



## INTELLIGENT CONTROL OF OIL TRANSPORTATION IN A PIPELINE NETWORK BY GENETIC ALGORITHM AND SIMPLEX METHOD

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*Abstract: In this work one used a genetic algorithm and the Simplex Method to achieve the intelligent control of a pipeline network. The combination of these two mathematical modelling tools, genetic algorithm and linear programming, gave rise to near-optimal results in a short computational time. The approach was applied to a field case, the Entre-Lomas Pipeline Network, which is composed of 16 tanks and linked pumps, and 66 kilometers of pipelines transporting the production of more than 100 wells to a pre-processing plant. The goal was to obtain a constant flow rate at the plant inlet, as short-term fluctuations make difficult the plant control besides acting upon the stability of physical and chemical processes.*

**Keywords:** *Oil transport optimization, genetic algorithm, linear programming.*

### 1. INTRODUCTION

The Entre-Lomas Pipeline Network consists of more than 100 wells, 16 main storage tanks, 16 pumps and 66 kilometers of interconnected pipelines. There are various tank capacity, different pipe size and material, and distinct pump characteristics. The liquid produced by the wells, a mixture of oil and water, is directed to storage tanks, after a primary separation of the free gas. This liquid mixture is then pumped through the pipeline network to the pre-processing plant – PPP. In the PPP takes place the oil-water separation and the salt extraction, before directing the oil for sale (Manning 1993). The effectiveness of the two processes occurring within the PPP depends, as much as possible, on a constant inlet flow-rate.

The problem of controlling the Entre-Lomas Network to achieve a near constant oil flow rate at the PPP inlet is a typical optimization problem. A quick analysis of the

problem shows that modeling a full day (24 hours) operation of a simpler network, consisting of 10 tanks and linked pumps, will require the solution of 480 variables if a time step of 1/2 hour is taken. This clearly indicates that alternative methods have to be used if the reduction of the computational time and effort is a goal.

The approach herein adopted is a hybrid procedure (Sun 1997), in which the problem is decomposed into  $T$  sub-problems, the number of periods composing the total time interval. These  $T$  problems are then solved sequentially, from the first to the last interval, recursively. Each sub-problem is solved in two steps, establishing the pump status (switched on/off) and calculating the pump flow rate in case the pump is switched on, respectively. As the decision upon the pump status depends only on integer variables, the solution is achieved by a Genetic Algorithm - GA methodology (Goldberg 1989). The second step depends on continuous variables; hence a linear programming - LP procedure, the Simplex Method (Bazaraa 1990), was used.

## 2. PROBLEM PRESENTATION

Consider the existence of a petroleum production field, composed by a set of wells. The oil production is stocked in  $n$  tanks. A tank collects the oil produced by various wells and is linked to one pump. The pump supplies the necessary energy to transport the oil through the pipeline network to the pre-processing plant - PPP. The objective is to set up a pump-operation program in order to obtain, as much as possible, a constant flow rate of oil at the PPP inlet. The pump operation program is subjected to a set of constraints, such as the minimum/maximum inventory in the tank, the maximum pressure inside the pipe and the characteristics of the pump (curve of head versus flow rate).

In this scenario the well production is a constant input value, i.e., it is the oil flow rate fed into the tank. The analysis is performed for a time interval composed of periods, i.e., the number of sub-problems. There are two types of pumps linked with the tanks: constant speed and variable speed pumps. Therefore, there are two states for the constant speed pumps: on and off. The operation of a pump with speed control is represented by a variable that can assume values within the interval  $[0, 1]$ , where 1 represents the pump working at its maximum flowrate. The mathematical formulation follows:

$$\text{Minimize } \sum_{t=1}^T (y_1^t + y_2^t) \quad (1)$$

Subject to:

$$y_1^t + y_2^t = x_0^t - m \quad ; t = 1, \dots, T \quad (2)$$

$$x_j^t = \sum_{k \in I(j)} x_k^t \quad ; j = 0, \dots, n; \quad t = 1, \dots, T \quad (3)$$

$$p_j(x_j^t) = \varphi_j(x_j^t) \quad ; j \in L; \quad t = 1, \dots, T \quad (4)$$

