Bulk Liquid Storage Optimisation in a Seaport Terminal

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Abstract

A Windows-based computer program, using a mixed integer linear programming optimisation model was developed as a decision-making aid for bulk liquids volume allocation at a Brazilian seaport terminal. Seven objective functions were selected for the optimisation model, which also considered chemical and physical behavioural constraints such as: tank capacity by type of bulk liquid to be stored; type of client request; tank structure and tank coverage characteristics; safety factors such as inflammability risks; possibility of tank transfers and liquids compatibility. The decision variables related to the proportion of tank capacity allocated to each client by time period. Preliminary results confirm potential gains due to the optimisation of tank volume utilisation and improved seaport terminals profitability. Finally, friendly interfaces increase flexibility for the final user.
Key words: mixed integer linear programming, bulk liquid storage.

1. Introduction

According to Codesp (2001), the Port of Santos has been Brazil's leading foreign trade seaport, accounting for 33% of all trade. The Latin America's biggest port is comparable to the most modern ports in the United States and Europe in terms of cargo volumes and procedures. It is an economic development agent for Southeast Brazil. Several terminals operate as Port Operators and provide handling services for bulk liquids. Figure 1 provides a general view of such terminals.

This study was concerned with the Alemoa district terminal at the Anchieta highway (linking Santos to São Paulo with total capacity of 72,000 CBM (approximately 453,000 brls) distributed in 86 tanks of various sizes. The tanks are built using 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" 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 the simultaneous operation of up to 20 vehicles per hour.

The terminal is also equipped with wastewater treatment and vapour emission control for all tanks as well as other facilities such as circulation areas, electronic truck scales, tank and pipeline manifold, shore tank to shore tank product transfer system, fire-fighting system, nitrogen purge and blankets for tanks and pipelines and finally environmental protection systems including high-level alarm and closed circuit operations.

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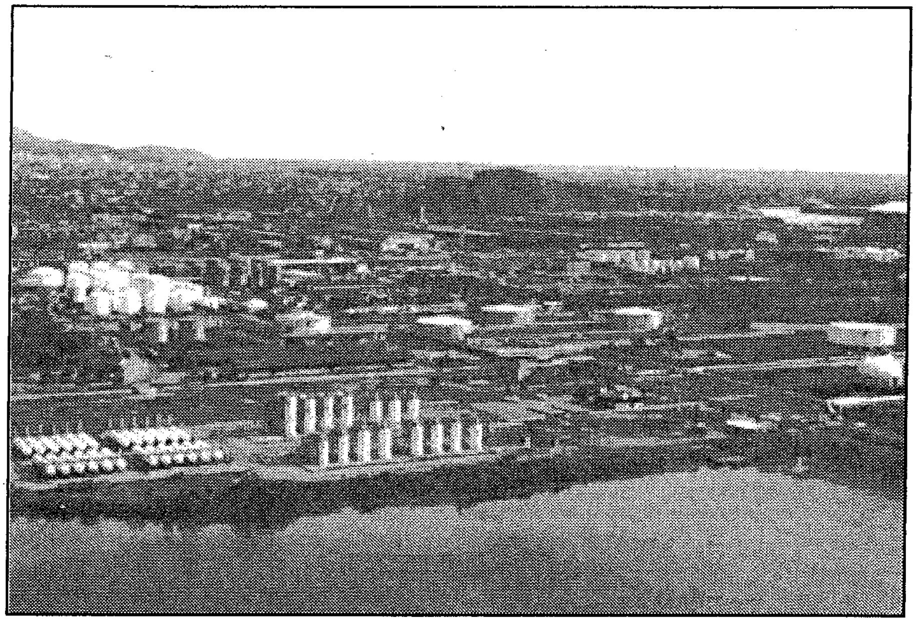

Figure 1. General view of Santos Port and Bulk Liquids Storage Terminals
[Source: Codesp, (2001)]

Most operations and administrative controls are computerised, offering quick feedback to customers. However volume allocation for bulk liquids although efficient was still done manually, relying on the experience of engineers and terminal operators. Bulk liquid transfers between ships and tanks demand high precision, safety and rapidity at the terminal, consequently requiring efficient allocation planning. Tank characteristics such as structure and coverage, density to support a particular bulk liquid, compatibility with previously stored liquids, as well as safety factors relating to inflammability risks in handling, transportation and storage operations, are examples of some of the binding constraints in such a decision process.

A Windows-based computer program, consisting of an input data base, report user interfaces and a mixed integer linear programming optimisation model was developed as a decision-making aid for bulk liquid volume allocation at that particular specific Brazilian seaport terminal.

