	-		Etal 100%	-
7	AcA 93%	AcA 91%	AcA 93%	-	AcA 93%	Etal 100%	-
8	PhoA 80%		PhoA 80%	-		PhoA 65%	-
9	Etal 100%		Etal 100%	-		Etal 100%	-
10	Etal 100%		Etal 87%	-			-
11	AcA 90%	AcA 93%	AcA 90%	-	AcA 90%	Etal 100%	-
12	PhoA 100%		PhoA 100%	-		PhoA 100%	-

Table 7 – Proportion of the tanks to be allocated to requests no. 1, 2, 3, 4 and 5 (sim. 5).

Tanks	Objective function						
	1	2	3	4	5	6	7
1	Etal 100%	Etal 98%	Etal 100%	-	Etal 98%	Etal 100%	-
2	Etal 100%	Etal 100%	Etal 100%	-	Etal 100%	Etal 100%	-
3	AcA 82%	AcA 82%	AcA 82%	-	AcA 82%	AcA 82%	-
4		PhoA 65%		-	PhoA 65%		-
5	Etal 95%	Etal 100%	Etal 95%	-	Etal 100%	Etal 95%	-
6	Tol 94%	Tol 94%	Tol 94%	-	Tol 94%	Tol 94%	-
7	Etal 100%	Etal 100%	Etal 100%	-	Etal 100%	Etal 100%	-
8	PhoA 80%		PhoA 80%	-		PhoA 80%	-
9	AcA 100%	AcA 100%	AcA 100%	-	AcA 100%	AcA 100%	-
10	Etal 100%	Etal 100%	Etal 100%	-	Etal 100%	Etal 100%	-
11	ProA 56%	ProA 56%	ProA 56%	-	ProA 56%	ProA 56%	-
12	PhoA 100%		PhoA 100%	-		PhoA 100%	-

Table 8 - Unoccupied volume (m^3) in the tanks that are actually used in the optimal solution, for the five simulations.

Simulation	Objective function						
	1	2	3	4	5	6	7
1	50	150	50		150	1650	
2	17.4	202.7	17.4	202.7	202.7	17.4	202.7
3	192.8	700	192.8	700	700	308.9	700
4	267.4	867.4	267.4		867.4	2052.7	
5	852.7	1352.7	852.7		1352.7	852.7	