$$x_i^t = \mu_i^t x_i^{\max} \quad ; i \in N; \quad t = 1, \dots, T \quad (5)$$

$$\mu_i^t x_i^t \leq x_i^{\max} \quad ; i \in C; \quad t = 1, \dots, T \quad (6)$$

$$v_i^{t+1} = v_i^t + z_i^t - x_i^t \quad ; t = 1, \dots, T; \quad i = 1, \dots, n \quad (7)$$

$$v_i^{\min} \leq v_i^t \leq v_i^{\max} \quad ; t = 1, \dots, T; \quad i = 1, \dots, n \quad (8)$$

$$p_j^t \leq p_j^{\max} \quad ; j \in L; \quad t = 1, \dots, T \quad (9)$$

$$\mu_i^t \in \{0,1\} \quad ; \quad t = 1, \dots, T \quad (10)$$

where:

- t, i, j : subscript denoting time, pump (or tank) and pipe, respectively.
- T : number of periods forming the total time interval.
- N : set of constant speed pumps.
- C : set of variable speed pumps.
- L : set of pipes forming the network.
- $y_1^t, y_2^t$  : surplus and deficit in regard to the desired mean flow m, respectively.
- $x_j^t$  : mean flow rate in line i during one period.
- $x_i^t$  : mean flow rate pumped from tank i during one period.
- $x_0^t$  : total inlet flow rate at PPP during one period.
- $v_i^t$  : inventory of tank i.
- $z_i^t$  : volume fed into the i tank during one period.
- m : desired flow rate.
- I(j) : set of pipes taking the flow into pipe j.
- $p_j(x_j^t)$  : pressure in pipe j when transporting the flowrate  $x_j^t$ .
- $\Phi_j(x_j^t)$  : function that returns the pressure in pipe j when transporting the  $x_j^t$  flowrate.
- $\mu_i^t$  : boolean variable indicating the state (on / off) of the i pump

The objective function, represented by Equation 1, minimizes the flow rate deviation in regard to the desired flow rate, which is obtained by Equation 2. Equation 3 gives the total flow rate in pipe j by summing up the flow rate of all pipes connected to it. The Equation 4 calculates the pressure (Pitts 1988, Bobok 1996) in a given pipe. Equations 5 and 6 express the operation of the constant and variable speed pumps, respectively. Equation 7 calculates recursively the tank inventory. Equations 8 and 9 impose lower and higher limits to the tank i inventory and a pressure limit for pipe j, respectively.

The optimal solution of such a large problem is rather difficult to achieve using any methodology of Mixed Integer Linear Optimization. Nevertheless, using heuristic methods one is able find quality sub-optimal solutions in a very short time.

### 3. PROPOSED METHODOLOGY

The proposed approach consists of a hybrid procedure, in which the problem is decomposed into T sub-problems, one for each time interval. These problems are then solved sequentially from the first to the last interval, recursively. Each sub-problem is solved in two steps. In the first step there is a decision upon the pumps that will be switched on during the actual period. The flow rate optimization during one period is performed in the second step. The first step procedures, or the *sub-problem of choice of pumps*, use a Genetic Algorithms - GA methodology (Michalewicz 1996), as only integer variables are involved. The variables of the second step, or the *sub-problem of pump dispatching*, are continuous and the solution uses Linear Programming - LP methodologies (Fang 1993).

#### 3.1 Sub-problem of choice of pumps

The decision upon the pumps scheduled to operate during a certain time interval is based on the following criteria:

1. Give a higher priority to tanks that are proportionally full;
2. Minimize the pressure in the pipes;
3. Calculate the flow rate in the network, balancing the branches;
4. Calculate, with minimum deviation, the desired flow rate at the PPP inlet.