2. The Mathematical Model

A mixed integer linear programming was developed considering many criteria for the objective function and a well-defined set of constraints. The following seven objective function criteria were selected from a longer list:

- Criterion 1: minimisation of tank unoccupied volume;
- Criterion 2: minimisation of total number of tanks used;
- Criterion 3: criteria 1 and 2 together;
- Criterion 4: minimisation of unoccupied tank volume in the tanks to be used without splitting client requests;
- Criterion 5: minimisation of unoccupied volume in the tanks to be used giving priority to bigger tanks;
- Criterion 6: minimisation of unoccupied tank volume in the tanks giving preference to smaller tanks;
- Criterion 7: minimisation of unoccupied tank volume in the tanks to be used without splitting client requests.

The following constraints were considered in the optimisation model:

- tank capacity by type of bulk liquid to be stored;
- 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.

Decision variables relates to the proportion of the tank capacity allocated to each client request by time period.

The mixed integer linear programming model, using GAMS (Brooke et al., 1992), was incorporated into a Windows-based computer program written in Borland Delphi, version 5.0 (examples provided in Appendix 1). Minimum hardware configuration to run the system is equivalent to a Pentium 233 MHz with 64 MB of RAM.

3. Application of the Optimisation System

The terminal under study has 110 different tanks that can be rented for bulk liquid storage. A case study was simulated using 12 tanks and 5 client requests, as described below. Tank capacities, densities and construction material characteristics are presented in Table 1.

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 1. Tank Characteristics in the Case Study.

Five client requests by 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.

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

Table 2. Client Request Specifications.

* Stored in tank 4, ** Stored in tank 1

3.1 Results for the Case Study

Five simulations were run, where simulations number 1, 2 and 3 consider the first three client requests – separately – and 12 available tanks. The results are presented in Tables 3, 4 and 5 below, respectively.

Simulation 4 considers the first three client requests simultaneously for the same 12 tanks. The three client requests cannot occupy the same volume in a tank at the same time. Results are shown on Table 6.

Finally, simulation 5 is an extension of simulation 4 which treats all five requests simultaneously, considering eventual transfers of requests 4 and 5. Results are presented in Table 7.

Tanks	Objective function criteria						
	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 3. Tank Volume Allocated to Request # 1 (Simulation 1).

Tanks	Objective function criteria						
	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 4. Tank Volume Allocated to Request # 2 (Simulation 2).

Tanks	Objective function criteria						
	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 5. Tank Volume Allocated to Request # 3 (Simulation 3).

Tanks	Objective function Criteria						
	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 6. Tank Volume Allocated to Requests # 1, 2 and 3 (Simulation 4).

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 7. Tank Volume Allocated to requests # 1, 2, 3, 4 and 5 (Simulation 5).

4. The Discussion of Results

Simulations 1, 2 & 3 show that the model can get an optimal solution without violating any constraint. There were no conflicts between requests and tank capacities and the constraints related to tank structure and tank coverage characteristics were respected (Phosphoric Acid was allocated to tanks 4, 8 and 12 which are recovered with rubber). Requests 2 and 3 were split among different tanks.

Simulation 4 found optimal solutions for simultaneous storage of the three first requests, except objective function criteria 4 and 7, which required no splitting. Note that request 1 of 6650 m^3 of Ethyl Alcohol exceeded the capacity of any single compatible tank. Simulation 5 found an optimal solution which respected all constraints, including liquid transfers between tanks. For instance, 450 m^3 of Propionic Acid originally stored in tank 4 with a capacity of 2000 m^3 were transferred to the smaller tank 11, with capacity of 800 m^3. Also 750 m^3 of Toluene originally in tank 1 with capacity of 2000 m^3 were transferred to tank 6 with capacity of 800 m^3.

Table 8 compares the results obtained for a physical indicator, named "unoccupied volume", obtained under each of the seven objective function criteria.

Simulation	Objective function Criteria						
	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	

Table 8. Unoccupied tank volume (m^3) for the Five Simulations.

Objective function criteria 1 and 3 had the smallest values for "unoccupied volume". Not splitting client requests (criteria 4 and 7); reduction of the number of tanks used (objective function 2); preference for bigger tanks (criteria 5) or smaller tanks (criteria 7) resulted in higher unoccupied tank volumes.

The computer program developed proved to be a useful tool for decision-making regarding tank allocation for bulk liquid storage at a selected Brazilian seaport terminal. Seven different objective function criteria provided the user with flexibility and confidence. User-friendly Interfaces for a mixed integer linear programming results in potential benefits due to better tank volume utilisation and, consequently, greater profitability of seaport terminals.

References

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Appendix 1. Windows Interfaces for the Bulk Liquid Storage Optimisation System