The implementation of these criteria is as follow:

- i) Give a higher priority to tanks that are proportionally full: If, during one period, there is no flow rate from the tanks to the PPP, calculate the inventory in the tanks. The tanks with the greatest inventory will have the highest priority, taking into account the range of operation of 35% and 80%. The model forecasts the inventory for the next 2 hours.
- ii) Calculate the oil volume pumped during one period: The pumps without speed control will deliver the maximum flow rate. Pumps with speed control can deliver any flow rate up to its maximum flow rate (100% nominal speed).
- iii) Calculate the pressure along the pipeline: The pressure along the pipeline is calculated (Martinez 1993, Streeter 1996) supposing all the pumps are operating simultaneously.
- iv) Balance the flow between the branches: This balancing has been applied to the pipeline network owned by Petrolera Perez Companc S.A. Figure 1 is a schematics of this network. Two branches form most of the network. The first branch is the longest one: begins at 1EC and ends at the 6CB. There is a second branch, starting at the tank 4PB and finishing at 2CB. The rest of the pipeline network consists of three isolated lines that have a direct connection with the PPP. If too many pumps belonging to the same branch operate at the same time, an overload in the other branch will appear in a near future iteration. Once the flow rates from the tanks are known, one calculates the mean flow rate for that specific branch. With these results available, the algorithm chooses the pumps, keeping the flow provided by them as close as possible to the desired mean flow rate for that specific branch.

### **The Genetic Algorithm**

The approach used to select the pumps that should be turned on was based on Genetic Algorithm – GA. The GA relies on concepts derived from evolution and genetics (Holland 1975), such as mutation, crossover, chromosome, selection, adaptability, etc. In a GA, every solution is seen as an individual (Reis 1997), with its own genetic characteristics belonging to a certain population. Given a set of tentative solutions, only the better-adapted ones will be selected to reproduce – via crossover – and generate new individuals, thus perpetuating their genetic information. These new individuals tend to be better fitted than their parents, what leads to the conclusion that after several generations, the population will be composed of highly adapted individuals – high quality solutions – since the worse solutions were replaced during the evolutionary process. Mutation acts as a diversity increment agent because after some generations, the population tends to loose diversity with all solutions being very similar.

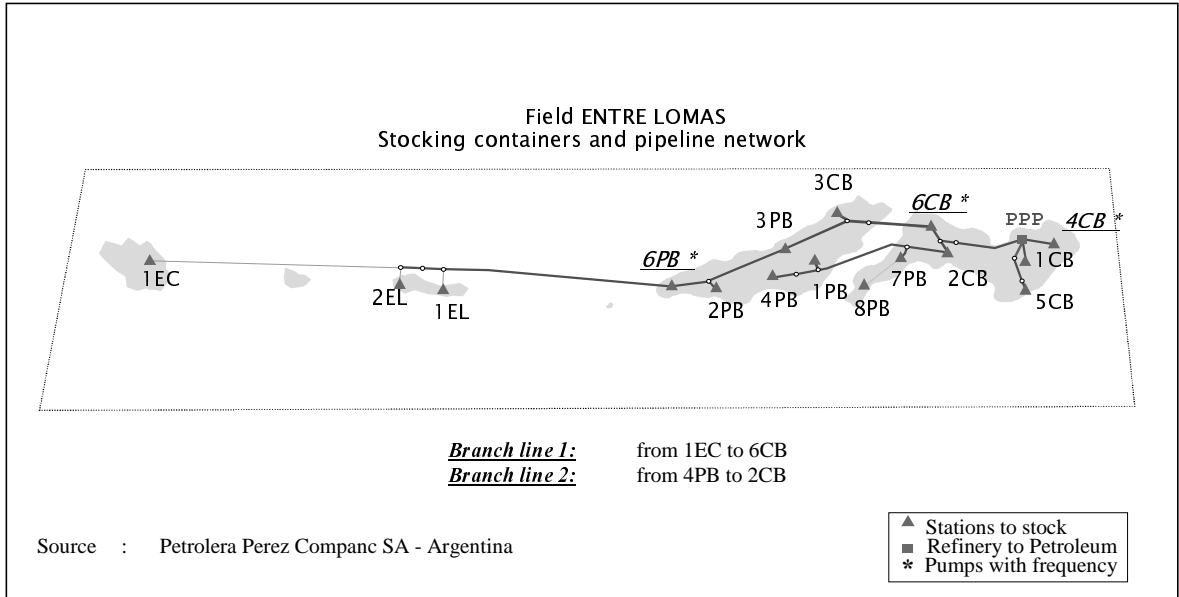


Figure 1: Pipeline network owned by Petrolera Perez Companc S.A - AR.

In the specific case studied in the present work, 16 tanks feed the network owned by Petrolera Perez Companc S.A. Therefore, one chose a vector with 16 elements to represent each individual where each position corresponds to a specific tank. If a specific position of the individual equals “1”, then the corresponding pump is selected to be on; conversely, if the position equals “0”, the pump is off.

The adaptability of the individual is related to the objective function of the problem that has to be optimized. The adaptability, or the fitness, must always be maximized. The adaptability is defined as:

$$f = \left( \alpha \cdot State_{OFF} + \beta \cdot Maxpressure + |M - TotalFlow| + \sum_j |goal\_path_j - flow\_path| \right)^{-1}$$

The first term of this function minimizes the tank inventory. The second represents the maximum pressure in the pipes. The third term is related to the mean flow to the pre-processing plant, obtained by the solution under evaluation. The last term balances the flow in the branches. The inversion in  $f$  is due to the fact that if all the terms are small, the individual is well and has a high fitness, and vice-versa.

### 3.2 Sub-problem of pump dispatching

The GA selects the pumps that will operate during one period. The total flow rate pumped by these selected pumps, however, it is not necessarily equal to the desired flow rate at the PPP inlet. Here comes the second step: the LP procedure to set up the operation of the selected pumps. As mentioned earlier, some pumps have speed control, others do not. Hence, one postulates that the pumps without speed control will work at their maximum capacity, to explore the flexibility inherent to the pumps with speed control. The LP procedure that establishes the pump dispatching policy during one period is given by:

$$\text{Minimize } y_1^t + y_2^t \quad (11)$$

Subject to:

$$y_1^t + y_2^t = x_0^t - M \quad (12)$$

$$x_j^t = \sum_{k \in I(j)} x_k^t ; j = 0, \dots, n \quad (13)$$

$$x_i^t = x_i^{\max} ; i \in N \quad (14)$$

$$x_i^{\min} \leq x_i^t \leq x_i^{\max} ; i \in C \quad (15)$$

Equation 14 fixes the maximum capacity of the pumps with no speed control. The Equation 15 sets the range of operation for the pumps with speed control. One should note that flexibility provided by the pumps with no speed control makes the deviation between the desired and calculated flow rate as small as possible. That means, the inventory of the tanks connect to pumps with speed control will act like slack variables, smoothing the deviation of the flow rate at the PPP inlet.

### 3.3 Overall procedure and implementation

The overall procedure that adds up the solution of every sub-problem over the time interval T is:

- 1) Read the data;
- 2) Do  $t = 1$ ;
- 3) Use GA to select the operating pumps;
- 4) Determine the dispatching policy using LP;
- 5) Update the volume of the tanks at the end of the period;
- 6) Do  $t = t + 1$ . If  $t = T$  then STOP, otherwise go to step 3.

The implementation of the GA used the C programming language (Weiss 1995). The LP problem used the computational package CPLEX (Cplex 1989-1994). To integrate both environments, the bridge linking the GA algorithm and CPLEX used procedures developed C. The GA algorithm run in 15 seconds for every period, executing around 500 generations. Then, the LP code optimized the flow in 5 more seconds, delivering high quality solutions, the deviation between calculated and desired flow rate always lesser than 5%. The computational environment was a G++ compiler (Stroustrup 1997), a Sparc IPX station, with 64MB of RAM memory, running SunOS 4.1.1.

## 4. RESULTS AND ANALYSIS

The results refer to the pipeline network depicted in Figure 1. The pumps that operate with speed control are connected with the tanks identified by 6PB, 6CB, and 4CB. Two scenarios have been studied, in terms of the period duration: ½ hour and 2 hours. The total time interval was 48 hours in both cases. In Table 1 there are the results for  $t = 1/2$  hour, Table 2 shows the results for  $t = 2$  hours. The first row indicates the period; the second, the calculated the percentage flow deviation related to the desired amount at the PPP inlet. The subsequent rows show the state of the pump and the tank inventory.

Note that the flow rate calculated by the GA is always greater than the desired flow rate, with a positive percentage deviation. This was due to the fact that the GA assumes the pumps with speed control driving its maximum flow rate. Afterwards, the LP adjusts these pumps to the desired flow rate.

The results in Tables 1 and 2 show that one achieved a constant flow rate in both scenarios, represented by a zero deviation of the LP flow compared to the desired flow. As one would expect, the second scenario showed greater fluctuation of the tank inventory, with limiting values ranging from 20% to 89%, in terms of the tank capacity.

Figure 2 shows the tank inventory histogram for both scenarios. For  $t = 1/2$  hour, the tank inventory always attended the security range, never surpassing 75% of the tank capacity. Most of them oscillated between 65% and 75%. For  $t = 2$  hours, there were some tanks surpassing 85% capacity, but most of them laying between 50% and 85%.

Focussing on the tank inventory fluctuation, the best results were achieved for  $t = 1/2$  hour. However, this meant a greater number of pump starts-ups, which have implications on equipment life, maintenance costs and energy consumption. Thus, one should search for a trade-off between high inventory and equipment depreciation when deciding upon the period of operation.

The graphic shown in Figure 3 reveals the relation between pump start-ups and the tank inventory, in terms of its maximum volume. In this plot appear the solutions for  $t = 1/2$  hour, 1 hour, 1 1/2 hour and 2 hours. The total time interval was fixed in 48 hours for all cases.

Table 1: Solutions for a 1/2 hour period.

1/2h	interval	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
Feed flow	LP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	GA	12	5,7	6,8	3,4	1,7	5,7	33	11	1,7	2,3	1,1	18	3,4	1,7	16	1,7	24	1,7	18	1,7	1,1	1,7	1,7	13
4PB	pump	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	0
	volume	62	61	59	64	62	61	59	64	62	61	59	64	62	61	59	64	62	61	59	57	62	61	59	64
1PB	pump	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	0
	volume	69	72	71	70	69	72	71	70	69	72	71	70	69	72	71	70	69	69	71	70	69	69	68	70
7PB	pump	0	0	1	0	1	0	0	1	0	0	1	0	1	1	0	1	0	1	1	0	0	0	0	0
	volume	69	70	69	69	69	69	70	69	69	70	69	70	69	68	69	68	68	67	66	67	68	68	69	69
2CB	pump	1	0	1	1	1	0	1	1	0	1	1	1	1	0	1	1	1	1	1	0	1	1	0	1
	volume	42	53	49	45	40	51	47	43	54	50	45	41	52	48	43	55	50	46	41	53	48	44	55	51
5CB	pump	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	0	1	1
	volume	42	40	39	45	43	41	40	38	44	42	41	39	37	43	42	40	38	44	43	41	39	45	44	42
1CB	pump	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	0	1	1	1
	volume	45	41	37	34	48	44	40	37	33	47	43	40	36	32	46	43	39	35	32	46	42	39	35	31
4CB	pump	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1
	volume	70	69	72	72	71	70	73	72	72	71	70	70	69	72	71	70	72	71	70	69	72	72	71	70
6CB	pump	1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	0	1	0	1	1	0	1	0	1
	volume	70	68	71	69	73	70	68	72	70	67	71	68	72	70	67	71	68	72	70	67	71	68	72	70
3CB	pump	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1
	volume	45	45	44	43	43	42	41	40	40	39	46	46	45	44	44	43	42	41	41	40	39	47	46	45
3PB	pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	volume	65	65	66	66	66	66	66	66	67	67	67	67	67	67	68	68	68	68	68	68	69	69	69	69
2PB	pump	0	0	1	1	1	0	1	1	0	1	1	0	1	1	1	1	0	1	0	1	1	1	1	0
	volume	69	70	70	69	69	70	70	69	70	70	69	71	70	70	69	68	70	69	71	70	70	69	68	70
6PB	pump	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	volume	67	67	67	66	65	65	67	68	67	66	65	67	67	65	67	66	69	68	70	69	68	67	66	67
1EL	pump	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1
	volume	70	70	69	73	72	71	70	70	69	73	72	72	71	70	70	69	73	72	72	71	70	70	69	69
2EL	pump	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	1	0	0	1	1	1	0
	volume	69	70	68	69	69	70	68	69	67	68	68	69	67	68	68	67	67	66	66	67	65	64	62	63
1EC	pump	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1	1	1	0	1	1	0	1	1	1
	volume	71	70	69	72	72	71	70	69	68	71	70	69	72	72	71	70	69	68	71	70	69	72	72	71
8PB	pump	0	0	0	1	1	0	0	1	0	0	1	0	1	0	1	1	0	0	0	1	1	0	0	0
	Volume	69	69	70	69	68	69	70	69	69	70	69	70	69	70	69	68	68	69	70	69	68	69	69	70

## 5. CONCLUSION

The use of a mixed approach, Genetic Algorithm - GA and Linear Programming - LP, to optimize the operation of oil pipeline networks showed to be a powerful tool. To test the procedures one analyzed a field case, the Entre-Lomas Network, which is composed of 16 tanks and linked pumps, and 66 kilometers of pipelines transporting the production of more than 100 wells to a pre-processing plant. The GA selected the pumps that should be switched on every period and the LP solved the pump dispatching policy. The combination of GA and LP made possible the decomposition of a rather complex problem in sub-problems. The goal was to obtain a constant flow rate at the plant inlet. Oil flow rates with minimum fluctuation, lesser than 5% of the desired one, at the inlet of a pre-processing plant, has been achieved in a very short time, about 20 seconds for every period composing the total time interval under analysis.

Table 2: Solutions for a 2-hour period.

2h	interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Feed flow	LP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	GA	1,7	16	10	1,7	1,1	2,3	1,7	1,7	34	1,7	1,1	24	1,7	1,7	15	24	10	1,7	3,4	16	2,3	1,7	5,1	1,7
4PB	pump	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	0	1
	volume	57	78	71	64	57	51	71	64	57	78	71	64	57	78	71	64	57	51	71	64	57	51	71	64
1PB	pump	1	0	1	1	1	1	0	1	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0
	volume	61	70	67	64	61	58	67	64	73	70	67	76	73	70	67	76	73	70	67	76	73	70	67	76
7PB	pump	1	1	0	1	0	0	1	0	0	1	1	0	1	1	0	0	0	1	0	0	0	0	0	0
	volume	61	57	60	56	58	61	57	60	62	58	55	57	54	50	52	55	57	54	56	58	61	63	66	68
2CB	pump	1	1	0	1	1	0	1	1	1	0	1	1	1	0	1	1	0	1	1	1	0	1	1	0
	volume	47	30	75	57	40	85	67	50	32	77	60	42	25	70	52	35	80	62	45	27	72	55	37	82
5CB	pump	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	0	1	1	1	1	0
	volume	58	51	44	37	62	55	48	41	35	28	52	45	39	32	56	50	43	36	60	54	47	40	33	58
1CB	pump	1	1	1	0	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	1
	volume	50	35	20	76	62	47	32	89	74	59	45	30	86	71	57	42	28	84	69	54	40	25	81	67
4CB	pump	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
	volume	77	75	74	72	69	82	80	77	84	81	79	80	77	76	74	76	75	73	70	68	81	79	76	74
6CB	pump	0	1	1	0	1	1	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	1	1
	volume	79	74	69	84	75	67	82	74	76	67	82	77	69	83	79	74	69	83	76	71	63	78	72	64
3CB	pump	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1
	volume	61	59	56	53	50	47	45	42	39	68	66	63	60	57	54	52	49	46	43	40	38	67	64	61
3PB	pump	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	volume	65	66	66	67	68	68	69	70	48	49	50	50	51	52	52	53	54	54	55	55	56	57	57	36
2PB	pump	0	1	0	1	1	1	1	1	0	0	1	1	0	1	1	1	0	1	1	0	1	1	1	0
	volume	70	68	74	72	69	67	64	62	68	74	72	69	75	73	70	68	74	72	69	75	73	70	68	74
6PB	pump	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
	volume	60	64	63	58	68	63	58	68	79	74	68	77	72	66	70	79	78	73	68	72	67	62	58	68
1EL	pump	1	0	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1
	volume	62	75	73	71	69	82	80	78	75	73	71	69	82	80	78	75	73	71	69	82	80	78	75	73
2EL	pump	1	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0
	volume	59	61	63	65	59	61	63	57	59	53	55	57	59	53	55	57	59	61	63	65	67	61	63	57
1EC	pump	0	1	1	1	1	1	0	1	0	1	1	1	0	1	1	1	1	1	0	1	1	0	1	1
	volume	76	73	69	66	63	59	71	68	80	76	73	69	81	78	75	71	68	64	76	73	69	81	78	75
8PB	pump	1	0	0	1	0	1	1	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	1
	volume	60	63	67	62	65	61	57	53	56	52	55	58	61	57	60	63	67	62	65	69	72	68	71	67



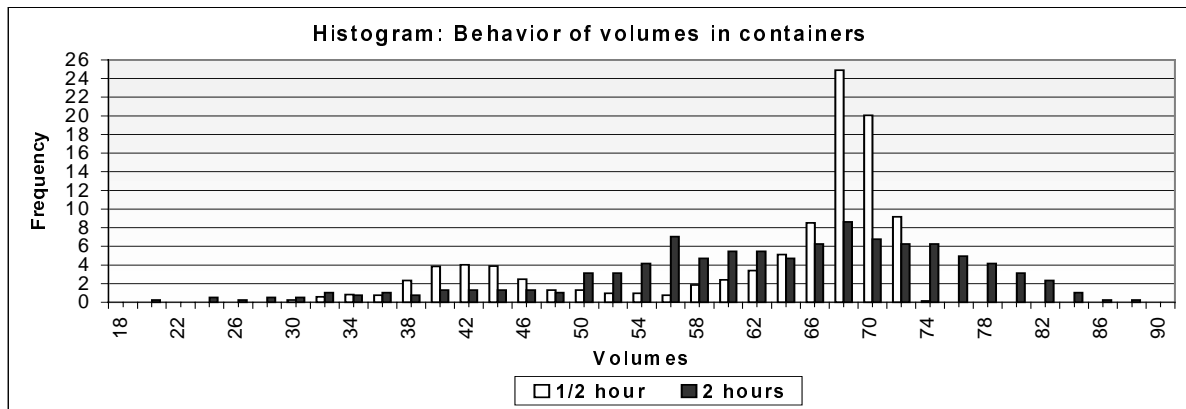


Figure 2: Histogram of the tank inventory

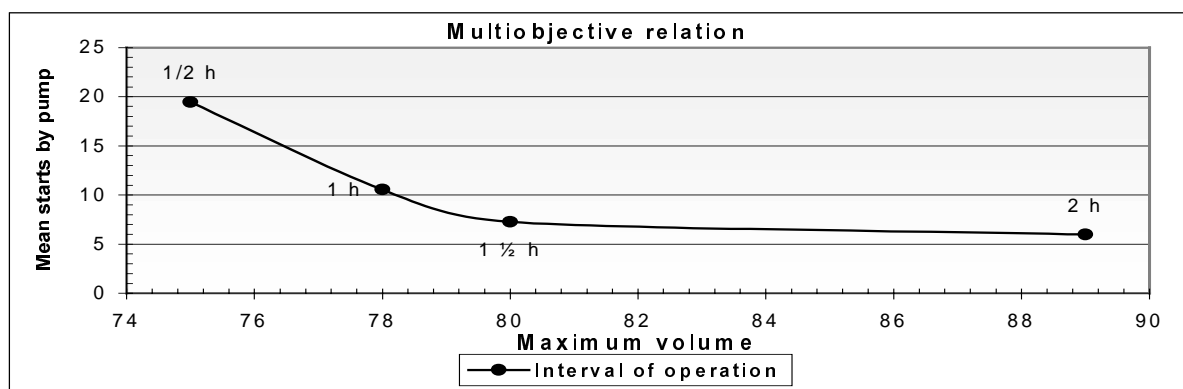


Figure 3: Relationship between number of pump start-up and tank inventory.

The constraints considered in field case test were the limits imposed to the tank inventory, the maximum pressured allowed in the pipes and the hydrodynamics balancing of the flow in different branches forming the network. Adding to the existing basis, one believes that additional constraints can be easily implemented, economic and operational ones, to improve the optimization of similar pipeline networks transporting oil, gas and even two-phase mixtures.

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